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Westinghouse Method Oriented Fuzzy Rule Based Tempo Rating Approach

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Abstract

One of the most important subjects within the time study activities is tempo rating. Determining the accurate tempo for the workers plays an important role for determining the normal time of the work. There are various methods for determining the pace. One of the basic ones is the Westinghouse method based on four factors that are used while regarding the performance of the operator; skill, effort, conditions and consistency. In the usual Westinghouse method, there is a scale of crisp numerical values for each factor. With this study, a fuzzy rule based method is used to determine the performance values of the workers depending on the vague decision making structure. Different from the existing structure of the Westinghouse method, a system consisting of fuzzy rules is developed for computing the performance rates. The developed system is tested on a numerical example for showing the applicability.

Keywords

Time study, performance rating, fuzzy rule based system.

1. Introduction

Besides motion study, time study is one of the two important elements constituting methods engineering. It is defined by The Industrial Engineering Terminology Standard (IIE, 1982) as "a work measurement technique consisting of careful time measurement of the task with a time measuring instrument, adjusted for any observed variance from normal effort or pace and to allow adequate time for such items as foreign elements, unavoidable or machine delays, rest to overcome fatigue, and personal needs". Time study is used when; there are short or long cycles of repetitive work, there are different types of work in a big range of variety or a part of the cycle is constituted by process control elements (Salvendy, 2001). Time study is accomplished by performing analysis of work, standardization of methods and making time study respectively (Karanjkar, 2008). As stated in the definition of the time study, determining the tempo of the workers is very important for obtaining an accurate time study. There are different types of pace rating methods in literature. Main ones are stated by Reddy (2002) as; performance rating, skill and effort rating, Westinghouse system of rating, synthetic rating, objective rating and physiological evaluation of performance level. Performance rating method is a subjective method and mainly depends on the judgment of the time study man. The worker’s pace is compared with three scales consisting of 100, 75 and 60 as the base for the normal performance (Reddy, 2002).

Skill and effort rating method was developed by Charles E. Bedaux in 1916. Time standards used in this method are expressed in point or "Bs" which corresponds to another name for a standard minute. Standard performance was regarded as 60 points or 60 Bs. 60Bs per hour was expected from a worker working at a normal pace (Reddy, 2002). In synthetic rating, performance rating is performed by comparing some manual element's observed times with the known time values of PMTS (Predetermined motion and time studies) elements whose time values are known. A ratio is obtained by dividing predetermined time for elements to average actual time value for the same element. This ratio is considered as the performance index or the rating factor for the worker for the specific element (Patil et al., 2008). In physiological evaluation of performance level, heart-beat rate and oxygen consumption are measured with the required electronic equipment to evaluate the physical work (Reddy, 2002). Objective rating method was developed by Mundel and Danner (1994). In this method, performance rating is considered as the multiplication of the pace rating factor and the job difficulty adjustment factor. Firstly the pace is judged regarding a standard pace independent of job difficulty then a second factor showing its relative difficulty is assigned (Salvendy, 2001). The job difficulties have been categorized by Mundel, the founder of the system, are as follows (Patil, 2008):

- Amount of body used
- Foot pedals
- Bi-manualness
- Eye-hand coordination
- Handling requirements
- Weight

In this study, a fuzzy rule based model is developed with the aim of determining tempo rating. The main contribution of this study to the relevant literature is the integration of fuzzy inference and tempo rating process. The proposed model is predicated on Westinghouse method which has a discrete structure. The developed model provides a continuous tempo rating structure so as to eliminate the above mentioned drawback of Westinghouse method. Moreover, the use of (0-100) rating scale with linguistic terms provides a higher level of ease of use in real life industrial systems when compared to Westinghouse method. Fuzzy rules are developed and performance rating of the worker is computed.

2. Westinghouse Method

It is meaningful to give information about Westinghouse method which constitutes the main essence of this study. The method is also called LMS carrying the initials of its founders' names (Lowry, Maynard and Stegemerten)(Karger and Bayha, 1987). This rating method was developed at Westinghouse and published in 1927. This method has four factors; skill, effort, conditions and consistency (Barnes, 1980). In Westinghouse method, there are six classes (poor, fair, average, good, excellent and superskill) of each factor as shown in Table 1. Moreover, each class has further two degrees (higher or lower). The worker is evaluated according to this table and performance rate is obtained. As shown in the table, there are crisp values for each linguistic evaluation. Tempo ratio (T_r) is calculated by summing the ratings with respect to each criterion. Then final tempo (T) value is obtained via the following formula

$$T=1+T_r \tag{1}$$

Table 1: The Westinghouse rating system (Salvendy, 2001)

Skill ratings			Environmental condition Ratings		
+0.15	A1	Superskill	+0.06	A	Ideal
+0.13	A2	Superskill	+0.04	B	Excellent
+0.11	B1	Excellent	+0.02	C	Good
+0.08	B2	Excellent	0.00	D	Average
+0.06	C1	Good	-0.03	E	Fair
+0.03	C2	Good	-0.07	F	Poor
0.00	D	Average	Consistency ratings		
-0.05	E1	Fair	+0.04	A	Perfect
-0.10	E2	Fair	+0.03	B	Excellent
-0.16	F1	Poor	+0.01	C	Good
-0.22	F2	Poor	0.00	D	Average
Effort ratings			-0.02	E	Fair
+0.13	A1	Excessive	-0.04	F	Poor
+0.12	A2	Excessive			
+0.10	B1	Excellent			
+0.08	B2	Excellent			
+0.05	C1	Good			
+0.02	C2	Good			
0.00	D	Average			
-0.04	E1	Fair			
-0.08	E2	Fair			
-0.12	F1	Poor			
-0.17	F2	Poor			

3. Fuzzy Rule Based System

A fuzzy rule-based system (FRBS) is considered as a systematic inference method that can perform the linguistic judgment of experts via fuzzy set theory. Takagi–Sugeno model and Mamdani model are the two main types of the fuzzy inference systems. Since it is a data driven approach, Takagi–Sugeno model utilizes developed membership functions and rules by using a training data set. The parameters for the membership functions and rules are subsequently optimized regarding the decrease in training error. On the other hand, the Mamdani model structure is developed on the basis of expert knowledge and training. Both models are similar and consider fuzzy inputs but, while Mamdani provides fuzzy outputs, Takagi–Sugeno provides crisp outputs Due to the fact that Mamdani approach does not exclusively depend on a data set, with sufficient expertise on the system involved, a generalized model for effective future predictions can be produced. In this study, the Mamdani type FRBS is developed to rate tempo of workers. Mamdani models have the advantage of presenting expert judgements and interpreting linguistic dependencies. The structure of Mamdani-type fuzzy logic rule is expressed as follows (Ustundag et al, 2011):

IF x_1 is A_1 AND x_2 is A_2 AND . . . AND x_n is A_n THEN y is B where x_i (i = 1, 2, . . ., n) are input variables and y is the output variable. A_1, A_2, . . ., A_n and B are the linguistic terms (say, L-Low, M-Medium, H-High) used for the fuzzy subsets (membership function distributions) of the corresponding input and output variables, respectively. The output of a fuzzy rule based model whose rule base is constructed using Mamdani-type fuzzy logic rules is obtained as follows (when centroid method is considered for defuzzification):

$$Y = \frac{\sum_{r=1}^{R^1} A^{\alpha r} C_{A^{\alpha r}}}{\sum_{r=1}^{R^1} A^{\alpha r}} \tag{2}$$

where $A^{\alpha r}$ is the area of fuzzy subset of output variable, covered by α membership value that is obtained by *rth* rule after fuzzy inference method; $C_A^{\alpha r}$ is the center distance of the area, $A^{\alpha r}$

$$\alpha = Min_{v=1}^{n} \mu_v(\chi_v) \tag{3}$$

where $1 \leq v \leq n$ is the number of input variables that appear in the rule premise, n is the total number of inputs. $R_l(R_l \subseteq R)$ is the number of rules fired out of a total of R rules present in the rule base for a set of input values. $\mu v(xv)$ is the membership function value for the x_v input variable.

4. The Proposed Fuzzy Rule Based Tempo Rating Model

In the proposed model tempo value is attempted to be determined by considering two main criteria of Westinghouse method, namely skill and effort. As mentioned in previous section, Westinghouse method consists of four inputs including environmental condition and consistency. In real life production systems, environmental conditions are regulated in an appropriate manner within ergonomics studies before work study applications. Therefore, environmental conditions are not handled in the proposed tempo rating model. Furthermore, due to the fact that consistency is regarded as time variability of a worker, it is included in effort rating.

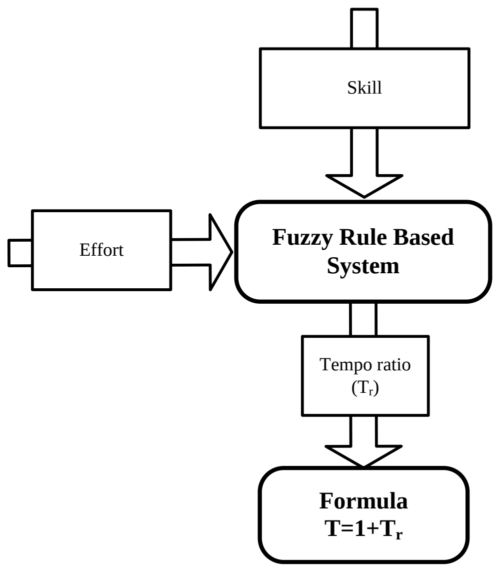

Figure 1: Fuzzy rule based system for tempo rating

The rating scale which is adopted in Westinghouse method is transformed to (0-100) scale for each input within the FRBS model so as to provide the convenience in judgments. For instance, skill, which has the range of [-0.22;0.15] in Westinghouse method, is evaluated within the range of [0;100] in the proposed model. Furthermore, the boundary values of the membership functions for linguistic terms in inputs and output are determined by considering this transformation. Tempo range is regarded as [0.50-1.38] as same as Westinghouse method. FIS Editor GUI of MATLAB Fuzzy Logic Toolbox is used for the development of FRBS. Figures 2 and 3 present the linguistic variables and the corresponding fuzzy numbers for skill and effort, respectively. Membership functions for tempo ratio is given in Figure 4.

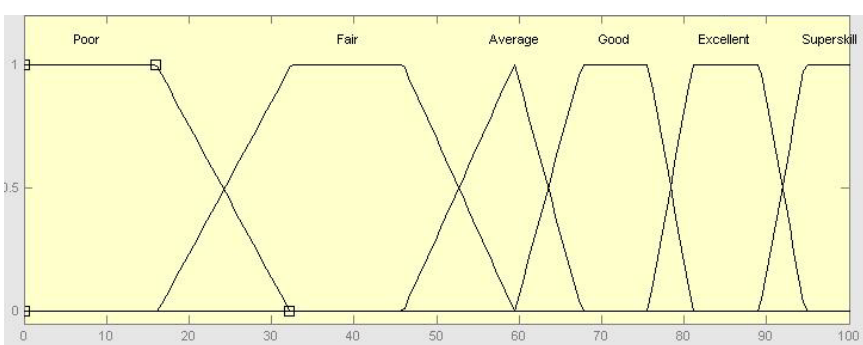

Figure 2: Membership functions for skill

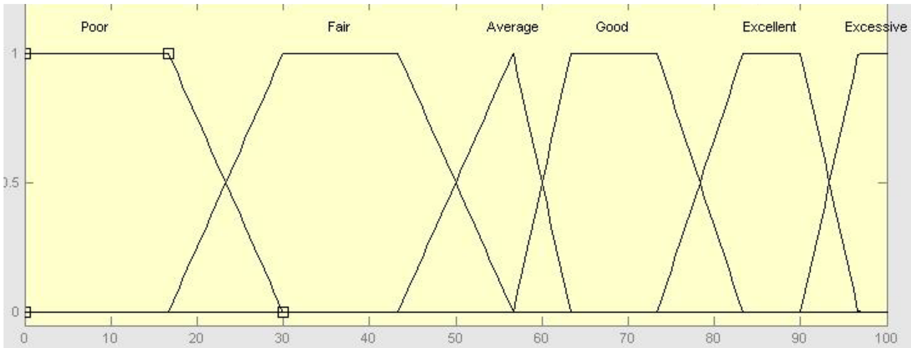

Figure 3: Membership functions for effort

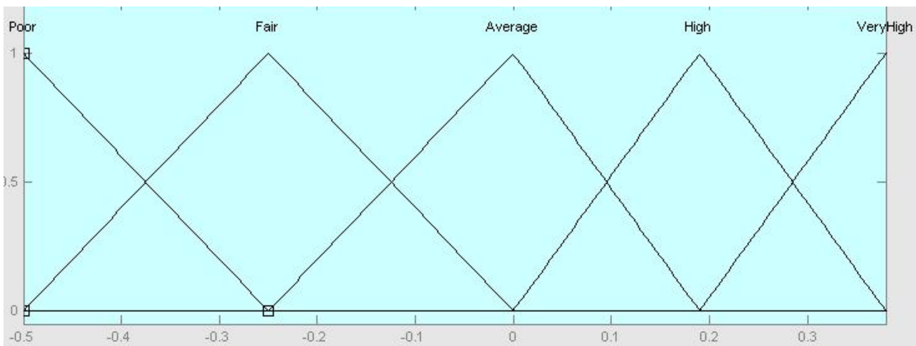

Figure 4: Membership functions for tempo ratio

36 rules are generated for tempo inference with different linguistic levels of skill and effort. Rules are generated via the judgments of two industrial engineers having 8-year experience about work study. Rules which are established for tempo rating are given in Table 2.

Table 2: Fuzzy rules for tempo rating

RULES		EFFORT RATINGS					
		Poor	**Fair**	**Average**	**Good**	**Excellent**	**Excessive**
SKILL RATINGS	**Poor**	Poor	Fair	Fair	Fair	Average	Average
	Fair	Fair	Fair	Fair	Average	Average	Average
	Average	Fair	Fair	Average	Average	Average	High
	Good	Fair	Average	Average	High	High	High
	Excellent	Average	Average	Average	High	Very high	Very high
	Super skill	Average	Average	High	High	Very high	Very high

5. Numerical Illustration

The developed FRBS is applied to different values of skill and effort. The suggested tempo value and number of active rules for each scenario are given in Table 3.

Table 3: Tempo values for different input values

Scenario No	**Skill**	**Effort**	**Tempo Ratio (T_r)**	**Tempo (T) (1+ T_r)**	**Number of rules considered**
1	63.50	83.33	0.072	1.072	2
2	18.00	35.40	-0.250	0.750	2
3	45.10	60.60	-0.129	0.871	2
4	68.20	44.80	-0.020	0.980	2
5	80.00	70.50	0.190	1.190	2
6	9.61	85.40	-0.020	0.980	2
7	77.60	21.50	-0.173	0.827	4
8	92.90	87.90	0.314	1.314	2
9	46.60	75.50	-0.021	0.979	4
10	29.80	78.00	-0.082	0.918	4
11	53.40	59.70	-0.138	0.862	4
12	69.70	96.30	0.194	1.194	2
13	90.90	57.70	0.042	1.042	4
14	65.80	31.90	0.089	1.089	2
15	61.80	58.70	0.039	1.039	2
16	82.50	77.50	0.207	1.207	2
17	70.20	59.70	0.063	1.063	2
18	78.60	62.60	0.145	1.145	4
19	95.30	82.30	0.303	1.303	2
20	11.60	17.10	-0.402	0.598	2

The first scenario is analyzed for showing the steps of the fuzzy rule based approach. As shown in Table 3, two rules are fired when skill rating is 63.50 and effort rating is 83.33. Since skill rating 63.50 is in the boundaries of "average" and "excellent" membership functions, there can be two options for this input. On the other hand, since effort rating 83.33 is only in the boundary of the "excellent" membership function, there is only one option. Regarding the combination, there are four rules fired such as:

Rule1
IF Skill **IS** *average* **AND**
Effort **IS** *excellent*
THEN Tempo ratio **IS** *Average*

Rule 2
IF Skill **IS** *good* **AND**
Effort **IS** *excellent*
THEN Tempo ratio **IS** *High*

Mamdani's fuzzy inference method is used in the implication process. For obtaining a crisp output value, defuzzification process is applied via Centroid method. The membership functions of the inputs and outputs of the related rules are shown in Figure 5. Moreover, the print screens of MATLAB Fuzzy Logic Toolbox for the same rules are shown in Figure 6.

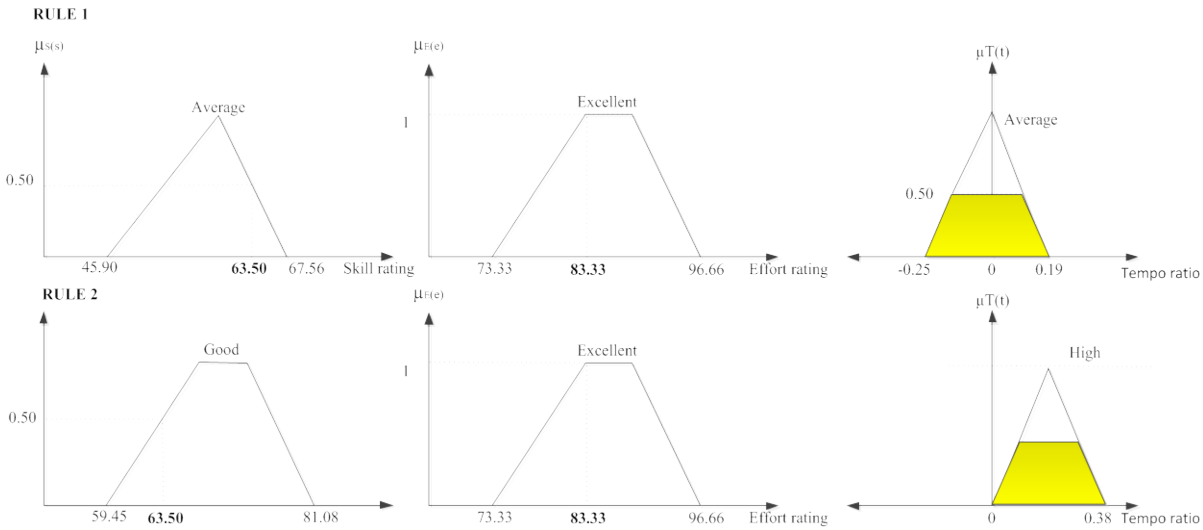

Figure 5: Inputs and outputs of the fired rules

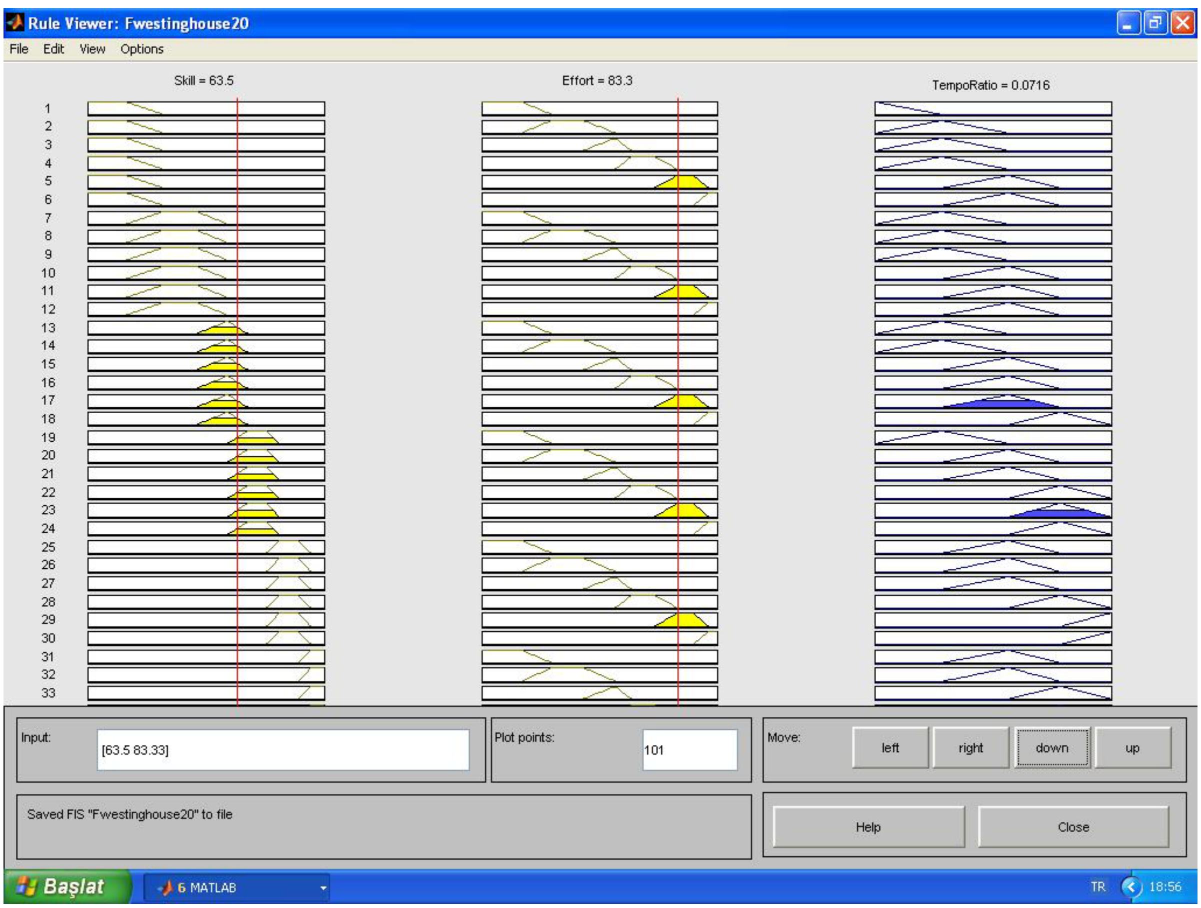

Figure 6: Print screens of the inputs and outputs in MATLAB Fuzzy Logic Toolbox.

When defuzzification is performed to the aggregation output fuzzy set as shown in Figure 7, the tempo ratio is obtained as 0.072. By applying the formula (1), the final tempo is found as 1.072.

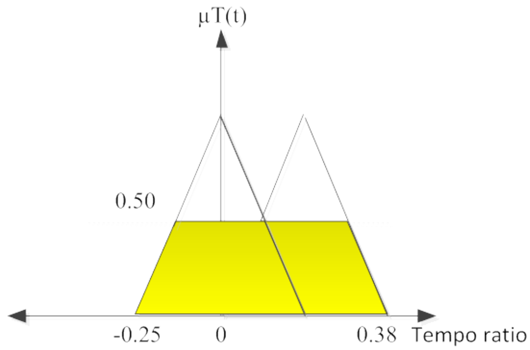

Figure 7: The aggregation output fuzzy set

6. Conclusion

Tempo rating can be regarded as a critical work study problem which is affected by various factors. Appropriate tempo rating provides effective labor and capacity planning in real life production systems. Even in industrial sized systems, wrong tempo rating occurs due to the lack of systematic approach, lack of experience, etc. In this study, fuzzy rule based system is developed with the aim of determining right tempo value. Skill and effort, two of the attributes in Westinghouse method, are considered. The tempo rating FRBS differs from Westinghouse method in terms of providing continuous output values. The inspiration for this study is to provide support to the work study engineers in tempo rating. Therefore, this study is thought to contribute to industry by effectively raising judgment capability for tempo rating. The proposed FRBS has the feature of applicability in terms of input evaluation and solution generation. Among the steps of the method, generating consistent rules appears to be most critical stage within the application. There are several research directions to be pursued in future. Additional methods including weight assignment to tempo criteria can be developed. Secondly, comparison with other tempo rating techniques can be performed. Last but not least, the approach can be applied to real life production processes.

References

Barnes, R.M., Motion and time study: design and measurement of work, 1980.

IIE, ANSI 1982.

Karanjkar, A., Manufacturing and Operations Management, *Nıralı Prakashan*, 2008

Karger, D. W. and Bayha, F.H., Engineered work measurement : the principles, techniques and data of methods, *Industrial Press*, New York, 1987.

Patil, S. B., Karad, A. A. and Kushare, P. B., Industrial Engineering & Management, *Technical Publications*, Pune, 2008.

Reddy, C.N.M.,, Industrial Engineering and Management through questions and answers, *New Age International Publishers*, New Delhi, 2002.

Salvendy, G., Handbook of Industrial Engineering: Technology and operations management, 2001.

Ustundag, A., Kilinc, M.S., Cevikcan, E., A Hybrid Fuzzy Risk Evaluation Model For Real Estate Investments, *Journal of Multi-Valued Logic & Soft Computing*, vol.17, pp. 339–362, 2011.