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ISSN 0543-5846
METABK 62(2) 299-302 (2023)
UDC – UDK 669.14: 621-462.002.2:531.01.083.3:477=111

MATHEMATICAL MODELING OF PIPES PRODUCTION FORECAST BASED ON POLYNOMIAL REGRESSION ANALYSIS (PRA)

Received – Primljeno: 2022-10 -11
Accepted – Prihvaćeno: 2022-12-20
Preliminary Note – Prethodno priopćenje

The paper analyzes some indicators of the production activity of Ukraine's metallurgical plants, which are under the auspices of Ukrtruboprom association for May-August 2022. Mathematical modeling of pipe production process forecast based on polynomial regression analysis was performed. The presented mathematical models provide adequate results for predicted indicators of economic activity of enterprises selected for analysis. The Russian military operations' negative impact on the hostilities' conduct in Ukraine is shown.

Keywords: steel, pipe, mathematical modeling, PRA, Ukraine.

INTRODUCTION

The globalization challenges of the early 2020s are extremely diverse [1-3]. The metallurgical industry in Ukraine had been one of the main ones in filling the country's state budget until 2022. That was due to several factors outlined in the studies. Meanwhile, one of the most high-margin segments of metallurgical market is the production of pipes.

It is notable that over the past five years, there has been a steady improvement in performance indicators at Ukraine's mining and metallurgical complex enterprises (MMC).

That was due to positive conjuncture in the world markets for metal products.

However, the current development stage of the Ukrainian economy is featured by extreme uncertainty due to the impact of martial law introduced in the country due to Russia's unprovoked armed aggression against the UN founding country, Ukraine. Hence, the paper that discusses state and prospects issues for developing the pipe industry of Ukraine's mining and metallurgical complex in 2022 is relevant.

Also, the topic's relevance is because the pipe enterprises of Ukraine are prominent players in the global market for manufacturers of such products. At the same time, mathematical modeling methods allow for predicting further development with high accuracy. Meanwhile, the models in the paper can consider the impact of hostilities on the changes' dynamics in the enterprises' production results.

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RESEARCH AIM AND OBJECTIVE

The research purpose is to highlight the development processes of the pipe industry market of the mining and metallurgical complex in May-August 2022 based on the information of Ukrtruboprom association enterprises. The development features analysis of metallurgical enterprises is the basis for mathematical modeling of the forecast of the pipe production process based on polynomial regression analysis.

Mathematical modeling is widely used in business and economics to study economic activity. Hence, main research task is to use such models to analyze and forecast specific economic processes based on real statistical information.

The proposed approach allows for predicting production processes and developing certain investment processes in the main sectors of the pipe industry.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Over the past five years, the MMC enterprises of Ukraine have got a steady performance improvement [1-3]. That was due to the positive situation in the world markets for metal products and pent-up demand because of the COVID-19 pandemic in 2019-2021. Also, a positive factor was the reorientation of Ukrainian enterprises to the sale of their metallurgical products in higher-margin sales markets in the EU and the USA.

That approach stimulated fundamental research development. Thus, in the metal forming theory, the development of the ideas about the plastic deformation nature of metal continued during this period, reflected, e.g., in [4, 5].

There is also some progress in the mathematical modeling of metallurgical processes. Thus, it is proposed to use modern multiprocessor computing technologies to control technological processes effectively to increase the speed and efficiency of computations, which allows controlling technological processes effectively. Thus, in [6], the development features and use of multiprocessor computers with their mathematical support and software for modeling the heat treatment modes of metal billets are proposed.

In recent years, statistical analysis methods using information technology tools have been widely used in various fields and have become a powerful tool for modern metallurgical engineers [7]. Those methods allow efficient, strictly scientific registration, processing, and analysis of the observations' results. Moreover, statistical data are often the only information source on phenomenon or process under study; hence, statistical analysis issues become the main ones in interpreting experimental data. Polynomial models are of practical importance, allowing for a reliable forecast regarding the results. Equally important today is the forecasting and planning of experimental studies. Ever-growing tests complexity, and their cost, make researcher look for optimal plans for arranging and running tests.

STATEMENT OF THE RESEARCH MAIN MATERIAL

At the current Ukraine development stage, the main challenge is the war of conquest unleashed by Russia on the country's territory, which significantly affects the economic indicators' dynamics. Table 1 shows the steel pipes summary production by some enterprises of Ukrtruboprom association for four months (May-August) of 2022 compared to the same period in 2021. For further detailed analysis, those two enterprises were selected since each is a leader in the pipe products market segment and exports most of the products.

As Table 1 shows, there is quite a significant drop in production for four months. The explanation is in the hostilities' intensification in Ukraine in the area where the production facilities of those business entities are located. It is also notable that, for convenience, out of 16 observations, i.e., weekly, only four are presented for approximation clarity, i.e., monthly data, which is the sum of the weekly results of production activities.

When studying economic indicators dependence based on real statistical data using the apparatus of the regression analysis theory, it can be noted that linear models are rare as they are used as a special case for the convenience and clarity of the ongoing economic process. In practice, there are more often models that reflect economic processes as non-linear dependencies. Forecasting the pipe production process is one of the most important tasks that enterprise managers and investors must solve to develop production. Linear forecasting models for such complex time series, particularly trend ones, only sometimes accurately and adequately describe the ongoing processes. This paper considers the forecasting problem by polynomial regression analysis.

Table 1 **Monthly production of steel pipes by Ukrtruboprom association enterprises**

Production of steel pipes, thousand tons:				
	LLC "Inter-pipe NZBT Niko Tube"	LLC PO "Oskar"	LLC "Centra-vis production Ukraine"	Ukrtruboprom association
May 2022	46,4	0,48	1,0	51,4
May 2021	52,8	0,2	1,5	59,4
June 2022	41,8	0,07	0,9	43,2
June 2021	60,3	0,166	1,5	67,0
July 2022	37,6	0,08	0,5	39,2
July 2021	59,6	0,208	1,5	63,3
August 2022	42,1	0,232	0,7	42,8
August 2021	59,3	0,203	1,5	67,2

The approach's principal feature is as follows. As a rule, the polynomial equations' parameters are estimated by the least squares method (LSM), which essentially means that the sum of the squared deviations of the actual levels of the series from the corresponding theoretical values should be the smallest. LSM leads to a system of so-called normal equations for determining the unknown parameters of the selected curves. That approach is valid because, as in linear regression, the corresponding functions are linear in parameters and non-linear in variables.

Non-linear regression on the included variables has no difficulties estimating its parameters. It is determined, as in linear regression, by LSM, as those functions are linear in parameters. Therefore, a polynomial of any order reduces to linear regression with its parameter estimation and hypothesis testing methods.

As the experience of most researchers shows, among non-linear polynomial regression, the second-degree equation is most often used; in some cases, a polynomial of the third order. Limitations in higher degrees' polynomials are held by requirement for homogeneity

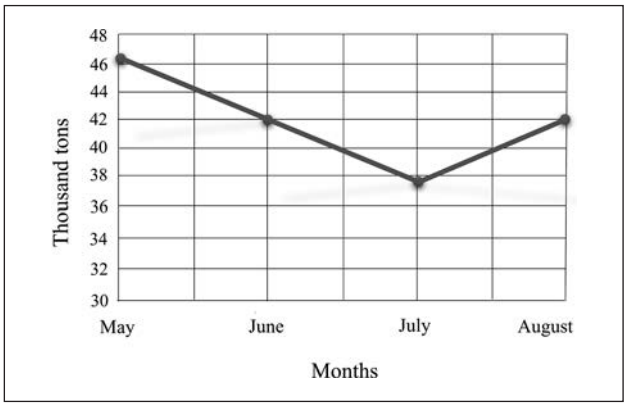

Figure 1 Output correlation field of Niko Tube enterprise

of a set under study: the higher polynomial order, the more bends the curve has, and, accordingly, a set is less homogeneous with resulting attribute.

First, consider the production output forecasting for Interpipe NZBT Niko Tube LLC. For that, we make a correlation field, shown in Figure 1.

In this case, we can put forward a hypothesis about a non-linear polynomial regression equation of the second degree. As for the interval of factor values, the relationship nature of the features under consideration changes: feedback changes to a straight line. Here, the LSM normal equation for a polynomial equation of the second degree has the form:

$$\begin{cases} n \cdot a_0 + a_1 \cdot \sum_{i=1}^{n} x_i + a_2 \cdot \sum_{i=1}^{n} x_i^2 = \sum_{i=1}^{n} y_i, \\ a_0 + a_1 \cdot \sum_{i=1}^{n} x_i^2 + a_2 \cdot \sum_{i=1}^{n} x_i^3 = \sum_{i=1}^{n} x_i \cdot y_i, \\ a_0 \cdot \sum_{i=1}^{n} x_i^2 + a_1 \cdot \sum_{i=1}^{n} x_i^3 + a_2 \cdot \sum_{i=1}^{n} x_i^4 = \sum_{i=1}^{n} x_i^2 \cdot y_i. \end{cases} \quad (1)$$

Where a_0, a_1, and a_2 are the coefficients of the regression equation.

Solving the system of equations (1) for a given sample of values, we get a second-order regression equation:

$$y = 2,26 \cdot x^2 - 13,09 \cdot x + 57,63 \quad (2)$$

Table 2 **Statistical characteristics of a billet for Niko Tube enterprise**

№	Characteristics	value
1	Estimation of mathematical expectation	41,98
2	Variance Estimation	12,92
3	Standard Deviation Estimation	3,59

To check the obtained mathematical model quality, the main statistical characteristics of a billet are determined. Such values are in Table 2.

To check the mathematical model quality at the first stage, we determine the value of the determination R^2 coefficient. For this, we use a relation of the form:

$$R^2 = \frac{\sum_{i=1}^{n} (\hat{y}_i - \bar{y})^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2}, \quad (3)$$

where: $\bar{y}$ is the mathematical expectation estimation of the observed feature, y_i is values of the observed trait in sample set, $\hat{y}_i$ is values of the observed trait according to the regression equation.

The determination coefficient value is obtained for the studied mathematical model, equal to R^2=0,92. That means that 92 % of the variation in the dependent variable is due to the influence of the independent variables, and only 8 % of the variation in the dependent variable is due to other factors acting selectively on the billet. To check the mathematical model adequacy, we use the Fisher criterion. *F* is the Fisher statistics computed from the relation of the form:

$$F_{набл} = \frac{R^2}{(1 - R^2)} \cdot (n - 2), \quad (4)$$

where *n* is the billet size.

For the considered mathematical model, according to relation (4), the observed value of the Fisher criterion *Fobser.* = 23 was determined. According to the table of Fisher distribution critical points with (1,2) degrees of freedom and at a significance level of 5 %, the Fisher criterion critical values are found. Where *Fcrit* = 18,51. Then get *Fobser.* > *Fcrit.* It means that determination R^2 coefficient value is statistically significant, and with a probability of 0,95, a conclusion is made about the adopted mathematical model adequacy.

For a lead period of one month, we find predicted output value at Niko Tube enterprise. Where, y_{pred} = 50,09 thousand tons of steel pipes.

Computing the confidence interval for the predicted value. Here, the equation for calculating the confidence intervals of the forecast relative to trend as a polynomial of the second or third order has the following form:

$$U_y = \hat{y}_{n+L} \pm t_\alpha \cdot S_{\hat{y}} \cdot \sqrt{1 + \frac{1}{n} + \frac{t_L^2}{\sum_{i=1}^{n} t^2} + \frac{\sum_{i=1}^{n} t^4 + 2t_L^2 \cdot \sum_{i=1}^{n} t_i^2 + n \cdot t_L^4}{n \cdot \sum_{i=1}^{n} t^4 - (\sum_{i=1}^{n} t_i^2)^2}}, \quad (5)$$

where *L* is the period lead times; $\hat{y}_{n+L}$ point forecast by model on (*n*+*L*)-th point in time; *n* is the number of observations in the time series; $S_{\hat{y}}$ is the standard error of the forecast indicator estimate; t_a is table value of Student's test for significance level α and the number of degrees of freedom equal to *n* – 2.

According to equation (5), the next confidence intervals are obtained: (35,79; 64,39). That means that with a confidence probability of 0,05, the steel pipes production by this enterprise will belong to this interval for a given lead period. Thus, based on a proposed mathematical model, this enterprise in September-October 2022 can reach May volumes of pipe production if shelling intensity from Russian occupation forces decreases or they are pushed to greater distances from the enterprise location.

CONCLUSIONS

Over the past five years, performance has been steady at the enterprises of the Mining and Metallurgical Complex of Ukraine. That was due to the positive situation in the world markets for metal products and the pent-up demand for them because of the COVID-19 pandemic in 2019-2021. Also, a positive role was played by the reorientation of Ukrainian enterprises to the sale of their metallurgical products in higher-margin sales markets in the EU and the USA. Moreover, international consumers prefer to conclude long-term contracts for the supply of products, which provides

Ukrainian metallurgists with stable income from working capital. The pipe companies selected for analysis are significant players in the global manufacturers of such products.

The mathematical model in the paper provides adequate results for the predicted indicators of economic activity of the enterprises chosen for analysis. Moreover, the second-order model allows assessing the trend line, while the third-order model is more adequate.

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Note: The responsible for the English language is M. Busygina, Ulsteinvik, Norway