A Comparative Analysis for Multi Attribute Selection of Non-traditional Machining Processes Using Fuzzy AHP and Fuzzy TOPSIS

[*1]Aysun Sagbas and [2]Ozan Capraz
[*1]Department of Industrial Engineering, Faculty of Corlu Engineering, Namık Kemal University, Turkey
[2]Department of Industrial Engineering, Faculty of Corlu Engineering, Namık Kemal University, Turkey

Abstract

New exotic work materials as well as innovative geometric design of products and components have been putting lots of pressure on capabilities of conventional machining processes to manufacture the components with desired tolerances economically. This causes to the development and establishment of Non-traditional Machining (NTM) processes in the industry as efficient and economic alternatives to conventional ones. Selection of the most appropriate NTM process under specified material and machining conditions requires taking into account different criteria affecting the NTM process selection decision. In the NTM decision making problems, the judgments of decision makers are usually vague. In order to model this kind of uncertainty in human preferences, fuzzy logic is applied very successfully. In this study Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) approaches are performed under fuzzy environment for selection the optimal NTM process.

Key words: Non-traditional Machining Process, Multi Criteria Decision Making, Fuzzy AHP, Fuzzy TOPSIS

1. Introduction

Non-traditional machining (NTM) processes are defined as a group of processes that remove excess material by various techniques involving mechanical, thermal, electrical or chemical energy or combinations of these energies but do not use a sharp cutting tools as it needs to be used for traditional manufacturing processes. Extremely hard and brittle materials are difficult to machine by traditional machining processes such as turning, drilling, shaping and milling [1]. NTM processes are employed where traditional machining processes are not feasible, satisfactory or economical due to special reasons. Due to the presence of various physicochemical and physic thermal phenomena in NTM processes, and lack of enough expertise in this field, it becomes quite difficult for the process engineers to select the most appropriate NTM process to be applied for generation of a specific shape feature on a given work material [2]. For detailed information on NTM processes, please see [3].

Although at present, numerous NTM processes are available to machine various complex shape geometries in different work materials, in this paper, seven NTM processes such as Abrasive Jet Machining (AJM), Electron Beam Machining (EBM), Electrochemical Machining (ECM), Electrical Discharge Machining (EDM), Chemical Machining (CHM), Laser Beam Machining (LBM) and Ultrasonic Machining (USM) are taken into consideration which can machine diverse

[*]Corresponding author: Address: Department of Industrial Engineering, Faculty of Corlu Engineering, Namık Kemal University, 59860, Corlu/Tekirdag TURKEY. E-mail address: asagbas@nku.edu.tr, Phone: +90282 250 2309 Fax: +90282 250 9924

materials [4, 5]. A comparative study between the alternative NTM processes helps in developing and deploying the available technologies by focusing onto the process characteristics.

In the literature, there are various papers that proposed models to solve the most appropriate NTM process selection problems. Yurdakul and Coğun [1] applied a multi attribute based selection procedure to help the user to shortlist the NTM processes containing only the feasible ones. Chakraborty and Dey [4] developed an Analytic Hierarchy Process (AHP)-based expert system to aid the NTM process selection decision based on the priority values for different criteria and sub criteria, as related to a specific NTM process selection problem. Chakladar and Chakraborty [6] proposed a combined Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and AHP methodology to select the most appropriate NTM process for a specific work material. Temuçin et al. [7] provided distinct systematic approaches both in fuzzy and crisp environments to deal with the NTM process selection problem. Das and Chakraborty [8] proposed an Analytic Network Process (ANP)-based approach to select the most appropriate NTM process taking into account the interdependency and feedback relationships among various criteria affecting the NTM process selection decision. Chandrasselan et al. [9] developed a web-based knowledge base system for identifying the most appropriate NTM process to suit specific circumstances based on some input parameter requirements, such as material type, shape applications, process economy, and process capabilities. Chandrasselan et al. [10] described the development of a knowledge-based system which could identify the most suitable NTM process from 20 alternatives of industrial importance. As the NTM process selection is being affected by several criteria, there is always a need for a structured approach for appropriate NTM process selection. This paper incorporates a comparative study by using fuzzy AHP and fuzzy TOPSIS approaches to aid the decision-makers in selecting the most appropriate NTM process for a given material and shape feature combination. The basic objective of the NTM process selection approach is to identify the attributes affecting the NTM process selection decision and obtain the most appropriate combination of those attributes in conjunction with real requirements of machining application.

2. Method

2.1. Fuzzy Analytic Hierarchy Process

Analytical Hierarchy Process introduced by Thomas L. Saaty during 1970s, is one of widely used multi-criteria decision making tool and is designed for solving complex problems taking into account multiple criteria. In fact, main characteristic of AHP approach is that it is based on pairwise comparison [11]. The crisp AHP is insufficient to handle uncertainty and imprecision in human preferences considering fuzzy nature of comparison process [12]. In order to model this kind of difficulty, fuzzy AHP is applied very successfully [12, 13].

There are several methods in fuzzy AHP that can be employed to determine criteria weights such as Van Laarhoven and Pedrycz’s [14] method, Buckley’s [15] method of geometric mean and Chang’s [16] method called degree analysis. In this study, fuzzy geometric mean method is applied to calculate the criteria weights.

The implementation phases of fuzzy AHP method can be described as follows:

- Step 1: Form a hierarchical structure of decision problem.
- Step 2: Form pairwise comparison matrixes which include linguistic variables.
- Step 3: Determine the fuzzy weights of criteria and alternatives.
- Step 4: Calculate the consistency index (CR) for the criteria and alternatives.
- Step 5: Perform hierarchical analysis.

In Step 2, linguistic variables used in pairwise comparison matrixes of fuzzy AHP are given in Table 1, which includes fuzzy values and its corresponding values of verbal expression.

Table 1. Linguistic variables used for the importance weight of criteria in fuzzy AHP

Verbal Expression	Fuzzy Value	Verbal Expression	Corresponding Value
Certainly Important	(7; 9; 9)	Certainly Unimportant	(1/9; 1/9; 1/7)
Highly Important	(5; 7; 9)	Highly Unimportant	(1/9; 1/7; 1/5)
Important	(3; 5; 7)	Unimportant	(1/7; 1/5; 1/3)
Less Important	(1; 3; 5)	Less Unimportant	(1/5; 1/3; 1/1)
Equal	(1; 1; 1)	Equal	(1/1; 1/1; 1/1)

2.2. Fuzzy Technique for Order Preference by Similarity to Ideal Solution

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method, developed by Hwang and Yoon [17] is another mostly used multi-criteria decision making tool. The aim of TOPSIS method is that chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from negative ideal solution [18].

Considering uncertainty and imprecision in decision making environment, traditional TOPSIS method is inadequate to model real life situation and therefore fuzzy TOPSIS is proposed to use decision problem. There are many applications of fuzzy TOPSIS in the literature [18, 19]. Chen [20] extended TOPSIS method to fuzzy environment. In this study, fuzzy TOPSIS method proposed by Chen [20] is employed to rank alternatives.

The implementation phases of fuzzy TOPSIS method can be described as follows [20]:

- Step 1: Identify the evaluation criteria.
- Step 2: Choose appropriate linguistic variables for evaluating criteria and alternatives.
- Step 3: Aggregate the weight of criteria and pool decision makers’ opinion.
- Step 4: Construct the fuzzy decision matrix and the normalized fuzzy decision matrix.
- Step 5: Construct the weighted normalized fuzzy decision matrix.
- Step 6: Determine Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS).
- Step 7: Calculate distance (S_i^* and S_i^-) of each alternative from FPIS and FNIS, respectively.
- Step 8: Calculate the closeness coefficient (CC_i) of each alternative.
- Step 9: According to the CC_i, the ranking order of all alternatives can be determined.

In Step 2, linguistic variables used in fuzzy TOPSIS method can be expressed in triangular fuzzy numbers as Table 2.

Table 2. Linguistic variables used for the importance weight of criteria and ratings in fuzzy TOPSIS [20]

Importance Weight of Criteria		Ratings	
Linguistic Variables	**Triangular Fuzzy Numbers**	**Linguistic Variables**	**Triangular Fuzzy Numbers**
Very Low (VL)	(0; 0; 0,1)	Very Poor (VP)	(0; 0; 1)
Low (L)	(0; 0,1; 0,3)	Poor (P)	(0; 1; 3)
Medium Low (ML)	(0,1; 0,3; 0,5)	Medium Poor (MP)	(1; 3; 5)
Medium (M)	(0,3; 0,5; 0,7)	Fair (F)	(3; 5; 7)
Medium High (MH)	(0,5; 0,7; 0,9)	Medium Good (MG)	(5; 7; 9)
High (H)	(0,7; 0,9; 1)	Good (G)	(7; 9; 10)
Very High (VH)	(0,9; 1; 1)	Very Good (VG)	(9; 10; 10)

The application steps of the proposed model are presented in Figure 1. In the model, Fuzzy AHP and Fuzzy TOPSIS approaches have been applied to NTM process selection problem.

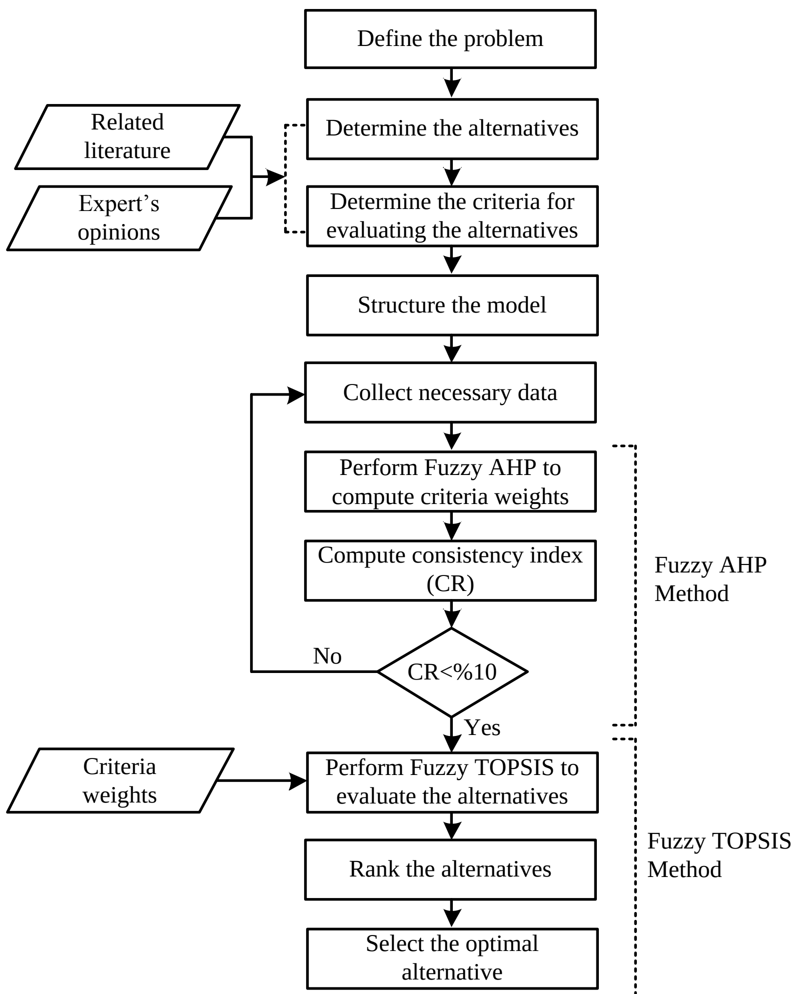

Figure 1. The steps of the proposed model

As can be seen in Figure 1, after determining alternatives and criteria for selection of the optimal NTM process, Fuzzy AHP approach is used to calculate the criteria weights while Fuzzy TOPSIS is used to rank the alternatives and select the optimal machining process.

3. Decision Support System for Machining Process Selection

Determination of the criteria required data for decision matrixes on the proposed decision support model is conducted through a questionnaire to specialists as well as deep discussions with experts, and making use of past studies [1, 4, 5]. In addition, the application of environment and machining conditions in NTM processes must be clearly defined since a NTM process used under a certain application might not be convenient for the another application [5]. In this study, therefore, an example of Yurdakul and Coğun [1]'s study is considered for determining the application of environment and machining conditions in order to illustrate the proposed model.

The application of environment and machining conditions are defined as follows [1]:

- Shape Application: Cylindrical through hole drilling
- Process Requirements: Hole D = 0,9 mm,
  Size tolerance 0,05 mm,
  Hole depth 1.1 mm (i.e. L/D = 1,22)

In this study, alternatives are focused on these seven machining process such as AJM, EBM, ECM, EDM, CHM, LBM and USM. On the other hand, process capability (*its sub-criteria*: tolerance, surface quality, processing speed), shape application (*its sub-criteria*: L/D – t/w ratio, hole diameter, cutting thickness) and process economy (*its sub-criteria*: capital investment, tooling and fixtures, power requirement, tool consumption) are the main criteria that should be used in the comparison of some distinct NTM processes. Figure 2 illustrates structure of the proposed model including criteria and alternatives.

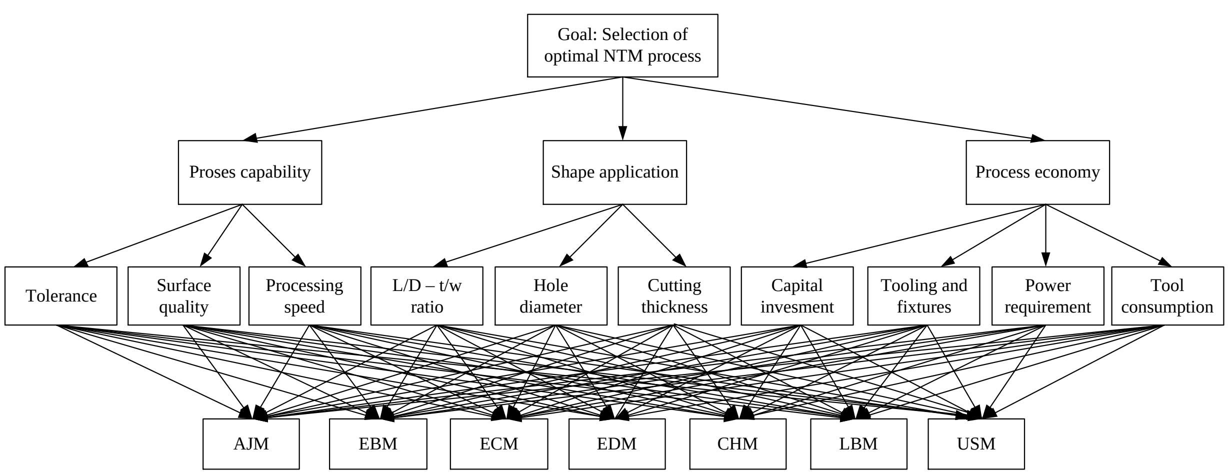

Figure 2. Structure of the NTM process selection

In the present study, stainless steel is selected during the evaluation phase of each alternative NTM process in terms of criteria. During constructing pairwise comparison of fuzzy AHP, verbal expression taken by experts and related literature are taken into account. As a result of fuzzy AHP method, fuzzy weights of main criteria and their sub-criteria, ranking of the criteria and the related consistency index are found in Table 3 and Table 4, respectively.

Table 3. Fuzzy weights of main criteria

Main Criteria	Weights	Ranking	Consistency Index
Process Capability	(0,103; 0,258; 0,733)	2	λ = 3,039 CR = 0,033
Shape Application	(0,054; 0,105; 0,297)	3	
Process Economy	(0,254; 0,637; 1,402)	1	

Table 4. Fuzzy weights of sub-criteria

Main Criteria	Sub-Criteria	Local Weights	Global Weights	Ranking	Consistency Index
Process Capability	Tolerance	(0,104; 0,268; 0,789)	(0,011; 0,069; 0,579)	2	λ = 3,074 CR = 0,064
	Surface Quality	(0,057; 0,117; 0,366)	(0,006; 0,030; 0,269)	3	
	Processing Speed	(0,225; 0,614; 1,434)	(0,023; 0,159; 1,051)	1	
Shape Application	L/D – t/w Ratio	(0,074; 0,126; 0,307))	(0,004; 0,013; 0,091)	3	λ = 3,009 CR = 0,008
	Hole Diameter	(0,292; 0,458; 0,704)	(0,016; 0,048; 0,209)	1	
	Cutting Thickness	(0,231; 0,416; 0,662)	(0,012; 0,044; 0,197)	2	
Process Economy	Capital Investment	(0,148; 0,490; 1,294)	(0,038; 0,312; 1,814)	1	λ = 4,24 CR = 0,089
	Tooling and Fixtures	(0,099; 0,283; 0,865)	(0,025; 0,180; 1,213)	2	
	Power Requirement	(0,056; 0,152; 0,553)	(0,014; 0,097; 0,775)	3	
	Tool Consumption	(0,034; 0,076; 0,261)	(0,009; 0,048; 0,367)	4	

As can be seen in Table 3, it is found that fuzzy weight of process economy (0,254; 0,637; 1,402) is the highest weight. After performing fuzzy AHP, obtained fuzzy criteria weights are used in fuzzy TOPSIS approach to rank NTM processes and select the optimal one. The distance of each alternative from FPIS and FNIS for each criterion and S_i^*, S_i^- and CC_i values for each alternatives can be found in Table 5, 6 and 7, respectively.

Table 5. The distance of each alternative from FPIS for each criterion

Criteria	AJM	USM	ECM	CHM	EDM	EBM	LBM
Tolerance	0,943	0,821	0,943	0,872	0,841	0,825	0,825
Surface Quality	0,908	0,908	0,906	0,954	0,954	0,973	0,936
Processing Speed	0,842	0,754	0,746	0,842	0,768	0,901	0,901
L/D – t/w Ratio	0,976	0,991	0,970	0,991	0,970	0,984	0,976
Hole Diameter	0,944	0,916	0,978	0,927	0,944	0,916	0,916
Cutting Thickness	0,932	0,922	0,932	0,932	0,922	0,922	0,932
Capital Investment	0,811	0,811	0,846	0,779	0,846	0,846	0,846
Tooling and Fixtures	0,782	0,782	0,826	0,763	0,889	0,756	0,756
Power Requirement	0,788	0,838	0,975	0,926	0,805	0,805	0,788
Tool Consumption	0,937	0,937	0,890	0,876	0,963	0,876	0,876

Table 6. The distance of each alternative from FNIS for each criterion

Criteria	AJM	USM	ECM	CHM	EDM	EBM	LBM
Tolerance	0,100	0,336	0,100	0,235	0,302	0,336	0,336
Surface Quality	0,156	0,156	0,156	0,078	0,078	0,047	0,109
Processing Speed	0,305	0,613	0,614	0,305	0,550	0,182	0,182
L/D – t/w Ratio	0,037	0,016	0,048	0,016	0,048	0,026	0,037
Hole Diameter	0,086	0,123	0,036	0,111	0,086	0,123	0,123
Cutting Thickness	0,104	0,116	0,104	0,104	0,116	0,116	0,104
Capital Investment	0,951	0,951	0,315	0,527	0,315	0,315	0,315
Tooling and Fixtures	0,493	0,493	0,352	0,635	0,210	0,707	0,707
Power Requirement	0,450	0,315	0,045	0,134	0,405	0,405	0,450
Tool Consumption	0,106	0,106	0,192	0,213	0,064	0,213	0,213

Table 7. The calculation of S_i^*, S_i^- and CC_i

	AJM	USM	ECM	CHM	EDM	EBM	LBM
S_i^*	8,865	8,681	9,011	8,861	8,902	8,804	8,753
S_i^-	2,789	3,225	1,961	2,356	2,173	2,470	2,577
$S_i^*+S_i^-$	11,653	11,906	10,971	11,218	11,075	11,275	11,329
CC_i	0,239	0,271	0,179	0,210	0,196	0,219	0,227
Ranking	2	1	7	5	6	4	3

For the alternative NTM processes, the ranking is also given in Table 7. It is observed that on the ranking of the NTM processes under given application environment, the best machining process is USM, the order of the rest is AJM, LBM, EBM, CHM, EDM and ECM in descending order.

4. Conclusion

Selection of the most appropriate NTM process for a manufacturing company is very important due to achieving high competitiveness in the market. Meanwhile, it is a complex and difficult problem because of the availability of wide-ranging alternatives, similarities among processes and lack of experienced experts in this field. As the selection of NTM process for different engineering applications involves complex process characteristics, cost considerations and in-depth technological knowledge regarding the applicability of those NTM processes. In this study, a comprehensive decision support model performing fuzzy AHP and fuzzy TOPSIS is developed to assist decision makers and process engineers in the selection of the most appropriate NTM process among the available alternative NTM processes while machining a desired shape feature on a given work material. The required data for the study is obtained via questionnaires given to experts and making use of past studies. The results reached with fuzzy AHP and fuzzy TOPSIS methods showed that USM is found to be the best alternative while ECM is the worst alternatives in the rank order for a given work material and machining conditions.

References

[1] Yurdakul M, Coğun C. Development of a multi-attribute selection procedure for non-traditional machining processes. Proceedings of the Institution of Mechanical Engineers 2003; 217: 993-1009.

[2] Jain VK. Advanced machining processes. New Delhi: Allied Publishers; 2002.
[3] Debroy C, Chakraborty S. Non-conventional optimization techniques in optimizing non-traditional machining processes: a review. Management Science Letters 2013; 3: 23-38.
[4] Chakraborty S, Dey S. Design of an analytic-hierarchy process-based expert system for non-traditional machining process selection. The International Journal of Advanced Manufacturing Technology 2006; 31: 490-500.
[5] Kul Y. Usage of multi criteria decision making methods in selection of non-traditional manufacturing methods. MSc Thesis, Gazi University, Institute of Science and Technology, Mechanical Engineering; 2012.
[6] Chakladar ND, Chakraborty S. A combined TOPSIS-AHP-method-based approach for non-traditional machining processes selection. Proceedings of the Institution of Mechanical Engineers-Part B: Journal of Engineering Manufacture 2008; 222(12): 1613-1623.
[7] Temuçin T, Tozan H, Valíček J, Harničárov M. A Fuzzy Based Decision Support Model for Non-traditional Machining Process Selection. 2nd International Conference Manufacturing Engineering & Management 2012; 170-175.
[8] Das S, Chakraborty S. Selection of non-traditional machining processes using analytic network process. Journal of Manufacturing Systems 2011; 30: 41-53.
[9] Chandrasselan ER, Jehadeesan R, Raajenthiren M. Web-based knowledge base system for selection of non-traditional machining processes. Malaysian Journal of Computer Science 2008; 21(1): 45-56.
[10] Chandrasselan ER, Jehadeesan R, Raajenthiren M. A knowledge base for non-traditional machining processes selection. The International Journal of Technology, Knowledge and Society 2008; 4: 37-46.
[11] Saaty TL. Decision making with the analytic hierarchy process. International Journal of Services Science 2008; 1(1): 83-98.
[12] Kahraman C, Cebeci U, Ulukan Z. Multi-criteria supplier selection using fuzzy AHP. Logistic Information Management 2003; 16(6): 382-394.
[13] Ayağ Z, Özdemir RG. A fuzzy AHP approach to evaluating machine tool alternatives. Journal of Intelligent Manufacturing 2006; 17: 179-190.
[14] Van Laarhoven PJM, Pedrycz W. A Fuzzy Extension of Saaty's Priority Theory. Fuzzy Sets and Systems 1983; 11: 229 -241.
[15] Buckley JJ. Fuzzy Hierarchical Analysis. Fuzzy Sets and Systems 1985; 17: 233-247.
[16] Chang DY. Applications of the Extent Analysis Method on Fuzzy AHP. European Journal of Operational Research 1996; 95(3): 649-655.
[17] Hwang CL, Yoon K. Multiple attributes decision making methods and applications. Berlin: Springer; 1981.
[18] Ertuğrul İ, Karakaşoğlu N. Comparison of fuzzy AHP and fuzzy TOPSIS methods for facility location selection. The International Journal of Advanced Manufacturing Technology 2008; 39: 783-795.
[19] Kahraman C, Ateş NY, Çevik S, Gülbay M, Erdoğan SA. Hierarchical fuzzy TOPSIS model for selection among logistics information technologies. Journal of Enterprise Information Management 2007; 20(2): 143-168.
[20] Chen CT. Extensions of the TOPSIS for group decision-making under fuzzy environment. Fuzzy Sets Systems 2000; 114: 1-9.