Machine Selection Application in a Hard Chrome Plating Industry Using Fuzzy SWARA and Fuzzy ARAS Methods

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ABSTRACT

Machines are one of the most important production elements used by companies in the production phase. Sudden deterioration in machinery creates a process that can lead to a production halt and therefore a delay in orders. For this reason, enterprises decide to replace their old machines with newer technological machines. This replacement decision is not easy as it includes many criteria and there are many alternative machines on the market. From this point of view, in this study, a real-life application of a company's machinery purchase was made with fuzzy SWARA and fuzzy ARAS methods based on multi-criteria decision-making method. Criterion weights were determined by the fuzzy SWARA method. In the evaluation of alternative machines, the fuzzy ARAS method was taken into consideration. In the study, the criteria determined by the company manager and his team in line with the company needs were taken into consideration. Afterward, four machines were determined among the most suitable machines in the market and frequently used. Finally, calculations were made to find the machine that best meets the criteria required by the company among these machines. As a result of the calculations, the machine needed by the company was decided and the results were interpreted.

Key Words: *Machine Selection, Multi-Criteria Decision Making, Fuzzy SWARA, Fuzzy ARAS*

JEL Classification: *M10, D70, D81*

Bulanık SWARA ve Bulanık ARAS Yöntemlerini Kullanarak Bir Sert Krom Kaplama Sektöründe Makine Seçimi Uygulaması

ÖZ

Makinalar işletmelerin üretim aşamasında kullandıkları en önemli üretim elemanlarındandır. Makinalardaki ani bozulma, üretimin durması ve dolayısıyla siparişlerdeki gecikmeye kadar gidebilecek bir süreci meydana getirmektedir. Bu sebeple işletmeler imkanları doğrultusunda eskiyen makinalarını daha yeni teknolojik makinalar ile değiştirme kararı almaktadırlar. Bu değiştirme kararı birçok kriter barındırması açısından ve piyasada birçok alternatif makine olmasından dolayı kolay bir karar değildir. Buradan hareketle bu çalışmada çok kriterli karar verme yöntemi tabanlı bulanık SWARA ve bulanık ARAS yöntemleri ile bir işletmenin makine satın alımına ilişkin bir gerçek hayat uygulaması yapılmıştır. Bulanık SWARA yöntemi ile kriter ağırlıkları belirlenmiştir. Alternatif makinaların değerlendirilmesinde ise bulanık ARAS yöntemi dikkate alınmıştır. Çalışmada, firma yöneticisi ve ekibinin işletme ihtiyaçları doğrultusunda belirlediği kriterler dikkate alınmıştır. Sonrasında, piyasada bulunan ve sıklıkla kullanılan en uygun makinalar arasından dört makine belirlenmiştir. Son olarak, bu makinalar arasından işletmenin ihtiyaç duyduğu kriterleri en iyi düzeyde karşılayan makinanın bulunması için hesaplamalar

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yapılmıştır. Yapılan hesaplamalar sonucunda işletmenin ihtiyaç duyduğu makinaya karar verilmiş ve sonuçlar yorumlanmıştır.

Anahtar Kelimeler: *Makine Seçimi, Çok Kriterli Karar Verme, Bulanık SWARA, Bulanık ARAS*

JEL Sınıflandırması: *M10, D70, D81*

INTRODUCTION

The two main resources for companies producing goods are humans and machines. Less developed companies make the production mostly with human resources and continue their activities with qualified personnel and limited machine support. However, companies that make high-volume production with advanced technology perform production mostly on a machine-based basis and use human resources for the operation of the machine. Depending on the place of use, a wide range from simple mechanical hand presses to robots can be put into machine class.

The production process is a critical strategic element for companies. The production function, which is one of the three main functions of the firm, is very important for companies to be successful. The success of the production function is directly related to the correct management of machinery, materials, manpower, and financial resources, which are the inputs of production processes. It is an important and strategic resource of the machine manufacturing process. Choosing the right machine enables companies to increase the quality, flexibility and efficiency in their production processes. To respond quickly to customer needs, the features of the machines they use in the production lines must be compatible enough to meet the strategic goals of the companies (Nguyen et al., 2014: 3078). Depending on the characteristics of the production line and the industry, the machine selection decision can be a very costly investment decision for businesses. Wrong decisions about machine selection can negatively affect businesses in terms of both production processes and costs. For this reason, companies decide on machine selection after a detailed evaluation process with the help of an expert team.

In the literature, the machine selection problem has been studied for stochastic linear programming model (Dong, 1989: 655), flexible manufacturing systems (Benitez et al., 2007: 544), decision support system selection (Tabucanon et al., 1994: 131; Wang and Chen, 2007: 384) and design flexible manufacturing systems (Yang and Hung, 2007: 126). Multi-Criteria Decision Making (MCDM) methodologies are used in different machine selection studies as follows: In a study, robot selection application was performed with the Fuzzy TOPSIS methodology in a problem where various quantitative and qualitative values for many alternatives were blurred (Chu and Lin, 2003: 284). In other studies, Luong presented an MS Excel-based system design that takes into account numerical and verbal values in computer integrated manufacturing selection, using database technology and Analytic Hierarchy Process (AHP) together (Loung, 1998: 45). In another study, a solution was proposed to the multi-criteria robot selection problem with the TOPSIS methodology (Agrawal et al., 1991: 1629). A solution was proposed with TOPSIS methodology to the problem of selection and evaluation of holding apparatus for flexible production systems (Agrawal et al., 1992: 2713). In a different study, AHP and Sensitivity Analysis were used together for material handling system selection (Banik and Chakraborty, 2006: 1237). Using the multi-feature utility theory and AHP, a methodology in which fuzzy values can be included in the robot selection problem has been proposed (Kapoor and Tak, 2005: 209). They have contributed to the search for a solution by proposing a fuzzy methodology for flexible production systems (Chen et al., 2000: 2079). To analyze more recent studies on machine selection, the author refers to Nedelijkovic et al. (2021) study.

When we look at the literature, the fuzzy SWARA method was previously used by 3PL selection (Mavi et al., 2017: 2401; Zarbakhshnia et al., 2018: 307), sustainable supplier selection (Rani et al., 2020), solar panel Selection (Rani et al., 2020), evaluation of Sustainability of the bioenergy production process (Mishra et al., 2020), sustainable remanufacturing supply chain risks (Ansari et al., 2020: 473), university website performance evaluation (Ulutas, 2019: 151), ranking of medical tourism destinations (Ghasemi et al., 2021), ranking the lean supply chain enablers (Sharma et al., 2021), construction project scheduling (Banihashemi et al., 2021) and green supplier Selection (Tas ve Cakir, 2021: 885).

According to the fuzzy ARAS method literature, this method has been used in green supplier selection (Mavi, 2015: 165), e-learning course selection (Jaukovic Jojic et al., 2020), freight distribution concept Selection (Jovcic et al., 2020), supply chain performance evaluation (Rostamzadeh et al., 2017), financial performance evaluation (Ghadikolaei and Esbouei, 2014: 163), duty-free product supplier selection (Fu et al., 2021), prioritizing high-performance innovation (Heidary et al., 2021: 1), sustainable recycling partner Selection (Mishra and Rani, 2021), smartphone selection (Rani et al., 2019), evaluation of dry sliding wear properties (Kumar and Rai, 2020: 449), evaluation investment potential tourism centers (Hatefi et al., 2019: 269) and 3PL selection (Rostamzadeh et al., 2020: 635).

As can be seen in the comprehensive literature review given above, fuzzy SWARA and fuzzy ARAS methodologies were not taken into account in the machine selection before. Therefore, it can be said that there is a gap in the literature since these methods are not used as hybrids for machine selection. This study aims to fill this gap in the literature by making a real-life application. The reason for using fuzzy logic in the study is that decision-makers can use linguistic expressions instead of precise expressions. Therefore, decision-makers had the opportunity to make more flexible decisions. The fuzzy SWARA method was used to determine the criteria weights. The reason for considering this method is that decision-makers have the opportunity to evaluate the criteria according to their priorities. To rank the alternatives, the fuzzy ARAS method was taken into account. This method is considered in this study because it is based on the principle of comparing with an ideal value when ranking the alternatives.

The remainder of the work is organized as follows. First of all, the fuzzy SWARA method, which is used to determine the criterion weights in the study, is mentioned. Afterward, the fuzzy ARAS method used to evaluate alternative machines is mentioned. In the next section, the problem considered in the study is given together with the solution steps. In the last section, the results are interpreted and future studies are mentioned.

I. FUZZY SWARA

Fuzzy SWARA methodology is given with its steps in this section. This method is a method in which only fuzzy expressions are used as difference in the process of making comparisons according to the classical SWARA method. The fuzzy SWARA method, which is built on fuzzy logic, allows the evaluation process, which is complicated due to the difficulties experienced while making a decision, to be done more effectively and close to reality.

This strategy allows decision makers to set their own priorities during the criteria evaluation process. It is stated that the importance of decision makers is higher in the fuzzy SWARA method compared to other methods, and the steps of this method are as follows (Zolfani and Saparauskas, 2013: 408):

1*st* Step: Sorting is done starting from the most important criterion.

2*nd* Step: The relative importance of each criterion is established starting with the second criterion, as shown in Table 1. Criterion *j* is compared to the prior criterion (*j*-1). Keršulienė et al. (2010) named this ratio “comparative significance of the mean value” and represented it with sj.

Table 1. Fuzzy evaluation scale (Vesković et al., 2018)

Linguistic variables used for criteria evaluation			
Linguistic variables	s_{jl}	s_{jm}	s_{ju}
Very Low	0,00	0,00	0,3
Low	0,00	0,25	0,5
Moderate	0,25	0,5	0,75
High	0,50	0,75	1
Very High	0,75	1	1

3rd Step: Calculate the coefficient (k_j) using Equation (1).

$$k_j = \begin{cases} 1 & j=1 \\ s_j+1 & j>1 \end{cases} \qquad (1)$$

4th Step: The importance vector (q_j) is calculated with the Equation (2).

$$q_j = \begin{cases} 1 & j=1 \\ x_{j-1}/k_j & j>1 \end{cases} \qquad (2)$$

where, the notation x_{j-1} refers to q_{j-1}.

5th Step: Fuzzy weight values (w_j) of the criteria in the problem are calculated by Equation (3).

$$w_j = \frac{q_j}{\sum_{k=1}^{n} g_k} \qquad (3)$$

w_j, *j*. shows the importance of the j^{th} criterion with fuzzy expression. During the calculations, the expressions will be displayed as $A_1 = (l_1, m_1, u_1)$ with triangular fuzzy numbers as $l_1 \le m_1 \le u_1$.

6th Step: Clarification process is applied by using Equation (4).

$$w_j = \frac{(w_j^u - w_j^l) + (w_j^m - w_j^l)}{3} + w_j^l \tag{4}$$

II.FUZZY ARAS

The Additive Ratio Assessment (ARAS) approach was developed by Zavadskas and Turskis in 2010. ARAS methodology is unusual in that it compares options performances to that of the optimal option. The following are the steps of the fuzzy ARAS approach (Turskis and Zavadskas, 2010: 423):

1st Step: Create a fuzzy decision matrix.

2nd Step: Expand the fuzzy decision matrix by adding one row with the best values for each criterion, as shown in Equation 5:

$$X = \begin{pmatrix} x_{01} & \cdots & x_{0n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix}, i = 0/m, j = 1/n \tag{5}$$

3rd Step: Normalizing the expanded fuzzyfication decision matrix $X^N = [x_{ij}^N]$

- Maximal values are normalized by using Equation 6:

$$x_{ij}^N = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \tag{6}$$

- Minimal values are normalized by using Equation 7:

$$x_{ij}^N = \frac{1}{x_{ij}}, \; x_{ij}^N = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \tag{7}$$

4th Step: Create weighted normalized decision matrix using Equation 8:

$$x_{ij}^s = x_{ij}^N (*) w_j \tag{8}$$

5th Step: Calculate the optimality function by using Equation 9:

$$S_i = \sum_{j=1}^{n} x_{ij}^s \tag{9}$$

where S_i is the optimal function of the i_{th} alternative. Defuzzification method can be considered by using Equation 10:

$$S_i = \frac{1}{3}(S_{il} + S_{im} + S_{iu}) \tag{10}$$

6th Step: Determining the alternative utility degree's values. The values K_i can be used to calculate the priority rankings of examined alternatives (i=1/m). Calculate the alternative A_i utility degree by using Equation 11. The best alternative should be the one with the highest K_i value.

$$K_i = \frac{S_i}{S_0} \tag{11}$$

III.MACHINE SELECTION A IN HARD CHROME PLATING COMPANY

In this part of the study, the selection of the machine using the fuzzy SWARA and fuzzy ARAS methodologies are mentioned. The company that chooses machinery is located in İzmir Kemalpaşa Organized Industrial Zone. The company subjects the materials to the lathe process after the incoming materials are plated in the hard chrome pools. With the increase in the order level, it has been determined that the existing turning machine is insufficient to reach the orders at the desired time. The company will purchase a new turning machine. For this purpose, the criteria for the machine needed were decided first, together with the company manager and his team, and alternative machines were evaluated. The steps of the methodologies are given in Figure 1.

Four different machines (M) were determined by the manager and his team (4 Decision-Makers (DMs) in total). One of the determined decision-makers is the owner and general manager of the company. Of the other three decision- makers, one is the assistant general manager, one is an engineer, and one is a purchasing specialist. Machine selection criteria determined according to the literature and the company needs are as follows:

- Price (C1) (Mançanares et al., 2015): Machine purchase cost.
- Performance (C2) (Maniya and Bhatt, 2011): Ensuring continuity in performance by fast and error-free production.
- Capacity (C_3) (Cakir, 2018): The amount of product produced per unit time.
- Quality (C_4) (Abdel-Kader, 2019): The machine is durable and high quality against environmental effects, as well as long life.
- Service and maintenance (C_5) (Karim and Karmaker, 2016): Providing service support, spare parts supply, and ease of maintenance of the machine against malfunctions.

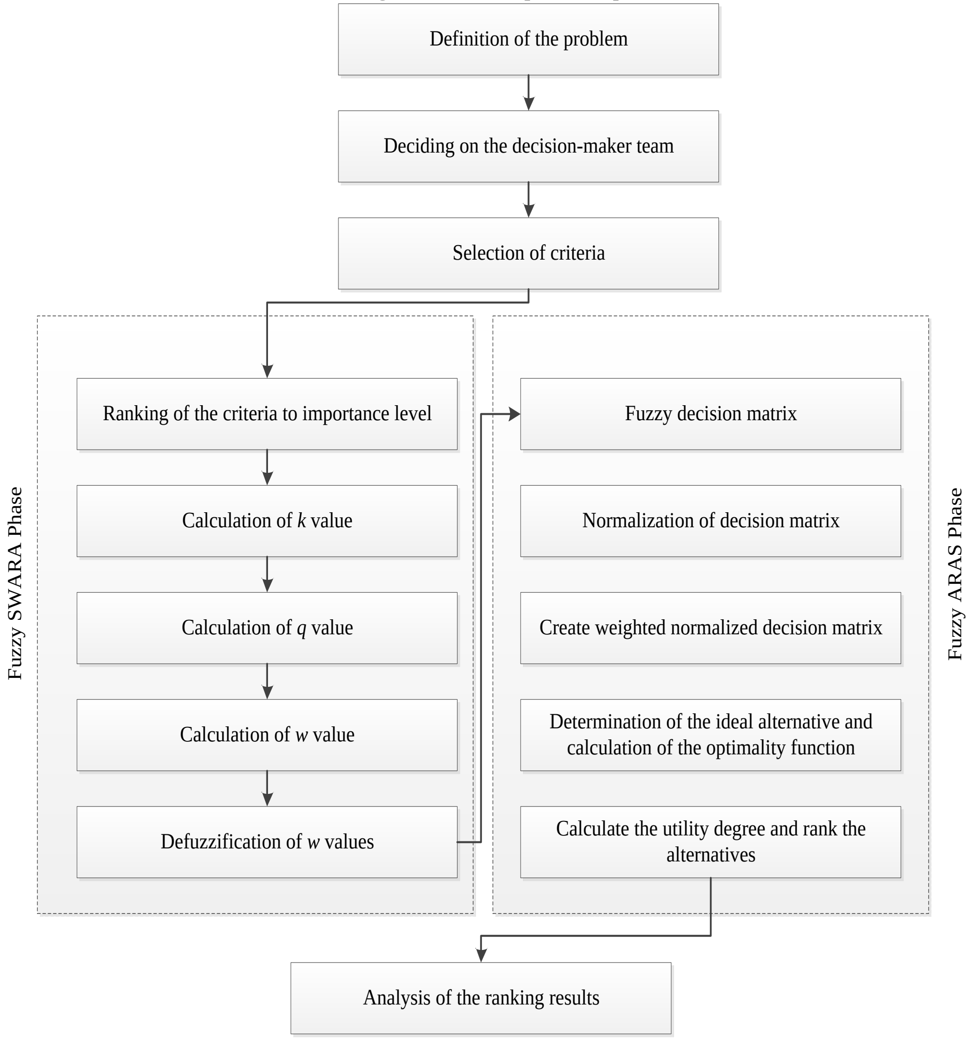
Fuzzy SWARA Phase

1st Step: Each DM evaluates and ranks the criteria. The ranking of the criteria determined by the DMs is presented in Table 2.

Table 2. Significance of the criteria for each DM

Criteria	Decision Makers			
	DM_1	DM_2	DM_3	DM_4
C_1	2	1	1	1
C_2	1	2	2	3
C_3	3	4	3	2
C_4	5	3	4	5
C_5	4	5	5	4

Figure 1. The steps of the problem



2nd Step: The j^{th} criteria compared with the *j-1* criteria. The comparison value of the criteria is determined concerning Table 1. The fuzzy values are provided in Table 3.

Table 3. Fuzzy evaluation average values

Fuzzy values	C_1	C_2	C_3	C_4	C_5
DM_1l	0,5	0,75	0,25	0	0
DM_1m	0,75	1	0,5	0	0,25
DM_1u	1	1	0,75	0,25	0,5
DM_2l	0,75	0	0	0,25	0
DM_2m	1	0,25	0,25	0,5	0
DM_2u	1	0,5	0,5	0,75	0,25
DM_3l	0,75	0	0,25	0	0
DM_3m	1	0,25	0,5	0,25	0
DM_3u	1	0,5	0,75	0,5	0,25
DM_4l	0,75	0,25	0,5	0	0

DM_4m	1	0,5	0,75	0	0,25
DM_4u	1	0,75	1	0,25	0,5
pjl	0,6875	0,25	0,25	0,0625	0
pjm	0,9375	0,5	0,5	0,1875	0,125
pju	1	0,6875	0,75	0,4375	0,375

3rd Step and 4th Step: k_j and q_j values are calculated using Equation (1) and Equation (2). The calculation results are provided in Table 4 and Table 5.

Table 4. Fuzzy calculated values of the methodology

Criteria	*pjl*	*pjm*	*pju*	*sjl*	*sjm*	*sju*
C_1	0,6875	0,9375	1,00	0,00	0,00	0,00
C_2	0,25	0,5	0,6875	0,75	1,00	1,00
C_3	0,25	0,5	0,75	0,5	0,75	1,00
C_4	0,0625	0,1875	0,4375	0,25	0,5	0,75
C_5	0,00	0,125	0,375	0,5	0,75	1,00

Table 5. k_j and q_j values

Criteria	*kjl*	*kjm*	*kju*	*qjl*	*qjm*	*qju*
C_1	1,00	1,00	1,00	1,000	1,000	1,000
C_2	1,75	2,00	2,00	0,571	0,500	0,500
C_3	1,5	1,75	2,00	0,381	0,286	0,250
C_4	1,25	1,5	1,75	0,305	0,190	0,143
C_5	1,5	1,75	2,00	0,203	0,109	0,071

5th Step and 6th Step: *Fuzzy weight values are* calculated using Equation (3). Finally the weight values are defuzzified using Equation (4) and the results are provided in Table 6.

Table 6. Final weights of the criteria

Criteria	*wjl*	*wjm*	*wju*	Defuzzified weights
C_1	0,406	0,480	0,509	0,465
C_2	0,232	0,240	0,255	0,242
C_3	0,155	0,137	0,127	0,140
C_4	0,124	0,091	0,073	0,096
C_5	0,083	0,052	0,036	0,057

As can be seen in Table 6, it was seen that the most important criterion was the "Price" criterion with a weight ratio of 46%. The second important criterion was the “Performance” criterion with a weight ratio of 24%. Afterwards, the "Capacity" criterion became the most important criterion with 14%. “Quality” and “Service and maintenance” criteria became the next important criteria.

Fuzzy ARAS Phase

1st Step and 2nd Step: The decision-makers are evaluated the alternative Machines (M) and the fuzzy decision matrix is provided in Table 7.

Table 7. Fuzzy decision matrix

Criteria	Fuzzy values	Ideal values	Machines			
			M1	**M2**	**M3**	**M4**
C_1	*l*	0	0	2,25	0,5	1
	m	0,25	0,25	3,25	1,25	2
	u	1,4	1,4	3,75	2,3	3
C_2	*l*	2,25	0,25	2,25	0,5	1,25
	m	3,25	1	3,25	1,25	2,25
	u	4	2,05	4	2,3	3,25
C_3	*l*	2,25	0	2,25	1	0,75
	m	3,25	0,25	3,25	1,75	1,75
	u	3,75	1,4	3,75	2,8	2,75
C_4	*l*	2,5	0	2,5	0,75	1,25
	m	3,5	0,25	3,5	1,5	2,25
	u	4	1,1	4	2,55	3,25
C_5	*l*	2,25	0,25	2,25	0	0,5
	m	3,25	0,75	3,25	0,75	1,5
	u	3,75	1,85	3,75	1,8	2,5

3rd Step and 4th Step: After calculation of fuzzy decision matrix, normalized fuzzy decision matrix is calculated in this step and the values are provided in Table 8. Calculated weights by considering fuzzy SWARA methodology are multiplied with the normalized fuzzy decision matrix values and the results are provided in Table 9.

5th Step and 6th Step: The fuzzy optimality function values (S_i) and utility grades (K_i) of the alternatives were calculated and given in Table 10. This table also shows the final ranking results obtained by the fuzzy ARAS method.

Table 8. Normalized decision matrix

Criteria	Fuzzy values	Ideal values	Machines			
			M1	**M2**	**M3**	**M4**
C_1	*l*	0,00	0,00	0,60	0,13	0,27
	m	0,04	0,04	0,46	0,18	0,29
	u	0,12	0,12	0,32	0,19	0,25
C_2	*l*	0,35	0,04	0,35	0,08	0,19
	m	0,30	0,09	0,30	0,11	0,20
	u	0,26	0,13	0,26	0,15	0,21
C_3	*l*	0,36	0,00	0,36	0,16	0,12
	m	0,32	0,02	0,32	0,17	0,17
	u	0,26	0,10	0,26	0,19	0,19
C_4	*l*	0,36	0,00	0,36	0,11	0,18
	m	0,32	0,02	0,32	0,14	0,20
	u	0,27	0,07	0,27	0,17	0,22
C_5	*l*	0,43	0,05	0,43	0,00	0,10
	m	0,34	0,08	0,34	0,08	0,16
	u	0,27	0,14	0,27	0,13	0,18

Table 9. Weighted normalized decision matrix

Criteria	*Fuzzy values*	Ideal values	Machines			
			M1	**M2**	**M3**	**M4**
C_1	*l*	0,00	0,00	0,24	0,05	0,11
	m	0,02	0,02	0,22	0,09	0,14
	u	0,06	0,06	0,16	0,10	0,13
C_2	*l*	0,08	0,01	0,08	0,02	0,04
	m	0,07	0,02	0,07	0,03	0,05
	u	0,07	0,03	0,07	0,04	0,05
C_3	*l*	0,06	0,00	0,06	0,02	0,02

	m	0,04	0,00	0,04	0,02	0,02
	u	0,03	0,01	0,03	0,02	0,02
C_4	*l*	0,04	0,00	0,04	0,01	0,02
	m	0,03	0,00	0,03	0,01	0,02
	u	0,02	0,01	0,02	0,01	0,02
C_5	*l*	0,04	0,00	0,04	0,00	0,01
	m	0,02	0,00	0,02	0,00	0,01
	u	0,01	0,00	0,01	0,00	0,01

Table 10. Fuzzy ARAS final results

Machines	**Fuzzy performance values**			S_i	K_i	**Final ranking**
Ideal	0,22	0,18	0,19	0,19	1,00	Ideal
M_1	0,01	0,05	0,12	0,06	0,31	4
M_2	0,46	0,38	0,29	0,38	1,95	1
M_3	0,11	0,15	0,18	0,15	0,76	3
M_4	0,20	0,24	0,23	0,22	1,15	2

The final evaluation results obtained by the fuzzy ARAS method are given in Table 10. As a result of these calculations, it has been seen that the machine that meets the criteria considered in the study at the most appropriate level is the second machine. Afterward, it was seen that the most suitable machine alternative was the fourth machine. The third and first machines were less preferred, respectively.

CONCLUSION AND RECOMMENDATIONS

Depending on the characteristics of the production line and the industry, the machine selection decision can be a very costly investment decision for businesses. Wrong decisions about machine selection can negatively affect businesses in terms of both production processes and costs. For this reason, companies need to make decide on machine selection after a detailed evaluation process with the help of an expert team.

A real-life application dealing with the machine selection problem is made in this study. The criteria were determined by considering the literature as needed by the business. After the decision-makers determined these criteria, alternative machines were determined. Fuzzy logic-based fuzzy SWARA and fuzzy ARAS methods have been taken into account in order to decide on the most suitable one of these machines. Five different criteria were determined for the machine needed (*price, performance, capacity, quality, service and maintenance*). The fuzzy SWARA method was used to decide on the weights of the determining criteria. After the weights were calculated, the stage of selection of the most suitable machine was initiated. At this stage, the decision-makers identified four different machines. The steps of the fuzzy ARAS method were applied for the most suitable machine selection. In line with the results obtained, it was seen that the most suitable one out of the four alternative machines was the second machine. Afterward, the fourth, third, and first machines were found as the best alternatives. In line with these results, a decision problem has been solved for decision-makers. However, the gap in the literature has been filled since these methods were not used as a hybrid problem in the literature before. The fact that the number of decision-makers and criteria is not high in the study can be said as the limits of the study. The use of hybrid methods used in this study in different types of problems (personnel selection, site selection) in companies can be considered in terms of future researches.

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