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METHODOLOGICAL PRINCIPLES OF FORMING SOCIO-ECONOMIC SECURITY OF ENTERPRISES OF THE REGION

Purpose. To form and scale up the system of principles that compose the methodological principles of shaping the socio-economic security of enterprises of the region.

Methodology. The study used the methodological principles of complex production systems, methodology for developing multifactor models, system multifactor analysis, methods of structural synthesis.

Findings. A multifactor economic and mathematical model was developed resulting in analyzing the factorial influence of the innovation and investment component upon the gross regional product. The system of principles that compose the basis of the methodological principles of shaping the socio-economic security of enterprises of the region was analyzed.

Originality. The methodology for forming the socio-economic security of enterprises of the region has been further developed. It has been proposed to include a background regularity or a background principle that is universal in nature into the system of principles. The reasonability of applying multifactor modeling in the shaping of the socio-economic security of an enterprise has been determined.

Practical value. The developed multifactor mathematical model in the form of a statistical multiplicative model afforded an opportunity to study the influence of individual components on the socio-economic security of enterprises in the region and to indicate ways to increase it, relying on the influence of these components. Consideration of the background as an attribute of the system ensures the functioning of the laws of composition of system relations. It is the region that can serve as the background in which an enterprise operates where multidimensionality of contradictory influences operates.

Keywords: *enterprise, region, socio-economic security, methodology, modeling*

Introduction. The rapid development of the economy is declarative of the emergence of new issues for the activities of enterprises. The formation of the external environment with reference to enterprises stimulates the activation of the principles of a systems approach for the sake of supporting fundamental properties within specified boundaries. Studying the enterprise as a complex economic system, we can make mention of the following: the accommodation of complex economic and production systems is represented in the change in the functioning of the system under conditions of environmental instability. Currently, the touchy situation in Ukraine significantly affects the processes of determining the ratio of the effective development of enterprises and the economic development of regions. Correspondingly, determining the viewpoints of stabilizing the socio-economic development of regions involves the activation of legislative activity. This confirms the relevance of the issue of forming regional development on the basis of the socio-economic security of enterprises. An important task is to increase the efficiency of the national economy, which has a significant impact on the development of regions, which in its turn requires stabilization and an increase in the level of socio-economic security of enterprises. Let us focus our attention on the fact of establishing the principal commonness of complex dynamic systems and the unity of the laws of their functioning. This equates to not only conscious approach to their study at a general theoretical level, but also a search for and application of the useful analogies and system isomorphisms. Let us make reference to the fact that in complex systems, it is not the material, but the information component that comes to prominence, which takes into consideration the qualitative, in fact, unique characteristics of both individual elements and the relationships between them. The study of stable states shows that an object, a system (enterprise, city, region, country) is the more stable, the greater the adaptive capabilities they have.

The essential parameters of such a complex economic and production system as an enterprise are the established characteristics of its functioning, namely: profit, profitability, output volume, sales volume, payroll, cost of production, etc. The systematic research on the formation of socio-economic security of enterprises in the region currently requires further development of the relevant methodological principles. One of the main principles of socio-economic security of enterprises is the principle of optimality. Up-to-datedness requires enterprises to build up their potential and ensure the conditions for competitiveness. This leads to a discussion among scientists on the conceptual provisions of socio-economic security of enterprises. The need for such a concept will make it possible for scientists to determine the range of problems and their implementation in the area of the security component of the enterprise. The definition of such a component contains both a scientific component and areas for practical implementation.

It is worth pointing out that the formation of socio-economic security of enterprises in the region is conditioned by a number of circumstances. First, under the conditions of instability of the external environment, increasing cost of resources, interruption of logistics chains, enterprises are faced with the task of ensuring socio-economic security, which is a significant tool for improving performance indicators, and also contributes to their sustainable development. Secondly, enterprises are characterized by the inefficiency of organizational and economic management mechanisms, focus only on the growth of financial indicators without taking into consideration the social component, as well as the non-availability of approaches and methods for assessing the state of socio-economic security, which limits the ability to timely identify risks and determine development areas. Thirdly, the ill-preparedness of enterprises to implement electronic services, digital platforms for the purpose of digitalization of management decisions or their slow use causes risks of financial costs, reduced competitiveness at the regional level, in the international market, which confirms the expediency of forming socio-economic security. Against this background, the formation of conceptual provisions of socio-economic security of enterprises is an implication for the development of enterprises, ensuring the stability of their functioning, and increasing profitability.

Meantime, in the aspect of forming conceptual provisions of socio-economic security of enterprises, an effective security component is of great importance, which ensures resilience to external challenges. It is the combination of these methodologies that is the basis for synergy in the further development of methodological principles for the formation of socio-economic security of enterprises. It is advisable to include the background principle when determining the methodological principles for the formation of socio-economic security of enterprises in the region. The background pattern, or background principle, is universal, general in nature and is widely used in technology, biology, medicine, meteorology, socio-economic environment, etc. The background is an attribute of the system, as the background of the system, stable processes often act, ensuring the functioning of the laws of composition in relation to the system. It is the region that can serve as the background in which the enterprise operates, where the multi-vector nature of regulations and legislative acts that contradict each other, the invasion of the external environment, operates.

Analyzing the enterprise as a system, contradictions between the external and internal environment are distinguished. Within the framework of the formation of the internal environment, under the influence of external influences, a new structure of consumers is formed, the economic component and legal relations undergo changes. When affected by the growing competition, the enterprise forms new internal transformations. In its turn, internal transformations of the system stimulate managers to look for new forms and methods of management. The process of effective enterprise management shall take into consideration all the risks and threats that are influenced by the external aggressive environment [1]. The essential complications of managing large production and socio-economic systems are the emergent system-specific properties. It is possible to identify, research, and quantify such features on the basis of statistical analysis. It is worth pointing out that the socio-economic security of an enterprise is a universal category. Consequently, there is a worthwhileness of further development of methodological principles for the formation of socio-economic security of enterprises in the region.

Literature review. The field of research on the socio-economic security of enterprises is not neglected by practicing scientists. Multi-vector and multi-aspect scientific publications contain significant informative and scientific potential. Analyzing scientific research in the area of forming the socio-economic security of enterprises in the region, one may note that researchers carry out in-depth analysis at all levels – state, regional ones. The author-scientist Yevsiukov O. P. studied the essence of state mechanisms of socio-economic security, its improvement under the conditions of globalization processes [2]. Socio-economic security at the regional level was studied by Petrenko N. O., Polishchuk O. A. Scientists focused their attention on the specifics of the development of the economic security of the region. It is worth mentioning that the improved methodology of "...assessment of the level of regional economic security, which includes a system of basic criteria-indicators that make it possible to quantitatively determine the level of economic security of the region..." [3]. It is important to notice that undoubtedly significant research by scientists concerns the regional level and cannot be fully applied to the security component of the enterprise [3]. Ivanova N. S. diligently analyzes the indicators of socio-economic development of regions. The specificity of this study is the review of a significant amount of statistical information. The scientist constructed regional clusters and analyzed the dynamics of the development of the relevant indicators [4]. Scientists also paid attention to studies on the essence and content of the definition of "economically secure". Thus, Romanovska Y. A in her studies defines the role of the category of socio-economic security. Its content is deepened in terms of the number of features taken into consideration. The scientist notes the expediency of considering socio-economic security according to the hierarchy – state, region, enterprise [5]. Practitioner scientists Kozachenko H. V., Onyschenko S. V., Zavora T. M. draw attention to the need to improve the methodology for assessing the regional aspect of socio-economic security. The authors note "...assessment of the socio-economic security of the region is based on the provisions of the conceptual and protective approaches to determining its status and nature..." [6]. A distinguishing feature of the scientific research of scientists is the definition of indicators that characterize not only quantitative factors, but also subjective content. The principles are determined, according to which an algorithm for assessing socio-economic security at the regional level is proposed [6]. It is beyond argument that the regional level of economic security is of paramount importance, but it should be noted that the well-being of regions is affected by the efficiency of enterprise activity. Authors Kopytko M. I., Malanchuk A. M. using certain research methods identified "...the essence of the socio-economic security of an enterprise taking into consideration current trends and features of development..." [7]. The scientists have investigated and identified the parameters of influence

on the level of socio-economic security of an enterprise. The activities of enterprises in the period since 2014 have been analyzed. Attention was focused on the consequences of the negative impact of the pandemic and hostilities within the territory of the state [7]. A new view is suggested on the formation of a synthesized security level that covers the entire hierarchy – state, region, enterprise. The team of authors Cherchyk L. M., Kolenda N. V., Matvijchuk N. M. and others developed "... conceptual principles of socio-ecological and economic security of micro-, meso-, macro-level objects..." [8]. The elements of the structure of the proposed system are accentuated and characterized [8]. Authors Zavora T. M., Ushakova Yu. S. draw attention to the diversity of approaches to the essence of the concepts of economic and social security of enterprises. Their categories are analyzed, and the author's approach to formulating the essence of the concepts of "socio-economic security" at the enterprise level is proposed [9]. The scientific work of Smirnaia S. M. stands out for its thoroughness. It is proposed to specify the thoroughness of the category of enterprise security from the point of view of "...a new category of economic security science..." [10]. The social component of enterprise security in the structure of sustainable development is emphasized. The author reveals the dialectical relationship between the concept of sustainable development and the socio-economic security of the enterprise [10]. The author's research by Zibrova O. V. also summarizes the social significance. The author analyzes social security and the influence of various ownership entities on it. Ethical principles are proposed as an element of increasing social security [11]. Cherep O., Olejnykova L., Bekhter L., Dubinina S., Lyschenko, O. propose to expand the security issue and consider it through the spectacle of business processes. The scientists form a new view supplementing the methodology of research on the socio-economic security of enterprises [12]. Scientists Pushak Yu., Lahodyenko V., Basiurkyna N., Nemchenko V., Lahodyenko N. conducted a study of economic security at enterprises of the agro-industrial complex. The scientists proposed a model, the parameters of which are quantitative indicators of the enterprise's activity. Analysis of the model makes it possible to calculate the levels of economic security of enterprises of the agro-industrial complex. The authors experimentally applied the obtained model calculations at enterprises of Eastern Europe [13]. Scientists Kolodiazhna I. V., Bukrina K. A. investigated the connection between the concepts of security in general and economic security in particular. A range of issues regarding increasing the economic security of an enterprise at the levels of the hierarchy of macro-, meso- and micro-levels has been identified. The authors logically link the efficiency of an enterprise's activities with ensuring its economic security. It is worth pointing out that in their conclusions the authors do not pay attention to the social component, which in a peculiar way narrows the practical significance of the study [14]. The importance of studying the impact of the efficiency of an enterprise's activities on socio-economic security is presented in the thorough work by the authors of the collective monograph [15]. A deep, comprehensive analysis of the activities of Ukrainian enterprises provides an opportunity to highlight aspects of the impact of each component on ensuring socio-economic security. Authors Prystems'kyj O. S., Hryvkivs'ka O. V., Sakun A. Zh. consider the economic security of enterprises as far as the categories of economic theory are concerned. The scientists pay special attention to the regulatory framework for ensuring the economic security of an enterprise. It is accentuated that the parameters of economic security should be presented in the financial state indicators [16]. Scientist Tsiutsiupa S. V. links the aspects of forming the economic security of an enterprise with competitiveness. It is suggested to consider the competitiveness of an enterprise as a component of its economic security [17]. The attention is drawn to the analysis and division of threats according to the life support of the enterprise [17]. Arkhypenko T. A., Ivanova M. I. underline the need for a more well-grounded approach to the formation of a categorical apparatus regarding the essence of managing the economic security of an enterprise. The authors deem appropriate to unify this category and propose the author's definition of "...effective use of resources in the formation of competitive advantages under changing conditions..." [18]. The priority side of the structural unit of the enterprise for eliminating threats to the internal and external environment [18]. Author Sosnovs'ka O. O. analyzes the methodological approach to assessing the level of economic security of enterprises in an integrated manner. The author relies in her research on the concepts in the economic security science. An algorithm for constructing an integral indicator for assessing the level of economic security of enterprises is proposed. The practical significance of the results obtained is mentioned, which gives grounds for the scientist to assert the universality of the proposed approach [19]. Generalization of the methodology for assessing the level of economic security of an enterprise is determined by Shilo Z. The scientist, analyzing scientific literary sources, focuses on a significant number of existing methodological approaches to determining the assessment of the economic security of enterprises, which differ in complexity and informativeness. As a consequence, the author finds it expedient to classify and systematize existing methods. The stages of such systematization are highlighted [20]. Such a generalization is proposed by Tkachenko T. P., Hrechko A. V. The authors suggest an indicative approach in the formation of the assessment of the security components of the enterprise activities on a reasonable basis. Highlighting the economic and mathematical approach in "designing models of the behavior of the economic security system of an enterprise", they focus on the worthwhileness of "... continuous monitoring of factors for identifying economic threats..." [21]. Authors Cherep A., Dashko I., Ohrenych Yu. place greater focus on the worthwhileness of digitalization of business processes at enterprises. It has been proved that digital technologies significantly affect the socio-economic security of enterprises. The study analyzes the systemic features of the functioning of mechanisms for ensuring socio-economic security [22]. The studies by Beridze T. M, Buhra A. V., Bondarenko O. O. are devoted to the security component of the enterprise in the area of ensuring their effective activity. The authors analyze the conditions for the stable functioning of enterprises in the regional aspect [23]. It

is important to note though, that the team of authors Cherep A., Voronkova V., Cherep O., Ohrenych Yu., Dashko I., Kotliarov V. explored the issue of the impact of the use of artificial intelligence on the state of socio-economic security of Ukraine as an entry condition for ensuring sustainable development, increasing the level of security [24].

The conducted analysis of scientific views on the issue of methodological principles for the formation of socio-economic security of enterprises in the region affords grounds to take up the position of the multi-vector nature of existing scientific research. A significant number of scientific publications are devoted to improving the essence and content of the concept of "economic security". What is important to notice is that insufficient attention is paid to the social component of security, which complicates the generalization of approaches and the formation of methodological principles. It must be taken into account, that modern realities cause changes in the conditions of enterprise activity, namely the influence of the regional component. This requires new approaches, and nonetheless further development of methodological principles for the formation of socio-economic security of enterprises in the region.

Unsolved aspects of the problem. The development of regions is associated with the development of relevant enterprises. The changing external environment requires adaptation and consistency of enterprise performance indicators to external and internal challenges. Such adaptation involves the formation of a security component. Systematic research involves the application of appropriate methodological principles. Further development of methodological principles for the formation of socio-economic security of enterprises in the region is relevant, which involves clarifying and supplementing the principles of research on such issues.

The purpose of the article is to form and scale up the system of principles that make up the methodological principles for shaping socio-economic security of enterprises in the region.

Methodology. The socio-economic security of enterprises in the region under current conditions is of particular importance in consideration of the difficult economic situation of the state. In its turn, the rapid development of IT technologies and applied mathematical methods based on them provide with the freedom to move to the latest methods of economic and mathematical modeling in general and socio-economic security of enterprises in the region individually. The application of appropriate methods confers the possibility for an adequate study of the functioning of enterprises in the region, taking into consideration the most significant relationships. In accordance with the improved methodological principles of the formation of the socio-economic security of enterprises in the region, the background principle assumes consideration of the relationship between the external environment and the object of research. The systematicity defines the relationship as a factorial relationship between the external environment, the region and the enterprise. There are good reasons to apply the background principle to each individual region, taking into account its respective peculiarities. Consideration of the factors of innovativeness and investment can be considered relevant for each region of the state. In view of the above, it is expedient to use the methodology for constructing a multifactor mathematical model. Factorial relationships in the formation of the socio-economic security of enterprises in the region should be determined by innovativeness and investment. These factors most significantly reflect the socio-economic factorial relationship between the enterprise and the region.

Results. Thus, according to the method of constructing a multifactor model, we have function F that connects the value of the gross regional product (GRP) Q, which is the output variable, with its input $\vec{q} = (q_1, q_2, ..., q_n)$ – a vector of individual components that affect the value of GRP

$$Q = F(\vec{q}). \quad (1)$$

It is clear that many factors affect the formation of the GRP value. The action of the relevant factors varies in their impact on the GRP value. Thus, to develop a mathematical multifactor model of socio-economic security, it is necessary to take into consideration not only the factors themselves, but also the degree of influence of each factor on the GRP value. According to the general approach to developing a mathematical model of the object under consideration, it is necessary to carry out structural construction of the model at the first stage. This stage involves processing the form of F dependence regardless of the values of the corresponding parameters. Let us perform, relative in some specified sense, the following operation: we "split" model F and the corresponding structure St and $c_1, c_2, ..., c_n$ parameters, which made it possible to display the model in the form of a pair

$$F = \left\langle St, \vec{C} \right\rangle, \quad (2)$$

where $\vec{C} = (k, c_1, c_2, ..., c_n)$ is a vector of model parameters.

The stage of structural synthesis involves the formation of the structure St of the model. The quantitative values of the indicators of $\vec{C}$ vector are not significant at this stage. The general understanding of the structure of the model is as a set of elements and the relationship between them. Finally, the theoretical and practical application of models differs in numerical structures.

GRP Q analysis as a multifactor model depending on the magnitude of its components q_i, (i = 1, 2, ..., n) shows that the structure of this model (1) can be represented as a static and multiplicative one.

In this case, the model can be represented as

$$Q = k \cdot q_1^{c_1} \cdot q_2^{c_2} \cdot ... \cdot q_n^{c_n}, \quad (3)$$

or in rolled up form

$$Q = k \cdot \prod_{i=1}^{n} q_i^{c_i}. \quad (4)$$

The determination of the values of the parameters k, $c_1, c_2, ..., c_n$ is not important, the type of dependence is important, that is, the multiplicativity of the structure St. Thus, we emphasize the identification stage. This stage involves determining the model parameters.

Let us determine the content of parameters $c_1, c_2, ..., c_n$ in the model (4). If parameter $c_i = 0$, then the component q_i is not taken into consideration.

To find out the content of parameters c_i we take the logarithm of (4) and calculate the partial derivative with respect to the variable q_i

$$\frac{1}{Q}\frac{\partial Q}{\partial q_i}=\frac{c_i}{q_i}. \quad (5)$$

Thus, according to formula (5), the value of the parameter c_i determines the sensitivity of the GRP value Q relative to the component q_i, that is, how much the value of the component q_i affects the GRP value Q.

The next stage of model synthesis is to determine the numerical values of the model parameters $\vec{C}=(k,c_1,c_2,\ldots,c_n)$.

Let us consider a model of an object characterized by an input and an output. Consequently, we emphasize the information that is necessary to identify *St* structure, $Q(t)$ output and, accordingly, the functioning of the object $\vec{q}(t)$ under actual conditions.

So, we emphasize the two

$$I(t)=\left\langle \vec{q}(t);Q(t)\right\rangle. \quad (6)$$

Establishing quantitative values of model (4) parameters is reduced to determining the parameters $\vec{C}=(k,c_1,c_2,\ldots,c_n)$ from the initial data (6), i.e.

$$\vec{C}=\varphi(St,I), \quad (7)$$

where φ is the identification algorithm that determines how to find parameters $\vec{C}=(k,c_1,c_2,\ldots,c_n)$, knowing *St* and *I*.

Given that static model (4) is considered, there are good reasons to use a non-adaptive identification algorithm to establish the values of the indicators. In this event, the initial data take the form (7). According to the non-adaptive identification algorithm, it is necessary to substitute data (7) into formula (4). As a result, we obtain a system of *N* equations with the *n* unknowns

$$k\cdot q_{1,1}^{c_1}\cdot q_{2,1}^{c_2}\cdot\ldots\cdot q_{n,1}^{c_n}=Q_1;$$
$$k\cdot q_{1,2}^{c_1}\cdot q_{2,2}^{c_2}\cdot\ldots\cdot q_{n,2}^{c_n}=Q_2;$$
$$k\cdot q_{1,N}^{c_1}\cdot q_{2,N}^{c_2}\cdot\ldots\cdot q_{n,N}^{c_n}=Q_N,$$

which is convenient to write in the form

$$k\cdot\prod_{i=1}^{n}q_{i,l}^{c_i}=Q_l,\quad (l=1,2,\ldots,N). \quad (8)$$

Consequently, the problem of non-adaptive determination of stable model (4) is reduced to solving equations (8).

If the system of equations is inconsistent, then the method of least squares is applied, that is, the total value of the disparity is minimized – the error of the right and left parts of the equations of the specified system. For this purpose, we form the function of the total discrepancy, represented as

$$F(k,c_1,c_2,\ldots,c_n)=\sum_{l=1}^{N}\left[k\cdot\prod_{i=1}^{n}q_{i,l}^{c_i}-Q_l\right]^2. \quad (9)$$

Function (9) is integral and equals zero when the right-hand side is equal to the left-hand side of the defined equations (8). It will be understood that the closer the right-hand sides of the system equations are to the left-hand sides, the smaller the value of the discrepancy function. The set forth above is the basis for the solution of system (8) to consider the parameters as

$$\vec{C}^*=(k^*,c_1^*,c_2^*,\ldots,c_n^*), \quad (10)$$

whose value minimizes the residual function (9)

$$F(k^*,c_1^*,c_2^*,\ldots,c_n^*)=\min_{k,c_1,c_2,\ldots,c_n}F(k,c_1,c_2,\ldots,c_n).$$

Consequently, to solve the above system of equations (8), it is sufficient to minimize the total error function (9).

To simplify the calculations, it makes sense to take the logarithm of function *Q*. As a result, formula (4) will be written as (11)

$$\ln Q=\ln k+\sum_{i=1}^{n}c_i\cdot\ln q_i. \quad (11)$$

For the convenience of further calculations, it is advisable to introduce the notation

$$\ln Q=y;\quad \ln k=c_0;\quad \ln q_i=x_i.$$

Then, we have the following dependence

$$y=c_0+\sum_{i=1}^{n}c_i\cdot x_i. \quad (12)$$

The specificity of such a structure lies in the linearity of the obtained functional dependence with respect to the parameters that must be found, c_0, c_1, c_2, ..., c_n.

In its turn, the total discrepancy function is written in the form

$$S(c_0,c_1,c_2,\ldots,c_n)=\sum_{k=1}^{N}\left(c_0+\sum_{i=1}^{n}c_i\cdot x_{i,k}-y_k\right)^2. \quad (13)$$

The presented analytical transformation makes it possible to realize the minimization of the discrepancy function (12). That is, the problem is reduced to solving a system of linear algebraic equations.

The simple form of the function (12) gives the possibility to solve the minimization problem by equating the derivatives of function (13) to zero, in accordance with the necessary condition for the existence of an extremum, that is

$$\frac{\partial}{\partial c_j}S(c_0,c_1,c_2,\ldots,c_n)=$$
$$=\frac{\partial}{\partial c_j}\left[\sum_{k=1}^{N}\left(c_0+\sum_{i=1}^{n}c_i\cdot x_{i,k}-y_k\right)^2\right]=0. \quad (14)$$

Function $S(c_0, c_1, c_2, \ldots, c_n)$ is a quadratic function. This determines the linearity of (14). In fact, defining the derivatives in (14), we have

$$\frac{\partial}{\partial c_0}\left[\sum_{k=1}^{N}\left(c_0+\sum_{i=1}^{n}c_i\cdot x_{i,k}-y_k\right)^2\right]=$$
$$=2\sum_{k=1}^{N}\left(c_0+\sum_{i=1}^{n}c_i\cdot x_{i,k}-y_k\right)=0;$$
$$N\cdot c_0+\sum_{i=1}^{n}c_i\cdot\varphi_{i,0}=\eta_0,$$

where

$$\varphi_{i,0} = \sum_{k=1}^{N} x_{i,k} \quad \eta_0 = \sum_{k=1}^{N} y_k;$$

$$\frac{\partial}{\partial c_j}\left[\sum_{k=1}^{N}\left(c_0 + \sum_{i=1}^{n} c_i \cdot x_{i,k} - y_k\right)^2\right] =$$

$$= 2\sum_{k=1}^{N}\left(c_0 + \sum_{i=1}^{n} c_i \cdot x_{i,k} - y_k\right)\cdot x_{j,k} = 0, \quad (j = 1,2,\ldots,n);$$

$$\sum_{k=1}^{N}\left(c_0 + \sum_{i=1}^{n} c_i \cdot x_{i,k} - y_k\right)\cdot x_{j,k} = 0;$$

$$c_0 \cdot \varphi_{0,0} + \sum_{i=1}^{n} c_i \cdot \varphi_{i,j} = \eta_j, \qquad (15)$$

where $\varphi_{0,0} = N$; $\varphi_{i,0} = \sum_{k=1}^{N} x_{i,k}$; $\eta_0 = \sum_{k=1}^{N} y_k$;

$\varphi_{i,j} = \sum_{k=1}^{N} x_{i,k} \cdot x_{j,k}$; $\eta_j = \sum_{k=1}^{N} y_k \cdot x_{j,k}$, $(j; i = 1,2,\ldots,n)$.

As we can see, (15) is a system of linear algebraic equations with respect to the identified parameters c_0, c_1, c_2, ..., c_n,

$$\begin{cases} c_0 \cdot \varphi_{0,0} + c_1 \cdot \varphi_{1,0} + \ldots + c_n \cdot \varphi_{n,0} = \eta_0 \\ c_0 \cdot \varphi_{0,1} + c_1 \cdot \varphi_{1,1} + \ldots + c_n \cdot \varphi_{n,1} = \eta_1 \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ c_0 \cdot \varphi_{0,n} + c_1 \cdot \varphi_{1,n} + \ldots + c_n \cdot \varphi_{n,n} = \eta_n \end{cases}, \qquad (16)$$

which is solved by standard methods.

For example, using Cramer formula

$$c_0^{\times} = \frac{\Delta_0}{\Delta}; \quad c_1^{\times} = \frac{\Delta_1}{\Delta}; \quad c_n^{\times} = \frac{\Delta_n}{\Delta}. \qquad (17)$$

Thus, the parameter values minimize discrepancy function (12), that is

$$S(c_0^{\times}, c_1^{\times}, c_2^{\times}, \ldots, c_n^{\times}) = \min_{c_0, c_1, c_2, \ldots, c_n} S(c_0, c_1, c_2, \ldots, c_n). \qquad (18)$$

Therefore, the multifactorial economic and mathematical model that describes the socio-economic security of enterprises in the region according to (4) and (18) will be written as

$$Q_m = e^{c_0^{\times}} \cdot \prod_{i=1}^{n} q_i^{c_i^{\times}}. \qquad (19)$$

Let us consider as an example a two-factor model of socio-economic security of enterprises in Poltava region, which will be written as

$$Q = k \cdot q_1^{c_1} \cdot q_2^{c_2}, \qquad (20)$$

where Q is GRP per capita, UAH; q_1 is capital investment per capita, UAH tho; q_2 is innovation costs, UAH thou; k, c_1, c_2 are parameters.

The values of the parameters included in formula (20) are found by way of identification according to the given statistical material for Poltava region [25]. Table 1 shows the corresponding statistical material.

In order to use the method of least squares in linear form to find the parameters in model (20), we apply the operation of taking the logarithm

$$\ln Q = \ln k + c_1 \ln q_1 + c_2 \ln q_2,$$

or

$$y = c_0 + c_1 x_1 + c_2 x_2, \qquad (21)$$

where

$$y = \ln Q; \quad c_0 = \ln k; \quad x_1 = \ln q_1; \quad x_2 = \ln q_2.$$

Herewith, the total discrepancy function will be written as

$$S(c_0, c_1, c_2) = \sum_{k=1}^{10} (c_0 + c_1 \cdot x_{1,k} + c_2 \cdot x_{2,k} - y_k)^2. \qquad (22)$$

According to the necessary condition for minimizing function (22), we equate to zero derivatives with respect to the unknown parameters c_i of its

$$\frac{\partial}{\partial c_i} S(c_0, c_1, c_2) = \frac{\partial}{\partial c_i} \sum_{k=1}^{10} (c_0 + c_1 \cdot x_{1,k} + c_2 \cdot x_{2,k} - y_k)^2 = \qquad (23)$$
$$= 0, \quad (i = 0,1,2).$$

Expanding condition (23), we obtain a system of three linear algebraic equations with three unknowns c_0, c_1, c_2

$$\begin{cases} 10 \cdot c_0 + c_1 \sum_{k=1}^{10} x_{1,k} + c_2 \sum_{k=1}^{10} x_{2,k} = \sum_{k=1}^{10} y_k \\ c_0 \sum_{k=1}^{10} x_{1,k} + c_1 \sum_{k=1}^{10} x_{1,k}^2 + c_2 \sum_{k=1}^{10} x_{1,k} x_{2,k} = \sum_{k=1}^{10} x_{1,k} y_k \\ c_0 \sum_{k=1}^{10} x_{2,k} + c_1 \sum_{k=1}^{10} x_{1,k} x_{2,k} + \sum_{k=1}^{10} x_{2,k}^2 = \sum_{k=1}^{10} x_{2,k} y_k \end{cases}. \qquad (24)$$

Table 1

Initial data [25]

No.	Years	Q	q_1	q_2	$y = \ln Q$	$x_1 = \ln q_1$	$x_2 = \ln q_2$	Q_m
1	2013	22,000	3,400	300,000	10.00	8.13	12.61	19,729.51
2	2014	30,000	4,000	340,000	10.31	8.29	12.74	25,469.63
3	2015	35,000	5,000	400,000	10.46	8.52	12.90	35,648.87
4	2016	39,000	7,000	420,000	10.57	8.85	12.95	43,722.79
5	2017	40,000	6,500	480,000	10.60	8.78	13.08	52,223.11
6	2018	50,000	6,000	500,000	10.82	8.70	13.12	53,939.18
7	2019	65,000	5,900	540,000	11.08	8.68	13.20	60,350.6
8	2020	80,000	10,500	600,000	11.29	9.26	13.30	88,545.11
9	2021	115,000	11,000	620,000	11.65	9.31	13.34	94,814.66
10	2022	124,000	13,000	700,000	11.73	9.47	13.46	121,895.7

Table 2

Results of calculating the coefficients of the system of equations (24)

No.	y	X_1	X_2	X_1^2	X_2^2	X_1X_2	yX_1	yX_2
1	10.00	8.13	12.61	66,12	159.05	102.55	81.31	126.10
2	10.31	8.29	12.74	68.79	162.22	105.64	85.50	131.30
3	10.46	8.52	12.90	72.54	166.39	109.87	89.12	134.97
4	10.57	8.85	12.95	78.39	167.65	114.64	93.59	136.88
5	10.60	8.78	13.08	77.08	171.13	114.85	93.03	138.62
6	10.82	8.70	13.12	75.68	172.20	114.16	94.13	141.98
7	11.08	8.68	13.20	75.39	174.22	114.61	96.22	146.28
8	11.29	9.26	13.30	85.73	177.01	123.19	104.53	150.21
9	11.65	9.31	13.34	86.60	177.89	124.11	108.44	155.42
10	11.73	9.47	13.46	89.73	181.14	127.49	111.10	157.85
sum	108.51	88.00	130.70	776.05	1,708.90	1,151.10	956.97	1,419.59

The results of calculating the sums available in the system of equations (24) are presented in Table 2.

According to the data in Table 2, the system of equations (24) is written as

$$\begin{cases} 10\cdot c_0 + 88.00c_1 + 130.70c_2 = 108.51 \\ 88.00c_0 + 776.05c_1 + 1{,}151.10c_2 = 956.97 \\ 130.70c_0 + 1{,}151.10c_1 + 1{,}708.90c_2 = 1{,}419.59 \end{cases}. \quad (25)$$

The Fisher matrix is as follows

$$\Phi = \begin{Vmatrix} 10 & 88 & 130.7 \\ 88 & 776.05 & 1{,}151.1 \\ 130.7 & 1{,}151.1 & 1{,}708.9 \end{Vmatrix}. \quad (26)$$

Since the determinant of the Fisher matrix (26) is not zero

$$\left|\Phi\right| = 1.906 \neq 0,$$

then the system of equations (26) has a single-valued solution. Let us find this solution

$$c_0 = \frac{\Delta_0}{\Delta} = -12.684; \quad c_1 = \frac{\Delta_1}{\Delta} = 0.383; \quad c_2 = \frac{\Delta_2}{\Delta} = 1.543. \quad (27)$$

Thus, taking into consideration (27), formula (21) is written as follows

$$y_m = -12.684 + 0.383 \cdot x_1 + 1.543 \cdot x_2. \quad (28)$$

Let us determine the significance of the regression coefficients of the equation obtained in the analyzed example. Let us determine the values of the semi-interval of the confidence interval of the mean value of each of the coefficients, which are summarized in Table 3. The value of Student's t-test is determined from the table. For the number 9 of degrees of freedom and a given 0.95 confidence probability, it is equal to 2.262.

According to the data given in Table 3, all coefficients of the regression equation (28) are significant.

To check the correspondence of the obtained mathematical model to the process studied, it is necessary to check its adequacy. This check is an estimate of the approximation error. To carry out this assessment, the method of comparing variances using the Fisher's ratio test for a given confidence probability α is applied. If the experimental value of the Fisher's ratio test is less than its theoretical value F_α, the model is considered adequate, otherwise the model is considered inadequate. The experimental value of Fisher's ratio test is taken equal of the ratio of the residual variance (the so-called adequacy variance) to the total experimental variance of the entire experiment

$$F_{residual} = \frac{S^2_{residual}(y)}{S^2(y)} = \frac{\dfrac{\sum_{i=1}^{10}\left(\tilde{y}_i - \overline{y}\right)^2}{n-d}}{\dfrac{\sum_{i=1}^{10}(y_i - \overline{y})^2}{n-1}}.$$

According to the tabular data, we have the following

$$F_{residual} = \frac{0.431}{0.330} = 1.3. \quad (29)$$

We determine the theoretical value of Fisher's ratio test using reference tables. For the significance level $q = 0.05$, and the number of degrees of freedom $k_1 = 10 - 3 = 7$ and $k_2 = 10 - 1 = 9$, we have the following

$$F_{theor} = 3.29.$$

Since

$$F_{residual} = 1.3 < F_{theor} = 3.29,$$

then with a given confidence probability the obtained regression equation adequately describes the phenomenon under study.

Table 3

Regression coefficients significance estimation

C_i	Sum of squares of the input matrix	Standard deviation of the regression coefficient	Half-interval value	Coefficient values	Significance
C_0	49.85	0.0114	0.0114 · 2.262 = 0.0261	12.68 > 0.0261	Completed
C_1	49.85	0.0114	0.0114 · 2.262 = 0.0261	0.383 > 0.261	Completed
C_2	49.85	0.0114	0.0114 · 2.262 = 0.0261	1.543 > 0.261	Completed

Taking into consideration the use of logarithms in calculations, we obtain

$$Q_m = e^{-12.684} \cdot q_1^{0.383} \cdot q_2^{1.543}.$$

Or

$$Q_m = 3.1 \cdot 10^{-6} \cdot q_1^{0.383} \cdot q_2^{1.543}. \quad (30)$$

The figure shows graphs of real GRP values and those calculated using the mathematical model (30).

A comparison of the graphs in the Figure shows that they are in fairly good agreement. Moreover, the calculated pair correlation coefficient is

$$r_{QQ_m} = 0.969. \quad (31)$$

According to the Chaddock scale, the inequality is fulfilled

$$0.9 < r_{QQ_m} < 0.99,$$

i.e. there is a "very high" relationship between the variables.

Thus, formula (31) represents a two-factor mathematical model of the socio-economic security of enterprises in Poltava region.

Conclusions. Under modern conditions, the issue of forming the socio-economic security of enterprises in the region is of great importance. With due regard for the instability of the external environment, the increase in the cost of resources, the inefficiency of organizational and economic management mechanisms, the important task for enterprises is the formation of socio-economic security, which serves as a significant tool for their development, improving performance indicators, identifying risks and threats, and increasing competitiveness.

The socio-economic security of enterprises in the region is determined by individual components that affect security. The construction of a multifactor mathematical model of the socio-economic security of enterprises in the form of a statistical multiplicative model gave the opportunity to study the influence of individual components on the socio-economic security of enterprises in the region. And, last but not least, to indicate ways to increase the socio-economic security of enterprises in the region, based on the influence of the components that determine this security.

Through the example of Poltava region, using the relevant statistical material, a two-factor mathematical model of the socio-economic security of enterprises in the region was developed. Capital investments per person and innovation costs were selected as factors, and the assessment of the socio-economic security of enterprises was GRP per person. The formed two-factor mathematical model of the socio-economic security of enterprises in the region made it possible to assess the simultaneous influence of the factors taken into consideration.

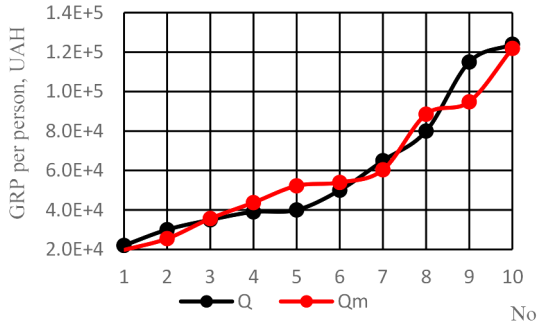

Fig. Graphs of real GRP values and calculated by the mathematical model (30)

The methodological principles of the formation of the socio-economic security of enterprises in the region are supplemented by the background principle, which is universal in nature. The background is an attribute of the system; stable processes that ensure the functioning of the laws of the composition of system relations often act as the background of the system. It is the region that can serve as the background against which an enterprise operates, where an aggressive external environment operates, the economic component and legal relations undergo changes.

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Методологічні засади формування соціально-економічної безпеки підприємств регіону

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Мета. Сформувати й розширити систему принципів, що складають методологічні засади формування соціально-економічної безпеки підприємств регіону.

Методика. При дослідженні були використані методологічні засади складних виробничих систем, методика побудови багатофакторних моделей, системний багатофакторний аналіз, методи структурного синтезу.

Результати. Сформована багатофакторна економіко-математична модель, що дозволило провести аналіз факторного впливу інноваційної та інвестиційної складової на валовий регіональний продукт. Проаналізована система принципів, що складають основу методологічних засад формування соціально-економічної безпеки підприємств регіону.

Наукова новизна. Набула подальшого розвитку методологія формування соціально-економічної безпеки підприємств регіону. Запропоновано включити в систему принципів фонову закономірність або фоновий принцип, що носить універсальний характер. Визначена доцільність застосування багафакторного моделювання при формуванні соціально-економічної безпеки підприємства.

Практична значимість. Побудована багатофакторна математична модель у вигляді статистичної мультиплікативної моделі дала змогу дослідити вплив окремих компонентів на соціально-економічну безпеку підприємств регіону та вказати шляхи її підвищення, спираючись на вплив цих компонентів. Врахування фону як атрибуту системи забезпечує функціонування законів композиції відносин системи. Саме регіон може слугувати тим фоном, в якому функціонує підприємство, де діє багатомірність суперечливих впливів.

Ключові слова: *підприємство, регіон, соціально-економічна безпека, методологія, моделювання*

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