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A Comprehensive AHP-TOPSIS Approach for Non-traditional Machining Process Selection in the Manufacturing Sector

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Abstract

Non-traditional machining processes (NTMPs) are being used more widely in modern industry as a result of the increased use of advanced materials in that sector. Selecting the best non-traditional machining process (NTMP) is essential to a manufacturing company's success and competitiveness. One way to think of the process of choosing the best NTMP for a given machining processes application is as a multi-criteria decision-making (MCDM) problem with a lot of competing criteria. The present study unveils a combination of two MCDM strategies for addressing NTMP selection: the procedure for Technique for Order of Preference by Similarity to Ideal Solution method. To assess the relative significance of the quality criteria considered, a pairwise comparison matrix of the Analytic Hierarchy Process (AHP) is utilized. The results obtained through the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method show how the MCDM method strategy can be used to solve complex NTMP select problems.

Keywords: Technique for order preference by similarity to ideal solution (TOPSIS), analytical hierarchy process (AHP), Non-traditional machining processes (NTMP), multi-criteria decision Making (MCDM), data envelopment

INTRODUCTION

In contemporary industry, non-traditional machining processes (NTMPs) are increasingly favoured for a diverse range of materials. These processes arose to address novel and unconventional machining needs unmet by traditional methods [1]. Each NTMP embodies a sophisticated multi-input/multi-output machining technique with unique capabilities, advantages, and limitations. While most NTMPs satisfy demands for high surface quality, low tolerance, minimal surface damage, and offer automation, flexibility, and productivity, selecting the optimal process for a specific application may vary under different conditions [2–5]. Consequently, NTMP users must assess various, sometimes conflicting criteria, such as material removal rate, accuracy, environmental factors, material properties, cost, and constraints, to identify the most suitable process. Moreover, considering the high cost of NTMP machine tools, making informed selections is paramount, as inadequate choices can have lasting impacts on a company's overall operations. The purpose of this paper is to introduce a Multi-

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Criteria Decision-Making (MCDM) model that will help choose the best NTMP based on a variety of effectiveness specifications. Initially, a pairwise comparison matrix derived from the AHP method was utilized to establish the relative significance of the quality criteria under consideration. Subsequently, the competitive NTMPs are ranked using the TOPSIS.

LITERATURE REVIEW ON NTMPS SELECTION

There is a scarcity of published works focusing on the selection of non-traditional machining processes (NTMPs) within a multi-criteria decision-making (MCDM) framework. Before delving into the selection of an appropriate NTMP, it is imperative to understand the specific nature of the application where the NTMP will be implemented. While an NTMP may demonstrate high efficiency for a particular application, changes in application type, materials, and other requirements can significantly impact its effectiveness. Consequently, defining the application domain explicitly should be the first step in the selection process. An AHP-based expert system was created by Chakraborty and Dey [6] to help decision-makers choose the best NTMPs for predetermined programs. This expert system relies on priority assessments for different criteria and sub-criteria associated with explicit NTMP selection problems. Additionally, Chakraborty and Dey [7] created a qualified system that takes consideration a range of process and outcome attributes and selects the NTMP based on Quality Function Deployment (QFD). To determine the overall scores of possible NTMPs, weights assigned to the NTMP selection criteria are used. Additionally, utilizing a combined AHP-TOPSIS-based approach, Das Chakladar and Chakraborty [8] selected the best NTMPs for preset machining uses. By taking materials needed, shape uses process economy, and process capabilities parameters into consideration, Edison Chandrasselan et al. [9] proposed a publicly accessible educational system to assist in determining the best appropriate NTMP. Among the twenty solutions with technical consequence that Edison Chandrasselan et al. [10] showed off a knowledge-driven method for figuring out which NTMP is best. Upon choosing the best Non-traditional Machining Process (NTMP) for a given machining implementation, the developed based on expertise system considers various substrate types alongside particular process flexibility requirements. For spherical holes, these limitations include depth-to-diameter ratio; for blind cavities, similar limitations include tolerance and corner dimensions, surface harm while taper that exist, width of cut, surface finish, and opening height. To determine which NTMPs would be best for immediate form production applications, Das Chakladar et al. [11] used a digraph-based taking decisions technique. Sadhu and Chakraborty [12] used a two-phase taking decisions model in a different study to determine the most feasible NTMPs according to particular shape attributes and work combos of materials. This framework merges an analysis of data envelopment (DEA) with a weighted general efficiency ranking method. Furthermore, to help in the process of choosing the best NTMPs, Das and Chakraborty [13] created a graphical user interface model based on the method known as the Analytic Network Process (ANP). The model takes into account the feedback interactions and interdependencies between different criteria that impact the decision-making process of the NTMP. The multi-objective optimization by ratio analysis (MOORA) approach was used by Chakraborty [14] to select NTMPs for a range of engineering applications. Temuçin et al. [15] addressed NTMP selection issues with a number of systematic techniques and a decision support model in both crisp and fuzzy scenarios. Karande and Chakraborty [16] employed a unified preference ranked organization method for enrichment evaluation (PROMETHEE) and Geometrical Analysis For Interactive Aid (GAIA) strategy to solve NTMP being chosen issues on my own.

The process engineers would have visual decision support from the proposed method.

Analytic Hierarchy Process (AHP) 2.1

Founded in the 1970s by Thomas Saaty, the methodology of analytical hierarchy (AHP) [17]. It is a superb management tool for difficult multi-criteria decision problems. Using pairwise comparison judgments, the approach can assist decision-makers in prioritizing alternatives and identifying the best option. Incorporating input from multiple experts in the weighting of criteria helps mitigate bias in

Table 1. Scale for pairwise comparisons.

Intensity of importance	Definition
1	Equal (equally important)
3	Moderate (moderately/weakly/slightly more important)
5	Strong (strongly more important)
7	Very strong (very strongly/demonstrably more important)
9	Extremely/more important
2, 4, 6, 8	The values between the two adjacent judgments

Table 2. Random index table.

N	1	2	3	4	5	6	7	8	9	10
RCI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51

decision-making processes and ensures impartiality. The Analytical Hierarchy Process (AHP) steps are used in this paper to establish the value weighting or order of significance of various specifications. The stages involved in the AHP method are outlined as follows:

1. Identify the problem and establish the proposed solution, followed by compiling a hierarchy of the encountered issues.
2. Determine the weight of criteria by pairwise comparison of each criterion. This comparison process employs the priority scheme outlined in Table 1.
3. Normalize the pairwise comparison matrix by calculating the sum of each column in the matched pair matrix. To obtain the standardized matrix, separate each column's value by the sum of the corresponding columns.
   $\bar{a}_{jk} = \frac{a_{jk}}{\sum_{i=1}^{m} a_{jk}}$
4. Calculate the synthesis weight by summing the values in each column of the normalization result matrix obtained from the comparison.
   $\sum Column = k_1 + k_2 + k_3 + \cdots . + k_n$
5. Multiply each column of the matched matrix in the same row to determine the eigenvalues, and then raise the result to the power of the current requirements number as well.
   $\lambda_1 = (k_1 + k_2 + k_3 + \cdots . + k_n)^{\frac{1}{n}}$
6. Divide each criterion's eigenvalue by the total number of eigenvalues to find the priority weight for that criterion.
7. Assess the significance of each criterion by dividing the synthesis weight by the priority weight.
8. Divide the total number of significant values by the total the quantity of criteria to find a maximum a Eigenvalue (λmax).
9. Evaluate the consistency of usage to ensure that decision-making judgments exhibit high consistency.
   $CI = \frac{(\lambda_{max} - n)}{n-1}$
   Where, n = Number of Elements, λmax = Maximum Eigen Value, and CI = Consistency Index

Verifying the hierarchy's consistency with the understanding that the computation is deemed correct if the consistency ratio (CI/IR) is less than or equal to 0.1. Table 2 shows the IR values.

Method for Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

The decision makers (DMs) can assess the best options with the aid of a Multi-Criteria Decision Making (MCDM) technique. Among multi-attribution decision making (MADM) models, the TOPSIS method is the most widely used approach. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), a multi-criteria choice evaluation technique, was initially introduced by Hwang and Yoon in 1981 [18].

This approach to decision-making is reasonable and easy to understand. TOPSIS chooses the option that shows the least geometric separation from the optimal solution in a positive direction. It assesses a set of alternatives by assigning weights to each criterion, normalizing the scores for each criterion, and calculating the performance of each criterion. The TOPSIS method facilitates the selection of suitable suppliers based on a diverse range of criteria.

Step 1: The structure of matrix:

$$X = \begin{bmatrix} x_{12} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$

Where, xij is a crisp value indicating the performance rating of each alternative Ai with regard to each criterion Cj.

Step 2: Calculate the normalized matrix X by using the following formula:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{J} x_{ij}^2}}$$

Step 3: Construct the weighted normalized decision matrix by multiplying:

$$V_{ij} = w_{ij}.r_{ij}$$

Step 4: Determine the positive ideal solution and negative ideal solution:

$$A^* = \{(max\ v_{ij} |\ j\ \in J), (min\ v_{ij} | j\ \in J')\}$$

$$A^- = \{(min\ v_{ij} |\ j\ \in J), (max\ v_{ij} | j\ \in J')\}$$

Step 5: Calculate the separation measure:

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}$$

Step 6: Calculate the relative closeness to the ideal solution:

$$C_i^* = {S_i^-}/{S_i^* + S_i^-}, 0 \leq C_i^* \leq 1$$

NUMERICAL ILLUSTRATION

In this study, we consider six non-traditional machining processes: Atomic Force Microscopy (AFM - MP1), Abrasive Jet Machining (AJM - MP2), Electron Beam Machining (EBM - MP3), Electrical Discharge Machining (EDM - MP4), Ultrasonic Machining (USM - MP5), and Water Jet Machining (WJM - MP6). Within these methods, standards of quality such as tolerance and surface finish (C1), power needs (C2), the rate of material elimination (C3), cost (C4), production (C5), tooling plus fixtures (C6), equipment utilization (C7), safety (C8), work item (C9), and shape feature (C10) are evaluated.

Among these criteria, C1 (mm), C2 (kW), and C3 (mm3/min) are quantitative measures with numerical values, while C4, C5, C6, C7, C8, C9, and C10 involve subjective assessments, for which a ranked value judgment on a scale of 1–5 (1 being the lowest, 3 being moderate, and 5 being the highest) is recommended. Criteria C3, C5, C8, C9, and C10 are considered beneficial attributes where higher

Table 3. Quantitative data/decision matrix.

	MP1	MP2	MP3	MP4	MP5	MP6
C1	2.5	2.5	2.5	3.5	1	2.5
C2	0.22	0.22	0.2	2.7	10	0.22
C3	3300	0.8	1.6	800	500	0.8
C4	1	1	4	3	2	1
C5	5	4	5	4	4	4
C6	2	2	2	4	2	2
C7	2	2	1	4	3	2
C8	3	3	3	3	1	3
C9	4	4	4	5	4	4
C10	1	1	1	1	1	1

values are preferred. Conversely, criteria C1, C2, C4, C6, and C7 are non-beneficial attributes, where lower values are preferable. While the data for various standards, such as C4, C5, and so on, may change over time, the data for rules C1, C2, and C3 are basic, so the relatedness is ensured to use a rating system of five points (Table 3).

Implementation of AHP for Calculating Criterion Weight

Getting the weights of the elements at each level of the hierarchy is the next step after building the hierarchy with the AHP technique. A set that contrasted matrix structures with regard to variables of the higher level represent all of the constituent parts for each level in the order of importance (Tables 4 and 5).

Consistency Validation

The maximum eigenvalue (λmax) is calculated to be 10.52, resulting in a Consistency Index (C.I.) of 0.06. To determine the Consistency Ratio (C.R.), we first refer to the Random Index (R.I.), which is the consistency index of each pairwise comparison matrix and depends on the number of items in the comparison.

If the C.R. exceeds 0.10, it indicates inconsistency between pairwise comparisons. Conversely, if the C.R. is less than 0.10, it suggests that the consistency of pairwise comparisons is reasonable. In this case, the calculated C.R. is 0.04, which is less than 0.10. Therefore, the consistency of the pairwise comparisons is considered reasonable.

Application of TOPSIS for Ranking of Alternatives

After completing the AHP calculations, the weights of the criteria. Here, these weights are the output of the AHP, which can be considered as the inputs of the TOPSIS in the next step (Tables 6–8).

Table 4. Pairwise comparison matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	1	1/2	3	2	1/3	1/4	1/5	1/6	5	4
C2	2	1	3	2	1/2	1/3	1/4	1/5	5	4
C3	1/3	1/3	1	1/2	1/2	1/6	1/7	1/8	2	3
C4	1/2	1/2	2	1	1/4	1/5	1/6	1/7	4	3
C5	3	2	5	4	1	1/2	1/3	1/4	7	6
C6	4	3	6	5	2	1	1/2	1/3	8	7
C7	5	4	7	6	3	2	1	1/2	9	8
C8	6	5	8	7	4	3	2	1	9	9
C9	1/5	1/5	½	1/4	1/7	1/8	1/9	1/9	1	1/2
C10	1/4	1/4	1/3	1/3	1/6	1/7	1/9	1/9	2	3

Table 5. Normalization of pairwise comparison matrix and weight calculation.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	Sum	Weight
C1	0.04	0.03	0.08	0.07	0.03	0.03	0.04	0.06	0.1	0.09	0.57	0.0573
C2	0.09	0.06	0.08	0.07	0.04	0.04	0.05	0.07	0.1	0.09	0.69	0.0695
C3	0.01	0.02	0.03	0.02	0.02	0.02	0.03	0.04	0.04	0.07	0.3	0.0296
C4	0.02	0.03	0.06	0.04	0.02	0.03	0.03	0.05	0.08	0.07	0.42	0.0417
C5	0.13	0.12	0.14	0.14	0.09	0.06	0.07	0.09	0.13	0.13	1.11	0.1108
C6	0.18	0.18	0.17	0.18	0.17	0.13	0.1	0.11	0.15	0.15	1.53	0.1531
C7	0.22	0.24	0.2	0.21	0.26	0.26	0.21	0.17	0.17	0.18	2.12	0.2116
C8	0.27	0.3	0.22	0.25	0.35	0.39	0.42	0.34	0.17	0.2	2.9	0.29
C9	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.04	0.02	0.01	0.16	0.0163
C10	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.04	0.04	0.02	0.2	0.0201

Table 6. Input values of the TOPSIS analysis.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
MP1	2.5	0.22	3300	1	5	2	2	3	4	1
MP2	2.5	0.22	0.8	1	4	2	2	3	4	1
MP3	2.5	0.2	1.6	4	5	2	1	3	4	1
MP4	3.5	2.7	800	3	4	4	4	3	5	1
MP5	1	10	500	2	4	2	3	1	4	1
MP6	2.5	0.22	0.8	1	4	2	2	3	4	1

Table 7. The weighted normalized decision matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
MP1	0.023	0.001	0.028	0.007	0.052	0.051	0.069	0.128	0.006	0.008
MP2	0.023	0.001	0	0.007	0.041	0.051	0.069	0.128	0.006	0.008
MP3	0.023	0.001	0	0.029	0.052	0.051	0.034	0.128	0.006	0.008
MP4	0.032	0.018	0.007	0.022	0.041	0.102	0.137	0.128	0.008	0.008
MP5	0.009	0.067	0.004	0.015	0.041	0.051	0.103	0.043	0.006	0.008
MP6	0.023	0.001	0	0.007	0.041	0.051	0.069	0.128	0.006	0.008

Table 8. The final evaluation and ranking of alternatives.

	S^+	S^-	C^*	Rank
MP1	0.0932	0.1145	0.5512	2
MP2	0.098	0.1104	0.5297	3
MP3	0.0938	0.1331	0.5865	1
MP4	0.1488	0.05	0.2514	6
MP5	0.0989	0.1089	0.5242	5
MP6	0.098	0.1104	0.5297	3

RESULT AND DISCUSSION

On the analysis of the outcomes, we conclude that alternative MP3 (EBM), with a maximum value of 0.5865, is followed closely by MP1 (AFM), making it the top-priority process within the group. It demonstrates a high capability to fulfill the majority of the buyer's required criteria for manufacturing. This study integrates the AHP and TOPSIS methods to bolster the decision-support process in selecting the most suitable supplier. To improve efficiency and ease of use, simple software like MS Excel was employed. Evaluating suppliers based solely on criteria will be sufficient for future applications of the model. Implementing this evaluation via simple software will expedite the process. TOPSIS and AHP serve as valuable decision-making tools due to their practicality, conciseness, and systematic approach.

These methods can effectively address multi-objective decision-making problems by providing a structured framework for quantitative sorting and rational selection of alternative models. This facilitates the identification and standardization of decision-making processes. However, it's essential to customize the decision-making system according to the specific circumstances of each enterprise, considering the multitude of criteria and rules involved in real-life scenarios. When employing TOPSIS and AHP for multi-objective decision problems, careful attention should be paid to certain considerations:

- The decomposition and simplification of multi-objective decision-making problems should focus on grasping the main factors without inadvertently omitting or adding essential elements.
- Different factors that exhibit significant differences should not be compared using the same criteria, as this may lead to inaccurate assessments.

CONCLUSION

This study employs the integration of the TOPSIS method with the AHP method to identify the optimal combination of machining techniques. By integrating these two methods, the AHP method is utilized to determine weighting coefficients, while the final rankings of observed alternatives are determined using the TOPSIS method. This approach enables decision-makers to effectively identify the most suitable non-traditional machining process (NTMP) from the given set of choices.

REFERENCES

1. Groover MP. Fundamentals of Modern Manufacturing: Materials, Processes, and Systems, John Wiley & Sons, Hoboken, 2010.
2. Mourão A, Neştian G, Slătineanu L, Gonçalves-Coelho AM. Selection of Non-Conventional Machining Systems Based on the Axiomatic Design Theory, Nonconventional Technologies Review. 2007; 11(4): 50–55.
3. Karande P. Chakraborty S. Application of PROMETHEE-GAIA Method for Non Traditional Machining Processes Selection, Manag Sci Lett. 2012; 2(6): 2049–2060.
4. Chakladar ND, Chakraborty S. A combined TOPSIS-AHP-method-based approach for non-traditional machining processes selection, Proc Inst Mech Eng J Eng B Manuf. 2008; 222(12): 1613–1623.
5. Chatterjee P, Chakraborty S. Nontraditional Machining Processes Selection Using Evaluation of Mixed Data Method, Int J Adv Manuf Technol. 2013; 68(5–8): 1613–1623.
6. Chakroborty S, Dey S. Design of an analytic-hierarchy-process-based expert system for nontraditional machining process selection, Int J Adv Manuf Technol. 2006; 31(5–6), 490–500.
7. Chakroborty S, Dey S. QFD-based expert system for non-traditional machining processes selection, Expert Syst Appl. 2007; 32(4): 1208–1217.
8. Hodonou C, Balazinski M, Brochu M, Mascle C. Material-design-process selection methodology for aircraft structural components: Application to additive vs subtractive manufacturing processes. Int J Adv Manuf Technol. 2019;103:1509–1517. DOI: 10.1007/s00170-019-03613-5.
9. Edison Chandrasselan R, Jehadeesan R. Web-based knowledge base system for selection of non-traditional machining processes, Malays J Comput Sci. 2008; 21(1): 45–56.
10. Edison Chandrasselan R, Jehadeesan R. A knowledge base for non-traditional machining process selection, International Journal of Technology, Knowledge & Society. 2008; 4(4): 37–46.
11. Das Chakladar N, Das R, Chakraborty S. A digraph-based expert system for non-traditional machining processes selection, Int J Adv Manuf Technol. 2009; 43(3–4): 226–237.
12. Sadhu A, Chakraborty S. Non-traditional machining processes selection using data envelopment Analysis (DEA), Expert Syst Appl. 2011; 38(7): 8770–8781.
13. Das S, Chakraborty S. Selection of non-traditional machining processes using analytic Network process, J Manuf Syst. 2011; 30(1): 41–53.
14. Chakraborty S. Applications of the MOORA method for decision making in manufacturing environment, Int J Adv Manuf Technol. 2011; 54(9–12): 1155–1166.

15. Temuçin T, Tozan H, Valíček J, Harničárová. A fuzzy based decision support model for nontraditional machining process selection, Proc. of 2nd International Conference on Manufacturing Engineering & Management, Slovakia. 2012, 170–175.
16. Karande P, Chakraborty S. Application of PROMETHEE-GAIA method for non-traditional machining processes selection, Manag Sci Lett. 2012; 2(6): 2049–2060.
17. Saaty TL. How to Make a Decision: The Analytic Hierarchy Process. Eur J Oper Res. 1970; 48: 9–26.
18. Hwang CL, Yoon K. Multiple Attribute Decision Making: Methods and Applications. 1981, Springer-Verlag, New York.

