Integrated Usage of Fuzzy Multi Criteria Decision Making Techniques for Machine Selection Problems and an Application

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Abstract

Enterprises struggled with fluctuations in market conditions and increased uncertainty due to the globalization process. Shorter product life cycles, changing and increased customer expectations and technological developments in particular have affected manufacturing firms. Correspondingly, technological development and machine and equipment selection are major issues that affects firms' performance and efficiency. In this study, a manufacturing firm's cutting-machine selection problem is solved using combined fuzzy Analytic Hierarchy Process (AHP) and fuzzy MOORA techniques. The aim of this study is to provide decision support for managers regarding the selection problem. The cutting-machine selection criteria were determined by considering the related literature, and also by consulting the company managers. After that, selected criteria weights were determined by fuzzy AHP and ranking cutting machine alternatives by fuzzy MOORA method. The study makes a recommendation for the most suitable cutting machine for the firm.

Keywords: Multicriteria Decision Making, Fuzzy-AHP, Fuzzy-MOORA, Machine Selection

1- Introduction

For all enterprises, market conditions have significantly changed with the globalization process. Shorter product life cycles, increased competition, changed customer expectations, increased technological developments, increased product diversification and differentiation, changed political conditions affect markets and put pressure on enterprises. The manufacturing industry is presently being affected by the structural changes caused by factors both internal and external to enterprises. The market conditions are becoming more dynamic, more global and more customer driven and manufacturing performance is no longer driven by the product price; instead other competitive factors, such as flexibility, quality, delivery and customer service have become equally important (Chan and Swarnkar, 2006). Success is related with efficient and effective resource usage, in this change and transformation process.

One of the most frequent problems facing companies is the selection of the most appropriate machine tool for the product in question, and the individual characteristics of the enterprise (Alberti et. al., 2011). The machine selection process has become very important issue for companies, because improper selection of a machine tool can negatively affect productivity, precision, flexibility and company's responsive manufacturing capabilities. These problems can negatively affect the overall performance of a production system. The speed, quality and cost of manufacturing largely depend on the type of the machine tool used (Arslan et. al. 2004; Ayağ and Özdemir, 2006).

The outputs of manufacturing system mostly depend on the appropriate selection and implementation of machine tools. However, the selection of a new machine tool is a time consuming and difficult process, requiring a considerable amount of advanced knowledge and experience, making this a challenging task for engineers and managers, and also for machine tool manufacturers or vendors. For a proper and effective evaluation, the decision maker may need to analyze a large amount of data and many factors may need to be considered (Ayağ and Özdemir, 2006).

The machine selection process is influenced by factors such as, the product, the firm's financial performance, characteristics, and the person using the machine. Thus, the process is specific to individual firm and cannot be generalized. Machine selection problem must be properly evaluated using Multiple Criteria Decision Making (MCDM) techniques, due to the number of factors inherent in an enterprise in the machine selection process.

It is frequently seen in the literature that MCDM approaches have been used for machine tool selection problems. AHP is the most frequently used in resolving to selection problems, either alone or integrated with different approaches. Ayağ and Özdemir (2006) used fuzzy AHP and cost/benefit ratio analysis for the machine selection problem. Yurdakul (2004) proposed an integrated AHP/ANP methodology for machine selection decision in accordance with product strategies. Duran and Aquila (2008) suggested a fuzzy AHP approach to computer aided machine selection decisions. Çimren et.al. (2007) also used fuzzy AHP approach to machine selection decisions. Dağdeviren (2008) suggested an integrated AHP and PROMETHEE approach for equipment selection problem. Luong (1998) used AHP and data-based technologies for computer aided manufacturing system selection. Önüt et.al. (2008) employed fuzzy AHP to calculate criteria weights, and used fuzzy TOPSIS for ranking alternatives in machine selection. Other studies include Park (1996), who used AHP and Simulation techniques for material handling equipment selection; Chen et.al. (2001), who used expert systems and AHP for material handling equipment selection and Oeltjenbruns et.al. (1995), who proposed AHP for a new investment decision analysis and using machine selection in a new production system with regards to strategic planning.

Taha and Rostam (2011) employed fuzzy AHP and artificial neural networks for machine selection decisions for flexible manufacturing cells; Lin and Yang (1996) proposed AHP approach for machining center selection decisions; İç and Yurdakul (2009) developed decision support system using fuzzy AHP and fuzzy TOPSIS for machining center selection; Ayağ (2007) worked with AHP and simulation techniques for machine selection problem; Koulouriotis and Ketipi (2011) proposed the fuzzy digraph method for robot selection and compared solutions with TOPSIS and Digraph methods; Bai and Yuang (2013) developed fuzzy MCDM model for optimal robot systems evaluation, determination and selection process for robot selection; Goh et.al. (1996) used weighted sum decision model, and Chu and Lin (2003) used fuzzy TOPSIS method. Other studies in the literature are as follows; Arslan et.al. (2004) developed a decision support system for the selection of machine tools; Mishra et.al. (2006) applied quick converging simulated annealing (QCSA) method, which is new type of fuzzy goal programming model for machine selection; Abdel-Malek and Resane (2000) proposed a hierarchical decision support system for equipment selection in the assembly line; in Tuzkaya et.al. (2010) fuzzy ANP were used to determine the criteria weights and used fuzzy PROMETHEE to evaluate alternatives for material handling equipment selection; Yurdakul and İç (2009) proposed spearman's rank correlation test and fuzzy TOPSIS methods for machine selection problem; Chen and Swarnkar (2006) focused on machining, set up and material handling cost through the use of fuzzy goal programming for machine selection problem in flexible manufacturing systems; Gopalakrishnan et.al. (2004) made use of decision support systems for machining center selection; Alberti et.al. (2011) used an artificial neural network for machine selection; Georgakellos (2005) proposed SCOR modelling for technology selection; Wang et.al. (2000) developed fuzzy MCDM model for machine selection in flexible manufacturing systems; Devedzic and Pap (1999) adopted a fuzzy linguistic approach to machine selection; Jun (2002) proposed data envelopment analysis to evaluate computer numeric control (CNC) machines with regards to system features and cost criteria; Integer programming model was used by Atmani and Lashkari (1998) for machine selection and operation allocation in flexible manufacturing systems to generate production planning model; Prego and Rangone (1998) compared linguistic variable concepts based on linguistic models, fuzzy goal theory and pairwise comparison based on fuzzy hierarchical models for advanced manufacturing technologies selection. It is clear that determining evaluation criteria for machine selection problems vary from company to company because of differences in firm requirements, firm culture and machine users.

In this study, cutting machine purchase decisions have been evaluated based on related decision criteria that are cost, energy consumption, rate of waste, consumable consumption, service support, warranty, maintenance time period and ergonomics. As in the related literature, fuzzy AHP method is used to determine criteria weights, while fuzzy MOORA approach is used to choose between alternatives. This study is considered to contribute to the literature, because it is the first to apply fuzzy MOORA method to machine selection.

In the second part of the study, we explained fuzzy sets and fuzzy numbers, and fuzzy AHP and fuzzy MOORA, the techniques used in the application section. In the third section, we evaluated the cutting machine purchase decision at ERFE shoe-trade firm, located in İstanbul, Turkey, and the results provide a degree of decision support for decision makers. In the last part of study, the results are evaluated and some recommendations are made for the future studies.

2- Methodology

The uncertainty and competition caused by the globalization process are becoming the most influential factors on business operations. Enterprises are struggling to survive in competitive conditions dominated by uncertainty. An enterprise's existence and success are highly dependent on the reliability and accuracy of decisions taken in markets subject to high levels of competition and uncertainty. Decision making can be briefly defined as a selection process between alternatives. However, the decision making process is becoming complicated in business life. This is because of the number of alternatives and criteria which affect the decision process and the decisions taken. In these circumstances, fuzzy MCDM techniques have advantages over traditional decision making techniques.

A combination of fuzzy AHP and fuzzy MOORA methods are effective in cutting machine selection. Fuzzy AHP method is appropriate for determining criteria weights, as demonstrated in the literature, while fuzzy MOORA approach is proposed for evaluating and ranking alternatives.

2.1. Fuzzy Set and Fuzzy Numbers

The concept of fuzzy set was introduced by Zadeh (1965). According to Zadeh (1965), a fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership function, which assigns to each object a grade of membership ranging between zero and one (Zadeh, 1965).

In the literature, it is seen that the most widely used fuzzy numbers are triangular and trapezoidal ones. The approach in this study is based on fuzzy numbers, the most preferred option due to their ease of calculation. The triangular fuzzy numbers can be denoted by (l, m, u). Its membership function $\mu_M(x): R \rightarrow [0,1]$ is equal to

$$\mu_M(x) = \begin{cases} \frac{x}{m-l} - \frac{l}{m-l}, & x \in [l,m], \\ \frac{x}{m-u} - \frac{u}{m-u}, & x \in [m,u], \\ 0, & otherwise, \end{cases} \quad (1)$$

Where $l \le m \le u$, l and u stand for the lower and upper value of the support of M respectively, and m for the modal value. Consider two triangular fuzzy numbers M_1 and M_2, M_1= (l_1, m_1, u_1) and M_2= (l_2, m_2, u_2). Their operational laws are as follows:

1. $(l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2),$
2. $(l_1, m_1, u_1) \otimes (l_2, m_2, u_2) = (l_1 l_2, m_1 m_2, u_1 u_2)$
3. $(\lambda, \lambda, \lambda) \otimes (l_1, m_1, u_1) = (\lambda l_1, \lambda m_1, \lambda u_1)$ $\lambda > 0, \lambda \in R$
4. $(l_1, m_1, u_1)^{-1} = (1/u_1, 1/m_1, 1/l_1)$ (Chang, 1996). (2)

2.2. Fuzzy AHP

AHP method, a general measurement theory, is one of the multi criteria decision making approaches. AHP is the most comprehensive application for multi criteria decision making, planning, resource allocation and solution of the problems (Saaty and Vargas, 2000).AHP method, is introduced by Saaty, aims to simplify the solution of the multi- attribute, multi-person, multi-period structural problems. Although the goal of AHP is to evaluate, it is not able to answer uncertainty in the same way as human thinking. In such problems, therefore, fuzzy AHP is recommended (Büyüközkan and Çiftçi, 2012). Decision makers use a fundamental 1-9 scale of absolute numbers to make pairwise comparison in the Saaty's approach. However, absolute values are not sufficient to make real life decisions. The advantage of fuzzy AHP method is that it provides to work at certain intervals in judgments rather than certain absolute values. Decision makers use natural linguistic emphasis as well as certain numbers to evaluate criteria and alternatives. Fuzzy AHP has an impressive capability to replicate human thought and perception, and has been used by many researchers in the literature (Heo et al., 2007).

Fuzzy AHP method is extensively used in selection process for increasing uncertainties effect on decision making. Fuzzy AHP method is frequently used in different areas such as supplier selection and evaluation (Sun, 2010; Xia and Wu, 2007; Chamodrakas and Martakos, 2010; Krishnendu et.al., 2012; Kılınçcı and Önal, 2011; Lee, 2009); evaluating performance of national R&D organizations (Jyoti and Deshmukh, 2008); optimal hospital locatin selection (Aydın and Arslan, 2010); evaluating the architectural design services (Li and Chen, 2009); project selection decisions (Enea and Piazza, 2004); evaluating the benefits of information-share decisions in supply chains (Perçin, 2008); marketing strategy selection (Mohaghar et.al., 2012); personnel selection problems (Güngör et.al., 2009); strategic analysis of electronic service quality in the healthcare industry (Büyüközkan et.al., 2011); weapon selection decisions (Dağdeviren vd., 2009).The fuzzy AHP method is used to determine criteria weights in the study, and is carried out as follows;

Step 1: Construct pairwise comparison matrices among all the elements/criteria in the dimensions of the hierarchy system.

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots \tilde{a}_{1n} \\ \tilde{a} & 1 & \dots \tilde{a}_{2n} \\ \vdots & \vdots & \ddots \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \dots & 1 \end{bmatrix}$$

$$\tilde{a}_{ij} = \begin{cases} \tilde{1},\tilde{3},\tilde{5},\tilde{7},\tilde{9} & criterion\ i\ is\ relative\ impor\tan ce\ to\ criterion\ j \\ 1, \quad i = j & \\ \tilde{1}^{-1},\tilde{3}^{-1},\tilde{5}^{-1},\tilde{7}^{-1},\tilde{9}^{-1} & criterion\ i\ is\ relative\ less\ impor\tan ce\ to\ criterion\ j \end{cases}$$

Decision makers used fuzzy five level scale (see table 1) to evaluate criteria.

Table 1: The Linguistic Assessment Variables and its Corresponding Scale in Terms of Triangular Fuzzy Numbers

Linguistic Variable	Triangular Fuzzy Scale	Triangular Fuzzy Reciprocal Scale
Equal	(1,1,1)	(1/1, 1/1, 1/1)
Moderate	(2,3,4)	(1/4, 1/3, 1/2)
Strong	(4,5,6)	(1/6, 1/5, 1/4)
Very Strong	(6,7,8)	(1/8, 1/7, 1/6)
Extremely Preferred	(8,9,9)	(1/9, 1/9, 1/8)

Step 2: To use geometric mean technique to define the fuzzy geometric mean and fuzzy weights of each criterion by Buckley (1985) as follows:

$$\tilde{r}_i = \left(\tilde{a}_{i1} \otimes \dots \otimes \tilde{a}_{ij} \otimes \dots \otimes \tilde{a}_{in}\right)^{1/n} \quad (3)$$

$$\tilde{w}_i = \tilde{r}_i \otimes \left[\tilde{r}_1 \oplus \dots \oplus \tilde{r}_i \oplus \dots \oplus \tilde{r}_n\right]^{-1} \quad (4)$$

Step 3: The result of the fuzzy synthetic decision reached by each alternative is a fuzzy number. The procedure of defuzzification is to locate the Best Nonfuzzy Performance value (BNP). To utilize the Center of Area (COA) method to find out the BNP is a simple and practical method, and there is no need to bring in the references of any evaluators, so it is used in this study.

$$BNP_{wi} = \left[(U_{wi} - L_{wi}) \oplus (M_{wi} - L_{wi}) \right] / 3 \oplus L_{wi} \quad (5)$$

L_{wi}, M_{wi}, U_{wi} values are triangular fuzzy numbers and respectively represent the lower, middle and upper values in the equation (Hsieh et al., 2004; Sun, 2010).

2.3. Fuzzy MOORA

MOORA is a multiobjective optimization by ratio analysis technique first used by Brauers and Zavadskas (2006). Although MOORA is a new technique in comparison with the other MCDM techniques such as AHP, TOPSIS, ELECTRE, VIKOR, it has become accepted in the literature. Table 2 shows that comparative performance of some MCDM techniques with regard to computational time, simplicity, mathematical calculations, stability and information type (Brauers ve Zavadskas, 2012).

Table 2: Comparative Performance of MCDM Techniques

MCDM Techniques	Computational Time	Simplicity	Mathematical Calculation	Stability	Information Type
MOORA	Very Less	Very Simple	Min.	Good	Quantitative
AHP	Very High	Very Critical	Max.	Poor	Mixed
TOPSIS	Moderate	Moderately Critical	Moderate	Medium	Quantitative
VIKOR	Less	Simple	Moderate	Medium	Quantitative
ELECTRE	High	Moderately Critical	Moderate	Medium	Mixed
PROMETHEE	High	Moderately Critical	Moderate	Medium	Mixed

MOORA is a relatively new technique by comparison with the other techniques used areas such as multi-objective contractor's ranking (Brauers et al., 2008a), evaluating privazition in a transition economy (Brauers and Zavadskas, 2006), multi-objective decision making for road design (Brauers et al., 2008b), project management decisions in a transition economy (Brauers and Zavadskas, 2010), ranking heating losses in a building with regard to different window and Wall design (Kracka et al., 2010), ranking different farming operations efficiency (Balezentis, 2011), selection of the best intelligent manufacturing system (Mandal and Sarkar, 2012), supply chain strategy selection (Dey et al., 2012), personnel selection (Balezentis et al., 2012), wireless network selection (Archana and Sujatha, 2012) and evaluation of the best living room conditions (Kalibatas and Turkis, 2008).

Fuzzy MOORA, used in the evaluation and ranking of the alternatives, was carried out in the following stages.

Step 1: Based on the expert opinions of the decision makers, develop the fuzzy decision matrix in which each criterion value is measured by using triangular membership function.

$$X = \begin{bmatrix} [x_{11}^l, x_{11}^m, x_{11}^n] & [x_{12}^l, x_{12}^m, x_{12}^n] & \dots & [x_{1n}^l, x_{1n}^m, x_{1n}^n] \\ [x_{21}^l, x_{21}^m, x_{21}^n] & [x_{22}^l, x_{22}^m, x_{22}^n] & \dots & [x_{2n}^l, x_{2n}^m, x_{2n}^n] \\ \dots\dots\dots & \dots\dots\dots & \dots & \dots\dots\dots \\ [x_{m1}^l, x_{m1}^m, x_{m1}^n] & [x_{m2}^l, x_{m2}^m, x_{m2}^n] & & [x_{mn}^l, x_{mn}^m, x_{mn}^n] \end{bmatrix}$$

Where $x_{ij}^l, x_{ij}^m, x_{ij}^n$ respectively denote the lower, middle and upper values of a triangular membership function for i^{th} alternative with respect o j^{th} criterion. Decision makers used the scale in table 3 to develop fuzzy decision matrix.

Table 3: Linguistic Variables Used in Evaluating the Alternatives

Linguistic Variables	Triangular Fuzzy Numbers
Very Weak	(0, 0, 1)
Weak	(0, 1, 3)
Moderate Weak	(1, 3, 5)
Moderate	(3, 5, 7)
Moderate Good	(5, 7, 9)
Good	(7, 9, 10)
Very Good	(9, 10, 10)

Step 2: Normalize the fuzzy decision matrix using vector normalization procedure.

$$r_{ij}^{l} = \frac{x_{ij}^{l}}{\sqrt{\sum_{i=1}^{m}\left[\left(x_{ij}^{l}\right)^2 + \left(x_{ij}^{m}\right)^2 + \left(x_{ij}^{n}\right)^2\right]}} \qquad (6)$$

$$r_{ij}^{m} = \frac{x_{ij}^{m}}{\sqrt{\sum_{i=1}^{m}\left[\left(x_{ij}^{l}\right)^2 + \left(x_{ij}^{m}\right)^2 + \left(x_{ij}^{n}\right)^2\right]}} \qquad (7)$$

$$r_{ij}^{n} = \frac{x_{ij}^{n}}{\sqrt{\sum_{i=1}^{m}\left[\left(x_{ij}^{l}\right)^2 + \left(x_{ij}^{m}\right)^2 + \left(x_{ij}^{n}\right)^2\right]}} \qquad (8)$$

Step 3: Determine the weighted normalized fuzzy decision matrix employing the following equations;

$$v_{ij}^{l} = w_j r_{ij}^{l} \qquad (9)$$

$$v_{ij}^{m} = w_j r_{ij}^{m} \qquad (10)$$

$$v_{ij}^{n} = w_j r_{ij}^{n} \qquad (11)$$

Step 4: Calculate the overall ratings of beneficial and non-beneficial criteria, the overall ratings of an alternative for lower, middle and upper values of the triangular membership function are computed as follows for benefit criteria,

$$s_i^{+l} = \sum_{j=1}^{n} v_{ij}^{l} \quad \left| j \in J^{\max} \right. \qquad (12)$$

$$s_i^{+m} = \sum_{j=1}^{n} v_{ij}^{m} \quad \left| j \in J^{\max} \right. \qquad (13)$$

$$s_i^{+n} = \sum_{j=1}^{n} v_{ij}^{n} \quad \left| j \in J^{\max} \right. \qquad (14)$$

For non-benefit criteria;

$$s_i^{-l} = \sum_{j=1}^{n} v_{ij}^{l} \quad \left| j \in J^{\min} \right. \qquad (15)$$

$$s_i^{-m} = \sum_{j=1}^{n} v_{ij}^{m} \quad \left| j \in J^{\min} \right. \qquad (16)$$

$$s_i^{-n} = \sum_{j=1}^{n} v_{ij}^{n} \quad \left| j \in J^{\min} \right. \qquad (17)$$

Step 5: Determine the overall performance index (S_i) for each alternative. For this, the defuzzified values of the overall ratings for beneficial and non-beneficial criteria for each alternative are computed using the vertex method as follows,

$$S_i\left(s_i^+, s_i^-\right) = \sqrt{\frac{1}{3}\left[\left(s_i^{+l} - s_i^{-l}\right)^2 + \left(s_i^{+m} - s_i^{-m}\right)^2 + \left(s_i^{+n} - s_i^{-n}\right)^2\right]} \qquad (18)$$

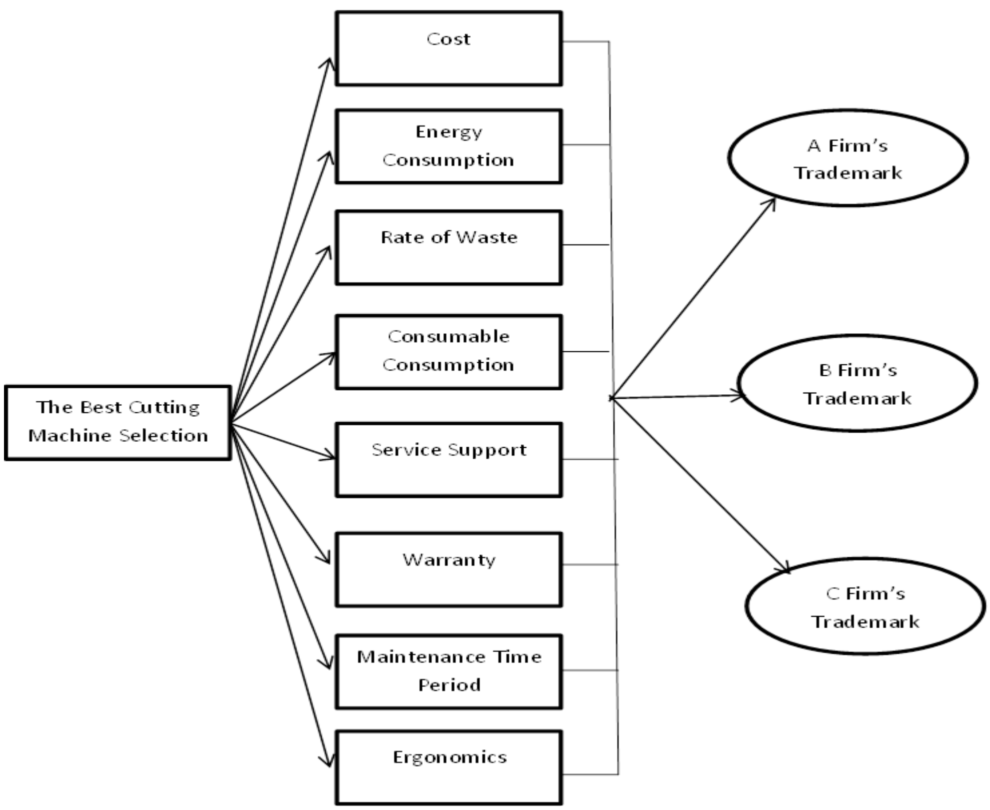
Step 6: Based on the descending values of overall performance index, rank the alternatives from the best to worst. The alternative with the highest overall performance index is the most favorable choice (Karande and Chakraborty, 2012)

3. Application

Our aim is to provide support for decision makers regarding cutting-machine purchase in Erfe Shoe-Making Ind. Trade Co. Ltd., using fuzzy AHP and fuzzy MOORA. Erfe Shoe-Making Ind. Trade Co. Ltd. started operations in 1993 as a shoe manufacturing firm producing vendor contract for leading retailers in the sector. In addition to contract work, %15 of its production is for its own registered trademark. The size of the factory is 2.250 square meters, and production is carried out in three production lines in which two of them are functioning. 2000 pairs of shoes are produced daily in the two lines and optionally are produced all kind of models. Except for the upper shoe operations, the entire process, including R&D, cutting, assembly, quality control, packaging and shipping take place within the factory. There are 80personnel, 7 administrative staff and 73 workers.

The firm believes that purchasing a cutting machine will improve efficiency. As a result of the market research, the firm is considering offers from three firms, named A, B and C. Machine selection varies from company to company according to the type of work done by the company, expectations from the machine, and the purpose of the machine will serve. In this regard, criteria affecting the purchase decision were determined after interviews with the vice general manager, industrial relations expert and the foreman who will use. The criteria were identified as follows; cost, energy consumption, rate of waste, consumable consumption, service support, warranty, maintenance time period, ergonomics. The firm's decision among the three options taken into consideration these criteria. The hierarchical structure of the problem is shown in figure 1.

Figure 1: The Hierarchical Structure of the Problem



Fuzzy AHP technique is used to determine the criteria weights for cutting machine selection in the study. Fuzzy decision matrix was created based on the opinion of decision makers, using Buckley's (1985) geometric mean method, shown in table 4.

Table 4: The Fuzzy Pairwise Comparison Matrix of Criteria

	Cost			Energy Consumption			Rate of Waste			Consumable Consumption			Service Support			Warranty			Maintenance Time Period			Ergonomics		
Cost	1,00	1,00	1,00	1,00	1,19	1,44	0,15	0,18	0,22	0,25	0,33	0,50	1,82	2,14	2,52	4,00	5,13	6,00	1,00	1,44	2,00	2,00	2,47	2,88
Energy Consumption	0,69	0,84	1,00	1,00	1,00	1,00	0,31	0,36	0,44	0,19	0,24	0,31	0,22	0,28	0,40	6,60	7,61	8,32	7,27	8,28	8,65	6,00	7,00	8,00
Rate of Waste	4,58	5,59	6,60	2,29	2,76	3,17	1,00	1,00	1,00	2,88	3,27	3,63	6,00	7,00	8,00	8,00	9,00	9,00	7,27	8,28	8,65	8,00	9,00	9,00
Cansumable Consumption	2,00	3,00	4,00	3,17	4,22	5,24	0,28	0,31	0,35	1,00	1,00	1,00	2,52	2,92	3,30	5,24	6,26	7,27	6,00	7,00	8,00	5,24	6,26	7,27
Service Support	0,40	0,47	0,55	2,52	3,56	4,58	0,13	0,14	0,17	0,30	0,34	0,40	1,00	1,00	1,00	5,77	6,80	7,56	1,00	1,12	1,26	0,63	0,78	1,00
Warranty	0,17	0,19	0,25	0,12	0,13	0,15	0,11	0,11	0,13	0,14	0,16	0,19	0,13	0,15	0,17	1,00	1,00	1,00	0,87	1,00	1,14	1,82	2,27	2,88
Maintenance Time Period	0,50	0,69	1,00	0,12	0,12	0,14	0,12	0,12	0,14	0,13	0,14	0,17	0,79	0,89	1,00	0,87	1,00	1,14	1,00	1,00	1,00	0,31	0,36	0,44
Ergonomics	0,35	0,41	0,50	0,13	0,14	0,17	0,11	0,11	0,13	0,14	0,16	0,19	1,00	1,29	1,59	0,35	0,44	0,55	2,29	2,76	3,17	1,00	1,00	1,00

Fuzzy weights are obtained for each criteria group by using equation 3,

$$\tilde{r}_1 = (\tilde{a}_{11} \otimes \tilde{a}_{12} \otimes \tilde{a}_{13} \otimes \tilde{a}_{14} \otimes \tilde{a}_{15} \otimes \tilde{a}_{16} \otimes \tilde{a}_{17} \otimes \tilde{a}_{18})^{1/8}$$

$$\tilde{r}_1 = (1*1*\ldots*2)^{1/8}, (1*1{,}1856*\ldots*2{,}4662)^{1/8}, (1*1{,}4422*\ldots*2{,}8845)^{1/8}$$

$$= (0.9281,\ 1.1353,\ 1.3875)$$

$$\tilde{r}_2 = (1.1280,\quad 1.3159,\quad 1.5389)$$

$$\tilde{r}_3 = (4.1285,\quad 4.6970,\quad 5.0563)$$

$$\tilde{r}_4 = (2.2782,\quad 2.7316,\quad 3.1679)$$

$$\tilde{r}_5 = (0.7804,\quad 0.9122,\quad 1.0595)$$

$$\tilde{r}_6 = (0.2992,\quad 0.3331,\quad 0.3883)$$

$$\tilde{r}_7 = (0.3409,\quad 0.3836,\quad 0.4464)$$

$$\tilde{r}_8 = (0.3891,\quad 0.4477,\quad 0.5220)$$

Criteria weights are calculated by using equation 4,

$$\tilde{w}_1 = \tilde{r}_1 \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3 \oplus \tilde{r}_4 \oplus \tilde{r}_5 \oplus \tilde{r}_6 \oplus \tilde{r}_7 \oplus \tilde{r}_8)^{-1}$$

$$= (0.9281, 1.1353, 1.3875) \otimes \begin{pmatrix} 1/(1.3875 \oplus \ldots \oplus 0.5220), \\ 1/(1.1353 \oplus \ldots \oplus 0.4477), \\ 1/(0.9281 \oplus \ldots \oplus 0.3891) \end{pmatrix}$$

$$= (0.0684,\quad 0.0950,\quad 0.1341)$$

$$\tilde{w}_2 = (0.0831,\quad 0.1101,\quad 0.1487)$$

$$\tilde{w}_3 = (0.3043,\quad 0.3928,\quad 0.4887)$$

$$\tilde{w}_4 = (0.1679,\quad 0.2285,\quad 0.3062)$$

$$\tilde{w}_5 = (0.0575,\quad 0.0763,\quad 0.1024)$$

$$\tilde{w}_6 = (0.0221,\quad 0.0279,\quad 0.0375)$$

$$\tilde{w}_7 = (0.0251,\quad 0.0321,\quad 0.0431)$$

$$\tilde{w}_8 = (0.0287,\quad 0.0374,\quad 0.0505)$$

Best non-fuzzy performance values are obtained from defuzzifying fuzzy criteria weights with Center of Area (COA) method by using equation 5,

$$BNP_{w1} = [(U_{w1} - L_{w1}) \oplus (M_{w1} - L_{w1})] / 3 \oplus L_{w1}$$
$$= [(0.1341 - 0.0684) \oplus (0.0950 - 0.0684)] / 3 \oplus 0.0684$$
$$= 0.0992$$
$$BNP_{w2} = 0.1140$$
$$BNP_{w3} = 0.3953$$
$$BNP_{w4} = 0.2342$$
$$BNP_{w5} = 0.0787$$
$$BNP_{w6} = 0.0291$$
$$BNP_{w7} = 0.0335$$
$$BNP_{w8} = 0.0389$$

Fuzzy MOORA approach is used to determine the alternatives after the weights of the criteria have been found by fuzzy AHP method. Fuzzy decision matrix about cutting machine selection is formed in line with the opinion of decision makers, shown in table 5.

Table 5: Fuzzy Decision Matrix Related with Cutting Machine Selection

	Cost			Energy Consumption			Rate of Waste			Consumable Consumption			Service Support			Warranty			Maintenance Time Period			Ergonomics		
A Firm	0,00	1,44	3,56	1,44	3,56	5,59	7,00	9,00	10,00	1,44	3,56	5,59	4,22	6,26	8,28	1,44	3,56	5,59	5,00	7,00	9,00	5,00	7,00	9,00
B Firm	0,00	0,00	1,44	0,00	0,00	2,47	7,00	9,00	10,00	4,22	6,26	8,28	7,61	9,32	10,00	5,59	7,61	9,32	5,00	7,00	9,00	5,00	7,00	9,00
C Firm	6,80	8,57	9,65	6,26	8,28	9,65	7,00	9,00	10,00	1,44	3,56	5,59	4,22	6,26	8,28	1,44	3,56	5,59	5,00	7,00	9,00	5,00	7,00	9,00

Normalized fuzzy decision matrix is obtained from vector normalization process by using equations6,7,8.

Table 6: Normalized Fuzzy Decision Matrix

	Cost			Energy Consumption			Rate of Waste			Consumable Consumption			Service Support			Warranty			Maintenance Time Period			Ergonomics		
A Firm	0,00	0,10	0,23	0,09	0,22	0,35	0,27	0,34	0,38	0,10	0,24	0,38	0,19	0,28	0,37	0,09	0,22	0,34	0,23	0,32	0,42	0,23	0,32	0,42
B Firm	0,00	0,00	0,10	0,00	0,00	0,16	0,27	0,34	0,38	0,29	0,42	0,56	0,34	0,42	0,45	0,34	0,46	0,57	0,23	0,32	0,42	0,23	0,32	0,42
C Firm	0,45	0,57	0,64	0,39	0,52	0,61	0,27	0,34	0,38	0,10	0,24	0,38	0,19	0,28	0,37	0,09	0,22	0,34	0,23	0,32	0,42	0,23	0,32	0,42

Weighted normalized fuzzy decision matrix is obtained by calculating weights obtained from fuzzy AHP, and normalizing fuzzy decision matrix components, using equations 9, 10 and 11.

Table 7: Weighted Normalize Fuzzy Decision Matrix

	Cost			Energy Consumption			Rate of Waste			Consumable Consumption			Service Support			Warranty			Maintenance Time Period			Ergonomics		
A Firm	0,00	0,01	0,02	0,01	0,03	0,04	0,11	0,14	0,15	0,02	0,06	0,09	0,01	0,02	0,03	0,00	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,02
B Firm	0,00	0,00	0,01	0,00	0,00	0,02	0,11	0,14	0,15	0,07	0,10	0,13	0,03	0,03	0,04	0,01	0,01	0,02	0,01	0,01	0,01	0,01	0,01	0,02
C Firm	0,04	0,06	0,06	0,04	0,06	0,07	0,11	0,14	0,15	0,02	0,06	0,09	0,01	0,02	0,03	0,00	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,02

Each alternative ranks are obtained with regard to benefit and non-benefit criteria using equations 12-17, and finally performance scores are obtained in equation 18.

Table 8: Performance Score Ranks of Alternative Machines

	S+			S-			S	Rank
A Firm	0,03	0,04	0,06	0,15	0,24	0,32	0,20	2,00
B Firm	0,05	0,06	0,07	0,18	0,25	0,32	0,20	3,00
C Firm	0,03	0,04	0,06	0,23	0,32	0,39	0,27	1,00

As shown in the table 8, C firm has the highest rank score compared to other firms. C followed by A and B respectively, showing that firm C's cutting machine is the best choice.

4. Conclusion

The companies should adapt themselves according to the rapidly changing and evolving market conditions in order to gain a sustainable competitive advantage. This transformation process will bring increase in demand and changes in market conditions as well as an increase in cost. However, the negative consequences of the increase in cost can be minimized by efficient and optimal use of resources. Fixed capital investment is one of the most important categories of cost. Within the fixed capital investments, purchasing a new machine significantly effects costs, therefore managers should focus on making a careful analysis of the decision making process.

The mistakes associated with machine selection causes inefficiency due to the inappropriate use of resources and decrease in the firm performance. The machine selection problem is company specific, including factors such as product category, the particular technicians available, the firm's corporate culture and financial position. There are many factors effecting the decision making process. MCDM (multi criteria decision making) techniques helps the decision makers on problems with multi criteria by presenting an approach and mathematical tools to analyze such a grift and multi-dimensional situations.

A group of experts, composed of vice CEO, industrial relations expert and a foreman, evaluated the cutting machine alternatives based on the following criteria; cost, energy consumption, rate of waste, consumable consumption, service support, warranty, maintenance time period and ergonomics .The weights of the criteria are calculated using fuzzy AHP and the selection itself is conducted with fuzzy MOORA.MCDM methods allow the combination qualitative and quantitative data, providing a flexible methodology that can help decision makers by enabling experts to express their evaluations through linguistic variables in the existence of uncertainty. As far as can be ascertained, there is no such previous study in the machine selection literature. Thus, the study makes a contribution to the literature in this respect.

According to the weights assigned to the criteria, the criterion with heaviest weight is scrap rate, respectively followed by consumable consumption, energy consumption, cost, service support, ergonomics, maintenance time period, and warranty. Evaluation of the alternatives revealed that the firm C has the highest value, and is therefore recommended to the management. The fuzzy MOORA method can easily be implemented in similar situations due to its ease of use, its use of fuzzy logic, and relatively affordable number of calculations when compared to other MCDM methods.

References

Abdel-Malek, L. and Resare, L.J. (2000). Algorithm Based Decision Support System for the Concerted Selection of Equipment in Machining/Assembly Cells. International Journal of Production Research, 38, 2, 323-339

Alberti, M.; Ciurana, J.; Rodriguez, C.A. & Özel, T. (2011). Design of a Decision Support System for Machine Tool Selection Based on Machine Characteristics and Performance Tests. Journal of Intelligent Manufacturing, 22, 263-277

Archana, M. and Sujatha, V. (2012). Application of Fuzzy Moora and GRA in Multi Criterion Decision Making Problems. International Journal of Computer Applications, 53, 9, 46-50

Arslan, Ç.M.; Çatay, B. & Budak, Erhan (2004). A Decision Support System for Machine Tool Selection. Journal of Manufacturing Technology Management, 15, 1, 101-109

Atmani, A. and Lashkari, R.S. (1998). A Model of Machine Tool Selection and Operation Allocation in FMS. International Journal of Production Research, 36, 5, 1339-1349

Ayağ, Z. (2007). A Hybrid Approach to Machine Tool Selection Through AHP and Simulation. International Journal of Production Research, 45, 9, 2029-2050

Ayağ, Zeki and Özdemir, R.G. (2006). A Fuzzy AHP Approach to Evaluating Machine Tool Alternatives. Journal of Intelligent Manufacturing, 17, 179-190

Aydın, Ö. and Arslan, G. (2010). Optimal Hospital Location with Fuzzy AHP. The Business Review Cambridge, 15, 262-268

Bai, Y. and Wang, D. (2013). Select the Optimal Robots and Manipulators Using the Fuzzy Multi-Criteria Decision Making. Research Journal of Computation and Mathematics, 1, 1, 1-7

Balezantis, A.; Balezantis, T. &Brauers, W.K.M. (2012). Multimoora-FG: A Multi-Objective Decision Making Method for Linguistic Reasoning with an Application to Personnel Selection. Informatica, 23, 2, 173-190

Balezentis, T. (2011). A Farming Efficiency Estimation Model Based on Fuzzy Multimoora. Management Theory and Studies for Rural Business ad Infrastructure Development, 5, 29, 43-52

Brauers, W.K.M. and Zavadskas, E.K. (2006). The Moora Method and Its Application to Privatization in a Transition Economy. Control and Cybernetics, 35, 2, 445-469

Brauers, W.K.M. and Zavadskas, E.K. (2010). Project Management by Multimoora as an Instrument for Transition Economies. Technological and Economic Development of Economy Baltic Journal of Sustainability, 16, 1, 5-24

Brauers, W.K.M. and Zavadskas, E.K. (2012). Robustness of Multimoora: A Method for Multi-Objective Optimization. Informatica, 23, 1, 1-25

Brauers, W.K.M.;Zavadskas, E.K.; Peldschus, F &Turskiz, Z. (2008b). Multi-Objective Decision Making for Road Design. Transport, 23, 3, 183-193

Brauers, W.K.M.; Zavadskas, E.K.; Turskis, Z. &Vilutiene, T. (2008a). Multi-Objective Contractor's Ranking by Applying the Moora Method. Journal of Business Economics and Management, 9, 4, 245-255

Büyüközkan, G. and Çiftçi, G. (2012). A Combined Fuzzy AHP and Fuzzy TOPSİS Based Strategic Analysis of Electronic Service Quality in Healthcare Industry. Expert Systems with Applications, 39, 2341-2354

Büyüközkan, G.; Çiftçi, G. & Güleryüz, S. (2011). Strategic Analysis of Healthcare Service Quality Using Fuzzy AHP Methodology. Expert Systems with Applications, 38, 9407-9424

Chamodrakas, I.;Batis, D. &Markatos, D. (2010). Supplier Selection in Electronic Market Places Using Satisficing and Fuzzy AHP. Expert Systems with Applications, 37, 490-498

Chan, F.T.S. and Swarnkar, R. (2006). Ant Colony Optimization Approach to a Fuzzy Goal Programming Model for a Machine Tool Selection and Operation Allocation Problem in a FMS. Robotics and Computer Integrated Manufacturing, 22, 353-362

Chan, F.T.S.;Ip, R.W.L. &Lau, H. (2001). Integration of Expert System with Analytic Hierarchy Process for the Design of Material Handling Equipment Selection System. International Journal of Materials Processing Technology, 116, 137-145

Chang, D.Y. (1996). Application of the Extent Analysis Method on Fuzzy AHP. European Journal of Operational Research, 95, 649-655

Chu, T.C. and Lin, Y.C. (2003). A Fuzzy TOPSİS Method for Robot Selection. International Journal of Advanced Manufacturing Technology, 21, 284-290

Çimren, E.;Çatay, B. & Budak, E. (2007). Development of a Machine Tool Selection System Using AHP. International Journal of Advanced Manufacturing Technology, 35, 363-376

Dağdeviren, M. (2008). Decision Making in Equipment Selection: An Integrated Approach with AHP and PROMETHEE.Journal of Intelligent Manufacturing, 19, 397-406

Dağdeviren, M.; Yavuz, S. &Klınç, N. (2009). Weapon Selection Using the AHP and TOPSİS Methods Under Fuzzy Environment. Expert Systems with Applications, 36, 8143-8151

Devedzic, G.B. and Pap, E. (1999). Multi Criteria Multistages Linguistic Evaluation and Ranking of Machine Tools.Fuzzy Setsand Systems, 102, 451-461

Dey, B.; Bairagi, B.; Sarkar, B. &Sanyal, S. (2012). A Moor a Based Fuzzy Multi Criteria Decision Making Approach for Supply Chain Strategy Selection. International Journal of Industrial Engineering Computations, 3, 649-662

Duran, O. and Aguila, J. (2008). Computer Aided Machine Tool Selection Based on a Fuzzy AHP Approach. Expert Systems with Applications, 34, 1787-1794

Enea, M. and Piazza, T. (2004). Project Selection by Constrained Fuzzy AHP. Fuzzy Optimization and Decision Making, 3, 39-62

Georgakellos, D.A. (2005). Technology Selection from Alternatives: A Scoring Model for Screening Candidates in Equipment Purchasing. International Journal of Innovation and Technology Management, 2, 1, 1-18

Goh, C.H.;Tung, Y.C.A. &Cheng, C.H. (1996). A Revised Weighted Sum Decision Model for Robot Selection. Computers Industrial Engineering, 30, 2, 193-199

Gopalakrishnan, B.;Yoshii, T. & Dappili, S.M. (2004). Decision Support System for Machining Center Location. Journal of Manufacturing Technology Management, 15, 2, 144-154

Güngör, Z.; Serhadlıoğlu, G. & Kesen, S. (2009). A Fuzzy AHP Approach to Personnel Selection Problem. Applied Soft Computing, 9, 641-646

Heo, E.; Kim, J. &Boo, K. J. (2007). Analysis of the Assessment Factors for Renewable Energy Dissemination Program Evaluation Using Fuzzy AHP. Renewable and Sustainable Energy Reviews, 14, 2214-2220

Hsieh, T.Y.; Lu, S.T. &Tzeng, G. H. (2004). Fuzzy MCDM Approach for Planning and Design Tenders Selection in Public Office Buildings. International Journal of Project Management, 22, 573-584

İç, Y.T. and Yurdakul, M. (2009). Development of a Decision Support System for Machining Center Location. Expert Systems with Applications, 36, 3505-3513

Jyoti, B.D.K and Deshmukh, S.G. (2008). Evaluating Performance of National R&D Organizations Using Integrated DEA-AHP Technique. International Journal of Productivity and Performance Management, 57, 370-388

Kalibatas, D. and Turskiz, Z. (2008). Multicriteria Evaluation of Inner Climate by Using Moor a Method. Information Technology and Control, 37, 1, 79-83

Klınçcı, Ö. and Önal, S.A. (2011). Fuzzy AHP Approach for Supplier Selection in a Washing Machine Company. Expert Systems with Applications, 38, 9656-9664

Koulouriotis, D.E. and Ketipi, M.K. (2011). A Fuzzy Digraph Method for Robot Evaluation and Selection. Expert Systems with Applications, 38, 11901-11910

Kracka, M.;Brauers, W.K.M. & Zavadskas, E.K. (2010). Ranking Heating Losses in a Building by Applying the Multimoora. Inzinerine Ekonomika- Engineering Economies, 21, 4, 352-359

Krishnendu, S.; Shankar, R.; Yadav, S.S. & Thakur, L.S. (2012). Supplier Selection Using Fuzzy AHP and Fuzzy Multi-Objective Linear Programming for Developing Low Carbon Supply Chain. Expert Systems with Applications, 39, 8182-8192

Lee, A.H.I. (2009). A Fuzzy Supplier Selection Model with the Consideration of Benefits Opportunities, Costs and Risks. Expert Systems with Applications, 36, 2879-2893

Li, J. and Chen, S. (2009). Evaluating the Architectural Design Services by Using Fuzzy AHP. The Business Review Cambridge, 13, 129-137

Lin, Z.C. and Yang, C.B. (1996). Evaluation of Machine Selection by the AHP Method. Journal of Materials Processing Technology, 57, 253-258

Luong, L.H.S. (1998). A Decision Support System for the Selection of Computer Integrated Manufacturing Technologies. Robotics and Computer Integrated Manufacturing, 14, 45-53

Mandal, U. K. and Sarkar, B. (2012). Selection of Best Intelligent Manufacturing System under Fuzzy Moor a Conflicting MCDM Environment. International Journal of Engineering Technology and Advanced Engineering, 2, 9, 301-310

Mishra, S.;Prakash; Tiwari, M.K. &Lashkari, R.S. (2006). A Fuzzy Goal Programming Model of Machine Tool Selection and Operation Allocation Problem in FMS: A Quick Converging Simulated Annealing Based Approach. International Journal of Production Research, 44, 1, 43-76

Mohaghar, A.;Fatmi, M.R.; Zarchi, M.K. & Omidian, A. (2012). A Combined VİKOR-Fuzzy AHP Approach to Marketing Strategy Selection. Business Management and Strategy, 3, 13-27

Oeltjenbruns, H.;Kolarik, W.J. &Schnadt-Kirschner, R. (1995). Strategic Planning in Manufacturing Systems-AHP Application to an Equipment Replacement Decision. International Journal of Production Economics, 38, 189-197

Önüt, S.; Kara, S.S. &Efendigil, T. (2008). A Hybrid Fuzzy MCDM Approach to Machine Tool Selection. Journal of Intelligent Manufacturing, 19, 443-453

Park, Y.B. (1996). ICMESE: Intelligent Consultant System for Material Handling Equipment Selection and Evaluation. Journal of Manufacturing Systems, 15, 5, 325-333

Perçin, S. (2008). Using the ANP Approach in Selecting and Benchmarking ERP Systems. Benchmarking: An International Journal, 15,5, 630-649

Prego, A. and Rangone, A. (1998). A Reference Framework for the Application of MADM Fuzzy Techniques for Selecting AMTS. International Journal of Production Research, 36, 2, 437-458

Saaty, T.L. and Vargas, L.G. (2000). Models, Methods, Concepts and Applications of the Analytic Hierarchy Process, Boston: Kluwer Academic Publishers

Sun, C.C. (2010). A Performance Evaluation Model by Integrating Fuzzy AHP and Fuzzy TOPSİS Methods. Expert Systems with Applications, 37, 7745-7754

Sun, S. (2002). Assessing Computer Numerical Control Machines Using Data Envelopment Analysis. International Journal of Production Research, 40, 9, 2011-2039

Taha, Z. and Rostam, S. (2011). A Fuzzy AHP-ANN Based Decision Support System for Machine Tool Selection in a Flexible Manufacturing Cell. International Journal of Advanced Manufacturing Technology, 57, 719-733

Tuzkaya, G.; Gülsün, B.; Kahraman, C. & Özgen, D. (2010). An Integrated Fuzzy Multi-Criteria Decision Making Methodology for Material Handling Equipment Selection Problem and an Application. Expert Systems with Applications, 37, 2853-2863

Wang, T.Y.; Shaw, C.F. &Chen, Y.L. (2000). Machine Selection in Flexible Manufacturing Cell: A Fuzzy Multiple Attribute Decision Making Approach. International Journal of Production Research, 38, 9, 2079-2097

Xia, W. and Wu, Z. (2007). Supplier Selection with Multiple Criteria in Volume Discount Environments. Omega, 35, 494-504

Yurdakul, M. (2004). AHP as a Strategic Decision Making Tool to Justify Machine Tool Selection. Journal of Materials Processing Technology, 146, 365-376

Yurdakul, M. and İç, Y.T. (2009). Analysis of the Benefit Generated by Using Fuzzy Numbers in a TOPSİS Model Developed for Machine Tool Selection Problems. Journal of Materials Processing Technology, 209, 310-317

Zadeh, L.A. (1965). Fuzzy Sets. Information and Control, 8, 338-353