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METHOD FOR FORECASTING THE TIME STANDARD OF MULTI-CHARACTERISTIC ITEM

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Summary. The purpose of this paper is to propose a method for determining the time standard of items based on several characters, where part of them is quantitative and some of them are qualitative (dichotomic). The method of determining the time standard of an item is based on Multiple Linear Regression where the dependent variable is the time standard for the production of a lot size of item and the characters of the item are the independent or regressor variables. In this paper we introduce the method for determining the time standard of an item, the way for measuring the qualitative independent variable. The method is illustrated on a case study in an Israeli plant in its research department of materials and processes. In this department a great variety of items were produced, each item has different characters.

Keywords: forecasting, time standard, multi-characteristic item

1. Introduction

In this paper we shall introduce the synthetic method [1] for determining the time standard for the production of a lot, where the time standard of an item is the time that is needed to produce the lot size of items. This method can be used for the forecasting of the time standard for the production of a product where the produced item has no fixed criteria but varies (like mass customization). To determine the time standard of a new product information is very important. It helps the plant to forecast in the future, the lead time, number of manpower, production costs etc., for each future orders of the new product. Over the years the development of work study techniques has provided a perspective that has enabled internal improvements in organization and also improved the effective and efficient use of materials and human resources [2]. For example, work study in tourism was applied in hotel housekeeping management [3]. We utilized the work study in an industrial plant for determining the time standard for the production of a lot. There are several methods for determining time standard such as: time and motion studies, work sampling, analytical estimation, Method Time Measurement (MTM) etc., for more details [4–6]. However, the classical methods are not applied where the produced item has no fixed criteria, but varies for each order. For example, when a plant produces tables, some of them vary in length, width, shape etc. Another problem arises when some of the variables are qualitative, and can't be measured quantitatively. For example, the shape of the table, its material of construction, etc., can't be measured quantitatively. For these variables we suggest to determine the value of these variables by using the Delphi method [7, 8] that we will described later. One of the problems that arises in such research is whether all the independent variables that were taken in the case study are relevant, or one can delete the non relevant variables in order to reduce the time and cost for forecasting the time standard of the item. On the other hand, we need to know the minimal information required to formulate the best function for forecasting the time standard.

In this paper we propose a method for forecasting the time standard of an item that has exclusive demands for production. We will find a formula that can forecast the time standard based on a minimum set of variables and we will give a method how to determine the value of the qualitative variables.

The paper is organized as follows: Section 2 describes the method for forecasting the time standard and Section 3 presents the Delphi method. Section 4 deals with the item and the description of the quantities and qualitative variables. In Section 5 we present the case study and Section 6 presents a summary and conclusions.

2. The method for forecasting the time standard

The method has several stages:

Stage 1: Defining the independent variables that characterize the item being researched. These variables are, either quantities that can be measured objectively, or qualitative (dicotomic) variables that are measured subjectively. The method for determining the qualitative variables is by the Delphi method that will be described in the next section.

Stage 2: Creating a sample of size n of items. For each item the timing of producing the item and the values of the independent variables from stage 1 were reported.

Stage 3: Finding the functional relation between the time and the other variables. In our case it will be the multiple linear regression.

Stage 4: Analyzed and testing if all the variables that were defined in stage 1 are needed for determining the time standard of an item, or we can delete part of them according to testing hypothesis.

3. The Delphi Method

The Delphi method was proposed in the early 1950s by researchers at RAND. Since then, it has attracted much attention. For example, a Google search using "Delphi + survey + forecasting" yielded 6800 hits in February 2004 [9]. The Delphi method involves independent anonymous forecasts made in two or more rounds by a group of heterogeneous experts who receive feedback between rounds. The procedures help overcome deficiencies in judgment. The method is named for Delphic oracle of ancient Greece, who purportedly had the power to predict the future. The method requires a group of experts to express their opinions. The opinions are then compiled and the summary of the results is returned to the experts, with special attention to those opinions that are significantly different, from the group averages. The experts are asked if they wish to reconsider their original opinions in the light of the group response. The process is repeated until an overall group consensus is reached [7]. We can summarize the Delphi method by 6 steps as follows:

Step 1 – Expert panel selection.

Step 2 – First round questionnaire distributed together with supporting data.

Step 3 – Statistical analysis of the first round responses.

Step 4 – Second round questionnaire distributed together with the results of first round and supporting information from experts.

Step 5 – Statistical analysis of the second round responses.

Step 6 – Third and further rounds as needed.

See [8].

[10] characterized the Delphi method, but in spite of their discussion they show the advantages of the Delphi method.

4. The Investigated item and the variables

4.1. The item

The item being researched is known as Mode I. This item is a stretching model that screws into stretching appliances to test attributes of the material such as: tensile strength, load, breaking strengtht oughness elastic stretching etc. Examples of items are shown in Fig.

4.2. The Independent Variables

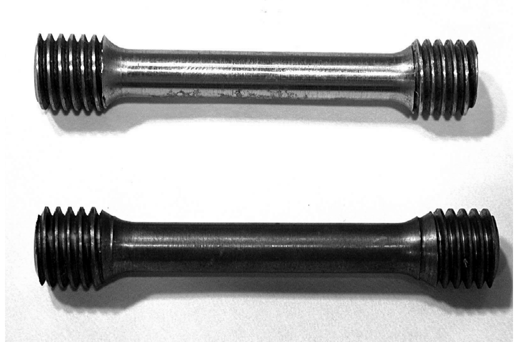
The independent variables are the set of variables that one can forecast the dependent variable-the time standard of an item is the time that is needed to produce the lot size of items, because each of them is correlated with the standard time (Table 1 and Table 2).

4.3. Dependent variable

The dependent variable is the time needed to produce the lot size of items.

5. The sample and the case study

A sample of 60 items (observations) that were produced in the past was taken. For each item the time that is needed to produce the lot size of item and all the independent variables were reported. The quantitative variables were reported from the data of the plant. While for the qualitative vari-



Photography of the item

Table 1. Quantitative variables

Symbol	Description	Units of measurement
X_1	Number of units	Lot size
X_2	Radius shoulder	Millimeter
X_3	Neck diameter	Millimeter
X_4	Parallelism	Millimeter
X_5	Gage length	Millimeter
X_6	Neck length	Millimeter

Table 2. Qualitative variables

Symbol	Description	Possible characteristics
X_7	Materials	stainless steels, copper magnesium aluminum, P.V.C steel brass
X_8	Threaded grips	M4, M6, M8, M10, 7/16W, M12,1/2W, M14, M16, M20, 7/16BSW,1/2BSW
X_9	Surface roughness	N5, N6, N7, N8, N9
X_{10}	Type specimen	Sheet, round
X_{11}	Machinery	C.N.C, N.C

ables the Delphi method was applied as follows: 13 questionnaires were sent to the workers and the manager. Each worker was asked to give a score from 1 to 9 for each one of the dicotomic variables. Here 1 indicates that it is very easy to produce the item, and 9 very hard to produce the item. On all the results average of the Delphi method was implied till the consensus of the scores, it took almost 5 rounds.

5.1. Selecting the relevant variables for the forecasting

When a problem of forecasting some dependent variable Y presented, based on k regressors variables $X_1, X_2, ..., X_k$, the most popular method is the multiple linear regression. When there are no constraints of money or economic for finding k variables, then it is desirable in the forecasting to utilize the information of all k variables in order to obtain the maximal coefficient of multiple correlation. But when there are limitations, then the question arises what is the minimal set of variables L from the whole group of k variables.

The formulation of the multiple linear regression in the first step is as follows:

$$Y = \beta_0 + \beta_1 X_1 +, ..., +\beta_k X_k + \varepsilon = X\beta + \varepsilon, \qquad (1)$$

where

X – a matrix of data ${}_nX_{k+1}$.

β – vector of parameters, $\beta = \left(\beta_0, \beta_1, ..., \beta_k\right)^T$.

ε – the error or white noise.

By the Least Squares Errors (LSE) method we found the estimation of the parameters $b = \hat{\beta} = \left(X^T X\right)^{-1} X^T Y$, then the predicated regression line is

$$\hat{Y} = b_0 + b_1 X_1 +, ..., +b_k X_k = Xb. \qquad (2)$$

In order to find the minimal set of variables (L), namely to delete the variables that have no significant influence of the dependent variable, we shall propose two methods:

Method A – We shall test the hypothesis on each variable separately by the following way:

$$H_0: \ \beta_j = 0,$$
$$H_1: \ \beta_j \neq 0.$$

The statistics for this test is:

$$T_j = \frac{b_j}{\sqrt{S^2 \left(X^T X\right)^{-1}_{jj}}} \sim t_{n-k-1}, \qquad (3)$$

where

j – the index of the variable $j = 0, 1, ..., k$.

b_j – the estimate of the coefficient β_j.

S^2 – Mean Square Error (MSE) of the observed variable Y_i and the predicted one $\hat{Y}_i$ according to the formula:

$$S^2 = \frac{\sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2}{n - k - 1}, \qquad (4)$$

$\left(X^T X\right)^{-1}_{jj}$ – the element jj (in the diagonal) of the inverse of the matrix $\left(X^T X\right)$.

If T_j (in equation (3)) is greater than $t_{n-k-1, \alpha/2}$ we shall reject the null hypothesis, namely the j variable will remain in the regression equation, and otherwise it will be deleted, for more details see [11, 12]. The disadvantage of the above method is that there is lack of consideration to the problem of multicollinearity between the independent variables themselves. In this case we delete a variable not because it is "bad", but because it is very highly correlated with the other variables. In this case we shall not reject H_0, namely this variable will be deleted.

There are several methods for discovering the multicollinearity:

1) As $\left(X^T X\right)^{-1}_{jj}$ is bigger the multicollinearity is great.

2) The determinant of $\left(X^T X\right)$ is approaching to zero, there is highly multicollinearity.

3) If the eigenvalues $\vec{\lambda}$ of $\left(X^T X\right)$ approaching to zero or $\frac{\lambda_{max}}{\lambda_{min}} > 10$, there is highly multicollinearity.

4) If in testing the hypothesis of the multiple correlation is significant, but all the testing of each coefficient separately in not significant, there is highly multicollinearity.

Method B – Stepwise

In this case we shall find in the sample of size *n* the multiple correlation of all *k* variables, $R^2_{Y,X_1,\dots,X_k}$ and the multiple correlation of a minimal set *L* of variables, $R^2_{Y,X_1,\dots,X_L}$ where *L* is the minimal set of variables by deleting and adding variables is the stepwise method, based on the following criteria if the multiple correlation $\rho^2_{Y,X_1,\dots,X_k}$ is equal or less that $\rho^2_{Y,X_1,\dots,X_L}$, by testing the hypothesis as follows:

$$H_0:\ \rho^2_{Y,X_1,\dots,X_k} = \rho^2_{Y,X_1,\dots,X_L},$$
$$H_1:\ \rho^2_{Y,X_1,\dots,X_k} > \rho^2_{Y,X_1,\dots,X_L}.$$

The statistics for this test is:

$$F = \frac{\left(R^2_{Y,X_1,\dots,X_K} - R^2_{Y,X_1,\dots,X_L}\right)/(k-L)}{\left(1 - R^2_{Y,X_1,\dots,X_K}\right)/(n-k-1)} \sim F_{,k-1,n-k-L}. \quad (5)$$

If F is less than the value in Table F with $k–L$, and $n–k–1$ degrees of freedom, and significant level α, then we shall not reject H_0, namely we can use the minimal model with *L* variables instead of the extended model with *k* variables. In this method there is no problem of multicollinearity, for more details see [12].

5.2. The Results

In the first step we run the regression model on all the 11 independent variables

$$Y = -20.340 + 0.406X_1 - 0.016X_2 - 0.122X_3 - 18.910X_4 + 0.026X_5 + 0.000X_6 + 0.818X_7 + 0.192X_8 - 0.076X_9 + 0.515X_{10} + 4.830X_{11}. \quad (6)$$

The multiple correlation coefficient of 11 variables is $R^2 = 0{,}915$. Notice that a part of the coefficients has a negative sign, it means that they have opposite relation with the dependent variable.

According to the first method (method A) of deleting each variable separately, X_2, X_3, X_4, X_5, X_6, X_9 were deleted, and we received a new regression equation:

$$Y = -18{,}168 + 0{,}394X_1 + 0{,}754X_7 + 0{,}147X_8 + 5{,}110X_{10} + 4{,}433X_{11}. \quad (7)$$

The multiple correlation coefficient of all 5 variables is $R^2 = 0{,}893$. In this case all signs of the coefficient are positive.

According to the stepwise method (method B) the best regression equation included 6 independent variables, all of them as in equation (7), but variable X_5 is added.

$$Y = -20.513 + 0.401X_1 + 0.012X_5 + 0.792X_7 + 0.201X_8 + 5.041X_{10} + 4.780X_{11}. \quad (8)$$

The multiple correlation coefficient of all 6 variables is $R^2 = 0{,}912$. If we compare the result of the separate coefficients with the stepwise method we can see that variable X_5 is not included in equation (7), not because this variable is "bad", but because it is very highly correlated with all the other variables (see Matrix of correlations, Appendix A). The elements in the matrix of correlations are or Pearson coefficient of correlation for the quantity variables or Spearman coefficient of correlation for the quality variables. On the other hand by the stepwise, variable X_5 is a variable that is included in the best regression equation. Summing up the minimal set of 6 variables reduces the number of variables by almost 50 %, but the multiple correlation coefficient reduces from 0,915 to 0,912, a reduction that is not significant.

6. Summary and conclusions

In this paper we present a method to determine the time standard of an item based on multiple criteria. We show that the stepwise method is recommended for deleting independent variables that are not relevant for the forecasting of the time standard for the production of a lot. In our case study we reduced the number of independent variables from 11 to 6, while the multiple correlation coefficient reduced only in 0,3 % (from 0,915 to 0,912). This idea can save in the future much money and time in collecting only data on part of the variables.

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References

1. Nadler, G. Motion and Time Study, McGraw-Hill Book Company, Inc., 1995, p. 510–527.

2. Douglas, C. C. Regression and Correlation, Hand Book of Industrial Engineering, 1998, p. 2501–2527.
3. Mehrez, A.; Israeli, A. A. and Hadad, Y. A work measurement application for hotel housekeeping management. *Tourism Economics*, Vol 6 (4), 2000, p. 359–370.
4. Hadad, Y. Work study, Logic-consulting and training systems, 5th ed. 1995 (in Hebrew).
5. Barnes, R. H. Motion and Time Study, Design & Measurement of Work, Wiley.7th ed. 1980.
6. Lawrence, S. A. Work measurement & methods improvement. John Wiley & Sons, inc. 2000.
7. Nahmias, S. Production and Operations Analysis, McGraw-Hill Irwin, 4thed., 2001, p. 58.
8. Kleindorfer, P. R.; Kunteuther, H. C. and Schoemaker, P. J. Decision Sciences an integrative perspective. Cambridge university press, 1993.
9. Armstrong, J. S. The Rowe and Wright paper on Delphi: an important contribution to forecasting. *International Journal of Forecasting*, Vol 18, 2002. 316 p.
10. Rowe, G. and Wrigh, G. The Delphi technique as a forecasting tool: Issues and analysis. *International Journal of Forecasting*, Vol 15, 1999, p. 351–381.
11. Brown, S. TQM and work study: partners in excellence. *Production & inventory management journal*, Vol 35 (3), 1994, p. 34–39.
12. Walpole, R. E. and Myers, R. H. Probability and Statistics for Engineers and Scientists. Macmillan Publishing Company, (Fourth Edition), 1990.

SUDĖTINGO GAMINIO GAMYBOS LAIKO NORMOS PROGNOZAVIMO METODAS

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Santrauka. Šio straipsnio tikslas – pasiūlyti gaminio gamybos laiko normos nustatymo metodą pagal daugelį kintamųjų, iš kurių vieni yra kiekybiniai, o kiti kokybiniai. Gaminio gamybos laiko normos metodas pagrįstas sudėtine linijine regresija. Čia gaminio gamybos laiko norma yra priklausomas kintamasis (masinei gamybai), o gaminio savybės yra nepriklausomi arba regresiniai kintamieji. Straipsnyje aprašomas minėtas metodas, pristatomas kokybinių kintamųjų įvertinimo principas. Metodas taikomas vienos Izrealio gamyklų Medžiagų ir procesų tyrimo skyriuje. Šiame skyriuje buvo pagaminta daug įvairių savybių gaminių.

Raktažodžiai: prognozavimas, laiko norma, sudėtingas gaminys.

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Appendix A: Matrix of correlation

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}
X_1	1	0.025	0.064	0.068	0.033	-0.078	-0.304	-0.090	0.036	0.102	-0.239
X_2	0.025	1	0.890	0.829	0.971	0.261	-0.087	-0.290	0.086	0.070	-0.207
X_3	0.064	0.890	1	0.965	0.951	0.272	-0.070	-0.380	-0.060	0.086	-0.262
X_4	0.068	0.829	0.965	1	0.895	0.358	-0.045	-0.360	-0.200	0.059	-0.312
X_5	0.033	0.971	0.951	0.895	1	0.260	-0.108	-0.330	0.000	0.062	-0.208
X_6	-0.078	0.261	0.272	0.358	0.260	1	0.045	0.090	-0.210	-0.009	-0.231
X_7	-0.304	-0.087	-0.070	-0.045	-0.108	0.045	1	0.007	0.053	-0.249	-0.099
X_8	-0.090	-0.287	-0.376	-0.359	-0.328	0.090	0.007	1	0.041	-0.067	0.086
X_9	0.036	0.087	-0.061	-0.204	-0.004	-0.211	0.053	0.041	1	0.104	0.286
X_{10}	0.102	0.070	0.087	0.059	0.062	-0.010	-0.249	-0.070	0.104	1	0.134
X_{11}	-0.239	-0.207	-0.262	-0.312	-0.208	-0.231	-0.099	0.086	0.286	0.134	1