INTEGRATION OF MULTI CRITERIA DECISION MAKING TECHNIQUES FOR SELECTION OF NON- CONVENTIONAL MACHINING PROCESSES

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Abstract

The role of non-conventional machining processes (NCMPs) in today's manufacturing environment has been well acknowledged. For effective utilization of the capabilities and advantages of different NCMPs, selection of the most appropriate NCMP for a given machining application requires consideration of different conflicting criteria. The right choice of the NCMP is critical to the success and competitiveness of the company. As the NCMP selection problem involves consideration of different conflicting criteria, of different relative importance, the multi-criteria decision making (MCDM) methods are very useful in systematically selection of the most appropriate NCMP. This paper presents the application of a recent MCDM method, i.e., the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method to solve NCMP selection which has been defined considering different performance criteria of four most widely used NCMPs. In order to determine the relative significance of considered quality criteria a pair-wise comparison matrix of the analytic hierarchy process (AHP) was used. The results obtained by the technique for order preference by similarity to ideal solution (TOPSIS) method which proves the applicability and potentiality of this MCDM method for solving complex NCMP selection problems. By the help of combining TOPSIS an AHP method which is based on comparison between various attributes and secondly based on fact that best alternative has least geometric distance from ideal solution and worst alternative has more geometric distance from an ideal solution. After applying combine approach among the available NCMP processes are AFM, AJM, EBM, EDM, USM and WJM.

Keywords: *Analytical Hierarchy Process (AHP), Multiple criteria decision-making (MCDM), Non-Conventional Machining Processes (NCMPs), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Optimization Techniques*

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1. Introduction

In today's industry, a number of non-conventional machining processes (NCMPs) are increasingly being used for processing of different engineering materials especially advanced materials having improved technological and mechanical properties. For many firms, having some core competency is necessary for making strategic decisions like technology selection decision. Since some of the consequences of technology selection occur at long-run, firms' survival at long term depends heavily on their ability to exploit some core competencies [1]. Making right decision is a basis for achieving high competitiveness on the global market through increase in productivity, product quality and flexibility. As the price of machine tools for NCMPs is very high, inadequate selection of the most appropriate NCMP has long-term consequences on the business of the entire company. However, selection of the most appropriate NCMP is a challenging task for decision makers [2] and moreover often a time-consuming task [3]. In the present work, firstly a MCDM model which can be used to select the most suitable NCMP considering different performance criteria has been defined. A pair-wise comparison matrix of the AHP method was then used to determine the relative significance of considered quality criteria, and finally the competitive NCMPs were ranked by using the TOPSIS method.

2. Literature Review

For some time, there have been a number of multi criteria decision-making (MCDM) tools, of which the Brown and Gibson model by Saaty is worth mentioning. In this method to date the critical criteria factor measures are solely dependent on the decision-maker which makes it difficult to implement. In addition, the optimality of the objective factor measures lying between 0 and 1 (obtained from the plotting of objective and subjective factor measures) is seldom reached; hence the post optimality analysis becomes difficult. All these above-mentioned procedures give rise to the AHP to deal solely with the subjective factors or the prioritized relationship between the objective factors.

For some time, there have been a number of MODM tools, of which the Brown and Gibson model by Saaty is worth mentioning. In this method to date the critical criteria (factor) measures are solely dependent on the decision maker, which makes it difficult to implement. All these abovementioned procedures give rise to the AHP to deal solely with the subjective factors or the prioritized relationship between the objective factors.

In TOPSIS method, one thing is ensured: the more a solution reaches the ideal solution and the more it leaves from the negative ideal solution, the more optimal it becomes. In this article TOPSIS combined with AHP fulfils the entirety of a MCDM process, dealing with both the subjective and objective attributes. The final step of TOPSIS shows the suitable alternatives based on the descending order of preference. For calculating the normalized matrix using the TOPSIS method, it is vital to have the objective or subjective estimates for each of the attributes as alternatives. After getting all the values of the decision matrix, it is ready for further analysis. Similarly, after the computation of the normalized matrix, the weighted, normalized matrix is found out were the relatedness of the attributes are accounted for by AHP. MADM are used to help decision-makers to find the best alternative from a fixed set.

MADM methods have been positively used in the selection of work materials, rapid prototyping processes, thermal power plants, industrial robots, evaluation of projects, mobile phones, product design, flexible manufacturing systems, performance measurement models for manufacturing organizations, plant layout design, and so on. Hwang & Yoon (1981) established TOPSIS to assess the alternatives while simultaneously considering the distance to the ideal solution and negative-ideal solution, regarding each alternative, and selecting the closest relative to the ideal solution as the best alternative. If each attribute has a monotone increasing (or decreasing) function, the ideal solution, which is composed of the best attribute values, and the negative ideal solution.

3. NCMPs Selection, Classification and its Types

Ability to machine advanced materials and fulfill the requirements of high dimensional accuracy and surface finish, made NCMPs one of the most used machining processes in today's industry. Quality performances are very important aspect for NCMPs because it helps to achieve proper tolerance and the required quality of cut, thus eliminating the need for post-processing. These are dependable not only on the machining process itself, but also on the machine tool and its control capabilities, thickness and type of material being cut and also the machining process parameter settings. Process performances are also important aspect while selecting the most suitable NCMP. It can be considered by taking into account either individually or collectively several indicators such as the specific cutting energy, cutting speed, specific cutting power and the like. Among these, cutting speed is one of the most important factors, and at the same time represents one of the major techno-economic performances of NCMPs

The NCMPs can be classified into three major categories based on different forms of energy viz (i) Mechanical: The mechanism utilizes high velocity particles or liquids as the transfer media for material removal from the work piece by erosion. Hydraulic pressure acts as a source of energy in these processes. Ultrasonic machining (USM), abrasive flow machining (AFM), magnetic abrasive finishing (MAF), abrasive jet machining (AJM),water jet machining (WJM), and abrasive water jet machining (AWJM) are some of the examples in this category.

(ii) Chemical or Electro-Chemical process: In chemical machining (CHM) process, material is removed through chemical dissolution of the work piece, which is in Contac with a chemically active reagent while in electrochemical process; it is through ion displacement mechanism, which requires high current as the source of energy and electrolyte as the transfer medium. Additionally, two or more than two forms of energy are combined together to develop hybrid NTM processes in order to enhance the machining capabilities of individual processes. Those processes include electrochemical machining (ECM), electrochemical grinding (ECG) and electrochemical honing (ECH).

(iii) Thermal or Electro thermal process wherein the fusion or vaporization of the small areas at the surface of the work piece removes the material. The source of energy utilized can be high voltage, amplified light or ionized material. Thermo-electrical processes include electrical discharge machining (EDM), wire EDM (WEDM), laser beam machining (LBM), electron beam machining (EBM), plasma arc machining (PAM), etc. EDM and WEDM processes require dielectric medium for transfer of energy. Some of the variants of these NTM processes are micro-EDM, computer numerical control (CNC) EDM, die-sinking EDM, rotary EDM, dry EDM, CNC WEDM and micro-WEDM. EBM process does not require any medium for energy transfer.

3.2 Formulation of the NCPM Selection Model

The present work is based on the evaluation of six NCMPs i.e., AFM (MP1), AJM (MP2), EBM (MP3), EDM (MP4), USM (MP5), and WJM (MP6) with execution standards that are tolerance and surface finish (C1), power prerequisite (C2), material removal rate (C3), cost (C4), productivity (C5), tooling and installations (C6), instrument utilization (C7), security (C8), work material (C9), and shape highlight (C10). Among these ascribes, C1 (mm), C2 (kW), and C3 (mm^3/min) are quantitative, having outright mathematical qualities, though C4, C5, C6, C7, C8, C9, and C10 have subjective measures for which a positioned esteem judgment on a size of 1–5 (1 is most minimal, 3 is moderate, and 5 is the most elevated) is recommended. C3, C5, C8, C9, and C10 are useful credits where high qualities are wanted; then again, C1, C2, C4, C6, and C7 are non-helpful ascribes for which low qualities are liked. The information for rules C1, C2, and C3 are basic, while the information for different standards like C4, C5, and so forth may change after some time, so the relatedness is guaranteed to utilize a five-point scale.

4. Methodology Adopted

Multiple criteria decision-making (MCDM) is considered as a complex decision-making (DM) tool involving both quantitative and qualitative factors. In recent years, several MCDM techniques and approaches have been suggested to choosing the optimal probable options. The purpose of this article is to systematically review the applications and methodologies of the MCDM techniques and approaches.

4.1 Analytic Hierarchy Process (AHP) Method

The AHP method was developed by Thomas L. Saaty [4-5-6], a mathematician. This method is a framework for effective decision-making on complex issues by simplifying and speeding up the decision-making process by solving the problem into its parts, arranging these parts or variables in a hierarchical order, assigning numerical values to subjective considerations about the importance of each variable and synthesize these various considerations to determine which variable has the highest priority and act to influence the outcome of the situation [7]. This AHP method helps solve complex problems by structuring a hierarchy of criteria, stakeholders of results, and by drawing various considerations to develop weight or priorities [8]. This method also combines the strengths of the feelings and logic concerned on various issues, and then synthesizes various considerations into the results that match our estimates intuitively as presented in the consideration already made [8-9]. In present work, we have used the following steps of AHP to help us to measure the relative importance or the weighted values of several criteria. [4] Then the importance of the second factor concerning the first is reciprocal. Ratio scale and the use of verbal comparisons are used for weighting of quantifiable and non-quantifiable elements.

Table 1. The fundamental scale

Intensity of Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation

2, 4, 6 and 8 can be used to express the intermediate value.
Reciprocals If activity *i* has one of the above numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i.*

<u>The steps to follow in using the:</u>
Step 1: Define the problem and determine the objective.
Step 2: Structure the hierarchy from the top through the intermediate levels to the lowest level.
Step 3: Construct a set of pair-wise comparison matrices for each of the lower levels. The numerical value for the element depends on Saaty Nine Point Scale shown in Table 1. There is n (n-1) / 2 judgments required to develop the set of matrices.
Step4: Having done all the pair-wise comparisons and entered the data, the consistency is determined using the Eigen value.
Step 5: To do so, normalize the column of numbers by dividing each entry by the sum of all entries. Then sum each row of the normalized values and take the average. This provides Principal Vector [PV].
Step 6: Find the consistency Index, CI, as follows:

$$CI = (\lambda_{max} - n)/(n-1)$$

Where n is the matrix size

Table 2. Random Index Table

N	1	2	3	4	5	6	7	8	9	10
RCI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

Judgment consistency can be checked by taking the consistency ratio (CR) of CI with the appropriate value in Table 2. The CR is acceptable, if it does not exceed 0.10. If it is more, the judgment matrix is inconsistent. To obtain a consistent matrix, judgments should be reviewed and improved.

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

A Multi-Criteria Decision Making (MCDM) technique helps the decision makers (DMs) to evaluate the best alternatives. TOPSIS method is a most common technique of multi-Attribution Decision Making (MADM) models. "Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)" is a method of multi-criteria decision analysis and this method was introduced by Hwang and Yoon in 1981. TOPSIS logic is rational and understandable. It chooses the alternative which has the shortest geometric distance from the positive ideal solution and compares a set of alternatives by identifying weights for each criterion, normalizes the scores for each criterion and calculates the geometric distance between each alternative and the ideal alternative in order to give the best score for each criterion. TOPSIS method helps to choose the right suppliers with a various finite number of criteria.

Step 1: The structure of matrix

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

Step 2: Calculate the Normalized the matrix D 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

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

Step 7: Calculate the total score and select the alternative closest to 1.

5. Problem Statement

To verify the integrated MCDM method for selection of most suitable NCMP for machining operation. This problem considers six non-conventional machining process are AFM (MP1), AJM (MP2), EBM (MP3), EDM (MP4), USM (MP5), and WJM (MP6) with execution standards that are tolerance and surface finish (C1), power prerequisite (C2), material removal rate (C3), cost (C4), productivity (C5), tooling and installations (C6), instrument utilization (C7), security (C8), work material (C9), and shape highlight (C10). Among these ascribes, C1 (mm), C2 (kW), and C3 (mm^3/min) are quantitative, having outright mathematical qualities, though C4, C5, C6, C7, C8, C9, and C10 have subjective measures for which a positioned esteem judgment on a size of 1–5 (1 is most minimal, 3 is moderate, and 5 is the most elevated) is recommended. C3, C5, C8, C9, and C10 are useful credits where high qualities are wanted; then again, C1, C2, C4, C6, and C7 are non-helpful ascribes for which low qualities are liked. The information for rules C1, C2, and C3 are basic, while the information for different standards like C4, C5, and so forth may change after some time, so the relatedness is guaranteed to utilize a five-point scale.

Table 3. Initial Decision Matrix

	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 4. Initial 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	1/5	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	1/2	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	1

Table 5. Normalization of Pairwise Comparison Matrix & 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	0.10	0.09	0.57	0.0573
C2	0.09	0.06	0.08	0.07	0.04	0.04	0.05	0.07	0.10	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	0.30	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	0.10	0.11	0.15	0.15	1.53	0.1531
C7	0.22	0.24	0.20	0.21	0.26	0.26	0.21	0.17	0.17	0.18	2.12	0.2116
C8	0.27	0.30	0.22	0.25	0.35	0.39	0.42	0.34	0.17	0.20	2.90	0.2900
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	0.20	0.0201

Table 6. Consistency Check of Criteria Weight

M1										M2	M3	M4	λ_{max}	CI	CR	
1	1	3	2	0	0	0	0	5	4	0.06	0.6	10.3	10.5	0.06	0.04	< 0.1
2	1	3	2	1	0	0	0	5	4	0.07	0.7	10.6				
0	0	1	1	0	0	0	0	2	3	0.03	0.3	10.1				
1	1	2	1	0	0	0	0	4	3	0.04	0.4	10.2				
3	2	5	4	1	1	0	0	7	6	0.11	1.2	10.8				
4	3	6	5	2	1	1	0	8	7	0.15	1.7	10.9				
5	4	7	6	3	2	1	1	9	8	0.21	2.3	11				
6	5	8	7	4	3	2	1	9	9	0.29	3.2	10.9				
0	0	1	0	0	0	0	0	1	1	0.02	0.2	10.3				
0	0	0	0	0	0	0	0	2	1	0.02	0.2	10.1				

Table 7. Normalized Matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
MP1	0.404	0.021	0.961	0.177	0.468	0.333	0.324	0.442	0.39	0.408
MP2	0.404	0.021	0	0.177	0.375	0.333	0.324	0.442	0.39	0.408

MP3	0.404	0.019	0	0.707	0.468	0.333	0.162	0.442	0.39	0.408
MP4	0.566	0.26	0.233	0.53	0.375	0.667	0.649	0.442	0.488	0.408
MP5	0.162	0.965	0.146	0.354	0.375	0.333	0.487	0.147	0.39	0.408
MP6	0.404	0.021	0	0.177	0.375	0.333	0.324	0.442	0.39	0.408
Weightage	0.057	0.069	0.029	0.041	0.11	0.153	0.211	0.290	0.016	0.020

Table 8. Weighted Normalized Matrix & Positive and Negative Ideal Solution

	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
A^+	0.009	0.001	0.028	0.007	0.052	0.051	0.034	0.043	0.008	0.008
A^-	0.032	0.067	0	0.029	0.041	0.102	0.137	0.128	0.006	0.008

Table 9. Performance Indexes

	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	0.0500	0.2514	6
MP5	0.0989	0.1089	0.5242	5
MP6	0.098	0.1104	0.5297	3

6. Results

In this present work, a MCDM model for the selection of the most appropriate NCMP considering different criteria, particularly related to quality performance, has been defined and solved by using integration of AHP and TOPSIS methods. The obtained results suggested that EBM is the best alternative, while AFM is the second one. AJM and WJM were the third and fourth alternatives in the rank. The key benefit of the TOPSIS approach is that it can account for a wide variety of quantitative and qualitative parameters while retaining a basic computational process. Furthermore, since the TOPSIS approach is easy to implement, it does not necessitate a strong background in mathematics and operational science, as well as the use of advanced software packages. In view of the outcomes, no doubt, it tends to be presumed that EBM cycle is the most ideal decision. Essentially, it tends to be asserted that the most exceedingly awful decision is EDM. Nonetheless, considering the way that positions of AFM choices are quite beautiful, which is on the second positioned position.

7. Discussion

A consolidated TOPSIS-AHP-technique is utilized to choose proper NCMP measure among different NCMP measure for a specific shape highlight on a given work material. This MCDM approach perceives distinctive NCMP measure determination ascribes and their interrelations for a given NCMP measure choice issue. This strategy can all the while take various quantitative and subjective NCMP measure determination ascribes. This consolidate technique verbalizes the data about the condition under which a particular NCMP measure isn't satisfactory for a predetermined machining application. The principle benefit of this master framework is that it doesn't need any inside and out mechanical information in regards to the appropriateness of the NCMP measures. The odds of mistake in this technique are less and can be applied to the ongoing MCDM, issue.

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