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CORRELATION BETWEEN THE EFFICIENCY OF MACHINERY AND EQUIPMENT AND THE PRODUCTIVITY OF WORKERS AND ITS EFFECT ON THE PERFORMANCE OF A METALLURGICAL UNDERTAKING

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In this paper the example of procedure of life and objectify work effectiveness analysis in metallurgical enterprise were presented. Besides, on the example of chosen units of metallurgical enterprise, results of analysis - based on methodic proposed in the article - were discussed.

***Key words**: production management, human resource management, efficiency of machinery and equipment, productivity of workers' labour*

Korelacija između učinkovitosti strojeva i opreme i proizvodnosti radnika i učinak na efikasnost metalurškog poduzeća. U ovome se članku predstavljaju primjer funkcioniranja i objektivna analiza učinkovitosti rada u metalurškom poduzeću. Pored toga, na primjeru odabranih jedinica metalurškog poduzeća raspravlja se o rezultatima analize koji se temelje na metodologiji koja je predložena u članku.

***Ključne riječi:** upravljanje proizvodnjom, upravljanje ljudskim resursima, učinkovitost strojeva i opreme, proizvodnost radne snage*

INTRODUCTION

Production is a reflection of the results of operation of an industrial undertaking and illustrates the efficiency in the management of particular manufacturing elements. A basic component of the manufacturing potential are fixed assets, and particularly machinery and equipment, which determine the production capacities. The condition and evolution of fixed assets, their technical and utility value, degree of activation and level of utilization are thus the determinants of activity of any undertaking.

Fixed assets are not the only element of the manufacturing process, but exist in interrelation with the remaining elements and should remain in proper proportion to them. The basis of fixed assets functioning is providing means of production for the workers, hence they are substitutive in character in relation to workforce [1]. One of the more important technical and economic indices illustrating the activity of an undertaking is efficiency, as identified with the term productivity. This index is a measure of the effectiveness of use of the undertaking's resources [2].

Efficiency is generally defined as the ration of the achieved effects to the incurred outlays X. This is the total productivity that reflects, at the same time, the technological level of manufacture, the methods of production organization and management, the employees' skills, as well as changes in the capital outlays and in the sphere of production system operation. In practice, partial productivity is dealt with, where outlays only form an element of the input vector. Therefore, the productivity of machinery and equipment and the productivity of employed workers, as well as that of inventories, energy or fixed capital can be distinguished [3].

The cause-and-effect character of efficiency suggests the existence of relationships between outlays and production effects. The productivity of two basic manufacturing elements, i.e. machinery and equipment and the labour of employed workers, defined as the ratio of the production volume to the man-hour worked, was subjected to examination. The purpose of the paper was to find of whether there are any relationships between the quantities examined, and if so, what is their strength, direction and form.

THE ANALYSIS OF CORRELATION BETWEEN THE PRODUCTION VOLUME AND THE EFFICIENCY OF MACHINERY AND EQUIPMENT

The production volume, which was considered to be the result of interaction of the efficiency of machinery and equipment, or the objectified work, was first put to analysis.

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The results of monthly observations for a period of five years from 2001 to 2005, carried out in a metallurgical undertaking, were analyzed.

In order to establish the relationship between the quantities examined, a scatter diagram has been plotted, which is shown in Figure 1. A clear positive correlation relationship is visible on this diagram, as the increase in machinery and equipment efficiency has a corresponding increase in production volume.

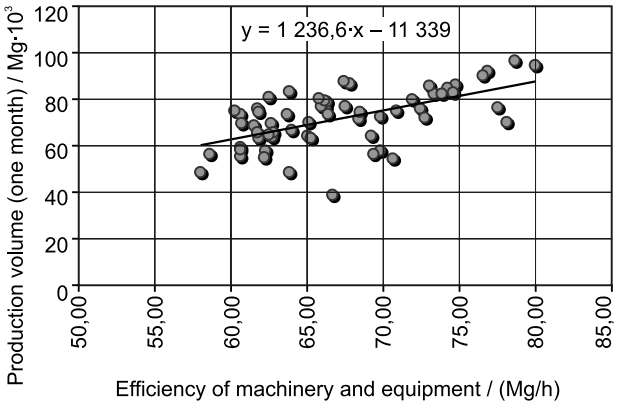

Figure 1. **Diagram of the scatter of production volume and machinery and equipment efficiency**
Slika 1. **Dijagram rasapa volumena proizvodnje i učinkovitosti strojeva i opreme**

To define the strength of the correlation relationship, the coefficient of linear correlation was used, as determined by the standardization of covariance, which is expressed by equation 1 [4]:

$$r_{yx} = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2 \sum_{i=1}^{n}(y_i - \overline{y})^2}} = \frac{C(X,Y)}{s_x s_y}, \quad (1)$$

where:

x_i, y_i - empirical values of variables,
$\overline{x}, \overline{y}$ - mean empirical values,
$C(X, Y)$ - covariance,
s_x, s_y - standard deviations.

In the case under examination, the Pearson correlation coefficient r_{yx} was 0,54, which means that the correlation relationship is moderate.

To determine, what part of the change in production volume is explained by the change in machinery and equipment efficiency, the determination coefficient was calculated, which represents the square of the Pearson correlation coefficient [5].

In the examined case, the determination coefficient, r_{yx}^2, was 0,29, which means that only approx. 30 % of the change in production volume was explained by changes in the efficiency of the industrialized work.

The determination of the correlation relationship between the quantities examined made it possible to estimate the parameters of the linear regression function of type I, which serves for analyzing relationships between the production volume and efficiency of machinery and equipment. The linear regression function of type I is expressed by equation 2 [6]:

$$\hat{Y} = f(x) = \alpha_1 x + \alpha_0, \quad (2)$$

where:

$\hat{Y}$ - theoretical values of the regression function $f(x)$, corresponding to a given level of execution of the variable X,
α_1 - coefficient of linear regression of the variable Y relative to X,
α_0 - free term.

The determination of the linear regression function made it possible to answer the question of by how much would the mean value of production volume increase with the increase in machinery and equipment efficiency by a unit. In the examined case, the linear regression function took on the following form:

$$\hat{Y} = 1236{,}6x - 11339.$$

This means that with the increase in machinery and equipment efficiency by 1 Mg/h, the production volume will increase by 1 236 tonnes per month.

For the evaluation of the straight line fit to the empirical points, the standard deviation of the residual component variance, as defined by equation 3 [4], was used:

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

where:

y_i - empirical values,
$\hat{y}_i$ - theoretical values, as determined from equation (2),
n - number of observations,
k - number of estimated regression equation parameters.

The standard deviation of residues, called also the mean error of estimation $s(z_i)$, amounted to 9 936,34, and this is the order of magnitudes of the misfit of the production

volume values to the theoretical values, as determined from the regression function.

In order to establish the percentage value of the error, the coefficient of variation, as expressed by equation 4 [4], was used:

$$V_s = \frac{s(z_i)}{\bar{y}}, \tag{4}$$

where:

s - standard deviation of residues,
$\bar{y}$ - mean value of the feature Y.

Calculated from equation 4, the coefficient of variation, V_s, amounted to 0,138, which represents an error in the order of 13,8 %.

THE ANALYSIS OF CORRELATION BETWEEN THE PRODUCTION VOLUME AND THE PRODUCTIVITY OF WORKERS' LABOUR

The production volume was recognized, as before, to be the result of the productivity of employed workers. Therefore, the strength and direction of the relationship between the two quantities was examined. The correlation relationship already appears on the scatter diagram and is, as in the first case examined, positive in character. The diagram of production volume and productivity scatter is shown in Figure 2.

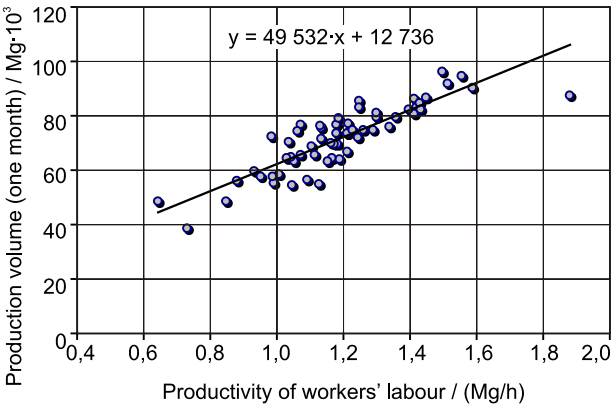

Figure 2. **Diagram of production volume and productivity scatter**
Slika 2. **Dijagram proizvodnog volumena i rasapa produktivnosti**

In order to deepen the analysis of the relationship between the examined quantities, the Pearson coefficient of linear correlation and the linear regression function of type I were established.

The correlation coefficient, established according to equation (1), amounted to r_{yx} = 0,87, indicating a strong correlation between the production volume and the productivity.

Whereas, the linear regression function (equation 2) in the analyzed case took on the following form:

$$\hat{Y} = 495326x + 12736.$$

It means, therefore, that an increase in the efficiency of live work by 1 Mg/h will result in an increase in production by 49 532 tonnes.

The error estimation based on equatione (3) and (4) found that the empirical values of production volume might differ from its theoretical values by 47,5 tonnes, on average, which represents an error in the order of 0,06 %.

In turn, the determination coefficient, r_{yx}^2, established to be equal to 0,75, means that 75 % of the changes in production volume have been explained by the changes in productivity.

MULTIPLE CORRELATION AND REGRESSION

As has already been shown in the paper, both the efficiency of machinery and equipment and the productivity of workers' labour have an effect on the production volume and remain in a clear correlation with it. Therefore, the interrelation between these three quantities was examined by means multiple correlation and regression. To this end, the coefficient of multiple correlation with the symbol R_w was used for the three variables in equation 5 [5]:

$$R_w = \sqrt{\frac{r_{12}^2 + r_{13}^2 - 2 \cdot r_{12} \cdot r_{13} \cdot r_{23}}{1 - r_{23}^2}}, \tag{5}$$

where:

r_{12} - coefficient of simple correlation between the dependent feature (1) and the independent feature (2),
r_{13} - coefficient of simple correlation between the dependent feature (1) and the independent feature (3),
r_{23} - coefficient of simple correlation between the independent features (2) and (3);

$$R_w = \sqrt{\frac{0,54^2 + 0,87^2 - 2 \cdot 0,54 \cdot 0,87 \cdot 0,42}{1 - 0,42^2}} = 0,89.$$

The joint effect of the machinery and equipment efficiency, X_1, and the workers' labour efficiency, X_2, on the production volume, Y, is very high, greater that the effect of each of the efficiencies.

The square of multiple correlation, as well as that of the Pearson coefficient of correlation, is called the determination coefficient [5]. In the case under examination, $R_w^2 = 0,79$,

which indicates that 79 % of changes in the efficiency of machinery and equipment and in productivity explains the changes in the formation of production volume in the metallurgical undertaking examined. Thus, other manufacturing factors have influence on the changes in production volume only in 21 %.

On the other hand, the equation of the linear regression function of type I for three variables is established based on equation 6 [5]:

$$\hat{Y} = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2,$$

where:

α_0 - free term,
α_1 - coefficient of linear regression of the variable Y relative to X_1,
α_2 - coefficient of linear regression of the variable Y relative to X_2.

In the case under examination, the regression equation took on the following form:

$$\hat{Y} = -10415{,}15 + 436{,}23 X_1 + 44334{,}8 X_2.$$

The obtained regression equation implies that with an increase in the machinery and equipment efficiency, X_1, by 1 Mg/h and with the fixed productivity X_2, the volume of monthly production will increase by 436,23 tonnes. Whereas, with an increase in the productivity X_2 by 1 Mg/h and the unchanged level of the machinery and equipment efficiency X_1, the volume of monthly production will increase by 44334,8 tonnes.

In the multiple regression examined, the estimated error established on the basis of equatione 3 and 4 amounted to nearly 8%.

CONCLUSIONS

Using the statistical correlation analysis to examine the relationship between the efficiency of machinery and equipment and productivity on the one hand and the production volume in the metallurgical undertaking on the other hand, a very high interrelation between the quantities examined has been found.

An increase in the efficiency of both machinery and equipment and of the workers' labour results in an increase in production volume.

Moreover, the joint effect of changes in the efficiency indices examined explains in 79 % the changes in developing production volume. This means that machinery and equipment and employed personnel are basic components of the manufacturing process in the undertaking examined and determine its production abilities.

The obtained results indicate also a correlation between the efficiency of machines and equipment and productivity. Thus, the level of the applied technology and engineering and the degree of their utilization by the undertaking will be determining the work of employees, and thereby the size and structure of employment.

It should also be noted that, in the undertaking examined, the increase in productivity by a unit will result in an increase in monthly production volume larger than the unit increase in the efficiency of machinery and equipment. This means a better use of working time by the workers compared to the effective time of the objectified work. This is likely to result from the obsolete level of technology and engineering and indicates a need for investments into this sphere of the undertaking's activity.

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