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ENSURING THE ENTERPRISE FUNCTIONING UNDER CONDITIONS OF UNCERTAINTY: PARAMETRIC ASSESSMENT

The study substantiates the importance of enterprise awareness of its environment for making managerial decisions under conditions of uncertainty. The object of the study is information and its asymmetry in the enterprise awareness of its environment when making decisions under conditions of uncertainty. Making management decisions in conditions of uncertainty requires a high-quality information base, which necessitates the need to improve approaches to assessing the impact of challenges on the enterprise functioning. The SPOD (Strengths, Problems, Opportunities, Definite) matrix is used to analyze enterprise challenges. It is emphasized that the classical SPOD matrix has a static nature and does not account for informational influences; therefore, it is proposed to extend it with a component U (Uncertainty) to reflect the dynamics of uncertainty. The entropic nature of economic processes is identified, revealing that increasing entropy reduces the resilience of economic systems and necessitates adaptive management. The proposed approach, based on the entropic measurement of uncertainty, enables a quantitative assessment of the degree of unpredictability of challenges. The variability of the enterprise environment under uncertainty imposes certain limitations on the applicability of the research results, particularly those related to the integration of non-formalized factors – socio-psychological, reputational, communicative – which are difficult to represent quantitatively. Ensuring the relevance of data is required to prevent overloading the matrix with excessive variables. The combining the SPOD/U method with an entropic assessment establishes a methodological foundation for evaluating environmental uncertainty of enterprise functioning. The research findings are particularly relevant for enterprises operating in the field of electronic communications.

Keywords: *information asymmetry, entropy, risk analysis, security, SPOD/U matrix, parametric uncertainty assessment, electronic communications.*

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1. Introduction

The vast majority of scientific research in conditions of uncertainty is devoted to security issues, since its provision contributes to the formation of a reliable basis for the sustainable functioning and development of economic entities. Adverse conditions for the enterprise functioning, caused by: martial law, inflationary processes, damage to agro-industrial complexes, damage to energy facilities, cyberattacks on critical infrastructure facilities, lead to an increase in threats and a violation of stability and, accordingly, a deterioration in the security of the enterprise. The issue of awareness of the environment, external and internal influences with a simultaneous increase in threats, which, when combined together, synergistically increase uncertainty, is acute. Therefore, solving the problems of informational influences, bias from the perception of the desired for the real, world perception from the angle of objectivity and cognitive processing of information is relevant and requires research.

The information field in which an enterprise operates can be considered a component of the economic security of an enterprise, since information is an economic resource and its further development, and most importantly, the correctness of decision-making, depends on the awareness of organizations about the environment, world trends, challenges. Cybernetics is the science of management in systems of various natures and flows of information related to management [1], which directly indicates the connection of the information component with decision-making based on it. The cybernetic direction continues to develop in conditions of increasing turbulence in the environment and not in vain, since information is a measure of uncertainty in the message during its transmission [2, 3], and today enterprises operate in conditions of asymmetric awareness of the environment. The role of information is increasing, since the media can shape perception and influence behavior, which makes them a powerful tool in political and military conflicts [4]. The works of scientists devoted to cybernetics are relevant, especially in terms of how digital media, propaganda and cyberstrategies influence modern war and geopolitical struggle, as well as the process of its course, the reaction of society.

Excess or lack of information regarding the conditions of the enterprise functioning leads to the adoption of ineffective decisions by business partners and, accordingly, the deharmonization of their interests, which is negatively reflected in the results of the enterprise activities. Issues related to eliminating the imbalance in awareness ("information asymmetry" [5]) of stakeholders for their effective decision-making to ensure the enterprise functioning in conditions of uncertainty remain relevant for resolution.

In [6], information asymmetry is considered from the following perspectives:

1) adverse selection (one of the parties is more informed about the transaction);

2) moral hazard (change in behavior of one of the parties after concluding the transaction, which accepts hidden risks, since the other party covers the costs);

3) signaling and screening (the informed party sends information, the uninformed party checks);

4) the role for micro and macroeconomics, namely:

– information asymmetry causes market gaps, in particular, a negative perception of quality goods and a decrease in consumer confidence;

– in the labor market, information asymmetry makes it difficult to identify the level of qualification of employees, which leads to an imbalance between wages and productivity;

– state regulation is manifested through regulatory acts aimed at the disclosure of financial information and the protection of consumer rights;

– economic security depends on transparency, trust and fair competition, which are significantly affected by information asymmetry;

– concealment of financial risks undermines corporate and financial stability, creating a threat of crisis phenomena and imbalances;

– in the field of cybersecurity, the level of openness of information about cyber risks and compliance with data protection standards is important;

– at the national and global levels, distortion or manipulation of information can cause sanctions pressure or increased protectionism, rhetoric of distortion.

The listed aspects of the theory indicate the impact of information on economic processes, information asymmetry leads to economic costs or benefits, sometimes unfair if the information is presented in a form that is beneficial to the enterprise.

Among other theories related to information, "information theory" is noted, in which "entropy" is the main category. This concept was first mentioned in thermodynamics, but later it was found out that the law of entropy is important for the economic process. Thus, in the scientific work [7], it is noted that the first thorough attempts to reveal the similarity in thermodynamic equations and equations of economic models are mentioned as early as 1941. In the work [8], attention is focused on the need to take into account entropy in information theory. The author believes that entropy is studied in thermodynamics and should be taken into account in information theory, since both are inherent losses: the first – energy, the second – data during their transmission, which one cannot but agree with.

In the paper [9] it is stated that the application of the concept of entropy in macroeconomics is possible in the part of research on the production function, and in microeconomics – in the part of research on consumer behavior, which includes, in addition to production, direct consumption of goods and services.

Entropy is defined as the degree of disorder at a certain point in time for any system, and for a closed system, entropy is constantly increasing, which leads to destruction. Similarly, entropy is inherent in business, its ignoring and inaction lead to business inefficiency, which will eventually cause its closure [10]. It is difficult to disagree with this opinion, since in uncertain conditions the degree of unpredictability and complexity of taking into account changes and factors is very high.

A number of scientists have found that economic systems are dissipative structures (open systems in which an increase in "entropy" is observed are called "dissipative"). The solution to the problem of entropy growth in dissipative systems and its negative impact on development is seen in the exchange of energy and information with other levels [11], which indicates the importance of environmental awareness.

Quite often, enterprises are described as complexly organized dissipative production and economic systems that function in uncertain conditions of the exogenous environment, with their inherent openness, nonlinearity, and disequilibrium [12].

As a result of the analysis of scientific works devoted to information, its role and significance in the economy, it is possible to conclude that there is a connection between the law of entropy and the economic process, and environmental awareness plays an important role in enterprise management. Since the issues of taking into account information asymmetry and assessing the impact of challenges on the enterprise functioning when making decisions on enterprise security management under conditions of uncertainty remain unresolved, the need to study this issue is becoming more urgent.

That is why *the object of research* is information, its asymmetry and the problem of disparities in the awareness of the enterprise about the environment when making decisions under conditions of uncertainty.

The aim of research is to substantiate the need to take into account entropy when making decisions on ensuring the security of an enterprise in conditions of current uncertainty, which is characterized by asymmetry and insufficiency of information about the environment.

To achieve the aim, the following tasks were set:

– to consider information theories and determine their role in decision-making under conditions of uncertainty;

– to analyze the security environment of the enterprise functioning (taking into account the complexity of its implementation under conditions of uncertainty) and summarize the results;

– to identify the main challenges to the enterprise functioning under conditions of uncertainty and assess the likelihood of their occurrence;

– to conduct a parametric assessment of the impact of challenges on the enterprise functioning using the entropy indicator.

2. Materials and Methods

The theoretical basis of research is the scientific achievements of scientists who studied the issues of information asymmetry, determined the importance of awareness of the conditions of the enterprise functioning when making decisions.

Analysis of the environment, under the conditions of current uncertainty, is proposed to be carried out using the matrix method – SPOD (Strengths, Problems, Opportunities, Definiteness) with the addition of the Uncertainties component, which will allow generalizing the results obtained and building plausible scenarios for the future conditions of the enterprise functioning. The main goal of the analysis (the first step in building the matrix) is to identify and structure internal strengths (Strengths, S), internal problems (Problems, P), external opportunities (O), external definiteness (Definiteness, D), as well as an additionally introduced component – external uncertainty (Uncertainties, U). In the second step, the factors are directly categorized (S, P, O, D or U) into a matrix with a short formulation-explanation. Next, the impact of factors is assessed by their intensity, probability and criticality according to the formed probability scale (scale 1–5) and the strength of the impact (intensity-impact: 1–5). The final stage is the determination of integral indicators (integral weighting) and ranking to identify the most influential factors. The analysis was performed using the Python software product (version 3.10) to implement automatic ranking and Bayesian refinement of probabilities; Excel (Google Sheets) – to create a structured SPOD/U matrix and calculate *I*, *p*, *Ip*, ranking. Also, to assess the impact of challenges (uncertainties) on the enterprise functioning, it is proposed to conduct their parametric assessment using the entropy indicator. Using the historical modeling method, the probabilities of risks for enterprises in the electronic communications sector were determined (based on historical data, assuming the preservation of similar patterns in future periods).

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3. Results and Discussion

The development of information and communication technologies, communication and negotiations using electronic means of communication, the emergence of new data transmission technologies, digitalization of services, increase the importance of information in the enterprise functioning and the life of society. However, the frequency of data transmission, its processing and presentation in the form of reports, documents, articles often leads to a violation of its integrity, the preservation of the original meanings. The information theory is a key aspect of understanding how information is measured and transmitted. The theory focuses on entropy, which measures the amount of uncertainty or disorder in the system. In the context of information theory, entropy can be interpreted as a measure of the informativeness of the message: the more uncertain or diverse the information is, the higher the entropy. The connection between entropy and information is fundamental, since the amount of information obtained from a certain event can be measured by the extent to which this event reduces uncertainty. Also, information cannot be received, transmitted or accepted without spending a certain amount of free energy, which emphasizes the physical limitations on information processing. Ultimately, information seems to "degrade" (information is subject to deformations, changes, asymmetry, which in thermodynamics is associated with the loss or direct deformation of energy), which is explained by the loss of accuracy and semantic completeness as a result of transmission and processing.

The conditions for the enterprise functioning, as already noted, are characterized by uncertainty, the lack of information about the development of future events directs research to the search for solutions to the problem of low predictability of the development and results of the activities of business entities.

In modern economics, the concept of equilibrium and awareness of the environment is refuted, since the theory of equilibrium of economic systems has undergone changes. New theories are being developed based on information asymmetry, when in the market environment one of the parties (stakeholder) is more informed than the other. In [13], such informational disparities are considered another dimension of the quality of the modern non-equilibrium economy.

The impact of information on economic markets is explored in the scientific work [14], which reveals key aspects of the role of information in economic processes and explains why information asymmetry can lead to market failures (when one party to a transaction has more or better information than the other and makes decisions faster).

Information theory is a branch of mathematical theory that studies the quantitative aspects of information, methods of its transmission, processing and storage. Given the volume and speed of information dissemination in cyberspace, the theory plays an important role, as it encompasses the concepts of entropy, which measures the amount of uncertainty in the system, and channel capacity, which determines the maximum speed of information transmission through a communication channel without loss [15].

The consequences of the challenges that enterprises are currently facing due to the war in Ukraine are difficult to predict. In addition, there are no approaches to their assessment that would take into account the asymmetry of awareness about them. Therefore, it is advisable to conduct an analysis of the security environment of an enterprise using a matrix method, namely the SPOD matrix of strengths, problems, opportunities (S – strengths, P – problems, O – opportunities, D – definiteness (opportunities)). The SPOD matrix in the study acts as a strategic tool used to analyze and understand the endogenous and exogenous environment of the enterprise and outline the general characteristics of challenges. The results of the matrix analysis should be used to generalize the results obtained and the opportunity of building future plausible scenarios regarding the further operating conditions of enterprises. To take into account the instability of the operating conditions of enterprises, it is proposed to supplement the SPOD matrix with the component U (Uncertainties), which will allow taking into account the impact of challenges in a dynamic environment.

The empirical basis of the study was formed on the basis of data from three leading providers of electronic communication services in Ukraine – PrJSC "Kyivstar", PrJSC "VF Vodafone" and LLC "Lifecell". According to the incident log reports and the results of internal audits of the studied enterprises, as well as official reports of the regulator NCEC (National Commission for State Regulation in the Spheres of Electronic Communications, Radio Frequency Spectrum and Postal Services), statistical reporting of CERT-UA [16–21], the identified factors were classified according to the SPOD/U categories and a matrix with analytical explanations of the content of each factor was formed (Table 1).

Based on the research results of the analysis of the constructed matrix of strengths, problems, opportunities and definiteness/uncertainty (SPOD/U) of the enterprise functioning providing electronic communication services, it was concluded that the stability and quality of service provision is maintained in regions that are geographically remote from the combat zone. The client base is stable (characterized by low churn) due to the long-term use of established services by consumers of a particular operator. In addition, high-quality communication is provided by three main providers of electronic communication services (PrJSC "Kyivstar", PrJSC "VF Vodafone", LLC "Lifecell"), which restrains the transition of consumers to competitors, so these companies continue to receive a steady increase in income from services.

Intellectual capital is listed as highly qualified, capable of working in the field of innovation and digitalization changes. It should be noted the strengthening of strategic partnerships with international organizations and telecommunications groups, which helps to accelerate integration and opens access to technologies and resources.

Among the exogenous problems, the following are distinguished: increasing costs for infrastructure maintenance, especially in combat zones; difficulties in accessing networks and their maintenance in the territories affected by the armed war of the Russian Federation against Ukraine and occupied; the difficulty of ensuring reliable network operation due to the proximity of certain territories to zones of active combat operations.

Exogenous opportunities are: the identification of an initiative to invest in the ICT sector with the aim of its restoration and strengthening by international partner countries and organizations; the growing need to stay connected for monitoring events and communication, online work and training; the potential for the introduction of new technologies in order to modernize and expand the range of services; promoting innovative development and restoration of infrastructure for the development of ICT areas at the institutional level.

Among the exogenous dangers, the following are distinguished: the duration of the conflict, the increase in inflation, currency fluctuations and economic instability, as a result, a decrease in the purchasing power of service consumers; uncertainty of the regulatory environment, which significantly affects investment and the development of strategic plans; high geopolitical tension and obstacles to financing from supporters of the country waging an armed war against Ukraine; uncertainty of strategic considerations regarding the development of the ICT sector in the near future.

After conducting a qualitative assessment of the factors influencing the enterprises of electronic communications services, the study focused on the quantitative assessment of the results – an integral assessment of the impact indicators and the ranking of environmental factors based on the results of the SPOD/U analysis. After structuring the factors into the SPOD/U matrix, an integral assessment of their impact was carried out. At this stage, complex (integral) indicators were calculated for each factor, which took into account the combination of previously assigned points for the intensity of the impact and the probability of manifestation, which allowed moving from a qualitative description of environmental factors to a quantitative assessment of their significance.

Integral weighting was performed by calculating a generalized influence index, which reflected the relative contribution of each factor to the overall configuration of the operating conditions of enterprises. Comparison of the obtained values allowed to rank the factors and identify those that have the greatest weight for enterprises in the electronic communications sector under conditions of uncertainty (Table 2).

Table 1

Strengths, Problems, Opportunities and Definiteness/Uncertainty Matrix (SPOD/U)

Indicator	Endogenous capabilities	Endogenous problems	Exogenous opportunities	Exogenous hazards
Strengths (S)	Diffuse infrastructure and network coverage, relocation of some equipment and facilities to safer regions. Stable customer base. Qualified personnel. Strategic partnership and close relationships with communication service providers in EU countries, single roaming	Destroyed and damaged infrastructure in war zones. Increased operating costs due to the reconstruction of damaged infrastructure. Costs for security measures. Increased risk to job security	Grants and assistance from foreign partners. Growing demand for roaming communication services, increasing data transfer volumes. Modernization and use of new technologies	Uncertainty of operating conditions due to loss of predictability of the duration of martial law. Economic instability. Regulatory uncertainty. Decrease in investment attractiveness
Problems (P)	High maintenance costs. Difficult access to equipment to electronic communications networks in combat zones. High probability of denial of service due to loss of network reliability. Reduced bandwidth due to network overload	Disruptions in service provision as a result of power outages. Reduced consumer solvency. Threats to information and cybersecurity due to the hybrid war waged by the aggressor for 10 years. Outflow of highly qualified specialists	Promotion and stimulation by the state of infrastructure restoration. Developing markets in rural areas. Digital infrastructure development programs and transformation processes aimed at building a digital state	Geopolitical risks. Market competition. Disruption of supply chains
Opportunities (O)	Potential for innovation and restoration of modern infrastructure. Expansion into new, underserved markets. Cooperation with global technology companies	Slow pace of reconstruction. Uncertainty of the investment climate. Complex regulatory environment	Deployment of 5G technology. Advanced digital services for remote work and education. Development of e-commerce, e-services, e-hryvnia, fintech	Prolongation of the conflict, aimed at depleting the economy, slowing down the development of the tertiary sector. Market fragmentation due to regional characteristics, differences. Consumers' revision of the basket of needs due to reduced incomes
Definiteness (D)/Uncertainties (U)	Available knowledge and intellectual potential for rapid recovery and stabilization of the market. Resilience and resilience to adverse circumstances. State support for the development of the ICT sector	Destruction of infrastructure Economic downturn affecting revenues. Increased competition from global players	International cooperation on the restoration of the ICT sector. Interest in ICT education. Potential growth in demand for communication services to ensure the educational process and remote work	Prolonged regulatory uncertainty. Escalation of the conflict. Potential nationalization or strict state control

Table 2

Integral indicators of influence and ranking of environmental factors according to the results of SPOD/U-analysis

S, P, O, D/U	Endo-, exogenous opportunities, problems, threats, Uncertainties	Intensity (I)	Probability (p)	Intensity – probability (Ip), ($I \cdot p$)	Weight (ω) ($I \cdot p/\Sigma I \cdot p$)	Weighted index ($\omega\ In$) ($\Sigma I \cdot p \cdot \omega$)	Aggregate weighted scores ($R_{\omega\ In}$) ($\Sigma\omega\ In$ by individual impact ($S, P, O, D/U$))
S	Endogenous opportunities	4	0.8	3.2	0.4211	1.348	2.292
S	Endogenous problems	3	0.2	0.6	0.0789	0.047	
S	Exogenous opportunities	4	0.6	2.4	0.3158	0.758	
S	Exogenous threats	3	0.3	0.9	0.1184	0.107	
S	Exogenous uncertainties	2	0.25	0.5	0.0658	0.033	
P	Endogenous opportunities	2	0.2	0.4	0.0396	0.016	2.659
P	Endogenous problems	5	0.7	3.5	0.3465	1.213	
P	Exogenous opportunities	3	0.4	1.2	0.1188	0.143	
P	Exogenous threats	5	0.6	3.0	0.297	0.891	
P	Exogenous uncertainties	4	0.5	2.0	0.198	0.396	
O	Endogenous opportunities	3	0.6	1.8	0.2609	0.470	2.398
O	Endogenous problems	2	0.15	0.3	0.0435	0.013	
O	Exogenous opportunities	5	0.7	3.5	0.5072	1.775	
O	Exogenous problems	2	0.2	0.4	0.058	0.023	
O	Exogenous uncertainties	3	0.3	0.9	0.1304	0.117	
D	Endogenous opportunities	2	0.4	0.8	0.2909	0.233	1.088
D	Endogenous problems	1	0.05	0.1	0.0182	0.001	
D	Exogenous opportunities	3	0.5	1.5	0.5455	0.818	
D	Exogenous threats	2	0.15	0.3	0.1091	0.033	
D	Exogenous uncertainties	1	0.1	0.1	0.0364	0.004	

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According to the results of the analysis, high intensity (*I*) with moderate probability (*p*) was assigned to the factors: extensive infrastructure, client base, qualified personnel, which are considered strengths (*S*) for the studied enterprises. It was noted that the average intensity *I* with increasing *p* is inherent in the stabilization of the regulatory environment, which creates opportunities for the enterprise (*O*): international support programs, digitalization, development of 5G technologies. Stable factors (*D*) are: regulatory regulation, contracts (have low *p* and low I_p) – important for strategic planning.

Problems (*P*) reflect existing operational and technical threats to the enterprise functioning: high maintenance costs, outdated equipment, vulnerabilities to energy outages (factors with high *Ip* when modeling outage scenarios (*U*)).

U (uncertainties) were studied: military actions, power outages, potential increase in cyberattacks, which were noted to have high probabilities of implementation in stress scenarios and a large impact on the *Ip* of all internal components.

Therefore, problems (*P*) form the largest total contribution to the risk profile, so it is necessary to first solve technical malfunctions and modernize the material base in order to prevent high probabilities of operational failures, vulnerability to external threats (should be taken into account when modeling scenarios in further studies). Opportunities are the second most important group (they can be activated as part of a risk mitigation strategy). Strengths are the most important resources, but they should be converted into practical measures to reduce *p*. Definiteness (*D*) is the stable factor that should be considered when planning.

Analysis of the strengths currently characteristic of enterprises supplying electronic communication networks allows to determine the prospects for solving the above problems as follows:

– strengthening strategic partnerships to accelerate the modernization and development of the ICT sector;

– attracting highly qualified specialists to implement the latest innovative solutions to ensure the reliability and operational efficiency of the network;

– cooperation with international humanitarian organizations and investors, fundraising platforms to ensure financing for restoration work;

– monitoring the potential for entering new markets in regions with an underdeveloped communication network;

– investing in 5G and digital services to meet the growing demand for high-speed Internet and digital communications;

– developing forward-looking and predictive plans for emergencies;

– investing in the security of information assets, in cybersecurity to protect against the growing number of cyber threats;

– flexibility of development plans and strategies to adapt to uncertain conditions, a changing regulatory environment due to integration into the European space;

– active cooperation with state and international organizations, institutions to solve economic and regulatory problems;

– systematic and permanent analysis of factors influencing the enterprise functioning providing electronic communications networks and services to overcome current uncertainty and build flexible development strategies, as well as rapid recovery and growth.

The challenges under which enterprises operate cause unpredictability and low predictability of events, therefore traditional methods of assessing the impact of the environment on the enterprise are ineffective. It is assumed that the approach to assessing uncertainty based on taking into account entropy, which allows measuring the uncertainty that is formed under today's uncertain business conditions of business entities, is appropriate for use.

As has already been found out, the concept of "entropy" is most often used in thermodynamics, as well as information theory, however, it has also found application in economic science to measure the uncertainty, diversity and complexity of the conditions in which business entities are. Therefore, in economics, entropy is most often used to analyze the unpredictability of the system, market or economic parameters, it is proposed to conduct a parametric assessment of the impact of challenges on enterprises using this indicator [22].

Using the approach based on entropy allows to obtain results with a two-dimensional distribution, to study a rectangular geometric region [23]. The obtained values, determined using the proposed distribution, are in good agreement with the experimentally measured values of the dynamics of various modifications for the propagation of entropy. Shannon entropy takes into account a continuous number of random variables, it is also possible to calculate the average entropy (AE), which summarizes the continuous and discrete impact of calls [24–26]. Entropy is additive, positive and equals zero only in the case of a uniform distribution.

It is important that when determining entropy, it is assumed to take into account the relationship with information, that is, data obtained from the environment, it is possible to graphically represent entropy in the segmentation of the efficiency image, having previously determined it by the formula

$$\mathrm{H}(\mathrm{X}) = -\sum_{i=1}^{n} p(x_i)\log_2 p(x_i), \tag{1}$$

where $\mathrm{H}(\mathrm{X})$ – entropy; (x_i) – the probability of a separate call for providers of electronic communication networks and services; log – natural logarithm with base 2.

The assessment of the probabilities of risk events for enterprises providing electronic communications services was carried out on the basis of historical (frequency) modeling, which involves determining the probability as the ratio of the number of incidents of a certain type to the total sample volume. Risk events recorded by service providers PrJSC "VF Ukraine", PrJSC "Kyivstar" and LLC "Lifecell", as well as by CERT-UA (the government computer emergency response team of Ukraine, which operates as part of the State Service for Special Communications and Information Protection of Ukraine), NCEC during 2022–2024 (a period of increased uncertainty in the conditions for the enterprise functioning due to the military actions of the Russian Federation against Ukraine) were analyzed. The sample was formed after cleaning the database in a total of 1200 incidents (*N*), which are grouped into five categories: destruction and damage to infrastructure; operational violations; cybersecurity threats; regulatory uncertainty; economic instability, the frequencies of which are respectively: 360 (*n1*); 240 (*n2*); 180 (*n3*); 120 (*n4*); 300 (*n5*).

The probability score (p_i) by group is calculated as the relative frequency

$$p_i = \frac{n_i}{N}, \tag{2}$$

where n_i – the frequency; *N* – the set of incidents.

The standard error is estimated by the formula

$$SE(p_i) = \sqrt{\frac{p_i(1-p_i)}{N}}. \tag{3}$$

The confidence interval is 95%

$$p_i \pm 1.96 \cdot SE(p_i). \tag{4}$$

According to the results of the calculations, the following intervals were obtained: infrastructure (0.274; 0.326); operational violations (0.177; 0.233); cyber threats (0.130; 0.170); regulatory instability (0.083; 0.117).

To check the stability of frequency probabilities, a Bayesian update was performed using beta distributions as a priori assumptions, based on the results of the calculations, a posteriori distribution of the estimate of confidence intervals was formed, adjusting the historical frequencies depending on the strength of the a priori assumptions in the conditions of uncertainty in the enterprise functioning providing electronic communications services.

Having analyzed the challenges of our time, the most significant ones were identified: destruction and damage to infrastructure; operational violations; cybersecurity threats; uncertainty of regulatory, institutional regulation; as well as economic instability. In order to smooth out the unpredictability and complexity of managing challenges under conditions of uncertainty in the enterprise functioning, it was proposed to determine entropy by calculated logarithms of probabilities. The listed challenges are measured by their corresponding probabilities (Fig. 1):

– destruction and damage to infrastructure (x_1) – 0.3;
– operational violations (x_2) – 0.2;
– cybersecurity threats (x_3) – 0.15;
– uncertainty of regulatory, institutional regulation (x_4) – 0.1;
– economic instability (x_5) – 0.25.

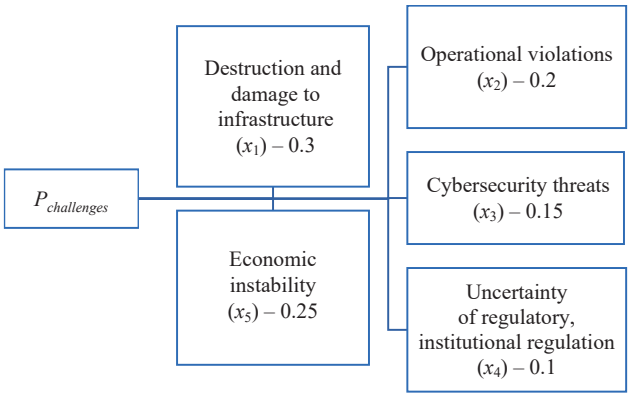

Fig. 1. Probabilities of uncertainty challenges for enterprises providing electronic communications networks and services

Given the five challenges currently identified as the most likely, formula (1) takes the form

$$H(X) = -(p(x_1)) \cdot log_2 \cdot p(x_1) + (p(x_2)) \cdot log_2 \cdot p(x_2) + (p(x_3)) \cdot log_2 \cdot p(x_3)) + (p(x_4)) + log_2 \cdot p(x_4) + (p(x_5)) \cdot log_2 \cdot p(x_5)). \quad (5)$$

Substituting the probabilities of challenges into formula (5), wit is possible to obtain

$$H(X) = -(0.3 \cdot log_2 \cdot 0.3) + (0.2 \cdot log_2 \cdot 0.2) + (0.15 \cdot log_2 \cdot 0.15) + (0.1 \cdot log_2 \cdot 0.1) + (0.25 \cdot log_2 \cdot 0.25) = 0.3 \cdot (-1.737) + 0.2 \cdot (-2.322) + 0.15 \cdot (-2.737) + 0.1 \cdot (-3.322) + 0.25 \cdot (-2.0) = -(-2.228) = 2.228.$$

As a result of the parametric uncertainty assessment using the entropy approach, the value of 2.228 was obtained, which indicates a high level of uncertainty of the system. The value is advisable to use for comparative analysis in dynamics or between different development scenarios, which allows to assess the trends in changes in the level of uncertainty. The calculation results and their graphical interpretation are presented in Fig. 2.

To assess entropy under definite (normal) conditions of enterprise functioning, the type of market structure (perfect competition, monopolistic competition, oligopoly, monopoly) is taken into account.

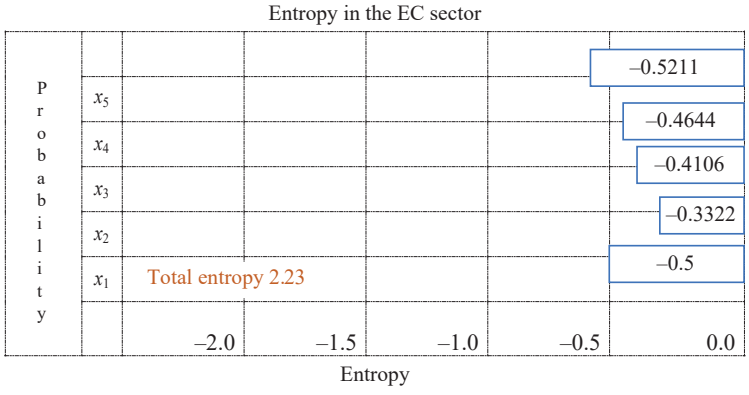

Fig. 2. Entropy in the ICT sector under uncertain conditions

The assessment in the study was conducted for enterprises in the field of electronic communication services, where the market type is considered competitive for Internet communication services. Meanwhile, in terms of volumes and types of communication services, the market type is close to oligopolistic, since services are provided by three main service providers: PrJSC "Kyivstar", PrJSC "VF Ukraine", LLC "Lifecell".

Entropy for enterprises operating under this type of market infrastructure varies within the limits of up to 1.5 bits.

In general, low entropy from 0 to 1 bit indicates high predictability, moderate entropy from 1 to 2 bits – low predictability; high – from 2 to 3 bits indicates the complexity of prediction and uncertainty [27].

Analysis of the operating conditions of enterprises characterized by uncertainty allowed to outline variables describing the impacts of challenges according to certain probabilities for each challenge, as well as to quantitatively measure the entropy in the environment of enterprise functioning.

Thus, *H(X)* of challenges for enterprises in the field of electronic communications is approximately 2.23 bits, which reflects the level of unpredictability and complexity in managing the identified challenges. Higher entropy indicates greater uncertainty and complexity in solving these problems. The resulting entropy value of 2.23 can be used by managers and stakeholders to make informed decisions regarding the strategy of enterprise security management and forecasting under conditions of low awareness (uncertainty).

The research results indicate that the combination of qualitative matrix analysis and a quantitative approach to measuring uncertainty creates a scientifically sound toolkit for a comprehensive assessment of the enterprise operating environment and making management decisions under conditions of uncertainty. The use of the SPOD/U matrix method together with entropy assessment forms the basis for building adaptive enterprise security management, focused on timely decision-making and minimizing the consequences of challenges under uncertain operating conditions.

Research limitations. Given the complexity and dynamism of the enterprise operating environment under uncertain conditions, it is worth considering the limitations of using the research results:

– the static nature of the model, since SPOD in its classical form does not take into account rapid changes in the enterprise external environment, economic instability, or the effects of information attacks (disinformation and distortion of information content in the media space). However, it is proposed to supplement the matrix with the component U (Uncertainly), which allows to take into account uncertainty, its dynamic and multidimensional nature and eliminate this bias;
– limited integration of informal factors, such as socio-psychological, reputational or communication aspects, which are amplified by the spread of disinformation and which are difficult to reflect in the matrix structure;

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– high complexity when the number of variables increases, therefore it is worth monitoring the data for relevance in order to reduce the effect of "matrix overload";
– in the case of involving experts in assessing the conditions of the enterprise functioning, the likelihood of subjectivity in the formation of the input data of the risk/impact matrix should be taken into account, which may distort the real picture of threats and opportunities, therefore it is worth carefully selecting experts.

In summary, it can be assumed that the above limitations can be anticipated and the research results can be applied in practice, by expanding the SPOD matrix for analyzing the environment and challenges with the "uncertainty" component (U-uncertainly). As a result, the quality of the output data for the parametric assessment of uncertainty and challenges in the enterprise functioning will improve.

Prospects for further research. The problem of low or excessive awareness of enterprises regarding the environment and challenges in the conditions of hybrid war and martial law remains and needs to be resolved. It is worth deepening the research results, developing approaches to assessing the uncertainty of the conditions of the enterprise functioning. Reliable initial data allow for the formation of effective decisions in the management of enterprises to ensure their security, so it is worth using the results obtained for further research.

4. Conclusions

1. According to the results of the analysis of information theories, it was determined that the parameter for understanding the nature of information processes is entropy, which characterizes the level of uncertainty in the system. In the context of making management decisions, it reflects the degree of risk and information ambiguity inherent in an uncertain environment. Reducing entropy, i. e. reducing uncertainty, is the goal of effective management, which is achieved through the formation of reliable initial data. At the same time, it was found that it is difficult to avoid information asymmetry today. Currently, enterprises are forced to make decisions in conditions of incomplete information, relying on the assessment of probabilities, forecasting and modeling of possible scenarios. Information theory served as a methodological basis for analysis, measurement, and allowed interpreting information as a dynamic category closely related to entropy.

2. The analysis of the security environment of the enterprise functioning, characterized by increased instability of the environment and an increase in the number of uncertain factors, indicates the ineffectiveness of classical approaches to environmental diagnostics. Therefore, the use of the SPOD matrix method with the addition of its component U (Uncertainties) was proposed. The introduction of the component U (Uncertainties) into the analytical matrix expanded the opportunities for conducting analysis in terms of assessing the variability of the external and internal environment. Based on the SPOD/U-analysis of risk factors, priorities were determined for planning to strengthen the stability of the enterprise operation to conditions of uncertainty, with the first priority being to strengthen the protection of energy supply and redundancy, secondly, to modernize equipment (including using xPON technology), and thirdly, to strengthen cyber protection.

3. It was established that in conditions of uncertainty, the enterprise functioning is affected by challenges, among which the following are significant (by the probability of their occurrence (p)): destruction and damage to infrastructure (p – 0.3) and economic instability (p – 0.25), which directly affect the sustainability of the enterprise functioning. Less significant, but requiring constant monitoring, are operational violations (p – 0.2), cybersecurity threats (p – 0.15) and uncertainty of regulatory regulation (p – 0.1). The results obtained allow for a systematic assessment of the risk environment of the enterprise functioning, making management decisions and developing adaptive strategies for ensuring economic security.

4. Given the limitations of traditional analysis tools in unstable operating conditions, the paper proposes an approach using the entropy measurement of uncertainty, which allows for a quantitative assessment of the degree of unpredictability of external influences and reflects the objective complexity of the conditions of the enterprise functioning. As a result of parametric estimation of the level of uncertainty using the entropic approach, the value of 2.228 was obtained, which indicates a high degree of entropy of the system. The value of the indicator reflects significant unpredictability of the external environment and instability of internal processes, which complicates the adoption of management decisions. A high level of uncertainty requires the implementation of adaptive security management mechanisms to minimize the negative impact of entropic factors on the enterprise stability.

Conflict of interest

The authors declare that they have no conflict of interest regarding this research, including financial, personal, authorship or other, which could affect the research and its results presented in this article.

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The manuscript has no related data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

Authors' contributions

***Olena Vynogradova*:** Validation, Formal analysis, Investigation, Writing – original draft, Writing – review and editing; ***Svitlana Lehominova*:** Methodology, Writing – original draft, Writing – review and editing; ***Tetiana Kapeliushna*:** Conceptualization, Methodology, Writing – original draft, Writing – review and editing; ***Alona Goloborodko*:** Formal analysis, Data curation, Visualization, Writing – review and editing.

References

1. Shyian, A. A. (2007). *Ekonomichna kibernetyka: vstup do modeliuvannia sotsialnykh i ekonomichnykh system.* Mahnoliia, 264. Available at: http://inrtzp.vntu.edu.ua/pmba/stf/mater/OMBES.pdf
2. Shannon, C. E. (1948). A Mathematical Theory of Communication. *Bell System Technical Journal, 27 (3),* 379–423. https://doi.org/10.1002/j.1538-7305.1948.tb01338.x
3. Kline, R. R. (2015). *The cybernetics moment: Or why we call our age the information age.* Baltimore: Johns Hopkins University Press, 336. Available at: https://archive.org/details/cyberneticsmomen0000klin
4. McLuhan, M., Hutchon, K., McLuhan, E. (1977). *City as Classroom: Understanding Language and Media.* Ontario: Irwin Publishing, 184. Available at: https://www.scribd.com/document/405514619/City-as-classroom-pdf
5. Akerlof, G. A. (1970). The Market for "Lemons": Quality Uncertainty and the Market Mechanism. *The Quarterly Journal of Economics, 84 (3),* 488–500. https://doi.org/10.2307/1879431
6. Georgescu-Roegen, N. (1971). *The Entropy Law and the Economic Process.* Cambridge, London: Harvard University Press. https://doi.org/10.4159/harvard.9780674281653
7. Hicks, J. R., Davis, H. T. (1942). The Theory of Econometrics. *The Economic Journal, 52 (208),* 350–352. https://doi.org/10.2307/2226237
8. Jakimowicz, A. (2020). The Role of Entropy in the Development of Economics. *Entropy, 22 (4),* 452. https://doi.org/10.3390/e22040452
9. Pomares, M. (2024). *Entropy and Economics.* arXiv:2407.00022. https://doi.org/10.48550/arXiv.2407.00022

10. Sanidas, E. (2008). *Entropy in economics: its measurement through primary data and its usefulness in business.* Lex et scientia, 44–59. Available at: https://www.researchgate.net/publication/42437357_ENTROPY_IN_ECONOMICS_ITS_MEASUREMENT_THROUGH_PRIMARY_DATA_AND_ITS_USEFULNESS_IN_BUSINESS
11. Foster, J. (2011). Energy, aesthetics and knowledge in complex economic systems. *Journal of Economic Behavior & Organization, 80 (1),* 88–100. https://doi.org/10.1016/j.jebo.2011.02.013
12. Shevtsova, H. Z. (2016). *Synerhetychnyi menedzhment pidpryiemstv.* Kyiv: NAN Ukrainy, In-t ekonomiky prom-sti, 454. Available at: https://iie.org.ua/wp-content/uploads/monografiyi/2016/2016_mono_Shevtsova.pdf
13. Wankhade, L., Dabade, B. (2010). *Quality Uncertainty and Perception Information Asymmetry and Management of Quality Uncertainty and Quality Perception.* Heidelberg, Dordrecht, London, New York: Springer. https://doi.org/10.1007/978-3-7908-2195-6
14. Stiglitz, J. E. (2003). Information and the Change in the Paradigm in Economics, Part 1. *The American Economist, 47 (2),* 6–26. https://doi.org/10.1177/056943450304700202
15. Raine, A., Foster, J., Potts, J. (2006). The new entropy law and the economic process. *Ecological Complexity, 3 (4),* 354–360. https://doi.org/10.1016/j.ecocom.2007.02.009
16. Finansovi rezultaty. *Vodafone Ukraina.* Available at: https://www.vodafone.ua/company/investors/finansovi-rezultaty
17. Richnyi zvit zi staloho rozvytku. *Vodafone Ukraina* (2024). Kyiv, 84. Available at: https://www.vodafone.ua/storage/image-storage/2025/04/25/753/source/shhoricnii-zvit-zi-stalogo-rozvitku-za-2024-rik_1745571916.pdf
18. Informatsiia dlia aktsioneriv ta steikkholderiv. *Kyivstar.* Available at: https://kyivstar.ua/about/investors-and-shareholders/issuers
19. Richni zvity za MSFZ. *lifecell.ua.* Available at: https://www.lifecell.ua/uk/pro_lifecell/finansovi-ta-operacijni-dani/richni-zviti/?flavour=full
20. *Richnyi zvit. Systemy vyiavlennia vrazlyvostei i reahuvannia na kiberintsydenty ta kiberataky.* Available at: https://scpc.gov.ua/api/files/72e13298-4d02-40bf-b436-46d927c88006
21. Zvity NKEK. *Natsionalna komisiia, shcho zdiisniuie derzhavne rehuliuvannia u sferakh elektronnykh komunikatsii, radiochastotnoho spektra ta nadannia posluh poshtovoho zviazku.* Available at: https://nkek.gov.ua/pro-nkek/zvity-nkek
22. Kremen, V. H. (Ed.) (2014). *Synerhetyka i osvita.* Kyiv: Instytut obdarovanoi dytyny, 348. Available at: https://drive.google.com/file/d/0B6UkMWiy4uKzS2V0cUludjdjaEE/view?resourcekey=0-q4dJbH6e31HAottbt0mFhw
23. Homonai, O. V.; Dziuba, I. M., Zhukovsky, A. I., Zhelezniak, M. H. et al. (Eds.) (2012). *Kvantova teoriia informatsii. Encyclopedia of Modern Ukraine.* Kyiv: The NASU institute of Encyclopedic Research. Available at: https://esu.com.ua/article-11530
24. Smith, C. E., Smith, J. W. (1996). Economics, ecology and entropy: The second law of thermodynamics and the limits to growth. *Population and Environment, 17 (4),* 309–321. https://doi.org/10.1007/bf02208231
25. De Castro, L., Yannelis, N. C. (2018). Uncertainty, efficiency and incentive compatibility: Ambiguity solves the conflict between efficiency and incentive compatibility. *Journal of Economic Theory, 177,* 678–707. https://doi.org/10.1016/j.jet.2018.02.008
26. Chen, J. (2002). An Entropy Theory of Value. *SSRN Electronic Journal.* https://doi.org/10.2139/ssrn.307442
27. Kapeliushna, T. (2024). *Upravlinnia bezpekoiu pidpryiemstv: teoriia ta metodolohiia.* Kyiv: DUIKT, 40. Available at: https://duikt.edu.ua/uploads/p_1537_29713705.pdf

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