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A hybrid algorithm based on fuzzy linear regression analysis by quadratic programming for time estimation: An experimental study in manufacturing industry

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ABSTRACT

In time studies, estimation of the standard times with direct or indirect measurement methods is particularly difficult in companies having complex production schedules or ones employing an inexperienced workforce. Such companies require new and specific time measurement procedures. In this study, a new time estimation algorithm based on fuzzy linear regression analysis (FLRA) by quadratic programming (QP) is proposed for specific manufacturing systems. In our study, data is provided by one of the biggest casting and machining companies in Europe. The database includes items that have similar production processes. A fuzzy linear regression model is built by using the previously measured standard times of a product family. The model developed is used for estimating the standard times of the remaining products. FLRA based on QP approach facilitates integration of the central tendency of least squares and possible properties of fuzzy regression. The main factors that directly impact standard times are determined and used for the estimation of the fuzzy standard times. Through utilization of sum of squares error (SSE) and index of confidence (IC), the important factors in the model are identified. The use of QP makes it possible to reconcile the minimization of the deviation of central tendency and the spreads of membership functions in a simultaneous manner. In this study, the efficiency of the proposed algorithms in casting companies is authenticated. Besides, it is seen that this estimation procedure could be implemented easily for various sectors using the relevant algorithms.

1. Introduction

In recent years, due to the exacerbating competition in the market, determination of the exact standard time of manufacturing products has become an essentiality [1]. It is very difficult to prepare manufacturing schedules, short and long term forecasts, capacity planning, pricing and some other technical and managerial activities in a company without accurate standard time. Unfortunately, direct or indirect work measurement procedures, e.g., time study, activity sampling, standard data synthesis, analytical estimation, comparison, prediction and elementary motion standards are insufficient in most cases to determine the exact standard time. For example, the cost of time study, as well as inadequate environmental conditions, can be prohibitive due to complex production processes. Thus, new and effective methods are needed to be developed regarding this issue. Some of the recent studies in the literature are outlined below.

Koelling and Ramsey [2] studied the effects of multimedia in developing and applying work measurement methods, Cohen et al. [3] examined successful integration of automatic speech recognition (ASR) into industrial systems and found that the generation of time standards is a time consuming process that always slows down the work measurement task and increases cost. By using ASR, 70% time reduction is achieved. Focusing on engineers using 100 industrial engineering programs in US, Freivalds et al. [1] tested the effect of work measurement and design systems on customer satisfaction. Praszkiewicz [4] presented the application of ANNs in small scale machining production, with a purpose similar to the study of Freivalds. Besides Eraslan [5] studied on the ANN method for standard time estimation of a specific manufacturing facility. Apart from the fact that there are some studies on the literature which use

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genetic algorithms or optimization techniques for forming materials both in manufacturing environment and in manufacturing system processes.

In this study, fuzzy linear regression analysis (FLRA) by quadratic programming (QP), based on indirect standard time estimation methodology is proposed. The proposed model uses Tanaka's quadratic programming approach [6]. The preferred QP approach has better performance for central tendency estimation than the linear programming approaches. The proposed algorithm provides an integration of the central tendency of least squares and possible properties of fuzzy regression. By using the QP, both the minimization of deviation of central tendency and estimated deviations in membership functions' spreads are investigated at the same time. This form is unique in the literature. The main factors that directly affect time are determined and the algorithm is used for estimating the fuzzy standard time. For time estimation process, time study results of semi-products or products, completed in advance, are used. Thereby, an algorithm based on FLRA by QP is applied to the manufacturing company.

Fuzzy linear regression was first introduced by Tanaka et al. in 1982 [7]. In their study, a regression problem with fuzzy output and crisp input was formulated as a mathematical programming problem. The objective was to minimize the total spreads of the fuzzy parameters subject to the constraint. The regression model was required to satisfy a pre-specified membership value in estimating the fuzzy outputs. Different researchers used Tanaka's approach to minimize the total spread of the output [8,9]. Sakawa and Yano [10], Kim and Bishu [11], Peters [9] considered the possibility and necessity of conditions for fuzzy equality. The fuzzy least-squares regression was first introduced by Dimond [12]. Tanaka and Lee [6] proposed an interval regression analysis based on quadratic programming approach. He et al. [13] examined the liaisons between productivity and consumer satisfaction in achieving profitability for firms from services sector in Hong Kong by FRA. Azadeh et al. [14] applied FRA for energy forecasting problems. Tseng and Hu [15] proposed a quadratic-interval Bass model that combines quadratic-interval regression with the Bass innovation diffusion model to solve a fuzzy relationship between explanatory and output variables and to provide forecasts of sales to decision makers. Wang and Tsaur [16] proposed a variable selection method as a branch and bound algorithm for a fuzzy regression equation with crisp input and fuzzy output. For a fuzzy regression equation with crisp data, Wang and Tsaur [17] have derived a relation which introduced the total sum of squares in vagueness plus the total sum of squares in estimation, and defined a partial value of index of confidence (IC) to be a criterion of variable selection. Hung and Yang [18] focused on the detection of outliers in fuzzy linear regression models. Hang and Yi [19] proposed a nonlinear programming model to identify the fuzzy input and output data for manpower forecasting.

Fuzzy regression models have been successfully applied to various problems such as engineering and technological forecasting. It can also be applied to the estimation of fuzzy process time in the manufacturing companies. Besides, instead of the crisp values of standard time, obtaining a fuzzy interval is more relevant to the real life problems where linguistic variables are commonly used. Fuzzy regression analysis (FRA) proves to be more flexible and rigorous than the traditional (non-fuzzy) approach.

In this study, we propose an FRA by quadratic programming (QP) for the estimation of indirect standard time. This study is organized as follows: fuzzy regression and FLRA by QP is reviewed in the next section, new algorithm is proposed for estimated fuzzy standard times in Section 3, and proposed algorithm based on FRA by QP is tested on an experimental data set provided by a casting company in Section 4. Experimental results and findings are discussed in the conclusion.

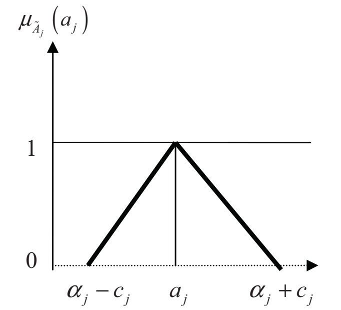

Fig. 1. A triangular fuzzy regression coefficient.

2. Fuzzy linear regression analysis (FLRA) by quadratic programming (QP) for the proposed algorithm

Regression analysis is an area of statistics that deals with the investigation of dependence of a variable upon one or more other variables. The dependence is usually assumed to have a particular mathematical form with one parameter [20]. The aim of regression analysis is to find an appropriate mathematical model and determine the best fitting coefficients of the model from the given data. This classical regression technique is useful in a non-fuzzy environment where the relationship among variables is crisply defined. However, it is very difficult to obtain an exact relationship. The use of statistical regression is restricted by some strict assumptions regarding statistical properties of the given data. However, the fuzzy regression does not need to have these properties. Therefore it could be applied to many real life problems in which the strict assumptions of statistical regression analysis cannot be met. FRA considers the use of fuzzy numbers. The use of fuzzy numbers involves the modeling of problems where the output variable is affected by imprecision. The goal of FRA is to find a regression model that fits all observed fuzzy data within a specified fitting criterion.

The basic model developed by Tanaka et al. [7] assumes a fuzzy linear regression function as:

$$\tilde{Y}_i = \tilde{A}_0 X_{i0} + \tilde{A}_1 X_{i1} + \tilde{A}_2 X_{i2} + \cdots + \tilde{A}_n X_{in} = \tilde{A} X_i \quad i = 1, \ldots, m \tag{1}$$

where $X_i = [X_{i0}, X_{i1}, \ldots, X_{in}]^T$ is an input vector; $\tilde{A} = [\tilde{A}_0, \tilde{A}_1, \ldots, \tilde{A}_n]$ is a vector of fuzzy coefficients in the form of symmetric triangular fuzzy number denoted by $\tilde{A}_j = (\alpha_j, c_j)$ with its membership function describes as

$$\mu_{\tilde{A}_j}(a_j) = \begin{cases} 1 - \dfrac{|\alpha_j - a_j|}{c_j} & \alpha_j - c_j \le a_j \le \alpha_j + c_j \\ 0, & \text{otherwise} \end{cases}$$

where α_j is its central value and c_j is the spread value and $c_j > 0$. Membership function $\mu_{\tilde{A}_j}(a_j)$ is given in Fig. 1.

$\tilde{Y}_i, (i = 1, \ldots, m)$ is the corresponding estimated output and has a fuzzy set that is characterized by symmetric triangular membership function $\mu_{\tilde{Y}_i}(y_i)$, with center $\bar{y}_i$, and spread e_i and $(\tilde{Y}_i = (\bar{y}_i, e_i))$. Membership function $\mu_{\tilde{Y}_i}(y_i)$ is denoted as

$$\mu_{\tilde{Y}_i}(y_i) = \begin{cases} 1 - \dfrac{|y_i - \bar{y}_i|}{e_i} & \bar{y}_i - e_i \le y_i \le \bar{y}_i + e_i \\ 0, & \text{otherwise} \end{cases}$$

Therefore formula (1) can be rewritten as

$$\tilde{Y}_i = (\alpha_0, c_0) X_{i0} + (\alpha_1, c_1) X_{i1} + \cdots + (\alpha_n, c_n) X_{in} \quad i = 1, \ldots, m \tag{2}$$