Method for estimating price procurement of standardized components. Case study – springs

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Abstract. This paper presents a mode for applying a methodology of estimating the price, presented in previous researches and applied for the price forecasting of springs for light / heavy load. By applying this methodology, the manufacturing companies will succeed in forecasting the procurement price from price offers given to the customers, offers related to similar quotation requests, for products with constructive characteristics comparable or different to the most currently proposed ones. The methodology proposed can be used for the procurement price forecasting for standard components from different equipment from manufacturing process systems. This methodology has as starting point a causal forecast model that is based on the hypothesis that the variable we want to forecast (the product procurement price) is related to another variable which in turn is related to the general environment. The methodology is exemplified by a case study on springs price forecasting. In the spring price estimation process different elements are considered, such as: the shape and the size of the items, the production costs, the profit margin practiced by the manufacturing company, the utility of the item etc.

1. Introduction
The present-day economy is characterized by a large number of manufacturers of standardized components for the manufacturing industry, but also by a wide variety of this type of products, a fact which leads to the need for manufacturers to provide quick and accurate forecasting of the components prices ordered by customers. This problem becomes very difficult to solve when we speak about products with a large variety of constructive features that can influence the procurement price.

In the production processes, the production cost is the key element, which has to be permanently monitored, since based on this cost, the selling price of the final product / service is established [1]. Also, estimating the production cost can determine the budget needed to implement a production project [2].

In most cases, in the production processes standardized elements that are found in the construction of many products / equipment are employed (machine tools, subassemblies, raw materials, materials, punchers, dies, tools, devices, etc.).

In general, for these standardized elements, the estimation of the purchase price is possible by integrating relations in computerized applications. The use of such estimation relations is a real advantage by concentrating the large volume of data contained in the product catalogues of the various suppliers of raw materials, materials and product components [3]. Thus, the estimation of the purchase
price for various elements used in the production processes is a major problem to be considered by the operational management of any company operating in the production field.

In order to estimate the purchase prices for various standardized components of the products used in the production processes, various forecast models can be used. These differ depending on the degree of complexity, the amount of data used, the time period for which the forecast is generated, but also on the ways (methods) of generating a forecast [4,5]. Forecast models have common characteristics, therefore forecasts are rarely perfect, involve uncertainty, but the goal of the forecast is to generate the best average over time and to keep forecast errors as low as possible. The best forecasts can be made for group items or families of parts / products as well as for short periods of time [5].

The stages of the forecast process, in case of establishing the purchase price for the standardized components of the products used in the production processes, are shown in figure 1.

![Figure 1. The stages of the forecast process, adaptation from [5].](image)

2. Methodology

In order to estimate the purchase prices of the standardized elements for the products used in the production processes, we will use a causal forecast model (simple linear regression; non-linear regression; multiple regression) that is based on the assumption that the variable we wish to forecast is related to another variable that is linked to the environment.

Thus, the problem is to identify the relations between the variable that interests us, in this case the purchase price and the independent variables, extracted from the constructive characteristics of the analysed component. These relations can be very complex and are materialized in the form of mathematical models that are used to forecast the variable analysed.

In the linear regression, the variables to be predicted are called dependent variables and are obtained from other variables named independent variables. These variables are arranged along a straight line, the dependent variable is linearly related to the independent variable, and the relation between the two is the equation of a straight line.

Nonlinear regression is applied when the graphical representation of the data implies a nonlinear trend. The most used nonlinear regression trends are parabolic, exponential and logarithmic.

Multiple regression is an extension of the linear regression and is an efficient predictive tool that can be utilized when multiple factors influence the variable to be predicted. Thus, if no linear regression is identified between the two variables, a relation between the dependent variable and several independent variables can be developed. Using the least squares method, mathematician Kenneth Levenberg, 1943, and researcher Donald Marquardt, in 1963, developed the Levenberg-Marquardt algorithm (LMA, Levenberg-Marquardt algorithm) [6] which aims to determine the parameters of nonlinear models. Most software applications for statistical analysis use this algorithm to determine the elements to be predicted [3].

For the analysed case study, the regression analysis of the data was performed using the NCSS 2007 (Number Crucher Statistical System) data analysis software. The mean squared deviation, (σ), and the correlation coefficient (R²) are defined as shown in equations (1) – (4) presented in [7,8].
\[
\sigma = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \bar{y})^2}{n-1}} \tag{1}
\]

where: \(\sigma\) - the average square deviation (standard error) of the residues; \(\sum_{i=1}^{n} (y_i - \bar{y})^2\) - the total variance, sum of squares of the total deviations (see equation (2)); \(y_i\) - the sampled values of the dependent variable; \(\bar{y}\) - the sample values mean of the dependent variable (see equation (3)); \(n\) - the number of elements (values) in the sample.

\[
\sum_{i=1}^{n} (y_i - \bar{y})^2 = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 + \sum_{i=1}^{n} (\hat{y}_i - \bar{y})^2 \tag{2}
\]

where: \(\hat{y}_i\) - the values of the predicted (approximate) dependent variable using the regression model; \(\sum_{i=1}^{n} (y_i - \hat{y}_i)^2\) - the unexplained variance, sum of squares of errors; \(\sum_{i=1}^{n} (\hat{y}_i - \bar{y})^2\) - the explained variance, the sum of the squares of the deviations due to the regression.

\[
\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n} \tag{3}
\]

\[
R^2 = 1 - \frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2} = \frac{\sum_{i=1}^{n} (\hat{y}_i - \bar{y})^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2} \tag{4}
\]

where: \(R^2\) the correlation coefficient, represents the extent to which the independent variable / variables influence the dependent variable; \(R = \sqrt{R^2}\) - the multiple correlation coefficient, it has values between 0 (if there is no connection between the dependent variable and the independent variables) and 1 (if there is a perfect connection).

3. Results

In this paper section, regression functions will be presented for estimating the purchase prices of two types of helical springs: rectangular wire springs for light loads and rectangular wire springs for heavy loads. The prices of the modeled elements were extracted from the catalogues of Rabourdin Industry companies [9].

3.1. Estimated purchase price for a rectangular wire spring for light loads

The geometric characteristics of a spring for light loads are shown in figure 2. The parameters presented in figure 2, express the following:

- \(L\) – the total length of the extended spring [mm];
- \(K\) – the load expressed in Newton necessary to obtain a stroke of one millimeter [N/mm];
- \(A\) – the load and recommended stroke for durability [N];
- \(B\) – the load and maximum working stroke [N];
- \(C\) – the load and approximate stroke of the compressed spring at the block [N].
Figure 2. The geometric characteristics of a spring for light loads [9].

In order to estimate the price, a relation of the third (3rd) degree is proposed, with four independent variables: (D-D1) noted by $x_1$; L noted by $x_2$; As noted $x_3$; K noted by $x_4$.

Meaning of the independent variables:

- (D-D1) – the difference between the diameter of the bore in which the spring is mounted and the diameter of the rod that is inserted into the spring [mm];
- L – the total length of the spring [mm];
- As – the area of the wire section from which the spring is made [mm$^2$];
- K – the load for obtaining a one-millimetre stroke [N/mm].

Values of these variables are presented in figure 3. The complete model contains 31 terms and has the form presented in equation (5).

\[
P_{est} = b_0 + b_1 \times x_1 + b_2 \times x_2 + b_3 \times x_3 + b_4 \times x_4 + b_5 \times x_1^2 + b_6 \times x_2^2 + b_7 \times x_3^2 + b_8 \times x_4^2 + \]
\[+ b_9 \times x_1 x_2 + b_{10} \times x_1 x_3 + b_{11} \times x_1 x_4 + b_{12} \times x_2 x_3 + b_{13} \times x_2 x_4 + b_{14} \times x_3 x_4 + b_{15} \times x_1^3 + b_{16} \times x_1^2 x_2 + \]
\[+ b_{17} \times x_1 x_2^2 + b_{18} \times x_1 x_3^2 + b_{19} \times x_1 x_4^2 + b_{20} \times x_2 x_3^2 + b_{21} \times x_2^2 x_3 + b_{22} \times x_2 x_4^2 + b_{23} \times x_3 x_4^2 + b_{24} \times x_1 x_2 x_3 + b_{25} \times x_1 x_2 x_4 + b_{26} \times x_1 x_3 x_4 + b_{27} \times x_1 x_3 x_4 + b_{28} \times x_2 x_3 x_4 + \]
\[+ b_{29} \times x_2 x_3 x_4 + b_{30} \times x_3 x_4 + \] (5)

Figure 3. Catalogue extract with the available range of springs [9].
The selection of the significant variables was made by running the stepwise regression option, by means of the NCSS statistical program. The following terms were retained: $b_6$, $b_{12}$, $b_{14}$, $b_{15}$, $b_{19}$, $b_{22}$, $b_{27}$. Thus, the purchase price can be estimated by means of the regression equation (6).

$$P_{est} = b_0 + b_1 \times L^2 + b_2 \times L \times As + b_3 \times As \times K + b_4 \times (D-D1)^2 \times L +$$

$$+ b_5 \times (D-D1)^2 \times K + b_6 \times L \times As^2 + b_7 \times (D-D1) \times L \times As$$  \hspace{1cm} (6)

The coefficients of the regression equation, determined using the NCSS software, have the following values: $b_0 = 0.5679049$; $b_1 = 0.00001668156$; $b_2 = 0.0007558876$; $b_3 = -0.0003406557$; $b_4 = 0.0003667076$; $b_5 = 0.00005508224$; $b_6 = 0.00006561943$; $b_7 = -0.0002853705$.

The correlation coefficient for the estimation function proposed has the value $R^2 = 0.998$.

The catalogue data utilized to estimate the regression equation coefficients and the estimation results (Pcat – catalog price and Pest - estimated price in Euro) are presented in table 1.

| No. | Reference   | D [mm] | L [mm] | D1 [mm] | As [mm²] | K [N/mm] | Pcat [Euro] | Pest [Euro] | Error [%] |
|-----|-------------|--------|--------|---------|----------|-----------|-------------|-------------|----------|
| 1   | 0355-010x025 | 10     | 025    | 5       | 1.87     | 10        | 0.87        | 0.79        | -9.28    |
| 2   | 0355-010x032 | 10     | 032    | 5       | 1.87     | 8.5       | 0.94        | 0.85        | -9.38    |
| 3   | 0355-010x038 | 10     | 038    | 5       | 1.87     | 6.8       | 1.02        | 0.91        | -11.13   |
| 4   | 0355-010x044 | 10     | 044    | 5       | 1.87     | 6         | 1.1         | 0.96        | -12.46   |
| 5   | 0355-010x051 | 10     | 051    | 5       | 1.87     | 5         | 1.17        | 1.03        | -11.94   |
| 6   | 0355-010x064 | 10     | 064    | 5       | 1.87     | 4.3       | 1.26        | 1.16        | -7.89    |
| 7   | 0355-010x076 | 10     | 076    | 5       | 1.87     | 3.2       | 1.41        | 1.29        | -8.83    |
| 8   | 0355-010x305 | 10     | 305    | 5       | 1.87     | 1.1       | 4.71        | 4.60        | -2.25    |
| ... | ...         | ...    | ...    | ...     | ...      | ...       | ...         | ...         | ...      |
| 102 | 0355-063x102 | 63     | 102    | 38      | 89.32    | 131       | 19.98       | 19.93       | -0.25    |
| 103 | 0355-063x115 | 63     | 115    | 38      | 89.32    | 116       | 22.45       | 22.30       | -0.68    |
| 104 | 0355-063x127 | 63     | 127    | 38      | 89.32    | 103       | 24.21       | 24.49       | 1.15     |
| 105 | 0355-063x152 | 63     | 152    | 38      | 89.32    | 84.3      | 29.36       | 29.11       | -0.87    |
| 106 | 0355-063x178 | 63     | 178    | 38      | 89.32    | 71.5      | 33.58       | 33.95       | 1.12     |
| 107 | 0355-063x203 | 63     | 203    | 38      | 89.32    | 61.7      | 38.01       | 38.65       | 1.68     |
| 108 | 0355-063x254 | 63     | 254    | 38      | 89.32    | 47        | 48.41       | 48.31       | -0.20    |
| 109 | 0355-063x305 | 63     | 305    | 38      | 89.32    | 38.2      | 58.61       | 58.08       | -0.90    |

3.2. Estimated purchase price for a rectangular wire spring for heavy loads

As presented in the above paper section, the considered product and its catalogue characteristics are presented in figures 4 and 5.

![Figure 4. Rectangular wire spring for heavy loads](image-url)
The purchase price can be estimated employing the regression equation (7).

\[ P_{est} = b_0 + b_1 \times L^2 + b_2 \times L \times A_s + b_3 \times A_s \times K + b_4 \times (D - D_1)^2 \times L + \\
+ b_5 \times (D - D_1)^2 \times K + b_6 \times L \times A_s^2 + b_7 \times (D - D_1) \times L \times A_s \]  

(7)

The coefficients of the regression equation, determined using the NCSS software, have the following values: 
- \( b_0 = 1.119996; \)
- \( b_1 = 0.000284313; \)
- \( b_2 = 0.000829207; \)
- \( b_3 = 0.000188563; \)
- \( b_4 = -0.00001635608; \)
- \( b_5 = -0.0001040125. \)

The correlation coefficient for the estimation function proposed has the value \( R^2 = 0.998. \)

The catalogue data utilized to estimate the regression equation coefficients and the estimation results are presented in table 2 (\( P_{cat} \) – catalog price and \( P_{est} \) - estimated price in Euro).

| No. | Reference | D  [mm] | L  [mm] | D1  [mm] | As  [mm^2] | K  [N/mm] | Pcat [Euro] | Pest [Euro] | Error [%] |
|-----|-----------|---------|--------|---------|------------|-----------|------------|------------|----------|
| 1   | 357-10x25 | 10      | 25     | 5       | 2.85       | 22.1      | 1.10       | 1.32       | 19.83    |
| 2   | 357-10x305| 10      | 305    | 5       | 2.85       | 17.5      | 1.17       | 1.38       | 18.21    |
| 3   | 357-10x32 | 10      | 32     | 5       | 2.85       | 17.1      | 1.26       | 1.44       | 14.56    |
| 4   | 357-10x38 | 10      | 38     | 5       | 2.85       | 17.1      | 1.34       | 1.51       | 12.47    |
| 5   | 357-10x44 | 10      | 44     | 5       | 2.85       | 15        | 1.41       | 1.59       | 12.50    |
| 6   | 357-10x51 | 10      | 51     | 5       | 2.85       | 12.8      | 1.41       | 1.75       | 11.27    |
| 7   | 357-10x64 | 10      | 64     | 5       | 2.85       | 10.7      | 1.57       | 1.91       | -3.01    |
| 8   | 357-10x76 | 10      | 76     | 5       | 2.85       | 7.5       | 1.97       | 2.45       | -3.16    |
| 9   | 357-10x89 | 10      | 89     | 5       | 2.85       | 7.5       | 1.97       | 2.45       | -3.16    |
| 100 | 357-63x127| 63      | 127    | 38      | 137.5      | 349       | 32.05      | 32.57      | 1.63     |
| 101 | 357-63x152| 63      | 152    | 38      | 137.5      | 276       | 36.75      | 37.49      | 2.01     |
| 102 | 357-63x178| 63      | 178    | 38      | 137.5      | 237       | 42.75      | 43.05      | 0.71     |
| 103 | 357-63x203| 63      | 203    | 38      | 137.5      | 210       | 48.35      | 48.58      | 0.47     |
| 104 | 357-63x254| 63      | 254    | 38      | 137.5      | 165       | 60.35      | 60.16      | -0.28    |
| 105 | 357-63x305| 63      | 305    | 38      | 137.5      | 134       | 72.35      | 72.15      | -0.28    |
| 106 | 357-63x32 | 63      | 32     | 38      | 137.5      | 630       | 23.6       | 24.11      | 2.17     |
| 107 | 357-63x76 | 63      | 76     | 38      | 137.5      | 485       | 26.4       | 25.48      | -3.48    |
| 108 | 357-63x89 | 63      | 89     | 38      | 137.5      | 485       | 26.4       | 25.48      | -3.48    |
The paper results outline the methodology for forecasting the procurement prices of standardized components and the mathematical models of forecasting the procurement prices for two types of springs. The price prediction models developed have a coefficient of determination ($R^2$) equal with 0.998, a value very close to 1, a fact which indicates that these models can characterize very well the relation between variables and are adequate for practical implementation by the manufacturing companies in the price forecasting process for standardized products.

4. Conclusions
In the research presented above, a complex model has been proposed that can be applied to estimate the purchase prices for standardized elastic elements, used in the manufacturing processes.

By employing the regression analysis and a data statistical analysis software (NCSS) a selection of the significant variables within the proposed model was made, starting from the catalogue prices for two types of springs (light-load springs and heavy-load springs).

The results obtained show that the models proposed for estimation predict with satisfactory accuracy the catalogue prices. Thus, this type of relations could be used by the manufacturing companies for estimating other elements that have similar constructive characteristics.

In this way, the producers will be able to respond more quickly to the demands of the customers, who request price quotations (price offers) in the shortest time possible, while reducing the cost for the process of costs calculation, a process that implies a longer time if the analytical cost calculation method is utilized.

5. References
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