Diagnostics of the State of Safety-Oriented Enterprise Management System Using Neural Networks

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Abstract **– Enterprise management is based on the need to make and justify management decisions that contribute to its development. It is almost impossible to determine the risk of a particular managerial decision, and excessive risk in the implementation of individual projects can lead to loss of business. Therefore, management faces the need to find a balance between benefits and risks, at which, on the one hand, it will be possible to develop a company and, on the other hand, adhere to postulates of safety-oriented management. Since management decisions cannot be foreseen for all possible situations and combinations of risk-benefit ratios, a universal model is proposed. It implies a golden ratio, depending on the limited number of current conditions, that would satisfy an enterprise management from the standpoint of sufficient justification on a decision. The article proposes a probabilistic neural network architecture and Matlab parameters of a probabilistic neural network for diagnosing the states of a safety-oriented control system. The proposed model in the form of a probabilistic neural network generates a response to input data on previous month under estimation, and forms an optimal state for a next month.**

Keywords **– managerial decision, economic security, risk, benefit, neural network.**

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1. Introduction

Economic development in most countries is characterized by instability in economic, political and other areas that directly affect the conditions of enterprises' operation and performance. In turn, the crisis of external environment and imperfection of enterprise' s internal processes is reflected in the system of their economic security, forcing management to seek new approaches to management and decision-making. One of such approaches is a safety-oriented approach, which is aimed not only at enterprise effectiveness, but also takes into account its safety operation.

Safety-oriented management is not an end in itself of an organization, goals are determined by owners in accordance with a company strategy and vision of its basic processes' development. The assertion of importance of economic security is beyond doubt in the face of emerging threats and dynamic changes in socio-economic situation in most countries. At the same time, the absolute leveling of economic efficiency is not entirely appropriate in conditions of high competition on the market. In this situation, in the context of the study, it is more appropriate to talk about a balanced approach between safety and cost-effectiveness, taking into account specifics of markets and industries.

In modern business conditions, it is incorrect to reject the task of ensuring the enterprise profitability, but in any case, the basis for decision-making and guidelines in the enterprise should be a combination of criteria to ensure both profitability and safety of its activities.

The implementation of the concept of safety-oriented management in practice involves compliance with its main provisions, considering it is extremely important to comply with the ratio of expected benefits and risks. Since it is almost impossible to determine the risk of a certain management decision without taking into account the specifics of doing business and the expected consequences of such a decision in certain market conditions at the time of the decision, it is advisable to use appropriate economic and mathematical tools. At the same time, the criterion of profit maximization under the condition of risk minimization will not always adequately show the real state of affairs, a situation in which it is necessary to show a minimum of activity (minimum risk) and maintain a certain level of "welfare" of managers is possible and even desirable, especially in a short term and the position of "hired managers". Instead, excessive risk in the implementation of individual projects can lead to the loss of business, because in a large business even one large-scale unrealized project can destroy all previous achievements and the company image.

It will be logical to find a balance of benefits and risks, which will make it possible to develop the company on the one hand and adhere to the postulates of safety-oriented management on the other. Accordingly, decision-making should be based on the results of an application of a certain economic and mathematical model, which takes into account a sufficient number of influencing factors that will ensure a reliable result for a particular enterprise in certain conditions of its activity.

In general, regarding the conceptualization of safety-oriented management in the research of scientists in various fields and research areas, it is appropriate to state the following. In the work by Zachko O. [25], it is noted that the safety-oriented methodology of project and program management is an effective mechanism for managing the reform and development of existing organizational and technical systems in conditions of limited resources, where the author, based on a review of literature, indicates that current trends in project management theory indicate a gradual transition from based on economic indicators to management based on values, safety indicators and social impact [25]. The above testifies to the interdisciplinary and intersectoral relevance of safety-oriented management and the active search for new scientific and methodological approaches to ensure the enterprise economic security and its development.

The conceptualization of safety-oriented management of innovative development of an industrial enterprise was studied in the work by Voloshchuk L. [22], which states that the general purpose of safety-oriented management of innovative development of an industrial enterprise is to ensure a satisfactory level of economic security in the process and as a result of innovative development, i.e., a certain desired state of economic security of innovative development, and the key task is to balance between innovation and development security in the system of their certain features [21].

Regarding the interpretation of safety-oriented approach to enterprise management, in our opinion, it is aimed at achieving the desired state of security and effective (profitable) operation of the enterprise in the presence of negative external and internal environments which is ensured by the adoption of management decisions by management entities of different levels. The main criteria, which make it possible to assess the importance and feasibility of implementing a safety-oriented approach to enterprise management, are safety and profitability. In addition to these two criteria, safety-oriented management should be based on flexibility, which will allow the system of economic security of enterprises to respond quickly and effectively to the dangers of the external and internal environment.

Despite some attention in the scientific society to the issues of security management, the practical implementation of the proposed approach in the enterprise management system, and the specifics of organizational and methodological support of this process are not fully covered and require further research.

In most studies on economic security and safety in general, the analysis of negative factors affecting the object of study is almost mandatory, but such analysis is more related to specific threats to the normal (safe) functioning of an individual entity. Accordingly, a significant number of scientists [8] focus on threats, because they are more specific and targeted and to level them it is necessary to activate the enterprise's economic security, or in its absence (or rather lack of formalized representation), such actions will be generated by the existing management system. That is, safety-oriented management will be directly manifested in practice.

As noted in [11], [12] there are four main sources of threats, namely: naturogenic (of natural origin); sociogenic (of social origin); anthropogenic (created by the activities of people and their social groups); man-made. Named sources determine the presence of different types of threats, and their composition differs slightly in the approaches of different scientific schools [2], [3], [17], but the most significant differences are observed taking into account sectoral and regional characteristics.

Analysis of approaches [9], [13], [18], shows the presence of internal and external threats to enterprise activity and a large group of specific threats. At the same time, some types of threats are "standardized", i.e., inherent in most industrial enterprises. Also, there are threats to material resources; threats to financial resources; threats to the safety of production technologies; threats to commercial activity [10]. Dyachenko O. among the threats inherent in construction companies includes: unstable political situation and imperfect legislation, emergence of new competitors on the market, reduced profitability of construction of typical housing, lack or insufficiency of state measures for the construction industry, instability of world currencies, increasing tax pressure, inflation, difficulties in concluding agreements with consumers and suppliers, the growth of the global financial crisis, threat of rising interest rates and lending conditions [6].

Given the peculiarities of the presented threats, it should be noted that reaction of the enterprise management system to existing threats and their consequences, involves emergence of a certain amount of costs. Such costs come in many forms and can have a significant impact on their overall volume. Thus, paper [14] highlights preventive costs - cost of developing and implementing measures to prevent threats; post-costs - cost of eliminating the consequences of threats; general costs - the cost of ensuring the enterprise's economic security, which is the sum of preventive and post-costs. We fully agree with this approach, as the lack of management's attention to threat prevention measures (with the appropriate amount of funding on such measures) as a result leads to post-costs, which can significantly outweigh the cost of prevention.

Melikhova T.O. builts for the first time "a schedule of interaction of economic security results and costs, depending on the length of the life cycle. Graphic analog model of interaction of results and costs, depending on the duration of a life cycle, as well as indicators of economic efficiency of costs for enterprise economic security" [16].

It should be emphasized that there are almost no universal approaches for determining the optimal cost for economic security. Thus, in economically developed countries, the generally accepted norm of contributions to an enterprise security regime is from 5 to 15% (in some countries up to 18-20%) of the company's profit before taxes. The amplitude of 10% arose due to different operating conditions of business structures in different countries. Thus, for Switzerland, the cost of enterprise security is usually 5-6%, and in Japan their value is about 16-18% [1]. Although not all costs of enterprise security can be directly attributed to the costs of ensuring economic security, however, most of them indirectly affect its level. Information about costs is accumulated in an enterprise accounting and analytical systems, and their detailing is carried out in accordance with managers' requests.

In [4] it is indicated that the system of accounting and analytical support for managing the economic security of business entities contains accounting and reporting flows in four main directions:

1) protecting owner's interests on property preservation;
2) finding out the directions for improving data on creation of certain services or responsible persons in cyberspace, formation of a reliable and secure enterprise information system;
3) avoiding or reducing the degree of risks of threats to economic security due to an increase in human resources;
4) development of economic security and minimization of unregulated factors to enhance safety in production and management by creating a labor protection department [4].

Today, the search for a "balance of interests" of all stakeholders within the enterprise is becoming increasingly important, as owners, managers and executors mostly have different views on strategic and operational processes (including in the field of resource support for the functioning of the enterprise economic security system). At the same time, formalization of manifestation of such a vision testifies to imaginary unanimity and unambiguity of interested subjects' opinions, manifested in the development strategy approval or the operational action program declaration. However, the realities show that traditional management approaches are not able to identify threats with a sufficient degree of efficiency, and reactions to negative impacts are delayed and do not provide the desired result. Thus, actions within a management system and economic security system in particular do not always have sufficient justification. Usually, actions are related to decisions, and decisions in most cases have an alternative in the degree of risk.

2. Research Method

Among the factors that affect conditions and, consequently, results of enterprise activity, it is necessary to identify those that a small change can cause significant changes in results of enterprise activity. In other words, we need to focus on the most "sensitive" aspects of such functioning. However, already at the beginning an important question arises: will the list of such "sensitive" aspects actually be constant? Will it depend on weather conditions, which are known to affect the immediate construction process? The answer is quite obvious. Of course, in the period when the weather conditions are favorable, the construction business is progressing. Basically, these are relatively warm and even hot periods of the calendar year. We can assume that this period in Ukraine lasts from April to October (only - seven months). Other months are relatively cold, so the period from November to March is divided into one during which the risks of stagnation of the construction business increase.

Along with seasonality, we need to recognize that the main task of the construction business is to sell construction materials and related products, while providing certain services (including loading, delivery, unloading). Therefore, during the period from April to October, the main goal is to maximize profits, while during the period from November to March, the priority is to minimize losses. Accordingly, enterprise operation conditions and factors influencing them will be different for these periods.

During the period from April to October we will have the following conditions:

1) growth in sales volumes, revenue and profit;
2) minimization of receivables;
3) effective motivation of employees;
4) sufficient level of resource provision;
5) flexibility of management and efficiency of reaction to external influence.

During the same period, the company is forced to deal with the following risks:

1) insufficient level of resource provision (it can be human resources, raw materials, energy resources, logistic component);
2) critical growth of receivables and lack of working capital;
3) slow reaction to changes in market conditions;
4) lack of stocks of finished goods to cover the "peak" demand;
5) low level of employee motivation.

Instead, during the period from November to March, enterprise operation conditions and factors influencing them will be shifted in the "opposite" direction:

1) growth in sales volumes, revenue and profit;
2) reduction in volume of accounts payable;
3) lack of resources;
4) slowing down the response to external influences by saving costs;
5) growth of stocks and "freezing" of assets.

The risks in this relatively unfavorable period are mainly related to the general "freezing", stagnation of the construction business:

1) lack of orders and effective demand;
2) exceeding the level of necessary resource provision for real needs (in particular, we are talking about human resources, because construction work in an unfavorable period is carried out at a slow pace);
3) critical growth of accounts payable and lack of working capital;
4) slow reaction to changes in market conditions;
5) low level of employee motivation.

Taking into account the specifics of the construction business, the processes of implementing peer-to-peer management should be modeled so that the management solution is both flexible and sustainable at the same time. This can be done on the basis of a model that will match the optimal state of its operation to any set of conditions for an enterprise operation (assessed on the basis of appropriate risks). In addition, such compliance should be reviewed over relatively short periods (time intervals), i.e., a new management decision should be made before each such period or a decision from the previous time interval should be confirmed. Of course, taking into account the above features of the favorable construction business during the calendar year, we must build two appropriate models of enterprise safety-oriented management.

We represent a set of conditions for functioning of an enterprise in a form of the set:

$$S = \{s_i\}_{i=1}^{N_S}, \qquad (1)$$

for the case of a favorable period from April to October, where N_S is the total number of such conditions for this period. Similarly, if N_B is the total number of conditions for the operation of an enterprise during the period from November to March, then the set:

$$B = \{b_k\}_{k=1}^{N_B} \qquad (2)$$

is a set of these conditions for an unfavorable period. For an example of the lists in the previous paragraph we have $N_S=N_B=5$, although, generally speaking, the conditions s_1, s_2, s_3, s_4, s_5 are practically opposite to conditions b_1, b_2, b_3, b_4, b_5. However, in the general case $N_S \neq N_b$, and the number of factors during an unfavorable period can significantly exceed the number of conditions conducive to the development of the construction business (from April to October).

During the favorable period, an enterprise can implement its system of safety-oriented management in several states, the list of which for the unfavorable period will probably be slightly different. So, let the U_S be the total number of possible states of the safety-oriented management system during the period from April to October. Then the set:

$$Q = \{q_j\}_{j=1}^{U_S} \qquad (3)$$

is a set of such states. Accordingly, if U_B is total number of possible states during the period from November to March, then the set:

$$A = \{a_l\}_{l=1}^{U_B} \qquad (4)$$

is a set of all possible states of a system during this period. The states themselves, both in set (3) and in set (4), are indicators of how the company will balance projects with benefits and risks, which in turn will provide a sufficient level of security. In other words, these states are elements of a safety-oriented management strategy that will be a certain optimal combination of these states. The period from April to October will have its own strategy, and the period from November to March – its own. At the same time, each state in the set (3) contains managerial decisions on changing the volume of production and the formation of funding sources through borrowing and attraction. But each state in the set (4) contains management decisions on changing the volume of inventories and the formation of expenditures to cover accounts payable. Thus, the states of the safety-oriented management system will contain only information about the differentiation of production volumes, stocks, borrowings, fund-raising, expenses. That is, this information will indicate to the company management what needs to be changed in the main strategy, which is unchanged during each of the two periods: the company has constant basic (initial) settings for production and formation of sources of financing through borrowings and fund-raising, and as well as the volume of stocks and the formation of expenditures to cover accounts payable. The difference between the periods is that from April to October the main emphasis is on profit maximization, i.e., production, borrowing and fund-raising volumes are higher than from November to March, when expenditures are relatively high, and the main emphasis is on minimizing losses.

From the point of view of economic feasibility, which also takes into account the inertia of macro- and microeconomic processes in the construction industry, a change in state cannot occur more often than once a month [23]. Therefore, the strategy of an enterprise in the construction industry in the period from April to October will consist of seven states:

$$D_S = \left\{ d_S^{(n)} \right\}_{n=1}^{7} \text{ with } d_S^{(n)} \in Q, \; n = 1, 2, ..., 7, \tag{5}$$

where $d_S^{(1)}$ - condition in April, $d_S^{(2)}$ - condition in May, ..., $d_S^{(7)}$ - condition in October. Accordingly, the strategy of the construction industry in the period from November to March will consist of five states:

$$D_B = \left\{ d_B^{(m)} \right\}_{n=1}^{5} \text{ with } d_B^{(m)} \in A, \; m = 1, 2, ..., 5, \tag{6}$$

where $d_B^{(1)}$ - condition in November, $d_B^{(2)}$ - condition in December, ..., $d_B^{(5)}$ - condition in March.

Thus, we need to build two functions that will determine (diagnose) the optimal state based on the sets of conditions (1) and (2) of an enterprise activity:

$$d_S^{(n)} = f\left[S(n)\right] \text{ and } d_B^{(m)} = g\left[B(m)\right], \tag{7}$$

where *S(n)* and *B(m)* are sets of conditions for respectively n-th and m-th months of favorable and unfavorable periods. In fact, we are talking about the reflection of a set of conditions in each month in a certain (optimal) state of safety-oriented management system. Such a mapping is quite easy to construct using a probabilistic neural network.

A probabilistic neural network is a computational procedure consisting of three stages, each of which is implemented on the corresponding layers: input, radial, and output [7]. A matrix is submitted to the input of a probabilistic neural network, in which each column of features corresponds to a certain class. In our case, the features are the conditions for functioning of an enterprise and the safety-oriented management system, and the classes are its states. So, we need to construct two matrices with sizes $N_S \times U_S$ (for the period from April to October) and $N_B \times U_B$ (for the period from November to March).

By submitting a certain vector of features (conditions) to the input, at the output of the probabilistic neural network we get a vector of zeros and one unit, which stands in one place, the index of which corresponds to the class (state) that is the closest (according to this neural network) to the given at the input of the set. If this neural network has been trained satisfactorily (testing did not reveal a high level of errors), then this condition can be considered optimal [5], [15].

If the characteristics are equivalent to the conditions, then the states and their number can be determined on the basis of percentage differentiation of production volumes, stocks, borrowings, fund-raising, expenses. For a probabilistic neural network as a model of management in a favorable period, it will be the adjustment of production volumes and the formation of sources of financing through borrowings and fund-raising. These can be, for example, the following adjustments: 0% (no adjustments), ±25 %, ±50 % separately for production volumes and borrowings and borrowings. There will be 25 states in total in this case. In turn, for a probabilistic neural network as a management model in an unfavorable period, the states will be determined by similar adjustments (in percentage) to the volume of inventories and the formation of costs to cover accounts payable, which will also give 25 states.

The construction of each matrix of safety-oriented management system is based on expert assessments. Let:

$$\mathbf{H} = \left[h_{ij} \right]_{N_S \times U_S} \tag{8}$$

be a matrix for a favorable period, where h_{ij} is the reference (most expected or probable) estimating value of the condition s_i in the state q_j. For a probabilistic neural network, we will normalize these values, so:

$h_{ij} \in [0; 1]$ for all $i = \overline{1, N_S}$ and $j = \overline{1, U_S}$. (9)

Similarly, let:

$$\mathbf{Z} = [z_{kl}]_{N_B \times U_B} \quad (10)$$

will be the matrix for the unfavorable period, where z_{kl} is the reference (most expected or probable) estimating value of the condition b_k in the state a_l, and:

$z_{kl} \in [0; 1]$ for all $k = \overline{1, N_B}$ and $l = \overline{1, U_B}$ (11).

Experts should give their estimates for each pair $\{s_i, q_j\}$ in the matrix (8) and for each pair $\{b_k, a_l\}$ in the matrix (10). In this case, the assessment scale is a unit interval with a step of 0.1 (i.e., the expert's assessment can be 0, 0.1, 0.2, 0.3, ..., 0.9, 1). The expert's estimate of the value (9) is a relative numerical characteristic of the strength of the influence of the condition s_i on profit maximization (during the period from April to October) in the state q_j. Similarly, the expert's estimate of the value (11) is a relative numerical characteristic of the strength of the influence of the condition b_k on minimizing losses (during the period from November to March) in the state a_l. If, for example, the adjustments can be only 1/4 part, the expert questionnaires for this case with the five conditions listed above will correspond to the matrices 5×9 (Table 1., Table 2.).

Table 1. Expert questionnaire for matrix (8) evaluation

Conditions (signs)	Conditions (percentage of production volume adjustment / percentage of financing adjustment through borrowing and fund-raising)								
i / j	1 (0/0)	2 (+25/0)	3 (0/+25)	4 (–25/0)	5 (0/–25)	6 (+25/–25)	7 (+25/+25)	8 (–25/+25)	9 (–25/–25)
1									
2									
3									
4									
5									

Table 2. Expert questionnaire for matrix (10) evaluation

Conditions (signs)	Conditions (percentage of inventory volume adjustments / percentage of expense adjustments to cover accounts payable)								
k / l	1 (0/0)	2 (+25/0)	3 (0/+25)	4 (–25/0)	5 (0/–25)	6 (+25/–25)	7 (+25/+25)	8 (–25/+25)	9 (–25/–25)
1									
2									
3									
4									
5									

Experts fill in the questionnaires, taking into account the listed relevant risks, based on the following considerations. For example, we have a state № 3, in which production volumes do not change, but borrowing and fund-raising increase by 1/4. For this case, the expert must enter in the questionnaire Table 1. (on a scale from 0 to 1 with a step of 0.1) the appropriate level of sales growth, minimization of receivables, the level of efficiency of employee motivation, adequacy of resources, the level of management flexibility and responsiveness to external influences, where 0 means no impact, and 1 will correspond to the direct impact on the situation in which borrowing and fund-raising increase by 25% at constant production volumes. Let a w-th expert assigns values (9) and (11) estimates $\tilde{h}_{ij}(w)$ and $\tilde{z}_{kl}(w)$ accordingly, where $w = \overline{1, W}$ and W - total number of experts. Then the relative error of this expert is calculated as follows:

$$\varepsilon_{ijw} = \frac{\left| \tilde{h}_{ij}(w) - \frac{1}{W} \cdot \sum_{w=1}^{W} \tilde{h}_{ij}(w) \right|}{\frac{1}{W} \cdot \sum_{w=1}^{W} \tilde{h}_{ij}(w)} = \frac{\left| W \cdot \tilde{h}_{ij}(w) - \sum_{w=1}^{W} \tilde{h}_{ij}(w) \right|}{\sum_{w=1}^{W} \tilde{h}_{ij}(w)}$$

for all $i = \overline{1, N_S}$, $j = \overline{1, U_S}$, $w = \overline{1, W}$ (12)

$$\delta_{klw} = \frac{\left| W \cdot \tilde{z}_{kl}(w) - \sum_{w=1}^{W} \tilde{z}_{kl}(w) \right|}{\sum_{w=1}^{W} \tilde{z}_{kl}(w)}$$

for all $k = \overline{1, N_B}$, $l = \overline{1, U_B}$, $w = \overline{1, W}$ (13)

By choosing a certain consistency threshold T> 0, we can assess the consistency of experts. The consistency threshold is selected on the basis of rational considerations and hypothetical capabilities of experts [20], [24].

Typically, this threshold is (in percent) from 5% to 25%. Therefore, if the condition:

$$\frac{1}{W}\cdot\sum_{w=1}^{W}\varepsilon_{ijw} < T \quad (14)$$

is met, then the expert estimates of the value (9) are consistent and then can be accepted:

$$h_{ij} = \psi_{(0.1)}\left(\frac{1}{W}\cdot\sum_{w=1}^{W}\tilde{h}_{ij}(w)\right), \quad (15)$$

where the function $\psi_{(0.1)}(x)$ performs rounding of a number x with accuracy 0.1. If inequality (14) is violated, the experts re-evaluate the value (9). At the same time, the threshold may need to be slightly increased (by 10 ... 20%). Similarly for an unfavorable period: if:

$$\frac{1}{W}\cdot\sum_{w=1}^{W}\delta_{klw} < T \quad (16)$$

is performed, the expert estimates of the value (11) are consistent and then can be accepted:

$$z_{kl} = \psi_{(0.1)}\left(\frac{1}{W}\cdot\sum_{w=1}^{W}\tilde{z}_{kl}(w)\right). \quad (17)$$

If inequality (16) is violated, experts re-evaluate the value (11). After the successful completion of expert evaluation procedures, when matrices (8) and (10) for favorable and unfavorable periods are already ready, we train a probabilistic neural network. The training itself is extremely fast, taking up to 0.08 seconds. Then the model of the enterprise safety-oriented management (or each of the periods) is used as follows. A small group of experts (possibly other experts - not necessarily those who have evaluated the matrices for favorable and unfavorable periods) provide their assessments of the relevant conditions (now without reference to any state, as it is, in fact, still unknown) on the same scale - from 0 to 1 in steps of 0.1. If the number of experts is only W_1, then these estimates are averaged according to the rules of the usual arithmetic mean, without rounding and binding to a scale with a step of 0.1: the estimated value of the condition will be:

$$\bar{h}_i = \frac{1}{W_1}\cdot\sum_{w_1=1}^{W_1}\tilde{h}_i(w_1), \quad (18)$$

and the estimated value of the condition b_k will be

$$\bar{z}_k = \frac{1}{W_1}\cdot\sum_{w_1=1}^{W_1}\tilde{z}_k(w_1). \quad (19)$$

Then the vector of averaged estimates is fed to the input of the corresponding neural network, which, in fact, implements the mapping (7), and it generates a response in the form of the optimal state (for the next month).

3. Results

We decided to consider one of the real examples for ALC "Khmelnytskzalizobeton" (Ukraine), for which we diagnosed the state of the safety-oriented management system during the period from November 2019 to March 2020. List of conditions and risks on the basis of which 18 experts had to evaluate the matrix (10) of the safety-oriented management system in an unfavorable period. Taking into account the limited number of experts, for which the optimal threshold of consistency is T = 0.25, it was decided to leave the percentage adjustments to the volumes of stocks and expenses to cover the accounts payable as minimal, that is, ±25%. Therefore, the experts worked with questionnaires such as in Table 2., after which their judgments were processed using the appropriate formulas (13):

$$\delta_{klw} = \frac{\left|18\cdot\tilde{z}_{kl}(w) - \sum_{w=1}^{18}\tilde{z}_{kl}(w)\right|}{\sum_{w=1}^{18}\tilde{z}_{kl}(w)} \quad \text{for all } k=\overline{1,5},\ l=\overline{1,9},\ w=\overline{1,18}. \quad (20)$$

In this case, condition (16), i.e., inequality:

$$\frac{1}{18}\cdot\sum_{w=1}^{18}\delta_{klw} < 0.25, \quad (21)$$

Has never been violated, i.e., inequality (21) was valid for all $w=\overline{1,18}$, $k=\overline{1,5}$ and $l=\overline{1,9}$. Therefore, expert estimates of the values (11) of the matrix (10) turned out to be consistent, and this matrix was built on the basis of the values (17):

$$z_{kl} = \psi_{(0.1)}\left(\frac{1}{18}\cdot\sum_{w=1}^{18}\tilde{z}_{kl}(w)\right) \quad \text{for all } k=\overline{1,5},\ l=\overline{1,9}. \quad (22)$$

Thus, the matrix of the unfavorable period:

$$\mathbf{Z} = [z_{kl}]_{5\times 9} = \begin{bmatrix} 0.2 & 0.8 & 0.3 & 0.2 & 0.1 & 0.5 & 0.9 & 0.3 & 0.2 \\ 0.1 & 0.2 & 0.6 & 0.2 & 0.1 & 0.1 & 0.8 & 0.3 & 0.1 \\ 0 & 0.1 & 0.1 & 0.3 & 0.2 & 0.1 & 0.1 & 0.4 & 0.4 \\ 0.3 & 0.2 & 0.2 & 0.6 & 0.4 & 0.2 & 0.1 & 0.2 & 0.7 \\ 0.5 & 0.1 & 0.1 & 0.5 & 0.9 & 0.1 & 0 & 0.4 & 0.7 \end{bmatrix} \quad (23)$$

became the basis for training the corresponding probabilistic neural network. Figure 1. shows the network architecture, and Figure 2. shows a list of its parameters.

The probabilistic neural network trained on the data in the matrix (23) was tested on 1000 examples for each state (that is, there were 9000 test cases in total), generated by the principle of adding additive noise to the matrix (23) [19]:

$$\tilde{\tilde{\mathbf{Z}}} = \mathbf{Z} + 0.1\cdot\Theta(5,9) + 0.03\cdot\text{rep}\{\Theta(1,9),5,1\} \quad (24)$$

where $\Theta(5,9)$ and $\Theta(1,9)$ is a 5×9- matrix whose elements are pseudo-random numbers taken from the standard normal distribution (with zero mathematical expectation and unit variance), and the operator $\mathrm{rep}\{\Theta(1,9),5,1\}$ repeats the string vector $\Theta(1,9)$ five times so that the result is a matrix of the same size as the matrix (23).

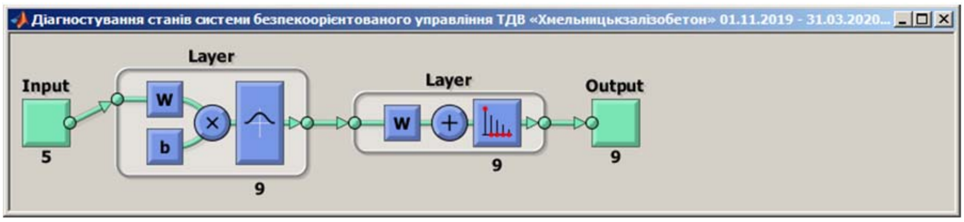

Figure 1. The architecture of a probabilistic neural network (shown in the Matlab environment with visualization of connections between layers) for diagnosing the states of the safety-oriented control system of ALC "Khmelnytskzalizobeton" during the period from November 2019 to March 2020

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    dimensions:
         numInputs: 1
         numLayers: 2
        numOutputs: 1
    numInputDelays: 0
    numLayerDelays: 0
 numFeedbackDelays: 0
 numWeightElements: 135
        sampleTime: 1
    connections:
       biasConnect: [1; 0]
      inputConnect: [1; 0]
      layerConnect: [0 0; 1 0]
     outputConnect: [0 1]
    subobjects:
             input: Equivalent to inputs{1}
            output: Equivalent to outputs{2}
            inputs: {1x1 cell array of 1 input}
            layers: {2x1 cell array of 2 layers}
           outputs: {1x2 cell array of 1 output}
            biases: {2x1 cell array of 1 bias}
      inputWeights: {2x1 cell array of 1 weight}
      layerWeights: {2x2 cell array of 1 weight}
    functions:
          adaptFcn: (none)
        adaptParam: (none)
          derivFcn: 'defaultderiv'
         divideFcn: (none)
       divideParam: (none)
        divideMode: 'sample'
           initFcn: 'initlay'
        performFcn: 'mse'
      performParam: .regularization, .normalization
          plotFcns: {}
        plotParams: {1x0 cell array of 0 params}
          trainFcn: (none)
        trainParam: (none)
    weight and bias values:
                IW: {2x1 cell} containing 1 input weight matrix
                LW: {2x2 cell} containing 1 layer weight matrix
                 b: {2x1 cell} containing 1 bias vector
    methods:
             adapt: Learn while in continuous use
         configure: Configure inputs & outputs
            gensim: Generate Simulink model
              init: Initialize weights & biases
           perform: Calculate performance
               sim: Evaluate network outputs given inputs
             train: Train network with examples
              view: View diagram
       unconfigure: Unconfigure inputs & outputs
```

Figure 2. Matlab-parameters of the probabilistic neural network for diagnosing the states of the safety-oriented control system of TDV "Khmelnitskyzalizobeton" during the period 01.11.2019 – 31.03.2020

The results of testing this neural network are shown in Figure 3., where the abscissa is the noise level $\Theta(1,9)$ (i.e., the level of errors in the vectors of the conditions provided by a small group of experts or, in fact, the management of the enterprise, at the network entrance), and the ordinate axis is the percentage of network errors $p(\sigma)$.

Generally speaking, the described test method is a model of inaccuracy or various errors in values (18) and (19). Therefore, as can be seen from Figure 3., the trained probabilistic neural network is quite an adequate tool for diagnosing the state of the safety-oriented control system of the ALC "Khmelnytskzalizobeton". Indeed, an average error of 5% can occur only under the worst conditions, when the level of inaccuracy or various errors in the values (19) will be too bad.

During the five months of the period from November 2019 to March 2020, the management of the ALC "Khmelnytskzalizobeton" provided the following data on the values (19):

1) $\{\overline{z}_k\}_{k=1}^{5} = \{0.1295,\ 0.0416,\ 0.3331,\ 0.2611,\ 0.8174\}$ in the beginning of November;
2) $\{\overline{z}_k\}_{k=1}^{5} = \{0.1479,\ 0.1132,\ 0.0208,\ 0.5081,\ 0.4308\}$ in the beginning of December;
3) $\{\overline{z}_k\}_{k=1}^{5} = \{0.6791,\ 0.3432,\ 0.1929,\ 0.2809,\ 0.0856\}$ in the beginning of January;
4) $\{\overline{z}_k\}_{k=1}^{5} = \{0.9564,\ 0.6922,\ 0.1271,\ 0.1564,\ 0.0329\}$ in the beginning of February;
5) $\{\overline{z}_k\}_{k=1}^{5} = \{0.2199,\ 0.6772,\ 0.0149,\ 0.2128,\ 0.0084\}$ in the beginning of March.

Further, the neural network has already been trained and determined the corresponding five states of the safety-oriented management system (Figure 4.).

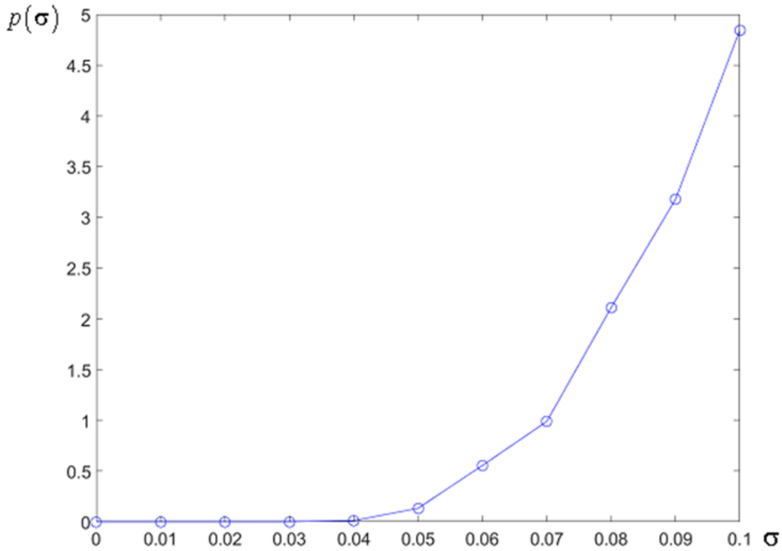

Figure 3. Dependence of the level of neural network errors on the noise level (i.e., on the level of inaccuracy of the input)

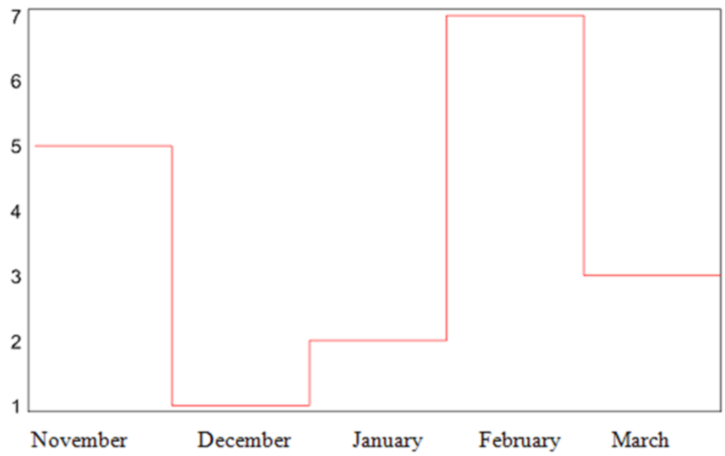

Figure 4. Optimal conditions of the safety-oriented management system of the ALC "Khmelnytskzalizobeton" during the period from November 2019 to March 2020

4. Conclusions

As we can see, during November and December, the best management decision was not to change inventories. In early November, expenditures to cover accounts payable decreased by 25%, after which there was no adjustment until early February. In January and February, inventories were increased twice by 25%, while in March they remained at the same level. Expenditures to cover accounts payable were increased twice by 25% in February and March.

From an economic point of view, receiving the estimated input data for the previous month, the model in the form of a probabilistic neural network generates a response to this data in the form of the optimal state for the next month. This approach is quite natural, because any construction company works on the basis of a certain list of established actions and factors, the change of which becomes necessary over a certain period of time (in our case, it is a month). It should be emphasized that the choice of the minimum percentage of differentiation of production volumes, stocks, borrowings, fund-rising, expenses is not tied exclusively to 25%. For enterprises with lower working capital, this value should be reduced to 20 ... 10%.

A feature of the developed approach is the possibility of its use in various areas of business, however, taking into account the relevant features, it determines the prospects for further research in this direction.

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