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Fuzzy applications of FUCOM method in manufacturing environment

Üretim ortamında FUCOM yönteminin bulanık uygulamaları

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Üretim Ortamında FUCOM Yönteminin Bulanık Uygulamaları

Araştırma Makalesi / Research Article

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ÖZ

Geleneksel üretim yöntemleri yeni geliştirilen yüksek dayanımlı, hassas / kırılgan ve karmaşık şekilli parçaların işlenmesinde sınırlıdır. Bu tür parçaları işlemek için konvansiyonel olmayan üretim yöntemleri gereklidir. İş parçası için en uygun üretim yöntemini seçmek hayati bir karar verme problemidir ve bu problemin çözümü günümüz üreticileri için çok önemlidir. Bu çalışmada, üç farklı FUCOM metodu bulanık TOPSIS ve bulanık WASPAS teknikleri ile birleştirildi. Bu geliştirilen yöntemleri test etmek için literatürden geleneksel olmayan imalat yöntemlerinin seçimi bir vaka çalışması olarak alınmıştır. Modelin başarılı sonuçlar verdiği görülmüştür.

Anahtar Kelimeler: FUCOM, WASPAS, geleneksel olmayan üretim yöntemi, bulanık ÇKKV.

Fuzzy Applications of FUCOM Method in Manufacturing Environment

ABSTRACT

Conventional manufacturing methods are limited in the machining of newly developed high strength, precision / brittle and complex shaped parts. Non-conventional manufacturing methods are required to machine such parts. Choosing the most suitable manufacturing method for the part is a vital decision-making problem and the solution of this problem is very important for today's manufacturers. In this study, three different Full Consistency Method (FUCOM) methods were combined with fuzzy Technique for Order Preference by Similarity to Ideal Solution method (fuzzy TOPSIS) and fuzzy weighted aggregated sum product assessment (fuzzy WASPAS) techniques. In order to test these developed methods, the selection of non-traditional manufacturing methods from the literature was taken as a case study. It is seen that the model produced successful results.

Keywords: FUCOM, WASPAS, nontraditional manufacturing method, fuzzy MCDM.

1. INTRODUCTION

One of the most important problems encountered in decision-making (DM) problems is the determination of criteria weights. In this context, many studies have been carried out in the literature. The researchers [1–4] agreed that weights of criteria change in terms of different models. In addition, there is no agreement on what the best method is. However, specific methods produce better results. Some authors classified the models into subjective and objective models [5,6].

Several authors applied various mathematical techniques and proposed specialized expert systems to choose appropriate non-traditional machining processes from the available options for various machining operations. Madic et al. [7] studied the feasibility of Multi-Objective Optimization on the basis of Ratio Analysis (MOORA) and Analytic Hierarchy Process (AHP) methods and they compared the results with the Technique for Order Preference by Similarity to Ideal Solution method (TOPSIS). Khandekar and Chakraborty [8] used fuzzy axiomatic design principles. Roy et al. [9] studied a novel way with hybridizing fuzzy AHP with Quality function deployment (QFD). Boral and Chakraborty [10] used the case-based reasoning (CBR) approach

Fuzzy multi-criteria decision-making models are selected to sort different options according to predetermined criteria with a single decision-maker or through group decision-making; it is foreseen that the alternatives' suitability against the criteria and the importance weights of the criteria can be evaluated using linguistic values indicated by fuzzy numbers [11]. Different approaches have been developed to solve fuzzy multi-criteria decision-making problems [11-15]. Abdullah [16] presented a brief review of the category in fuzzy multi-criteria decision-making. Several real-life applications were presented in the study. Fuzzy set theory has been improved by new fuzzy type sets. These are type 2 fuzzy sets and type n fuzzy sets containing uncertainty about the membership function [12]. The Intuitionistic fuzzy sets presented by Atanassov [17] extend the fuzzy sets to an additional degree called the degree of uncertainty. Also, Hesitant approach has been used in different studies in the literature [18-21].

Fuzzy TOPSIS based researches can be divided into three groups. Several researchers developed new fuzzy TOPSIS methods or changes past methods. Ye and Li [23] developed the TOPSIS technique via probability

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theory. Fuzzy triangular numbers were used for the evaluation. Hero et al. [24] developed the fuzzy hierarchical TOPSIS method for multi-criteria evaluation of industrial robotic systems. Chen and Wei [25] improved the methodology of Chen and Hwang [22] and explained the degree of each option and the weight of each criterion in linguistic terms that can be expressed in fuzzy triangular numbers. Kannan et al. [26] used the fuzzy TOPSIS method to rank green suppliers of a Brazilian electronics company. Wang [27] evaluated the financial performance of Taiwanese container transport companies via fuzzy TOPSIS. Chu [28] used the fuzzy TOPSIS technique to solve the site location problem. Mandic et al. [29] developed an integrated fuzzy multi-criteria model to assess the financial performance of banks. Fuzzy AHP was used to evaluate weights. A fuzzy TOPSIS technique was used in the evaluation of banks. Zhang and Lu [30] developed an integrated fuzzy group decision-making technique to handle the uncertainty of decision-makers' preferences. Decision-makers used fuzzy triangular numbers. Tsaura et al. [31] used a mixed-method to determine the quality of service to the airline. AHP was used to obtain criterion weights and TOPSIS method was used for ranking.

Efficient use of machining and machine tool data are important for manufacturing companies. Therefore, the use of machine learning in production is of increasing interest. However, it is still at the beginning of growth potential and is currently being used less in the machining sector [32-34].

Conventional manufacturing methods are limited in the processing of newly developed high strength, precision / brittle and complex shaped parts. Non-conventional manufacturing methods are required to process such parts. Choosing the most suitable manufacturing method for the part we will process is a significant decision-making problem and the solution of this problem is very important for today's manufacturers. The Full Consistency Method (FUCOM) method is a new technique used to weigh criteria in the literature. This technique is a semi-objective / objective evaluation method, which reduces the comparison of criteria within each other, and optimizes the criteria weights with the optimization algorithm with few comparisons. In this study, three different FUCOM methods were combined with fuzzy TOPSIS and fuzzy weighted aggregated sum product assessment (WASPAS) techniques. In order to test these developed methods, the selection of non-traditional manufacturing methods from the literature was taken as an example problem. In the second part of the study, the techniques used are explained. In the third part of the study, the problem of choosing a non-traditional manufacturing method is explained. In the following sections, the results are discussed.

2. MATERIAL and METHOD

2.1. Fuzzy TOPSIS Model

Chen developed a fuzzy TOPSIS algorithm. The steps are explained below [35]:

2.1.1. Specify the decision matrix

The decision-making matrix is given in Eqs.1-2:

$$D = [\widetilde{x_{ij}}] \quad (1)$$

$$\widetilde{x_{ij}} = (a_{ij}, b_{ij}, c_{ij}) \quad (2)$$

x_{ij} elements show ith decision-making points according to the jth evaluation criteria. Triangular fuzzy numbers describe these linguistic variables, n shows the number of criteria and m represents the number of alternatives (j=1,2,3…n and i=1,2,3.…m).

2.1.2. Calculate the standard decision matrix

The normalized fuzzy decision matrix is denoted by $R = [\widetilde{r_{ij}}]_{m\times n}$ Standard decision-making matrix is computed by using the decision-making matrix as follows (Eqs.3-4). B and C are benefit and cost criteria, respectively.

$$\widetilde{r_{ij}} = \frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \,.\, c_j^* = max c_{ij} \; if \; j \in B \quad (3) \quad j\in B$$

$$\widetilde{r_{ij}} = \frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}} \,.\, a_j^- = min a_{ij} \text{ if } j\in C \quad (4) \quad j\in C$$

Standard decision-making matrix is given below (Eq.5):

$$R_{ij} = [\widetilde{r_{ij}}]_{m\times n} \quad (5)$$

2.1.3. Calculate the weighted decision matrix

In this step, the standard decision-making matrix is multiplied by the weights (wj), and weighted decision-making matrix (Vij) is obtained (Eqs.6-7).

$$V_{ij} = [\widetilde{v_{ij}}]_{m\times n} \quad (6)$$

$$\widetilde{v_{ij}} = \widetilde{r_{ij}}(.)\widetilde{w_j} \quad (7)$$

2.1.4. Calculate the ideal and negative ideal solutions

The ideal solution set is computed using Eqs.8-9.

$$A^* = (\widetilde{v_1}^*, \widetilde{v_2}^* \ldots . \widetilde{v_n}^*) \quad (8)$$

The negative ideal solution set is computed using the

$$\tilde{v}_j^* = (1,1,1) \quad (9)$$

equations (Eqs.10-11):

$$A^- = (\widetilde{v_1}^-, \widetilde{v_2}^- \dots . \widetilde{v_n}^-) \quad (10)$$

$$\tilde{v}_j^- = (0,0,0) \quad (11)$$

2.1.5. Calculate the distinction measure

The calculation of ideal distinction (S_i^*) measure and negative ideal distinction measure (S_i^-) is given in Eqs.12-13.

$$S_i^* = \sum_{j=1}^{n} d_v\,(\widetilde{v_{ij}}, \tilde{v}_j^*) \quad (12)$$

$$S_i^- = \sum_{j=1}^{n} d_v\,(\widetilde{v_{ij}}, \tilde{v}_j^-) \quad (13)$$

2.1.6. Calculate the proximity values relative to the ideal solution

Ideal and negative ideal distinction measures are used to find proximity values (Eq.14):

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \quad (14)$$

2.2. Fuzzy WASPAS

The calculation steps are given below [36]:

Step-1 Define the decision matrix: The decision-making matrix is given in Eqs.15-16:

$$\tilde{X} = [\widetilde{x_{ij}}] \quad (15)$$

$$\widetilde{x_{ij}} = (a_{ij}, b_{ij}, c_{ij}) \quad (16)$$

x_{ij} elements show ith decision-making points according to the jth evaluation criteria. Triangular fuzzy numbers describe these linguistic variables, n shows the number of criteria and m represents the number of alternatives (j=1,2,3…n and i=1,2,3.…m).

Step-2: Normalization of $\tilde{\boldsymbol{X}}$ decision matrix

Step-3: Calculation of the weighted decision matrix $\tilde{\mathbf{X}}_{\mathbf{q}}$ for the Weighted Sum Model (WSM), $\tilde{\mathbf{X}}_{\mathbf{P}}$ for the Weighted Product Model (WPM).

Step-4: Calculation of optimality function values for WSM and WPM in Eq.17 and 18, respectively.

$$\widetilde{Q_i} = \sum_{j=1}^{n} \widetilde{\widetilde{x_{ij}}} \quad (17)\ i=1 \text{ to } m.$$

$$\widetilde{P_i} = \prod_{j=1}^{n} \widetilde{\widetilde{\widetilde{x_{ij}}}} \quad (18)\ i=1 \text{ to } m.$$

For defuzzification, the center-of-area can be applied (Eqs. 19-20).

$$Q_i = \frac{1}{3}(Q_{i\alpha} + Q_{i\beta} + Q_{i\delta}) \quad (19)$$

$$P_i = \frac{1}{3}(P_{i\alpha} + P_{i\beta} + P_{i\delta}) \quad (20)$$

Step-5: Calculation of the integrated utility function value ($\boldsymbol{K_i}$).

$$K_i = \lambda \sum_{j=1}^{m} Q_i + (1-\lambda) \sum_{j=1}^{m} P_i \quad (21)$$

$$\lambda = \frac{\sum_{i=1}^{m} P_i}{\sum_{i=1}^{m} Q_i + \sum_{i=1}^{m} P_i} \quad (22)$$

Step-6: Selection an alternative with maximal $\boldsymbol{K_i}$ value

2.3. Full Consistency Method (FUCOM)

FUCOM reduces the likelihood of an error due to the following: (1) few comparisons and (2) defined restrictions when calculating optimal values of criteria. FUCOM calculates the error value of the weight vectors to validate the model. However, to determine the weights of the criteria for the other models (Best Worst Method (BWM), AHP models), the two-way comparison appears to be high, while FUCOM eliminates this problem [37]. The model is given below (Eqs. 23-26):

$$\min X$$
$$\text{s.t.}$$
$$\left|\frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)}\right| \le X\ \forall_j \quad (23)$$
$$\left|\frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \le X\ \forall_j \quad (24)$$
$$\sum_{j=1}^{n} w_j = 1\ \forall_j \quad (25)$$
$$w_j \ge 0\ \forall_j \quad (26)$$

X shows the consistency, $\varphi_{k/(k+1)}$ is the comparative priority among the observed criteria. The steps are given below:

1. Criteria are ranked from the highest importance to the lowest.
2. Comparison of the ranked criteria is performed, and the comparative priority is determined.
3. The final weights are calculated using formulas 23-26.

Using the same procedure of Best-Worst method, FUCOM linear and FUCOM euclidean were proposed in this study. More information is given in the reference study [37].

2.4. Steps of the Proposed Method

The steps of the proposed model give more details about the proposed method (Fig. 1). A novel hybrid approach was used.

Step 1. Define criteria/alternative matrix. Step 2. Calculate criteria weights using FUCOM methods (FUCOM linear/non-linear and euclidean) Step 3. Apply fuzzy TOPSIS/WASPAS methods using criteria weights calculated in Step 2. Step 4. Compare the results with Spearman Correlation Test.

Figure 1. The steps of the proposed model.

In this study, non-conventional machining methods selection problem was used to test the proposed method. This problem includes seven different criteria and nine different methods (Step 1). Seven criteria weights were calculated by FUCOM technique. In the criteria scoring stage, a study in the literature was used [38] (Step 2). Then, nine different methods were ranked using fuzzy TOPSIS/WASPAS method. Triangular fuzzy numbers were used (Table A.1.). Performances of quantitative criteria are described as triangular fuzzy number (l, m, u). Lower limit, average and upper limit values are expressed as follows (Step 3):

Lower Limit (L): It means the process values obtained in cases where the process is applied in unfavorable conditions.

Average (M): Process values given by the process in general. It can also be expressed as application values.

Upper limit (U): Process values obtained by experienced users in very favorable conditions.

The ranking results were compared with Spearman Test (Step 4).

3. CASE STUDY

A case study was taken from the literature study [38]. The detailed explanation of the problems is given in these study Abbreviations are provided in Table 1 for non-traditional machining processes. The case study is given in Table A.1.

Table 1. Abbreviation of the non-conventional machining methods

AJM	Abrasive jet machining
USM	Ultrasonic machining
ECM	Electrochemical machining
EDM	Electrical discharge machining
EBM	Electron beam machining
LBM	Laser beam machining
CHM	Chemical machining
AWJM	Abrasive waterjet machining
RUSM	Rotary ultrasonic machining

Drilling operation is carried out for of the turbine engine combustion chamber. Generally, the EBM method is used. Process-related requirements are given below.

Workpiece material: Superalloy.

Formal Competence: Hole Drilling Process.

Qualification: Diameter D = 0.9 mm, Tolerance 0.05mm, L / D = 1.22.

4. RESULTS AND DISCUSSION

Comparison of the best and worst criteria according to the other criteria are given in Table 2 for the case study. According to the case study (Table A.1.), the cost is chosen as the best criterion, whereas surface damage is selected as the worst criterion. Based on Kulu et al.'s [38] study, the criteria are scored.

Table 2. Pairwise comparison of case study

	S. finish	**S. damage**	**Taper**	**MRR**	**WM**	**Cost**
Worst criterion: Surface damage	0.5	1	1	0.33	0.25	0.14
Best criterion: Cost	5	7	3	2	3	1

The criteria weights of the case are presented in Tables 3-4 in terms of different FUCOM techniques. The cost has the highest criterion weight while surface finish, surface damage and taper have the lower criteria weights in terms of three different FUCOM methods.

Table 3. Criteria weights of FUCOM method (Euclidean and Non-linear)

Criteria	Weights/Obj.function
(s.finish-s.damage-taper-MRR-WM-cost)	0.059,0.059,0.059,0.235,0.118,0.47 /5.54e-7

Table 4. Criteria weights of FUCOM method (Linear)

Criteria	Weights/Obj.function
(s.finish-s.damage-taper-MRR-WM-cost)	0.07,0.06,0.04,0.26,0.11,0.46 /0.88

The ranking results are given in Table 5. Spearman correlation test was performed with the literature results [38]. Fuzzy TOPSIS linear and WASPAS are used during the calculation. Electrochemical machining is the best method in terms of all results. According to Spearman correlation test, the results were significant at 5% level. The rankings are nearly the same.

Table 5. Proposed methods and their rankings with Spearman correlation test

Proposed methods	Rankings	Spearman correlation (coefficient(r)and p) [38]
Fuzzy TOPSIS linear/FUCOM nonlinear	6-4-1-7-2-8-9-5-3	0.75/0.02
Fuzzy WASPAS/FUCOM nonlinear	6-5-1-7-2-8-9-3-4	0.867/0.002
Fuzzy TOPSIS linear/FUCOM euclidean	6-4-1-7-2-8-9-5-3	0.75/0.02
Fuzzy WASPAS/FUCOM euclidean	6-5-1-7-2-8-9-3-4	0.867/0.002
Fuzzy TOPSIS linear/FUCOM linear	6-4-1-7-2-8-9-5-3	0.75/0.02
Fuzzy WASPAS/FUCOM linear	6-5-1-7-2-8-9-3-4	0.867/0.002
Fuzzy AHP+TOPSIS [38]	4-6-1-9-3-8-7-2-5	-

In this study, a highly flexible method is proposed for decision-makers by hybridizing a semi-objective method with fuzzy numbers. In terms of sensitivity analysis, three different weighting techniques and two different ranking techniques were used and the study produced successful results. It can be said to be superior compared to the methods in the literature. The results of the study are consistent with each other and with the literature studies.

5. CONCLUSIONS

Conventional manufacturing methods are limited in the machining of newly developed high strength, precision / brittle and complex shaped parts. Therefore, non-conventional production methods are required to process such parts. Selection of the most suitable production method for the workpiece is a vital decision-making problem and the solution of this problem is very important for manufacturers. In this study, a new hybrid decision-making approach which has not been used in literature before was proposed. This newly developed approach has been applied to the problem of non-traditional manufacturing method selection. The FUCOM method is a semi-subjective method, which makes it easier to calculate criteria weights than other methods. Different FUCOM methods were combined with fuzzy TOPSIS and fuzzy WASPAS methods. The results of the study were compared with the Spearman correlation test. According to the test, the rankings at the 5% significance are the same. The newly developed model has produced successful results. In future studies, FUCOM technique can be used with different multi-criteria decision-making techniques. In addition, the developed approach can be tried for different case studies.

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APPENDIX

Table A.1. Criteria-alternative matrix for case study [38]

	Surface finish			Surface damage			Taper			MRR			WM			Cost		
	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u
1.AJM	1.25	0.6	0.25	0.03	0.025	0.02	0.006	0.005	0.004	20	50	200	8	9	10	12	17	22
2.USM	0.75	0.5	0.25	0.03	0.025	0.02	0.005	0.004	0.003	300	600	2100	2	3	4	20	25	30
3.ECM	1.5	1	0.2	0.006	0.005	0.004	0.003	0.002	0.001	500	2000	14000	8	9	10	31	36	41
4.CHM	2.5	2	0.5	0.006	0.005	0.004	0.4	0.3	0.2	15	40	140	5	6	7	16	21	26
5.EDM	3	2	0.3	0.03	0.02	0.01	0.003	0.002	0.001	100	800	1300	8	9	10	27	32	37
6.EBM	4	3	1	0.03	0.025	0.025	0.25	0.2	0.15	0.3	2	6	5	6	7	19	24	29
7.LBM	1.5	1	0.4	0.15	0.1	0.05	0.06	0.05	0.04	0.1	2	5	5	6	7	17	22	27
8.AWJM	0.4	0.3	0.2	0.03	0.025	0.02	0.004	0.003	0.003	300	600	2000	8	9	10	13	19	24
9.RUSM	0.75	0.5	0.25	0.03	0.025	0.025	0.005	0.004	0.003	400	800	2400	2	3	4	22	27	32