A NEW APPROACH TO WESTINGHOUSE TEMPO RATING SYSTEM WITH FUZZY LOGIC

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Abstract

When calculating the production cost of a product, two basic items are taken into consideration. The first is the material cost and the second is the labor cost. Material costs can be calculated very clearly due to the lack of personal judgment. Because the amount of material used for the production of that product is certain. However, the calculation of labor costs may not always be as simple and precise. The amount of product produced per unit time directly affects product costs. Therefore, to calculate the costs correctly, the number of parts produced per unit time must be calculated correctly. At this point, production times per product gain importance. It is not considered sufficient to use the values on the chronometer when calculating the production times of parts or products. Standard production times are calculated by adding performance and tolerance values to the chronometer values. Worker performance may vary from person to person. Performance varies depending on worker ability, effort, consistency and working environment. This difference in performance becomes very important in manual production processes. In automatic production processes, this difference is especially important when disassembling and assembly processes of the parts to the automatic machines. Tempo rating systems have been proposed to standardize worker performances and to minimize the negative effects of performance differences between individuals. The Classical Westinghouse Method (CWM) is one of the common use tempo rating system. In the CWM, the performance of the worker is calculated by using skill, effort, environmental conditions, and consistency values. Evaluations of these four criteria are obtained by observing by decision-makers. In this study, the fuzzy rule-based Westinghouse method is developed because decision-makers use linguistic expressions to evaluate worker performance. The proposed Fuzzy Westinghouse Method (FWM) is applied to a part of the company that produces automatic cutting machines in order to prove its validity. As a result of the study, it is determined that the proposed model produces more sensitive values.

WESTINGHOUSE TEMPO DERECELENDİRME SİSTEMİNE BULANIK MANTIK İLE YENİ BİR YAKLAŞIM

Anahtar Kelimeler

Tempo derecelendirme sistemi, klasik Westinghouse metodu, normal zaman, bulanık mantık, bulanık Westinghouse metodu

Öz

Bir ürünün üretim maliyeti hesaplanırken iki temel öğe dikkate alınır. Bunlardan birincisi malzeme maliyeti ve ikincisi işçilik maliyetidir. Kişisel mühakeme eksikliği nedeniyle malzeme maliyetleri çok net bir şekilde hesaplanabilir. Çünkü o ürünün üretimi için kullanılan malzeme miktarı belidir. Bununla birlikte, işçilik maliyetlerinin hesaplanması her zaman bu kadar basit ve kesin olmamakta. Birim zamanda üretilen ürün miktarı, ürün maliyetlerini doğrudan etkiler. Bu nedenle maliyetleri doğru hesaplamak için birim zamanda üretilen parça adedinin doğru hesaplanması gerekir. Bu noktada ürün başına üretim süreleri önem
Parça veya ürünlerin üretim süreleri hesaplanırken kronometredeki değerlerin kullanılması yeterli görülmemektedir. Standart üretim süreleri, kronometre değerlerine performans ve tolerans değerleri eklenerek hesaplanmaktadır. Çalışan performansı kişiden kişiye değişebilir. Performans, çalışanın yeteneğine, çabasına, tutarlılığına ve çalışma ortamına bağlı olarak değişmektedir. Performanstağın bu fark, manuel üretim süreçlerinde çok önemlidir. Otomatik üretim süreçlerinde bu fark özellikle parçaların otomatik makinelere montaj ve demontaj işlemlerinde önemlidir. Çalışan performanslarını standartlaştırarak ve bireyler arasındaki performans farklarının olumsuz etkilerini en aza indirme için tempo derecelendirme sistemleri önerilmiştir. Klasik Westinghouse metodu, yaygın kullanılan tempo derecelendirme sistemlerinden biridir. Klasik Westinghouse metodunda işçinin performansı beceri, çaba, çevre koşulları ve tutarlılık değerleri kullanılarak hesaplanır. Bu dört kriterin değerlandirmeleri karar vericiler tarafından gözlemlenen bir列 demonstrated. Bu çalışmadada, karar vericilerin çalışan performansını değerlendirme için dilsel ifadeleri kullanması nedeniyle bulanık kural tabanlı Westinghouse metodu geliştirilmiştir. Önerilen bulanık Westinghouse metodu, geçerliliğini kanıtlamak için otomatik kesme makineleri üreten bir şirketin bir bölümüne uygulanmıştır. Çalışma sonucunda önerilen modelin daha hassas değerler ürettiği tespit edilmiştir.

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1. Introduction

The main purpose of every profit-oriented business is to make a profit by producing products and/or services and offering them to the end user. In the simplest way, profit is obtained by subtracting production costs from the sales price of the product. The rise in production costs results in higher prices in a fixed profit margin. If the market of the product determines the price, then the rising costs will reduce the profit margin. In today's competitive business world, companies need to keep production costs as low as possible in order to sustain their market presence. First of all, it is very important to calculate the cost of parts correctly. For example, if the cost of a product is underestimated, this will result in a low price recommendation to the customer. In this case, lower profits can be made and even financial losses can be obtained. On the contrary, if the costs are calculated higher than they are, then the product price will be increased and fewer customers will be reached. Unit product costs are influenced by different factors such as product quality, labour and technology used, product design. In this direction, production costs can be reduced by increasing labour productivity as a result of standardization, simplification, and elimination of activities that do not add value. The work-study approach has been developed for this purpose.

The work study consists of two main techniques: method study and time study. The purpose of the method study is to eliminate non-value added processes and to obtain the fastest and most accurate method of performing value added processes. Time study is a methodology in which the time duration of each activity of a subject is recorded in order to create the workflow and achieve efficiency and effectiveness through eliminating waste and simplifying work (Chebolu-Subramanian, Sule, Sharma, Mistry 2019). Firstly, a process should be standardized with the method study, then the production times should be determined by the time study. In this study, the proposed method is developed to use in time study activities.

The main activities of the work-study method are shown in Figure 1. Firstly, the product or part on which the work-study method will be applied is determined. When determining this part, it is useful to give priority to the problematic parts that create bottlenecks in production. The second stage is a critical examination of the production stages of the product in full detail within the scope of the method-study. The most suitable method for the production of the related product is determined by developing solutions for the problems occurring during the production phase. Then the method is documented and standardized. After the
determination of most appropriate method and elimination of non-value added processes by the method-study, the time study phase is started. In the time study method, the observer first measures the production times. These times are called chronometer values (CV) because these values are read directly from the chronometer. Performance and tolerance coefficients are not added. In the next step, the performance value (P) of the observed worker is determined using any tempo rating method. Normal Time (NT) is obtained by multiplying this determined performance value with the chronometer value measured by the observer (Eq. 1).

\[
Normal\ Time\ (NT) = Chronometer\ Value\ (CV) \times\ Performance\ Value\ (P)
\] (1)

Figure 1. Main activities of the work-study method

Next, A Tolerance Value (T) is determined by considering the weight of the part to be observed, the temperature of the working environment, the working position, noise, vibration in the working environment. In the last phase, the Standard Time (ST) is obtained by multiplying the Normal Time with the Tolerance Value. Standard Times are used for all cost calculations or for calculation of production times (Eq. 2).

\[
Standard\ Time\ (ST) = Normal\ Time\ (NT) \times Tolerance\ Value\ (T)
\] (2)
This study proposed a suggestion for the tempo rating method used to determine performance in the time study method. Tempo rating is the evaluation of the working speed of the worker according to the standard speed concept of the observer. This standard is the normal speed that qualified workers can achieve with normal work (Bircan and Iskender 2005).

The Classical Westinghouse Method (CWM) is one of the tempo rating methods. CWM is based on four factors which are skill, effort, environmental conditions, and consistency (Lehto and Landry 2012). In the CWM, numeric values are used instead of linguistic variables while determining the performance value. However, these numerical values are defined as intermittent values. For instance, according to the skill factor, a worker should have a value between +0.15 and +0.13 to be considered "Perfect". Similarly according to the skill factor, a worker should have a value between +0.11 and +0.08 to be considered "Excellent". As can be seen in Table 1 there is no a linguistic equivalent for the +0.12 value between "Perfect" and "Excellent" for skill factor in the CWM. It is aimed to obtain an alternative of CWM that can produce more precise results by ensuring intermediate values. In the proposed method the intermediate values is taken into consideration by using fuzzy logic approach. Thus, it is aimed to obtain more realistic values for each limit value between "Perfect" and "Excellent" for skill factor in the CWM. It is aimed to obtain an alternative of CWM that can produce more precise results by ensuring intermediate values. In the proposed method the intermediate values is taken into consideration by using fuzzy logic approach. Thus, it is aimed to obtain more realistic values for each limit value between "Perfect" and "Excellent" for skill factor in the CWM.

2. Performance Rating

While the operator is working during a task, evaluation of the speed, pace or the tempo (the terms are used synonymously to refer to the speed of movement) is an important part of the time study. The operators speed must be judged by the analyst during the time working. This is called performance rating. There are several methods that is used for performance rating (Lehto and Landry 2013). These are briefly described below (Barnes 1980; Suwittayaruk, Van Goubergen, 2011).

Synthetic Rating: This method effort to provide a rating that is not influenced by human judgments by using predetermined time values which were evaluating an operator’s speed. Performance rating factor can be found by the ratio of predetermined time value and the actual time value of an element. The computation of the performance rating factor’s formula is given below (Eq. 3) (Barnes 1980; Matias 2001).

\[ R = \frac{P}{A} \]  

where

\[ R = \text{Performance Rating Factor} \]
\[ P = \text{Predetermined Time for the element} \]
\[ A = \text{Average Actual Time for the same element} \]

Thus the determined factor can be applied to other manual elements being studied.

Objective Rating: The purpose of this method is to reduce the amount of judgement in the time study. The procedure of this method is consist of two steps (Barnes 1980; Matias 2001);

a. The degree of speed observed to an objective speed standard that is the same for all jobs. In this rating, attention is not paid to the difficulty of work and its limiting effect on possible speed; therefore, a single tempo standard can be used instead of multiple mental concept.

b. Not all jobs can be performed at standard pace, because in practice they will all be more or less difficult than the job where standard pace is created. The factors affecting the pace of work, as indicated by experimental or practical evidence, are as follows as:

- Total amount of body involved in the element
- Foot pedals
- Bimanualness
- Eye-Hand Co-ordination
- Handling requirements
- Weight handled or the resistance encountered
Performance Rating: This method known as “Speed Rating” or “Effort Rating”. In this method, the time study analyst only takes into account the success rate per unit time. The analyst compares the performance displayed with its normal performance concept for the operation under examination (Barnes 1980; Matias 2001).

Physiological Rating: Physiologists demonstrated the validity of using the oxygen consumption rate to measure energy consumption. Subsequent studies have shown that the change in heart rate is also a reliable measure of physical activity. In this method, the change in heart rate and oxygen consumption values of a worker while performing a job is determined as tempo (Barnes 1980; Matias 2001).

In this study, performance rating approach of CWM is discussed. CWM is developed by Westinghouse Company in 1927 (Bircan and İskender 2005). The need for full understanding and adequate training is strongly emphasized in the use of the technique to achieve consistent and accurate results. The system gives numerical weights to skill, effort, conditions, and consistency as found during a study. To what extent variables affect the productivity of an employee helps the analyst to make a more precise overall assessment. It is important to understand the concepts of skill, effort, conditions and consistency before the application of the method (Matias 2001).

As the time study analyst observes the operator, the analyst notes the skills, effort, conditions and consistency for each job along with their codes. The numerical degree of factors is then algebraically added to the nominal 100 percent to produce a finished rating (Matias 2001). The linguistic variables of the rating factors and their performance values are given in Table 1.

| Level    | Skill | Effort | Conditions | Consistency |
|----------|-------|--------|------------|-------------|
| Perfect  | A1    | 0.15   | A1         | 0.13        | 0.06        | A           | 0.04        |
|          | A2    | 0.13   | A2         | 0.12        |
| Excellent| B1    | 0.11   | B1         | 0.10        | B           | 0.04        | B           | 0.03        |
|          | B2    | 0.08   | B2         | 0.08        |
| Good     | C1    | 0.06   | C1         | 0.05        | C           | 0.02        | C           | 0.01        |
|          | C2    | 0.03   | C2         | 0.02        |
| Average  | D     | 0      | D          | 0           | D           | 0           | D           | 0           |
| Fair     | E1    | -0.05  | E1         | -0.04       | E           | -0.03       | E           | -0.02       |
|          | E2    | -0.10  | E2         | -0.08       |
| Poor     | F1    | -0.16  | F1         | -0.12       | F           | -0.07       | F           | -0.04       |
|          | F2    | -0.22  | F2         | -0.17       |

CWM is useful in other ways. For example, the skill factor provides a basis for estimating the potential benefits of training if one can estimate the change in skill resulting from the training program. Similarly, the effort factor might be useful to evaluate a prospective incentive program, and the conditions factor allows for an estimate of performance due to changes in working conditions (Lehto and Landry 2012).
3. The Proposed Method

Fuzzy Westinghouse Method (FWM) includes 4 input and 1 output parameter. The input parameters of the FWM are determined as “Skill”, “Effort”, “Working Conditions” and “Consistency” to meet the CWM. The output parameter of the FWM is “Performance”. Furthermore, due to the fact that consistency is regarded all parameters of CWM are included in “Performance” value. This value is attempted to be determined by considering these 4 main input parameters shown in Figure 2.

CWM includes 5 levels for determining the performance of operators. These levels; Poor, Fair, Average, Good, Excellent, Perfect; are integrated to create membership function. Membership functions have both triangular and trapezoidal fuzzy numbers and these are determined by taking into consideration points of CWM, shown in Table 1. Interval values of membership functions are shown in Table 2. The rating scale adopted in the CWM is used creating the membership functions to be attain consistent minimum and maximum values. For instance, range of the Skill [78, 115], Effort [83, 113], Working Conditions [93, 106] and Consistency [96, 104] are evaluated within these range in the FWM. Considering these ranges of the input parameters, the output parameter of the model, Performance, is evaluated as range of [50, 135].

In this study, Mamdani fuzzy inference system (Mamdani and Assilian 1975) is used and the model is created using fuzzy logic toolbox of Matlab software. Due to the lack of training set and the...
characteristic of the CWM, Mamdani model structure is developed on the basis of expert knowledge and training. In the proposed model, “and” / “or” processes (Eq. 4, Eq. 5) which are established between fuzzy rules “min” / “max” values (Eq. 6, Eq. 7) are preferred respectively (Pourjavad and Mayorga 2019).

\[
\mu A(x) \text{ and } \mu B(x) = MIN\{\mu A(x), \mu B(x)\}
\]
\[
\mu A(x) \text{ OR } \mu B(x) = MAX\{\mu A(x), \mu B(x)\}
\]
\[
\mu R(x, y) = MIN\{\mu A(x), \mu B(x)\}
\]
\[
\mu R(x, y) = MAX\{1 - \mu A(x), MIN\{\mu A(x), \mu B(x)\}\}
\]

There are many defuzzification methods as center of gravity, bisector of area, smallest of maximum, mean of maximum and largest of maximum etc. For subtraction “min”, for addition “max” and for defuzzification “largest of maximum (LOM)” specifications are defined. In this study, LOM, which has maximum membership to the overall implied fuzzy set is preferred. This defuzzification method where crisp value is calculated as Eq. 8 (Namazov and Bastürk 2010). Structure of proposed model is shown in Figure 3.

\[
u_{LOM} = x_{max}
\]

Figure 3. Inputs and Output of Proposed Model
Triangular and trapezoidal membership functions are both used for membership functions and showed as overlapped. The membership functions of inputs are presented in Figure 4. The membership functions of “Performance” are presented in Figure 5.

![Figure 4. Membership functions of inputs](image1)

![Figure 5. Membership functions of output](image2)

In the proposed model 491 rules are generated for Performance according to the relationship between state and control variables by the experts. Rules are generated via the judgments of three industrial engineers having 10-15 year experience about work study. The rule base is briefly shown in Figure 6(a). Performance result of state variables for any value in the predefined ranges are obtained as in Figure 6(b).
Figure 6. (a) Rule base, (b) Performance evaluation display

4. Application of the Proposed Method

The proposed FWM is applied in a machine manufacturing company. Work-study process is carried out on an important part of the machine. This part which is the connection element of the machine is called sheet bar. The part and technical drawing are presented in Figure 7. Ethics committee approval was not required in the study, research and publication ethics were followed.

Figure 7. (a) the part: sheet bar (b) technical drawing of the part
The part is assembled to the product at the end of 5 operations after coming to the plant as raw material. These operations are cutting, universal milling, CNC processing, universal milling, and metal blackening respectively. The number of observations should be determined before starting the observation process. The number of observations is calculated in the work-study area with Eq. 9 (5% tolerance and 95% confidence interval) (Kanawaty 1992).

\[ N = \left[ \frac{n\sum x_i^2 - (\sum x_i)^2}{\sum x_i} \right]^2 \]  

(9)

where

\( x_i \): the value of the \( i \)th trial observation of the related operation  
\( n \): the number of trial observations  
\( N \): the number of required observations to predict within the desired sensitivity and confidence interval

Trial observations are performed to determine the number of observations required. In the literature, a certain amount is not determined for the number of trial observations. In this study, 5 experimental observations are made. The values of 5 trial observations are given in Table 3. Table 3 identifies the number of required observations for each process. These numbers vary between 5 and 13. In this study, the number of observations required for each process is 15.

Table 3
The values of trial observations

| Process           | Cutting | Universal Milling | CNC Processing | Universal Milling | Metal Blackening |
|-------------------|---------|-------------------|----------------|-------------------|------------------|
| \( n_1 \)         | 19.3    | 480.5             | 298.3          | 70.3              | 120.9            |
| \( n_2 \)         | 20.1    | 475.8             | 302.1          | 69.9              | 122.1            |
| \( n_3 \)         | 21.2    | 476.8             | 299.3          | 68.7              | 118.7            |
| \( n_4 \)         | 20.1    | 479.3             | 301.4          | 67.9              | 119.3            |
| \( n_5 \)         | 20.3    | 481.9             | 303.9          | 70.3              | 121.9            |
| \( N \)           | 13      | 5                 | 7              | 7                 | 10               |

In the next step, the performance values of the workers in each process are determined through observation. Performance values for the FWM are determined with Matlab software (Table 4).

Table 4
Performance values for CWM and FWM

| Process           | Skill  | Effort | Env. Cond. | Consis. | Performance Value for CWM | Performance Value for FWM |
|-------------------|--------|--------|------------|---------|---------------------------|---------------------------|
| Cutting           | 113    | 102    | 102        | 101     | 118                        | 115                       |
| Universal Milling | 103    | 108    | 104        | 104     | 119                        | 120                       |
| CNC Processing    | 106    | 105    | 104        | 101     | 116                        | 112                       |
| Universal Milling | 111    | 105    | 102        | 103     | 121                        | 119                       |
| Metal Blackening  | 100    | 105    | 93         | 98      | 96                         | 95                        |

15 observations are made for each process and standard times are calculated. According to the company policy, the tolerance value is determined as 115% for each process. The number of observations, numerical values of each factor affects the performance, performance value, normal time and standard time for CWM and FWM for each processes are shown in Table 5-Table 9.
In Table 5, the values of the 15 observations discussed for the cutting process are measured. For example, while the first observation is calculated as approximately 27 seconds according to CWM, this value is calculated as 26.3 seconds according to FWM. The difference between the averages of the 15 observations is calculated as 0.705 seconds, and this difference is very low since the cutting process is a short process.

Table 5
Normal and Standard time for cutting process according to CWM and FWM

| Obs. | Time for Cutting | Effort | Cons. | Performance Value for CWM | Normal Time for CWM | Normal Time for FWM | Tolerance | Std. Time for CWM | Std. Time for FWM |
|------|-----------------|--------|-------|---------------------------|---------------------|---------------------|-----------|------------------|------------------|
| 1    | 19.9            | 113    | 102   | 102                        | 101                 | 118                 | 115       | 23.482           | 22.885           |
| 2    | 19.5            | 113    | 102   | 102                        | 102                 | 118                 | 115       | 23.010           | 22.425           |
| 3    | 19.8            | 113    | 102   | 102                        | 102                 | 118                 | 115       | 23.364           | 22.770           |
| 4    | 21              | 113    | 102   | 102                        | 102                 | 118                 | 115       | 24.780           | 24.150           |
| 5    | 20.1            | 113    | 102   | 102                        | 102                 | 118                 | 115       | 23.718           | 23.115           |
| 6    | 21.2            | 113    | 102   | 102                        | 102                 | 118                 | 115       | 25.016           | 24.380           |
| 7    | 20.1            | 113    | 102   | 102                        | 102                 | 118                 | 115       | 23.718           | 23.115           |
| 8    | 20.4            | 113    | 102   | 102                        | 102                 | 118                 | 115       | 24.072           | 23.460           |
| 9    | 20.3            | 113    | 102   | 102                        | 102                 | 118                 | 115       | 23.954           | 23.345           |
| 10   | 21.2            | 113    | 102   | 102                        | 102                 | 118                 | 115       | 25.016           | 24.380           |
| 11   | 21              | 113    | 102   | 102                        | 102                 | 118                 | 115       | 24.780           | 24.150           |
| 12   | 20.8            | 113    | 102   | 102                        | 102                 | 118                 | 115       | 24.544           | 23.920           |
| 13   | 19.7            | 113    | 102   | 102                        | 102                 | 118                 | 115       | 23.246           | 22.655           |
| 14   | 20.2            | 113    | 102   | 102                        | 102                 | 118                 | 115       | 23.836           | 23.230           |
| 15   | 21.2            | 113    | 102   | 102                        | 102                 | 118                 | 115       | 25.016           | 24.380           |

In Table 6, the values of the 15 observations discussed for the universal milling process are measured. For example, while the first observation is calculated as approximately 657 seconds according to CWM, this value is calculated as 662.5 seconds according to FWM. The difference between the averages of the 15 observations is calculated as 5.8 seconds.

Table 6
Normal and Standard time for universal milling process according to CWM and FWM

| Obs. | Time for Universal Milling | Effort | Cons. | Performance Value for CWM | Normal Time for CWM | Normal Time for FWM | Tolerance | Std. Time for CWM | Std. Time for FWM |
|------|---------------------------|--------|-------|---------------------------|---------------------|---------------------|-----------|------------------|------------------|
| 1    | 480.1                     | 103    | 108   | 104                        | 104                 | 119                 | 120       | 571.319          | 575.12           |
| 2    | 475.8                     | 103    | 108   | 104                        | 104                 | 119                 | 120       | 566.202          | 570.96           |
| 3    | 475.6                     | 103    | 108   | 104                        | 104                 | 119                 | 120       | 565.964          | 570.72           |
| 4    | 480.3                     | 103    | 108   | 104                        | 104                 | 119                 | 120       | 571.557          | 576.36           |
| 5    | 480.5                     | 103    | 108   | 104                        | 104                 | 119                 | 120       | 571.795          | 576.60           |
| 6    | 475.8                     | 103    | 108   | 104                        | 104                 | 119                 | 120       | 566.202          | 570.96           |
| 7    | 476.7                     | 103    | 108   | 104                        | 104                 | 119                 | 120       | 567.273          | 572.04           |
| 8    | 479.4                     | 103    | 108   | 104                        | 104                 | 119                 | 120       | 570.486          | 575.28           |
| 9    | 481.9                     | 103    | 108   | 104                        | 104                 | 119                 | 120       | 573.461          | 578.28           |
| 10   | 481.7                     | 103    | 108   | 104                        | 104                 | 119                 | 120       | 573.223          | 578.04           |
| 11   | 475.8                     | 103    | 108   | 104                        | 104                 | 119                 | 120       | 566.202          | 570.96           |
| 12   | 479.4                     | 103    | 108   | 104                        | 104                 | 119                 | 120       | 570.486          | 575.28           |
| 13   | 480.3                     | 103    | 108   | 104                        | 104                 | 119                 | 120       | 571.557          | 576.36           |
| 14   | 480.1                     | 103    | 108   | 104                        | 104                 | 119                 | 120       | 571.319          | 576.12           |
| 15   | 480.5                     | 103    | 108   | 104                        | 104                 | 119                 | 120       | 571.795          | 576.60           |
In Table 7, the values of the 15 observations discussed for the CNC processing process are measured. For example, while the first observation is calculated as 397.9 seconds according to CWM, this value is calculated as 384.2 seconds according to FWM. The difference between the averages of the 15 observations is calculated as 14.6 seconds.

In Table 8, the values of the 15 observations discussed for the universal milling process are measured. For example, while the first observation is calculated as 97.6 seconds according to CWM, this value is calculated as 96 seconds according to FWM. The difference between the averages of the 15 observations is calculated as 1.7 seconds.
zy logic approach. In the future study, a
lated for
erence between the average of 15
s
errors that may occur due to the individual opinion
be challenging. Thanks to the fuzzy
expressions and adding them to the calculations can
finding the numerical equivalent of linguistic
based on the observation of the decision maker,
performance of the workers. Especially in methods
may not be sufficient
demand balance). However, tempo rating methods
overtime work), production volume (supply
calculation of salary management (salary policy,
for companies because of providing the correct
performance with minimum error is an advantage
in a process will benefit at many points.
involved in a process are measured. For example, while the first observation
is calculated as 132.5 seconds according to CWM, this value is calculated as 131.2 seconds according to FWM. The difference between the averages of the 15 observations is calculated as 1.5 seconds.

5. Conclusion
The main cost items of a company are material cost and labor cost. The daily production amount is effective in the labor cost of a part. Proper evaluation of the performance of the worker involved in a process will benefit at many points. The first one is the correct calculation of labor costs, daily production quantities, deadlines and fair management of the wage-price policies. As a result of performance evaluations, low performance workers can be trained to increase their performance levels. Calculating operator’s performance with minimum error is an advantage for companies because of providing the correct calculation of salary management (salary policy, overtime work), production volume (supply-demand balance). However, tempo rating methods may not be sufficient to reflect the actual performance of the workers. Especially in methods based on the observation of the decision maker, finding the numerical equivalent of linguistic expressions and adding them to the calculations can be challenging. Thanks to the fuzzy logic approach, errors that may occur due to the individual opinion of the observer can be minimized.

In this study, the performance rating approach of CWM is discussed with the fuzzy logic approach. The proposed FWM is applied to the company that produces automatic cutting machines in order to provide its validity. Obtaining more sensitive values with the proposed method will result in more accurate calculations in the studies where these values will be used. For example, when Table 7 is examined, the difference between the average of 15 observations according to CWM and the average according to FWM is determined as approximately 15 seconds. With the FWM approach, a lower standard time of about 15 seconds is achieved. Although this value seems to be a small difference when considering 1 product, its effect will increase as the number of products increases. In addition, differences arising from other operations increase the amount of error on the total standard time. In the study, performance values are calculated for each process separately. However, the tolerance value is pre-determined as 115% and is used in the calculation of standard times. This approach has been adopted to determine the limits of the study. However, tolerance values vary according to the working position of the operators, the weight of the work piece, environmental conditions and the mental and physical fatigue it creates. In cases where the tolerance value will be calculated separately, healthier results can be obtained thanks to the fuzzy logic approach. In the future study, a fuzzy-based approach may be proposed for calculating tolerance values. In this way, process-based tolerance values can be determined.

Table 9
Normal and Standard time for metal blackening process according to CWM and FWM

| Obs. | Obs. Time for Metal Blackening | Skill | Effort | Env. Cond. | Cons. | Performance Value for CWM | Performance Value for FWM | Normal Time for CWM | Normal Time for FWM | Tolerance | Std. Time for CWM | Std. Time for FWM |
|------|-------------------------------|-------|--------|------------|------|--------------------------|--------------------------|---------------------|---------------------|-----------|----------------|----------------|
| 1    | 120.1                         | 100   | 105    | 93         | 98   | 96                       | 95                       | 115.296             | 114.095             | 115       | 132.590         | 131.209       |
| 2    | 118.3                         | 100   | 105    | 93         | 98   | 96                       | 95                       | 113.568             | 112.385             | 116       | 131.739         | 130.367       |
| 3    | 122.1                         | 100   | 105    | 93         | 98   | 96                       | 95                       | 117.216             | 115.995             | 117       | 137.143         | 135.714       |
| 4    | 119.3                         | 100   | 105    | 93         | 98   | 96                       | 95                       | 114.528             | 113.335             | 118       | 135.143         | 133.735       |
| 5    | 118                           | 100   | 105    | 93         | 98   | 96                       | 95                       | 113.28              | 112.100             | 119       | 134.803         | 133.399       |
| 6    | 122.8                         | 100   | 105    | 93         | 98   | 96                       | 95                       | 117.888             | 116.660             | 120       | 141.466         | 139.992       |
| 7    | 120.8                         | 100   | 105    | 93         | 98   | 96                       | 95                       | 115.968             | 114.760             | 121       | 140.321         | 138.860       |
| 8    | 121.9                         | 100   | 105    | 93         | 98   | 96                       | 95                       | 117.024             | 115.805             | 122       | 142.769         | 141.282       |
| 9    | 118.6                         | 100   | 105    | 93         | 98   | 96                       | 95                       | 113.856             | 112.670             | 123       | 140.043         | 138.584       |
| 10   | 119.3                         | 100   | 105    | 93         | 98   | 96                       | 95                       | 114.528             | 113.335             | 124       | 142.015         | 140.535       |
| 11   | 121.9                         | 100   | 105    | 93         | 98   | 96                       | 95                       | 117.024             | 115.805             | 125       | 146.280         | 144.756       |
| 12   | 119.6                         | 100   | 105    | 93         | 98   | 96                       | 95                       | 114.816             | 113.620             | 126       | 144.668         | 143.161       |
| 13   | 120.2                         | 100   | 105    | 93         | 98   | 96                       | 95                       | 115.392             | 114.190             | 127       | 146.548         | 145.021       |
| 14   | 119.8                         | 100   | 105    | 93         | 98   | 96                       | 95                       | 115.008             | 113.810             | 128       | 147.210         | 145.677       |
| 15   | 119.9                         | 100   | 105    | 93         | 98   | 96                       | 95                       | 115.104             | 113.905             | 129       | 148.484         | 146.937       |
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Contribution of Researchers

Determination of the problem, deciding on the solution method, and application of the proposed method were realized by all authors simultaneously. Merve Cengiz Toklu and Alper Kiraz were prepared manuscript formatting and editing.

Conflict of Interest

We have no conflict of interest to declare.

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