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FORECASTING OF RISKS EFFECT ON PRODUCT PROFITABILITY BY MEANS OF NARX NEURAL NETWORK

The paper proposes the use of NARX neural network of forecasting the impact of foreign economic contract risks on the profitability of an aircraft factory. Levenberg-Marquardt method serves as an optimization technique for quality function. This approach allows minimizing the negative impact of risks on the effectiveness of foreign economic activity of an aircraft factory.

Keywords: *contract; product profitability; risk; forecasting; neural network.*

Саміра Т. Пілецька

ПРОГНОЗУВАННЯ ВПЛИВУ РИЗИКІВ НА РЕНТАБЕЛЬНІСТЬ ПРОДУКЦІЇ ІЗ ЗАЛУЧЕННЯМ НЕЙРОННОЇ МЕРЕЖІ NARX

У статті запропоновано проведення прогнозування впливу ризиків зовнішньоекономічного контракту на рентабельність продукції промислового авіапідприємства із залученням нейронної мережі NARX. Методом оптимізації функціонала якості виступає метод Левенберга-Марквардта. Це дозволить мінімізувати негативний вплив ризиків на ефективність зовнішньоекономічної діяльності промислового авіапідприємства.

Ключові слова: *контракт; рентабельність продукції; ризик; прогнозування; нейронні мережі.*

Форм. 6. Табл. 3. Рис. 3. Літ. 13.

Самира Т. Пилецкая

ПРОГНОЗИРОВАНИЕ ВЛИЯНИЯ РИСКОВ НА РЕНТАБЕЛЬНОСТЬ ПРОДУКЦИИ С ПРИВЛЕЧЕНИЕМ НЕЙРОННОЙ СЕТИ NARX

В статье предложено проведение прогнозирования влияния рисков внешнеэкономического контракта на рентабельность продукции промышленного авиапредприятия с привлечением нейронной сети NARX. Методом оптимизации функционала качества выступает метод Левенберга-Марквардта. Это позволит минимизировать негативное влияние рисков на эффективность внешнеэкономической деятельности промышленного авиапредприятия.

Ключевые слова: *контракт; рентабельность продукции; риск, прогнозирование; нейронные сети.*

Problem statement. Financial mechanism of foreign trade is a set of specific financial techniques and instruments, as well as regulatory and informational provision, by which export-import contracts and agreements are effectively implemented and relevant international bank payments and movement of financial flows are carried out, thus increasing financial independence of a company (Piletska, 2010). The key tool in foreign trade is a foreign trade contract, through which the methodological components emerge, depending on the level of organization. Economic efficiency of contracts is largely affected by risks, the minimization of which can improve the efficiency of an enterprise foreign trade. Performance of a contract is determined by such indicator as the profitability of foreign trade contract, the forecasting of which reduces negative risk consequences.

Recent research and publications analysis. Important contribution to the study of the levels of risk forecasting was made by such scholars as N. Balabanov (1996),

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V. Vitlinskiy and P. Velikoivanenko (2004), M. Vnukova and V. Smoliak (2003), J. von Neumann and O. Morgenshtein (1970), N. Podolchak (2002), B. Raysberg et al. (2004) and others. These and other researchers explored the essence of the "risk" concept, classified risks, developed the methods for their evaluation and forecasting etc.

Unresolved issues. Nevertheless, there remain insufficiently developed issues of neural network assisted forecasting of external contract risks influence on the performance of an aircraft factory.

The research objective is to develop the models for forecasting the impact of external economic contract risks on the profitability of an aircraft factory applying the NARX neural network.

Key research findings. To determine the impact of external contract risks on the profitability of an aircraft factory the nonlinear autoregressive model with exogenous inputs (NARX) is used.

Figure 1 shows the architecture of a generalized recurrent network based on multilayer perceptron. This model has a single input, which adapts to the memory of delay lines, consisting of q elements; also this model has a single $u(n)$ output, closed with the input through the memory delay lines consisting of q elements as well. The content of these two memory blocks is used to supply the perceptron input layer.

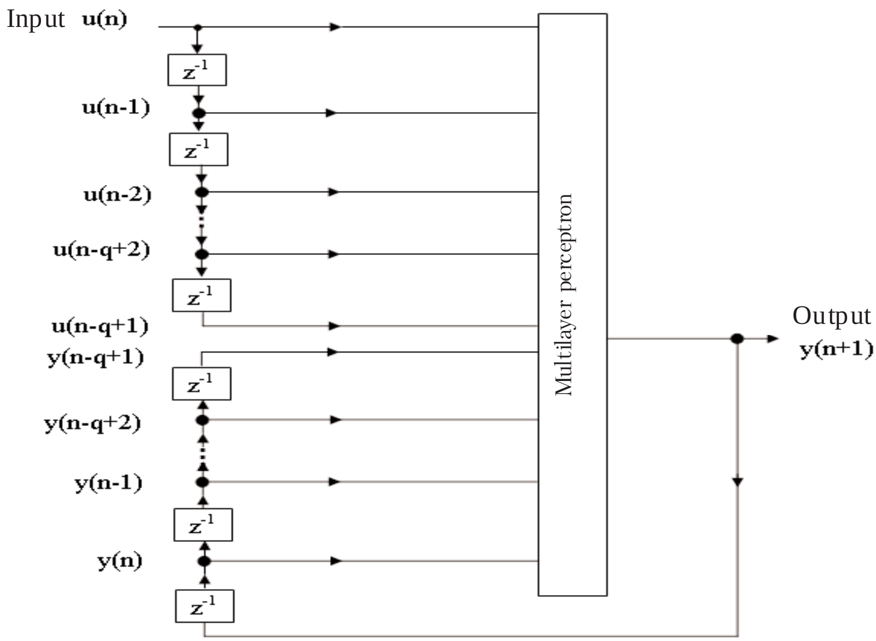

Figure 1. **Architecture of nonlinear autoregressive model with exogenous inputs (NARX)** (Haykin, 2006)

Since one of the important features of any neural network is the ability to generalize knowledge, neural network performs exercise on a set of training samples while it generates the expected results in the view of its input data pertaining to the same set but not participating in the learning process.

In the process of selecting the training data, information on the number of areas, among which this data is distributed, plays an important role.

If the maximum number of domains, into which N'' dimensional space is allocated by n'' hyperplanes, is indicated as $R''(n'',N'')$; then:

$$R''(n'',N'') = \sum_{i=0}^{N''} C_{i''}^{n''}; \qquad (1)$$

$$C_{i''}^{n''} = \begin{cases} \dfrac{n''!}{i'' \times (n''-i'')!} & \text{for } n'' \geq i'' \\ 0 \text{ for } n'' < i'' \end{cases}. \qquad (2)$$

If the problem to be solved consists of m'' classes of data, the selection of the minimum number of neurons must be performed so as to simultaneously fulfill the following requirements:

$$R''(n'',N'') \geq m'' \text{ and } \; R''(n''-1,N'') < m''. \qquad (3)$$

Determination of the number of neurons in each layer of neural network permits not only to determine the number of domains, but also the number of segments of hyperplanes, which restrict these domains (Figure 2). It should be noted, that the assessment of the number of hyperplanes' segments is quite important for the determination of the size of the set of training sample.

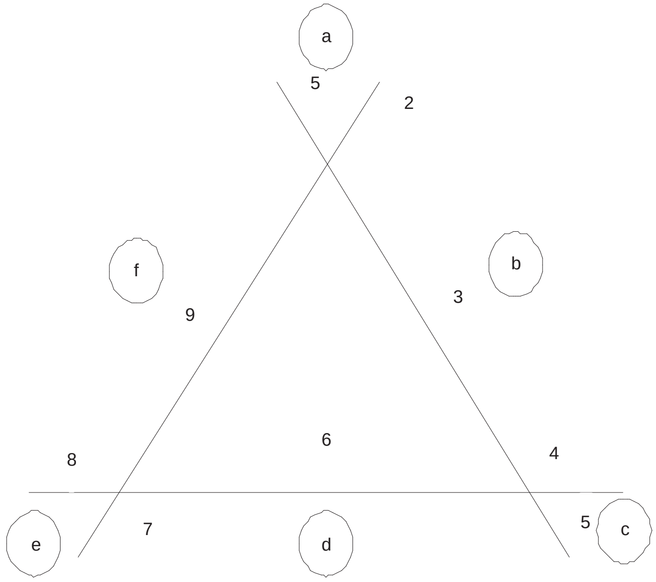

Figure 2. **Illustration of the way to create neural network hyperplanes and data domains** (Kalinina, 2009)

According to the Kolmogorov-Arnold-Hecht-Nielsen theorem (Kizim et al., 2006) it is possible to determine the required quantity of synaptic weights in a multilayer network:

$$\frac{m' \times N'}{1+\log_2 N'} \leq Lw \leq m' \times \left(\frac{N'}{m'} + 1 \right) \times (n' + m' + 1) + m', \qquad (4)$$

where n' is the input signal dimension; m' is the output signal dimension; N' is the number of elements in a training set.

The number of neurons in the hidden L'' layers can be defined as follows:

$$L'' = \frac{Lw}{n' + m'}, \tag{5}$$

where L'' is the number of neurons in hidden layers of a neural network.

After defining the neural network architecture, the network initialization process and data pre-processing are performed. Initialization of a network is carried out by using initialization functions, each possessing its own name and assigning appropriate values to the elements of the weights matrix and to the components of the displacement vector of each layer.

Before the neural network training, the normalization of input vectors is performed, which permits transforming them into unit vectors in accordance with the following expression:

$$u(n')^* = \frac{u(n')}{\sqrt{u_1^2 + \ldots + u_{n'}^2}}; \quad y(n')^* = \frac{y(n')}{\sqrt{y_1^2 + \ldots + y_{n'}^2}}, \tag{6}$$

where $u(n')^*$ and $y(n')^*$ are normalized current values of the input and output signals.

Determination of the signal error $e(n' + 1)$ is done by subtracting the estimate $\hat{y}(n'+1)$ from $y(n' + 1)$. To reduce this value, a proper method of teaching neural network, i.e. the optimization method of functional quality, must be thoroughly selected.

It should be noted, that stochastic algorithms require a relatively large number of training steps, and in global optimization algorithms in the absence of a priori information about the nature of objective function the search difficulty increases exponentially with the increase of dimensionality of the problem to be solved. Conjugate gradient method is very sensitive to the accuracy of calculations. In the method, which takes into account the negative gradient direction, and the method, which includes calculation of the Hesse matrix at several steps of the algorithm, the number of additional variables also increases, making it difficult to use them for training fair-sized neural networks. Therefore, to find the optimum functional quality in multilayer networks the methods of Gauss-Newton and Levenberg-Marquardt are often used. But the method of Levenberg-Marquardt serves as a combination of a simple gradient method and the Gauss-Newton method, allowing removal of their main drawbacks (Ranganatan, 2004).

Thus, forecasting the risk exposure of foreign economic contract profitability of an aircraft factory assisted by the NARX neural network, with Levenberg-Marquardt method as an optimization technique of quality function, leads to a more reliable result.

Formal assessment of the degree of neural network training can be performend using the error function, error-based indicators of which are used to draw conclusions on the quality of network debugging so as to solve the problem set. That is, function errors serve as a criterion for the neural network training. Quite often the following quality criteria are used: the sum of squared deviations, mean square error (*MSE*), combined error, mean absolute error (*MAE*).

It should be noted, that the mean square error of training samples should not exceed the value of the tested one.

G.V. Prysenko and Y.I. Pavikovich (2005) stress that the indicators of the root-mean square error (*RMSE*) and of the mean absolute percentage error (*MAPE*) in percentage permit to determine the overall adequacy of the model (Table 1).

Table 1. **Determination of the overall adequacy of the model**
(Prysenko and Pavikovich, 2005)

RMSE, MAPE	**Forecasting accuracy**
Less 10%	High
10–20%	Good
20–40%	Satisfactory
40–50%	Poor
Over 50%	Unsatisfactory

Neural network model of forecasting the impact of foreign economic contract risks on profitability assumes full determinancy of all its elements; the latter characterize the environmental impact on contract fulfillment.

Let's perform the implementation of neural network model for forecasting the impact of foreign economic contract risks on the profitability of an aircraft factory.

Having determined the overall architecture of the neural network (Figure 2), we move to the equally important process of creating samples: training, reference and test set.

To do so, it is necessary to submit the original data of the model as a matrix chart, which permits building the diagrams of scattering, combining consistently each of the elements of the model, allowing to accurately determine the number of segments of hyperplanes.

The next step in the process of building models for forecasting the impact of foreign economic contract risks on the profitability of an aircraft factory is to determine the number of synaptic weights Lw and the number of neurons in the hidden layers L''.

Since a number of input parameters of the developed neural network do not change with time during the study period, they appear to be white noise. By getting rid of these input parameters, we significantly reduce the measure of mean square error of neural network model for forecasting the impact of foreign economic contract risks on profitability of an aircraft factory.

As noted above, the number of input items combines in itself all the elements of the economic and mathematical model for forecasting the impact of foreign economic contract risks on profitability, that is: $n' = 9$; $m' = 1$; $N' = 40$.

Based on the existing measures the number of synaptic weights Lw is defined:

$$\frac{1\times 40}{1+\log_2 40} \le Lw \le 1\times\left(\frac{40}{1}+1\right)\times(9+1+1)+1,$$

6 synaptic weights $\le Lw \le 452$ synaptic weights.

Having obtained the calculations of the values of synaptic weights Lw in this study, the number of neurons in the hidden layers L'' is defined:

- at 6 synaptic weights: $L'' = \frac{6}{9+1} = 0{,}6 \approx 1$ neuron;
- at 452 synaptic weights: $L'' = \frac{452}{9+1} = 45{,}2 \approx 45$ neurons.

The neural network will have one hidden layer of neurons with nonlinear activation functions, which gives the possibility to approximate nonlinear dependencies, and the output layer contains 1 neuron with linear activation function, which is necessary to extrapolate dependencies. To simulate the dynamic system, delay lines are set to the inputs of the neural network.

As noted by V.A. Meshcheryakov (2004), according to Kolmogorov's theorem, a sufficient number of neurons in a hidden layer should not exceed 2 x Z'' +1, where Z'' is the number of delay inputs.

To the input of the model the risk factors for foreign economic contract (probability of their appearance) are supplied (Table 2), and to the output – the profitability of foreign trade contract.

Table 2. **Indicators supplied to the input of neural network model,** *developed by the author*

Risks of foreign trade contract	
Risk	Characteristics
Political and economic risks	
The risk of loss due to deterioration of the political situation in Ukraine	Change of political regime in Ukraine
The risk of loss due to deterioration of the political situation in a counterpart country	Change of political regime in a counterpart country
The risk of loss due to deterioration of the economic situation in Ukraine	Economic crisis in Ukraine
The risk of loss due to deterioration of the economic situation in a counterpart country	Economic crisis in a counterpart country
Contractual risks	
The risk of losses due to the type of payment	Unprofitable choice of the type of payment by contract
The risk of loss during transportation of equipment	Unprofitable choice of transportation or a delivery mode
The risk of losses due to the type of currency by contract	Resistance of currency, specified in the contract
The risk of loss with an increase of the rate of inflation in Ukraine	Increase of the inflation rate in Ukraine
The risk of foreign partner	Delay of payment by contractor under the contract or loss of the ability to perform payments

Since the choice of neural network architecture rests on the shoulders of the developer, the choice is made in favor of a two-layer network with 10 neurons in a hidden layer (Figure 3).

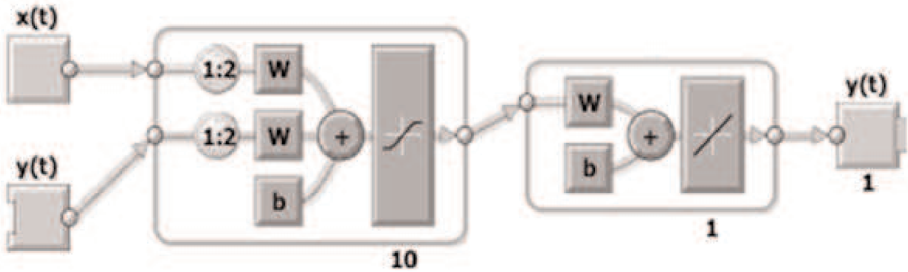

Figure 3. **The structure of forecasting of the impact of foreign economic contract risks on the profitability assisted by NARX nonlinear autoregressive neural network,** *constructed by the author*

Normalization of input and output vectors of the model of forecasting the impact of foreign economic contract risks on profitability is done, thus reducing the learning process of neural network and narrowing the value of mean square error.

The next step is the training of the designed neural networks. In this case the sum of quadratic deviations of the network outputs from the actual data is taken for evaluation.

Before the developed neural networks start operating, it is necessary to test the reliability degree of the results of network calculations on a test array of input vectors, which permits drawing the conclusions on the adequacy of the developed models.

As the test check of the developed neural networks allows recognizing the developed model as an adequate one, so let's move on to the process of forecasting the output parameters of neural networks (Table 3).

Table 3. **Relative errors of the forecasted values of product profitability by contract,** *calculated by the author*

No	Actual value, ratio	Calculated value of profitability, ratio	Relative error, %
1	0.4691	0.2034	20.27
2	0.4793	0.1551	13.50
3	0.4893	0.2360	24.67
4	0.4983	0.2373	19.67
5	0.5148	0.1688	21.44
6	0.5046	0.1768	13.60
7	0.5019	0.2361	16.94
8	0.5249	0.1908	15.18
9	0.5256	0.2813	24.67
10	0.5326	0.1954	16.00
11	0.4954	0.2510	28.45

Computation results for the index of product profitability as per foreign economic contract, listed in Table 3, indicate that the mean absolute percentage error (MAPE) does not exceed 20%, and this suggests the adequacy of the developed neural network model and the quality of forecasting, which can be attributed to the "good" group.

The following **conclusions** can be drawn here:

- forecasting the impact of foreign economic contract risks on profitability of an aircraft factory is suggested to be conducted by means of NARX neural network;
- Levenberg-Marquardt method serves as an optimization technique of quality function;
- forecasting assisted by NARX neural network will minimize the negative impact of external contract risks on the performance of an aircraft factory.

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Стаття надійшла до редакції 11.03.2013.