Estimating Modulus of Elasticity (MOE) of Particleboards Using Artificial Neural Networks to Reduce Quality Measurements and Costs

Procjena modula elastičnosti (MOE) iverice uz pomoć umjetnih neuronskih mreža radi smanjenja opsega i troškova kontrole kvalitete

ABSTRACT • There are a large number of costs that enterprises need to bear in order to produce the same product at the same quality for a more affordable price. For this reason, enterprises have to minimize their expenses through a couple of measures in order to offer the same product for a lower price by minimizing these costs. Today, quality control and measurements constitute one of the major cost items of enterprises. In this study, the modulus of elasticity values of particleboards were estimated by using Artificial Neural Networks (ANN) and other mechanical properties of particleboards in order to reduce the measurement costs in particleboard enterprises. In addition to that, the future values of modulus of elasticity were also estimated using the same variables with the purpose of monitoring the state of the process. For this purpose, data regarding the mechanical properties of the boards were randomly collected from the enterprise for three months. The sample size (n) was: 6 and the number of samples (m): 65 and a total of 65 average measurement values were obtained for each mechanical property. As a result of the implementation, the low Mean Absolute Percentage Error (MAPE), Mean Absolute Deviation (MAD) and Mean Squared Error (MSE) performance measures of the model clearly showed that some quality characteristics could easily be estimated by the enterprises without having to make any measurements by ANN.

Keywords: estimate, modulus of elasticity, particleboard, ANN

SAŽETAK • Tvrtke u proizvodnji imaju velik broj troškova, a cilj im je proizvesti kvalitetne proizvode po što pristupačnijoj cijeni. Stoga nizom mjera nastoje smanjiti proizvodne troškove, ali ponuditi jednako kvalitetan proizvod po nižoj cijeni. Danas su kontrola i provjera kvalitete jedna od glavnih stavki troškova poduzeća. U ovom istraživanju procijenjene vrijednosti modula elastičnosti i drugih mehaničkih svojstava iverice primijenom umjetnih neuronskih mreža (ANN) kako bi se smanjili troškove kontrole kvalitete. Osim toga, uz pomoć istih varijabli procijenjene su buduće vrijednosti modula elastičnosti radi praćenja stanja procesa. S tim ciljem poduzeće je tri mjeseca nasumično prikupljalo podatke o mehaničkim svojstvima ploča. Istraživanje je provedeno na uzorku

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1. INTRODUCTION

1.1. Artificial neural network

An ANN is a soft computing technique for output prediction, classification, data fitting, and model recognizing during complex systems (Taghavifab, 2013). ANN are constructed from simple operational elements in a serial form. These elements have been inspired by biological neural elements (Mafakheri et al., 2012).

A typical ANN configuration consists of an input layer, hidden layers and an output layer (Cho et al., 2014). Hidden layer(s) and output layer can consist of one or more neurons, while the input layer feeds the neurons in the hidden layer(s) with input values. Each neuron in the hidden layer(s) is interconnected with all the neurons in the output layer. The number of neurons in each layer depends on the user and the scale of the problem (Tumac, 2016).

The function of the network is described as follows:

\[ y_j = f\left(\sum w_{ij}x_i\right) \quad (1) \]

where \( y_j \) is the output of node \( j \), \( f \) is the transfer function, \( w_{ij} \) is the connection weight between node \( j \) and node \( i \) in the lower layer, \( x_i \) is the input signal from the node \( i \) in the lower layer node \( j \).

One of the most important features distinguishing ANN from other methods is the fact that it is capable of learning. The learning process is defined as the calculation of the connection weights to provide the best result with the given data. ANN keeps the information it collects during learning as connection weights between nerve cells (Kurt et al., 2017).

2. MATERIALS AND METHODS

2.1. DATA

The samples were taken from the enterprise, which operates in three shifts per day, for three months in accordance with the sampling plan determined by...
the enterprise. The boards, from which the samples were taken, were 18 mm in thickness, 630 kg/m³ in density and 2100 mm × 2800 mm in size, and they were produced for internal furniture applications (including furniture) under dry conditions. The sizes and parts of the samples used for the tests were determined in accordance with the TS EN 310 (1993), TS EN 311 (2005), TS EN 319 (1999) and TS EN 320 (2011).

For the estimation of the modulus of elasticity, averages of the boards, the internal bond strength, surface soundness, screw withdrawal strength and post-sanding thickness were used. In the study, MATLAB software was utilized for developing the ANN models and for training and estimating the data. 70% of the total of 65 samples with the sample size (n) of 6 for each mechanical property was allocated for training, 15% for validation and 15% for testing.

2.2 Network architectures

Multilayer Perceptron (MLP) was used as the most appropriate ANN model for the estimation. The MLP, which is commonly used in the literature, consists of an input layer taking the data from outside, an output layer giving the network output to outside and at least one hidden layer between the two of them (Hamzacebi, 2008; Akcan and Kartal, 2011). The MLPs are networks trained as feed-forward and supervised with full connection between layers (Haykin, 1998; Beale et al., 2010).

The studies conducted showed that the single hidden layer gave successful results at any desired degree of accuracy in nonlinear complex structured function approximations. There is no fixed rule for determining the number of neurons in the hidden layer. In general, keeping the number of hidden neurons low may lead to a learning problem in the network, while keeping the number of hidden neurons high may cause the network to memorize instead of learning. Therefore, 1 to 10 tests were made in order to determine the number of hidden neurons in the models and the best result was found to be 8.

Since the output neuron is directly connected to the studied problem, it is taken equal to the number of dependent variables to be estimated in estimation problems. Sigmoid activation function, which is mostly used in ANN, was preferred as the activation function.

The structure of the ANN model developed for the modulus of elasticity is shown in Figure 1. The values of post-sanding thickness, internal bond strength, screw withdrawal strength and surface soundness of the boards were used as input variables. The output variable, i.e. the modulus of elasticity, was the variable to be estimated.

After the number of neurons in the layers were determined for the ANN model, dependent and independent variables were normalized to be used in the system. In the normalization process, a linear transformation formula in the range of 0 to 10, namely Min-Max normalization, which is commonly used in the literature, was used as shown by Eq. 2.

\[ x_n = \frac{x_n - x_{min}}{x_{max} - x_{min}} \]  

After the normalization process, the data was transferred to the program, and training of the network, one of the most important steps, was commenced. At this stage, the data was presented to the network and the network was ensured to be trained.

In order for the model to be installed to give the optimum result, 81 different variations between the values of 0.1 – 0.9 were tried for each model by keeping the number of epochs at 1000, and efforts were made to determine the most appropriate momentum and learning coefficient values. After the training of the network was completed, test and validation processes were carried out and the estimation process started.

Since the future values of the dependent variables used in the input layer are necessary in the estimation stage, first of all, these values were estimated by ARIMA (Box-Jenkins) method and re-normalized and future quality values were estimated.

2.3 Performance evaluation

Mean Squared Error (MSE), Mean Absolute Deviation (MAD) and Mean Absolute Percentage Error (MAPE) were used as performance criteria in the study.

![Figure 1. Structure of the ANN model for elasticity module](image-url)
as shown by Eq. 3. Since these are criteria frequently used in the literature and each measure has its own limitations, more than one performance criteria can be used to solve any problem (Gentry et al., 1995).

\[
MSE = \frac{1}{n} \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 \\
MAD = \frac{1}{n} \sum_{i=1}^{n} |y_i - \hat{y}_i| \\
MAPE = \frac{1}{n} \sum_{i=1}^{n} \frac{|y_i - \hat{y}_i|}{y_i} \times 100
\]

(3)

where, \(y_i\) is the actual observation values, \(\hat{y}_i\) the estimated values, and \(n\) is the number of forecasts.

3 RESULTS AND DISCUSSION
3 REZULTATI I RASPRAVA

3.1 Data analysis, model selection and forecast
3.1. Analiza podataka, odabir modela i prognoza

Before starting the training of the modulus of elasticity, firstly, the learning and momentum coefficients were tested with different variations and the results were compared. 81 different test results, the MSE values of 5 momentum and learning coefficients giving the best performance are given in Table 1. The most appropriate learning coefficient for the modulus of elasticity was determined as 0.6 and momentum coefficient as 0.8, respectively.

After the most appropriate parameters for the model were determined, the training of network stage started. The graph showing the change of error values, training status and regression values regarding the training, validation and test sets in each iteration of the modulus of elasticity values as a result of network training is included in Figure 2. The graph shows that over 85% of the training, validation and test regression values were successful. The best MSE value was obtained as 0.0023615 at the 44th iteration.

In order to see the training success and estimation ability of the model, the network was tested with test data, which it had never seen before, and successful results were obtained. Table 2 shows the comparison of the estimation values of the test set estimated by the model and the actual values and the error performance criteria MSE, MAD and MAPE. MAD value for modulus of elasticity was found to be 70.89, the MAPE value was found to be 3.022 and the MSE value was found to be 6969.58. The results show that network training is successful and able to make effective estimations.

After the successful completion of the training, the estimation process started. Figure 3 shows a graphical representation of the actual modulus of elasticity averages and the estimated modulus of elasticity averages used for the test. As it can be seen from the figure, the estimation accuracy of the present average is quite good and some test values are estimated very closely to the actual values. In addition, the graph also shows the change in the future 25 averages of the modulus of elasticity values. The model estimated that there would be a periodic decrease in the estimated values of the modulus of elasticity.

The literature shows that the results of ANN are more successful than other statistical methods. In their study, Gungor et al. (2004), Yucesoy (2011) and Ersen

| Trial Number | Learning rate | Momentum rate | MSE  |
|--------------|---------------|---------------|------|
| Broj ponavljanja | Koeficijent učenja | Koeficijent momenta |      |
| 19           | 0.3           | 0.1           | 0.00321 |
| 28           | 0.4           | 0.1           | 0.00424 |
| 29           | 0.4           | 0.2           | 0.00367 |
| 44           | 0.5           | 0.8           | 0.00298 |
| 53           | 0.6           | 0.8           | 0.00286 |

| Sample / uzorak | Actual values / stvarna vrijednost | Projected values / procijenjena vrijednost | MAD | MAPE | MSE |
|-----------------|-----------------------------------|--------------------------------------------|-----|------|-----|
| 56              | 2411.83                           | 2496.9161                                  | 85.08274 | 3.527721 | 7399.073 |
| 57              | 2337.66                           | 2407.9113                                  | 70.24465 | 3.004904 | 4934.311 |
| 58              | 2508.16                           | 2458.7836                                  | 49.38302 | 1.968889 | 2438.683 |
| 59              | 2262.30                           | 2298.7184                                  | 36.38505 | 1.608298 | 1323.872 |
| 60              | 2542.50                           | 2504.2217                                  | 38.27826 | 1.505536 | 1465.225 |
| 61              | 2253.50                           | 2435.5461                                  | 182.0461 | 8.078371 | 33140.780 |
| 62              | 2387.00                           | 2499.2648                                  | 112.2648 | 4.703176 | 12603.390 |
| 63              | 2387.00                           | 2439.8620                                  | 52.86204 | 2.214581 | 2794.395 |
| 64              | 2232.83                           | 2287.4963                                  | 54.66296 | 2.448143 | 2988.039 |
| 65              | 2398.16                           | 2370.4538                                  | 77.71284 | 1.155584 | 768.0014 |
| Average / prosječna vrijednost |                        |                                             | 70.8922 | 3.02152 | 6969.58 |
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(2016) compared the ANN with different estimation methods such as Moving Averages, Exponential Smoothing, Simple-Multiple Regression, Box Jenkins, and they found that ANN method gives better estimation results than other methods. Also, using ANN, Cook and Shannon (1992) have accurately and successfully predicted the parameters of the composite panel production process (about 70%).

**Figure 2** Performance results for the modulus of elasticity ANN model

**(Slika 2.)** Rezultati ANN modela za modul elastičnosti

(10-1) 10-2 10-3 10-4 10-5

**Figure 3** Modulus of elasticity ANN estimation graph (N/mm²)

**(Slika 3.)** Procijenjeni ANN graf modula elastičnosti (N/mm²)
The most appropriate learning coefficient in the ANN model developed to estimate the modulus of elasticity was determined as 0.6 and momentum coefficient as 0.8. It is seen that the regression values of the model in training, testing and validation stages are above 85 %. When the values estimated by the model and the performance results of the actual modulus of elasticity were examined, the MSE value was found to be 6969.58, the MAPE value was found to be 3.022 % and the MAD value was found to be 70.89. It is seen that the performance values obtained are very successful, sufficient and usable for the enterprise. Likewise, in the literature, the models with MAPE values below 10 % are classified as “very good” (Lewis, 1982; Witt and Witt, 1992). Moreover, as it can be seen in Figure 3, the actual and estimated values for the modulus of elasticity are very close to each other. Also, in the estimation of future values of modulus of elasticity, it was determined that the method used in estimating the input variables (ARIMA) was effective and that the results varied according to the performance of the method used.

In general, the use of other mechanical properties as input variables in order to estimate the values of the modulus of elasticity and the fact that it gave successful outcomes showed that some quality values in the enterprises can also be estimated without making any measurements. This is extremely important in terms of reducing the measurement costs of the enterprise. Besides, the possibility of forecasting the future state of these values with ANN shall also enable the enterprise to take precautions against possible problems in advance.

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5 REFERENCES

5. LITERATURA

1. Aiken, M.; Krosop, J.; Vanjani, M.; Govindarajulu, C.; Sexton, R., 1995: A Neural network for predicting total industrial production. Journal of End User Computing, 7: 19-23.

2. Akcan, A.; Kartal, C., 2011: The forecasting of stock prices in ISE insurance index with artificial neural networks. The Journal of Accounting and Finance, 51: 27-40.

3. Asilkan, O.; Imak, S., 2009: Forecasting the future prices of the Second-hand automobiles using artificial neural networks. Suleyman Demirel University, The Journal of Faculty of Economics and Administrative Sciences, 14: 375-391.

4. Balestrino, A.; Bini Verona, F.; Santanches, M., 1994: Time series analysis by neural networks: Environmental temperature forecasting. Automazione e Strumentazione, 42: 81-87.

5. Beale, M. H.; Hagan, M. T.; Demuth, H. B., 2010: Neural network toolbox 7 User’s guide. The MathWorks Inc., Natick, MA.

6. Chen, C. H., 1994: Neural networks for financial market prediction. In: Proceedings of the IEEE International Conference on Neural Networks, 2: 1199-1202. https://doi.org/10.1109/ICNN.1994.374354.

7. Chiang, W. C.; Urban, T. L.; Baldridge, G. W., 1996: A neural network approach to mutual fund net asset value forecasting. Omega, 24: 205-215. https://doi.org/10.1016/0305-0483(95)00059-3.

8. Cho, S.; Lim, B.; Jung, J.; Kim, S.; Chae, H.; Park, J.; Park, S.; Park, J. K., 2014: Factors affecting algal blooms in a man-made lake and prediction using an artificial neural network. Measurement, 53: 224-233. https://doi.org/10.1016/j.measurement.2014.03.044.

9. Cook, D. F.; Shannon, R. E., 1992: A predictive neural network modeling system for manufacturing process parameters. International Journal of Production Research, 30 (7): 1537-1550. https://doi.org/10.1080/00207549208948106.

10. Elminir, H. K.; Areed, F. F.; Elsayed, T. S., 2005: Estimation of solar radiation components incident on Helwan site using neural networks. Solar Energy, 79: 270-279. https://doi.org/10.1016/j.solener.2004.11.006.

11. Ensen, N., 2016: The Estimation and Comparison in Turkey’s Export and Import Values of Wood and Wood Products Using Artificial Neural Networks and Box-Jenkins Methods. Ph.D. Thesis, Karadeniz Technical University, Graduate School of Natural and Applied Sciences, Forest and Industrial Engineering, 207 pp.

12. Fu, Z.; Avramidis, S.; Zhao, J.; Cai, Y., 2017: Artificial neural network modeling for predicting elastic strain of white birch disks during drying. European Journal of Wood and Wood Products, 75 (6): 949-955. https://doi.org/10.1007/s00107-017-1183-x.

13. Gately, E., 1996: Neural networks for financial forecasting. John Wiley, New York.

14. Gentry, T. W.; Wiliamowski, B. M.; Weatherford, L. R., 1995: A comparison of traditional forecasting techniques and neural networks. Intelligent Engineering Systems Through Artificial Neural Networks, 5: 765-770.

15. Glogovac, M.; Filipovic, J., 2018: Quality costs in practice and an analysis of the factors affecting quality cost management. Total Quality Management and Business Excellence, 29 (13-14): 1521-1544. https://doi.org/10.1080/14783363.2016.1273105.

16. Gungor, I.; Kayacan, C.; Korkmaz, M., 2004: Artificial Neural Networks Use in the Forecasting of Industrial Wood Demand and Comparison with Different Estimation Methods. National Operations Research and Industrial Engineering (ORIE) Congress, Cukurova University, Adana.

17. Haas, D. J.; Milano, J.; Flitter, L., 1995: Prediction of helicopter component loads using neural networks. Journal of the American Helicopter Society, 40: 72-82. https://doi.org/10.4056/JAHS.40.72.

18. Hadavandi, E.; Shavandi, H.; Ghanbari, A., 2010: Integration of genetic fuzzy systems and artificial neural networks for stock price forecasting. Knowledge-Based Systems, 23: 800-808. https://doi.org/10.1016/j.knosys.2010.05.004.

19. Hamzaçebi, C., 2008: Improving artificial neural networks: Performance in seasonal time series forecasting. Information Sciences, 178: 4550-4559. https://doi.org/10.1016/j.ins.2008.07.024.

20. Haykin, S., 1998: Neural Networks: A comprehensive foundation, 2 ed. Prentice Hall PTR Upper Saddle River, NJ, USA.

21. Ho, S. L.; Xie, M.; Goh, T. N., 2002: A comparative study of neural network and box-jenkins ARIMA model-
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