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RISK ASSESSMENT AND RISK ANALYSIS FOR PRODUCTION ACTIVITIES UNDER THE CONDITIONS OF MARITAL STATE

ОЦІНКА ТА АНАЛІЗ РИЗИКІВ ВИРОБНИЧОЇ ДІЯЛЬНОСТІ В УМОВАХ ВОЄННОГО СТАНУ

Summary. The article is devoted to the problem of determining the military risks characteristics and the development of mathematical formalization methods to identify at the initial stage signs of an increase in the level of risks. In the research process, the following was applied: a comparative analysis to identify the indirect influence of war risks on other risks; analytical method for identifying features of military risks; methods of mathematical formalization to detect at the initial stage aperiodic fluctuations of time series of risk parameters for timely hazard forecasting. Specific features of military risks are determined. A complex mathematical approach is proposed to identify signs of an increase in the risks level at the initial stage of their formation in order to ensure the flexibility of production activities management, increase the adaptability of the enterprise to threats, and acquire the ability of the enterprise to survive. Mathematical formalization methods are proposed for detecting aperiodic harmonic fluctuations of a time series, as a manifestation of risk, and forecasting production activity in conditions of significant uncertainty of the risks parameters. The proposed mathematical formalization approaches will make it possible to detect signs of an increase in the level of risks at the initial stage of their formation to ensure flexibility in the production activities management.

Keywords: production activities, uncertainty, risk, risk analysis, risk assessment, classification of risks, enterprise, martial law, military risk, forecast, mathematical formalization, time series, aperiodic fluctuations, risk-based approach, risk management, business sustainability, production process management.

Анотація. Дослідження присвячене аналізу ризиків виробничої діяльності в умовах воєнного стану та розробці математичних методів для формалізації процесу їх виявлення на ранніх стадіях підвищення рівня небезпеки. В умовах воєнного стану підприємства стикаються зі значними загрозами, які впливають на весь спектр виробничих ризиків. Серед основних загроз можна виділити: ракетно-бомбові удари по інфраструктурі, порушення логістичних ланцюгів, знищення контрагентів, зменшення купівельної спроможності населення, зростання інфляції, подорожчання кредитів та дефіцит трудових ресурсів. Воєнні ризики змушують переглянути концептуальні підходи до ризик-орієнтованого менеджменту: змінити організацію виробничих

процесів, підходи до планування, прогнозування та оцінки додаткових витрат. Аналіз таких загроз повинен охоплювати всі етапи та напрями діяльності підприємства. В зв'язку з цим необхідно чітко класифікувати воєнні ризики на прямі та опосередковані, а також оцінювати вплив усієї сукупності військових загроз. У рамках дослідження були виявлені особливості воєнних ризиків, розроблено математичний апарат для їх оцінки та формалізації виявлення на початкових етапах, що сприяє підвищенню адаптивної спроможності підприємств і забезпечує їх виживання. Прямі воєнні ризики, такі як ракетно-бомбові удари, пропонується аналізувати за допомогою часових рядів. Один ряд характеризує удари по підприємствах певної галузі, інший – по регіонах, де знаходиться підприємство. Оцінювання в реальному часі дозволяє ідентифікувати аперіодичні гармонійні коливання, що перевищують фоновий рівень. Для формалізації виявлення таких коливань запропоновано використовувати фрактальний аналіз, індекс Герста, методику R/S-аналізу та «клітинковий» метод обчислення фрактальної розмірності, кластерний аналіз. Прогнозування діяльності підприємств в умовах високої невизначеності воєнних ризиків здійснюється із застосуванням методу «випадкового дощу». Розроблені математичні методи дозволяють своєчасно виявляти та оцінити ризики, забезпечуючи гнучке управління виробничими процесами та підвищення стійкості підприємств.

Ключові слова: виробнича діяльність, невизначеність, ризик, аналіз ризиків, оцінка ризиків, класифікація ризиків, підприємство, воєнний стан, військовий ризик, прогноз, математична формалізація, часові ряди, аперіодичні коливання, ризик-орієнтований підхід, управління ризиками, стійкість бізнесу, управління виробничими процесами.

Statement of the problem. Threats to enterprises in the conditions of martial law have a significant impact on the entire complex of risks, which cover all aspects of production activity. Production is threatened not only by rocket-bomb attacks on its infrastructure, on logistics chains, on counterparties, but also by a decrease in the purchasing power of the population as a result of the war, an increase in inflation, an increase in the cost of loans, a shortage of labor resources, etc.

The full-scale war of the Russian Federation against Ukraine led, according to the UN report, to the reduction of the Ukrainian economy by more than 35%, the result of which is that the monthly deficit of the state budget of Ukraine increased by more than 5,000 million dollars [1]. As a result, macro-economic risks of a significant scale were formed, which pose a threat not only to the economy of the country as a whole, but also to every subject of economic activity.

War reduces the adaptive capacity of economic activity subjects to threats. A significant change in the level of risk in a short time can put an enterprise on the verge of survival, therefore, a predictive assessment of threats in conditions of dynamic changes in risk parameters is important.

War risks also fundamentally changed the conditions of enterprise management, which, in turn, had to change the organization of production activities, methods of planning and forecasting production, etc. This, accordingly, not only requires a change in risk-oriented peacetime approaches, the development of new methods of assessing military threats, requires not only taking into account the level of losses from the specified risks, but also indicates the need to identify them in a short period of the formation of the impact of risks. The above determines the direction of research accordingly.

Analysis of recent research and publications. The difficulty of introducing new approaches to risk management for production activities during wartime, planning, forecasting and, accordingly, the use of organizational measures to neutralize threats illustrates the significant divergence of views of scientists on this issue.

Thus, in Butkevych's article [2], it is proposed to increase attention to "weak signals...conducting business activities" in wartime conditions. In our opinion, military threats and the factors they affect cannot be classified as "weak signals".

The application of risk management approaches standardized by international standards, in particular the ISO 31000:2018 "Risk management" standard, developed for peacetime, for the management of an enterprise in war conditions does not provide relevant results, especially when a war zone is approaching the location of the enterprise, or recognition of this enterprise as a desirable target for the aggressor, contrary to the conclusions given in the article [3], which, we note, was published in the midst of a full-scale war, during which practitioners had already outlined some directions for taking into account the risks of war.

The proposal by scientists [4] of risk management approaches that are effective in peacetime, the failure to take into account war risks when forming schemes for the main stages of an enterprise's activity in wartime, the introduction of risk management tools designed for the delayed action of threats, in our opinion, in the conditions of a state of war is quite questionable.

The position of scientists [5], according to which the main factor of the influence of military risks on the activity of the enterprise is their uncertainty, which causes, according to scientists [5], improper organization of management to neutralize the effects of military threats also seems doubtful.

The use of qualitative analysis of military risks [6] does not provide opportunities for the introduction of organizational measures to neutralize or avoid dangers and necessitates the use of quantitative analysis methods. But the introduction of these methods requires weighted decisions regarding the

choice of the method of mathematical formalization as a basis for quantitative analysis. Thus, modeling the impact of war risks using Boolean algebra [7] does not provide sufficiently relevant results, since the quantitative impact of war threats cannot be sufficiently accurately determined using the mathematical approaches proposed [7].

The above points to the relevance of determining the features of the impact of military risks and, taking into account these features, the development of methods for the mathematical formalization of identifying signs of an increase in the level of risks at the stage of their formation, which will provide the opportunity to introduce relevant management decisions to avoid and (or) neutralization of threats.

Highlighting previously unsolved parts of the overall problem. It was established that military risks have a system-forming nature for the entire complex of production activity risks and, in addition to direct influence, form an indirect influence on all other types of risks. It was established that if in the theory of risks the weight of the risk is used as the main characteristic of the impact of the threat, then in the conditions of war such characteristics also become the speed of risk change and the acceleration of the risk change.

The purpose and objectives of the article. The purpose of the article is to determine the features of military risks and develop methods of mathematical formalization of identifying signs of an increase in the risks level at the initial stage to ensure the flexibility of managing production activities, increase the adaptability of the enterprise to threats, and acquire the ability of the enterprise to survive. The above determines the tasks: detection of aperiodic harmonic fluctuations of the time series, as a manifestation of risk, at the stage of their formation, and forecasting of production activity in conditions of significant uncertainty of the parameters of all types of risks.

Presentation of the main material. Military risks not only shape the probability of loss of warehouse stocks, means of production, and personnel. The very fact of military aggression leads to radical changes in all spheres – economic, political, social, etc. And these changes are not limited to the macro level – they also affect all aspects of production for each enterprise.

Therefore, wartime threats require a change in the paradigm of risk-oriented management of production activities, changes in the organization of production, changes in planning and forecasting, changes in the assessment of the growth of additional costs. In particular, the impact of war risks should be considered for the entire production chain, for all directions and areas of production activity.

This, on the one hand, requires the classification of military risks of direct impact on production and the risks of indirect impact, and, on the other hand, requires the formation of an assessment of the impact of the entire set of threats during a state of war.

The risks of the indirect influence of war threats include the entire range of risks to peacetime production activities, which have been sufficiently fully and repeatedly described in scientific studies, in particular [4]: macroeconomic, financial, fiscal, technological, organizational, corporate risks, etc.

The terminological definition of "risk of indirect influence" is not the same as the concept of "insignificant risks". The severity of the risks of indirect influence under the appropriate conditions and under a certain industry affiliation of the enterprise can create a significant level of danger to production activity.

The conducted research made it possible to establish that war risks not only significantly increase all types of peacetime risks, but also sometimes lead to the formation of new threats that were not previously inherent in certain groups of risks. Thus, the threat of a deficit of the state budget as a result of military operations, which according to the accepted classification belongs to macroeconomic threats, has the following consequences: an increase in taxes for enterprises; rising prices for energy and other resources, etc. This, in turn, is a multiplier for the growth of other risks, in particular financial (significant inflation, higher credit costs, reduction of investments), a decrease in the level of competitiveness for subjects of economic activity, that is, it forms the second level of indirect influence of military risks.

The indirect effect of war threats on other risks for producers can be illustrated by the following examples. As an indicator of macroeconomic risks and their changes caused by military threats, the Financial Stress Index (see Fig. 1) and its five main sub-indices can be used as indicators of the level of risk in the areas of macro-financial danger. Macroeconomic indicator – the financial stress index varies in the interval (0...1), where 1 is the maximum, catastrophic level of stress. The dynamism of its change illustrates the speed of the threats emergence and changes in its magnitude from an insignificant to a catastrophic level in the conditions of a state of war. The indirect influence of war risks on the value of the Financial Stress Index is indicated by the correlation of significant military threats and the acquisition of peak values by the Index during the growth of the level of military threats (see Fig. 1).

A study of the dynamics of the employed population indicator also testifies to the significant indirect influence of war risks (see Fig. 2). This, in particular, is indicated by the break in the steady trend of the period 2013–2014 in 2014, the year of the beginning of the Russian aggression against Ukraine. More indicative is the breakdown of the trend of the steady level of the number of the employed population in the period 2015–2021 in 2022 – at the beginning of a full-scale war. The indicated indirect influence of war risks, in this case, leads to the threat of labor resources loss by the economy of Ukraine as a whole and by each subject of economic activity in particular.

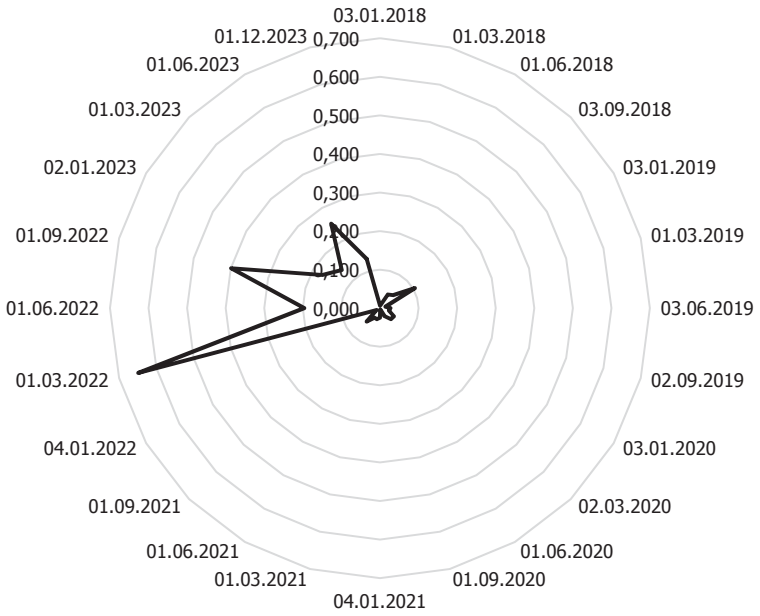

Fig. 1. Dynamics of the financial stress index

Source: compiled by the author based on NBU data [8]

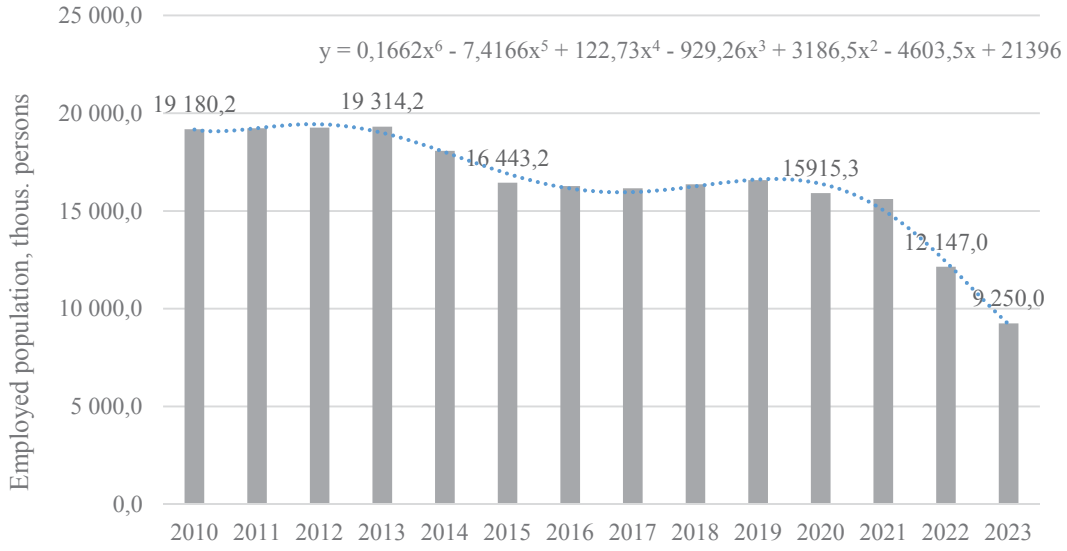

Fig. 2. Dynamics of the number of employed population, thousand persons.

Source: compiled by the author based on the data of the State Statistics Service [9]

Breaking down the derivatives of the graphs of the financial stress index, the dynamics of the number of the employed population coincides in time with the escalation of military operations, which confirms the thesis about the shortening of the time interval of the military threats influence even on those risks of production activities that are not directly related to military risks. Therefore, the task of neutralizing military risks necessitates an increase in the speed of threat detection, which should contribute to reducing the time of development, adoption and implementation of management and production decisions.

This determines the specifics of military risks:

1. Military risks have a system-forming nature for the entire set of risks of production activity.
2. Military threats create new risks for the activities of business entities, which differ significantly from the risks inherent in the measurement of time in terms of the nature of the action, the magnitude of the impact, and the time interval during which they grow from insignificant to catastrophic.
3. Military risks are characterized by a significant level of uncertainty both in terms of magnitude and direction of action. Their features make

long-term relevant planning of production impossible for individual areas of the company's activity, in particular, financial activity.

4. If in the theory of risks the main characteristic of the influence of the threat was the weight of the risk, then in the conditions of war such characteristics also become the speed of change of risk and the acceleration of change of risk.

5. War risks significantly increase those groups of risks that, it would seem, have no direct connection with wartime threats, for example, significant changes in a short time in market demand, changes in the level of competition in the industry market, etc.

6. Military risks, due to the significant level of uncertainty of their factors and the significant dynamism of change determine the need for adaptive management to maintain the stability of production activities.

7. Military risks cause the need for significant variability of strategic plans to ensure the appropriate adaptability of the enterprise.

8. Measures to prevent the impact of military risks may form threats of the second level, less serious, but, at the same time, requiring appropriate management measures.

The first point of the above list indicates the peculiarity of military risks established in the course of the research, the results of which are presented in the presented article – they are significant not only in terms of the weight of the impact on production activity, but also in terms of the systemic nature of the impact on the entire set of risks for the specified activity.

The specified impact of war risks on other risks can be not only negative, but in some cases, even benefit a specific production. For example, with proper adaptive capacity of an enterprise to wartime threats, its competitiveness increases, and if competitors leave the market as a result of wartime risks, this enterprise can occupy vacated market niches.

The eighth point of the above list can be illustrated by the following example. In order to reduce the level of the company`s destruction threat of infrastructure by a rocket-bomb strike, management often introduces the dispersion of warehouse stocks and even production infrastructure facilities, which leads to an increase in the volume of internal logistics of the company. Since the number of personnel, as a rule, does not increase, this leads to an increase in the load on each employee, which, accordingly, increases the risk of industrial injuries, causes an increase in the Employee Turnover Index, and leads to a decrease in the efficiency of production processes. This, accordingly, requires additional management measures.

As a result of the wide range of military risks and their features indicated above, the mathematical apparatus for assessing threats, formalizing the detection of signs of an increase in the risks level at the initial stage to ensure the flexibility of managing production activities, increasing the adaptability of the enterprise to threats, acquiring the ability of the enterprise to survive, should have a comprehensive nature.

Thus, the military risks of direct action, in particular, the risks of missile and bomb strikes, are proposed to be determined by two time series – a series describing missile and bomb strikes on enterprises of the industry to which the specified enterprise belongs and a series describing missile and bomb strikes on the region where the company is located. The assessment should be carried out in real time and should be aimed, in particular, at the detection of aperiodic harmonic oscillations, greater than the background level, of the time series at the moment of their formation.

Timely detection of such fluctuations will enable prompt adjustment of production activities, which will reduce the impact of the hazard. At the same time, this applies only to direct military threats.

The problem of assessing dynamic changes in time series of risk parameters that are indirectly affected by military threats is the lack of proper official statistics of changes in the specified parameters in real time. Therefore, in the process of implementing the research results, the entire range of information sources – both official and unofficial – was used.

For example, analysis of job search sites was used to assess changes in the risk of loss of personnel potential: Djinni.co; Work.ua; Rabota.ua; Layboard.com; Dou.ua; OLX.ua. The integration of the data of these sites by areas – the number of vacancies and the number of resumes of job seekers made it possible to assess the level of supply and demand not only in the labor market as a whole, but also in individual areas and, most importantly, to ensure the proper statistical significance of data samples and conduct an assessment in the mode real time.

For the mathematical formalization of the process of detecting aperiodic harmonic oscillations of indirect military threats time series, and acquiring the possibility of automated software tracking of the appearance of these oscillations, it is proposed to use fractal analysis. For this, it is necessary to calculate the fractal dimension, the Hurst index [10] in real time, and, on this basis, apply the method of sequential R/S analysis.

This will make it possible to detect in a timely manner against the background of "white noise" the tendency to increase the amplitude of the indicative parameter. The justification for the possibility of applying Mandelbrot fractal analysis in this case [11] is due to the fact that the Hausdorff-Bezykovich dimension $D(X)$ of the fractal set of parameters of military risks is almost never an integer.

The fractal dimension of the time series of war risk parameters can be found using the "cell" method with variable sizes of the square cells of the fractal grid in

the dimeric plane of the time series graph, using the formula given in the work [12]:

$$D = \lim_{\varepsilon \to 0} \log n(\varepsilon) \Big/ \log \varepsilon^{-1} \quad (1)$$

де n – the number of cells; ε – the size of the square side.

On the one hand, the definition of the fractal dimension as a fractional value contradicts Hausdorff's conclusion, according to which the number of squares should be determined by a whole number, but, on the other hand, the localization of the extremes of the time series $y(\tau)$, where τ – time, under forced displacement of the fractal grid can fluctuate in the interval $(n,n–1)$. Also, for fixing the size of the square side (ε) and value ($y_{\max}–y_{\min}$), you can calculate the optimal number of squares $(y_{\max}–y_{\min})/\varepsilon$ and to determine that this quantity is predominantly a fractional value, that is, it meets the Mandelbrot requirement [9]. At the same time, since the error does not exceed the size of the square side, it is possible to use the formula in further calculations (1).

The use of the Hurst indicator makes it possible to detect an increase in the level of white noise, which can also be a sign of risk, due to the increase in the amplitude of the indicative parameter.

$$H = -\frac{n}{2} + \log\{\sum\nolimits_{\tau=1}^{n} \left[y(\tau_i) - \bar{y} \right]\} / S_\tau \quad (2)$$

де n – the number of cells; $y(\tau_i)$ – the current value of the square side; $\bar{y}$ – the mean value of the square side; S_τ – standard deviation.

Consider the time series Y, which consists of m observations: $Y = \{y_i\}_{i=1}^{m}$.

Let's divide this series into segments and find the average values for the initial segments $\bar{y}_\tau$. The deviation is determined by the formula

$$y_{\tau,t} = \sum\nolimits_{i=1}^{t} \left(y_i - \bar{y}_\tau \right) \quad (3)$$

where t – time ($t \in \tau$).

The amplitude of the deviation is determined by the formula

$$R_{\tau,t} = \max_{1 \le t \le \tau} y_{\tau,t} - \min_{1 \le t \le \tau} y_{\tau,t} \quad (4)$$

where $R_{(\tau,t)}$ – deflection amplitude.

Next, the standard deviation is calculated for each segment of the time series:

$$S_{\tau,t} = \sqrt{t^{-1} \sum\nolimits_{i=1}^{t} \left(y_i - \bar{y}_t \right)^2} \quad (5)$$

The rate of change in the amplitude of the deviation is proposed as an estimated risk parameter ($\frac{dR_{\tau,t}}{dt}$) and acceleration ($\frac{d^2R_{\tau,t}}{dt^2}$).

The limits of the change intervals are determined by an expert for each subject of economic activity separately.

Next, the so-called *R/S*-trajectory, i.e., functional dependence, is built $\log_{10}(R_{(\tau,t)} / S_{(\tau,t)}) = f\{\log_{10}(t)\}$ and the linear regression equation is formed:

$$\log_{10}\left(\frac{R_{\tau,t}}{S_{\tau,t}} \right) = \log_{10} A + H \log_{10}(t) \quad (6)$$

where A – constant, H – Hirst index.

Construction of the H-trajectory on the basis of this equation can provide the value of the average length of the aperiodic cycle. Also for using the indicator $V_{(\tau,t)} = R_{(\tau,t)} / (\sqrt{t}\ S_t)$ growth, stabilization and decline of the aperiodic cycle can be detected.

Forecasting production activity in conditions of significant uncertainty of the parameters of all risks types during the war requires the use of special methods. For this, it is proposed to use the "random rain" method, since it is used to determine the rate of attractor`s on the response surface of the objective function. The response surface is modeled in call "potential field" which is recognized as a function

$$U = \varphi(a,b,c\ldots) \quad (7)$$

where U – potential; φ – functional dependence; $a,b,c\ldots$ – in particular, the parameters by which risk is determined are unclear.

The type of function and algorithm for calculating fuzzy parameters depends on expertly defined fuzzy production rules. Under the modified model of random rain, which generates branched cellular structures, the risk parameters change randomly, forming so called "clustering centers". For m clustering centers, their weight is determined

$$w_j = M_j / \sum\nolimits_{j=1,m} M_j \quad (8)$$

where j = 1,…m – clustering center index; M_j – number of threats to j clustering center.

The initial conditions of the potential field for an arbitrarily determined instant of time are normalized; the probability of clustering corresponds to the probability of two mutually independent events: the presence of a center (cell) of clustering and provision of conditions for clustering by a normalized potential field – $U(a,b,c\ldots)$. Since the clustering process is implemented purely in the nodes of the square cell, therefore the clustering probability is defined as

$$P(a,b,c\ldots) = U(a,b,c\ldots) P^*(a,b,c\ldots) \quad (9)$$

where $P(a,b,c\ldots)$ – clustering probability; $P^*(a,b,c\ldots)$ – the probability of finding a square cell on the attractor. In this case, the attractor can be understood as a dangerous approach to an object that has a priority character as a target of missile and bomb strikes, or a risk trend that is under the indirect influence of military threats. Obviously, always $P^*(a,b,c\ldots)>0$, which results in a non-zero probability of clustering in conditions of war risks.

The specified methods of mathematical formalization will allow detecting signs of an increase in the level of risks at the initial stage to ensure the flexibility of production activities management.

Conclusions. It was established that military risks have a system-forming nature for the entire complex of production activity risks and, in addition to direct influence, form an indirect influence on all other types of risks. It was established that if in the theory of risks the main characteristic of the impact of the threat was the weight of the risk, then in the conditions of war such characteristics also become the speed of change of risk and the acceleration of risk. It is indicated that military risks, due to the significant level of uncertainty of their factors and the significant dynamism of change, determine the need for adaptive management to maintain the stability of production activities.

It is noted that for a wide range of threats, the different nature of changes in risks and directions of their influence, in order to increase the adaptability of the enterprise, the mathematical apparatus for detecting and assessing the level of threats should have a comprehensive nature. Thus, the military risks of direct action are proposed to be determined by two time series – a series describing missile and bomb attacks on enterprises of the industry to which the specified enterprise belongs and a series describing missile and bomb attacks on the region where the enterprise is located. The assessment should be carried out in real time and should be aimed, in particular, at the detection of aperiodic harmonic oscillations, greater than the background level, of the time series at the time of the formation of these oscillations.

For the mathematical formalization of the process of detecting aperiodic harmonic oscillations of time series of indirect military threats, it is proposed to use fractal analysis. The use of the Hurst indicator makes it possible to detect an increase in the level of white noise, which can also be a sign of risk, due to the increase in the amplitude of the indicative parameter. It is proposed to use the H-trajectory to determine the average length of the aperiodic cycle. Also for using the indicator $V_{(\tau.t)} = R_{(\tau.t)} / (\sqrt{t}\ S_t)$ it is proposed to determine the growth, stabilization and decline of the aperiodic cycle. Forecasting production activity in conditions of significant uncertainty of the parameters of all types of risks during the war requires the use of special methods. For this, it is proposed to use the "random rain" method, since it is used to determine the rate of change of the attractor on the response surface of the objective function.

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