MULTI - DIMENSIONAL CRITERIA AIDED SELECTION OF MACHINING PROCESSES

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Abstract This paper deals with the selection of machining processes based on multi-dimensional criteria where the attributes of the processes are conflicting in nature and have incommensurable units. The system considers twelve conventional and non-traditional machining processes and six conflicting criteria. "Technique for Order Preference by Similarity to Ideal Solution" (TOPSIS), developed by Hwang and Yoon in 1980, has been applied for the evaluation of ranking of machining processes. The methodology has been adopted to enable a user to first narrow down the list of various machining processes available to a shortlisted acceptable alternatives in the presence of multiple, conflicting-in-nature, criteria. A method has been devised to tradeoff among the alternatives to make it possible to rank them according to their suitability for the desired application. This process selection procedure allows rapid convergence from a very large number to a manageable shortlist of potentially suitable processes using an "elimination search" routine. The methodology presented in this article may provide a strong decision support to machining process selection. The selection process gives a clear indication about the appropriate application of TOPSIS for potential uses in machining process selection.

Keywords: Machining process selection, MCDM, TOPSIS, Decision-making.

NOMENCLATURE

D: Decision matrix comprising of 'm' alternatives and 'n' attributes,
m: Number of alternatives of 'D'matrix,
n: Number of attributes of 'D' matrix,
$D^/$: Pair-wise comparison matrix,
W: Weight matrix,
$w_1, w_2, \ldots\ldots\ldots, w_n$: Elements of 'W' matrix,
α: Maximum eigen-value of 'W' matrix,
I: Incidence matrix
R: Normalized decision matrix,
r (i, j): An 'i th row, 'j' th column element of 'R' matrix,
a (i, j): An 'i th row, 'j' th column element of 'D' matrix,
V: Weighted normalized matrix,
v (i, j): An 'i th row, 'j' th column element of 'V' matrix,
A_i^*: Ideal solution for 'i' th alternative, V_i^*: An 'i' th element of A^*,
V_i^-: An 'i' th element of A^-,
A_i^-: Negative-ideal solution for 'i' th alternative,
S_i^*: Separation measure of 'i' th alternative from ideal solution,
S_i^-: Separation measure of 'i' th alternative from negative-ideal solution,
C_i^*: Relative closeness to ideal solution for 'i' th alternative,
λ_{max}: Principal eigen-value of $D^/$ matrix,
I.I.: Inconsistency Index of $D^/$ matrix,
R.I.: Random consistency Index of $D^/$ matrix,
I.R.: Inconsistency Ratio of $D^/$ matrix.

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INTRODUCTION

Need for Machining Process Selection

All machining processes have two purposes, one is to change the form of raw materials and the other is to produce required surface finish. These basic two purposes are achieved by controlling some factors. They are – the shape of surface, the shape of cutter or tool, the nature of relative movement between the tool and workpiece, the type of surface finish, etc.

The selection of machining processes primarily depends on shape and size of the working material, material of the part to be produced, the machining accuracy and surface finish required, the lot size, quality of the manufactured part, and besides all these criteria, personal preferences. The cost of production is a vital issue in selecting a particular machining process.

In the traditional machining process selection problem, a limited number of potentially suitable processes are first narrowed down from a list of all machining processes depending upon the suitability of operation for a particular job. This is done as some machining processes will obviously be unsuitable because of their capacity, power, strength, rigidity, performance characteristics etc. do not conform to the requirement for performing the operation for a particular part. Among all the suitable processes, a particular process is then selected depending upon its cost effectiveness.

In the event of today's global competition, the process selection has an important role in minimizing cost of production process without sacrificing the product quality. A technique called "Technique for Order Preference by Similarity to Ideal Solution" (TOPSIS) [C.L.Hwang and K. Yoon], may be adopted to choose the solution from the set of alternative machining processes in conflicting criteria environment. TOPSIS tradeoffs among the alternatives to make it possible to rank the most suitable machining processes. This technique allows rapid convergence from a very large number to a manageable shortlist of potentially suitable welding processes.

Many researchers proposed numerous methods for selection of machining processes. Sen, G.C. and Bhattacharyya, A. proposed the traditional machining process selection through cost analysis. They considered the size of the workpiece and capacity of the machine tool, strength and rigidity of the machine tool, power required for the machining operation, accuracy and surface finish desired, availability of machine tool for the selected process, etc.

MULTI-DIMENSIONAL CRITERIA AIDED SELECTION PROCESS

A selection problem is considered as an MCDM problem if there appears at least two conflicting criteria and if there are at least two alternative solutions to the problem. There are two conditions of MCDM approach. One condition is the presence of more than one criterion. The other condition is that the criteria must be conflicting by nature. Table 1 (a) and 1 (b) clearly show the nature of conflicting and non-conflicting criteria respectively.

Table-1 (a): Nature of conflicting criteria

	X_1	X_2
A_1	170	345
A_2	425	250

Table-1 (b): Nature of non-conflicting criteria

	X_1	X_2
A_1	170	345
A_2	425	510

The problems of MCDM are widely diverse. Even with the diversity, the problems share some common characteristics, viz., presence of multiple objectives / attributes (at least two), presence of conflict among criteria, presence of incommensurable units. The goal to MCDM problems is either to design the best alternative or to select the best one among the previously specified finite alternatives.

The MCDM philosophy is broadly classified into two categories – Multiple Attribute Decision-Making (MADM) and Multiple Objective Decision-Making (MODM). MADM uses finite number of discrete alternatives.

The Multi Attribute Decision Making method should have a set of quantifiable objectives, should possess a set of well-defined constraints, and should have a process to obtain some tradeoff information between the stated and unstated objectives.

The methodology – TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) -- is an MADM process.

An MADM problem is expressed in matrix form (D) of size m x n. The element v (i, j) of the 'D' matrix indicates the value of alternative 'i' for the attribute 'j'. The structure of a 'D' matrix is shown in Fig. 1.

Attributes

Alternatives	X_1	X_2	X_3	………	X_n
A_1	v_{11}	v_{12}	v_{13}	……….	v_{1n}
A_2	v_{21}	v_{22}	v_{23}	………..	v_{2n}
A_3	v_{31}	v_{32}	v_{33}	………...	v_{3n}
.	.	.	.	……….	.
.	.	.	.	……….	.
A_m	v_{m1}	v_{m2}	v_{m3}	……….	v_{mn}

Fig.1 Structure of 'D' matrix

Table-2: The nine-point scale of pair-wise comparison

Intensity of relative importance	Definition
1	Equally important
3	Moderately preferred
5	Essentially preferred
7	Very strongly preferred
9	Extremely preferred
2, 4, 6, 8	Intermediate importance between two adjacent judgements

TOPSIS MODEL

TOPSIS – Technique for Order Preference by Similarity to Ideal Solution – developed by C.L. Hwang and K. Yoon, is a method for cardinal preference to attributes. Ching-Lai Hwang and Kwangsun Yoon developed this technique based upon the concept that the chosen alternative should have the shortest Euclidean distance from the ideal solution and the farthest from the negative-ideal solution.

Assume that each attribute takes the monotonically increasing (or decreasing) utility, then it is easy to locate the "ideal" solution which is composed of all best attribute values attainable, and the "negative-ideal" solution composed of all worst attribute values attainable.

The approach is to take an alternative that has the (weighted) minimum Euclidean distance to the ideal solution in a geometric sense.

TOPSIS considers the distances to both the ideal and the negative-ideal solutions simultaneously by taking the "Relative Closeness" to the ideal solution.

ALGORITHM FOR TOPSIS METHODOLOGY

Fig. 2 shows the procedures to be followed in selecting a particular plant. The decision matrix 'D' is of m x n. The matrix $D^{/}$ compares the attributes. Hence, there must be a relative scale of importance for pair-wise comparison. Saaty, T.L. (1980) introduced a nine-point scale of relative importance for pair-wise comparisons (Table 2).

Using this scale the $D^{/}$ matrix may be formed. The values assigned to each element of $D^{/}$ matrix are the choice of decision-maker. There must be a "check" regarding the level of inconsistency of the decision-maker [Saaty, T.L.]. The level of inconsistency may be checked by evaluating λ_{max} and subsequent calculation of I.I. and I.R. These can be found from equations 3, 4 and 5. By eigen-vector method,

$D^{/}. W = \alpha. W.$

Therefore, $(D^{/} - \alpha. I). W = 0$ (1)

and for non-trivial solution,

$\det (D^{/} - \alpha. I) .W = 0$ (2)

The value of 'α' found from equation 2 is used in equation 1 to get the matrix 'W'.

$I.I. = (\lambda_{max} - n) / (n - 1)$ (3)

$R.I. = [1.98 \times (n - 2)] / n$ (4)

$I.R. = I.I. / R.I.$ (5)

The acceptable value of I.R. lies within 10%. For I.R. more that 10%, the judgmental values given to each element of $D^{/}$ matrix are to be changed and then equations 3,4 and 5 are to be followed to recheck the new values. Level of consistency in the $D^{/}$ matrix implies that the decision exhibits a coherent judgement in specifying the pair-wise comparison of the attributes.

The elements of normalized D matrix are easily found from equation 6.

$$r (i, j) = a (i, j) / (\Sigma (a (i, j))^2)^{1 / 2} \quad (6)$$

Each element of the weighted normalized matrix is calculated from equation 7.

$$v(i, j) = w_j \times r (i, j) \quad (7)$$

Now, the domain of solution has to be fixed. To fix the domain, ideal and negative-ideal solutions are to be calculated. The ideal solution is composed of all best attribute values attainable, whereas the negative-ideal solution is composed of all worst attribute values attainable. The calculation follows equations 8 and 9 respectively.

$$A_i^* = \{[\max_{j=1;i=1,\dots,m} v(i,j)], [\max_{j=1;i=1,\dots m} v(i,j)], \dots, [\max_{j=n;i=1,\dots,m} v(i,j)]\}$$

$$= \{ V^*_1 , V^*_2 , \dots, V^*_n \} \quad (8)$$

$$A_i^- = \{[\min_{j=1;i=1,\dots,m} v(i,j)], [\min_{j=1;i=1,\dots m} v(i,j)], \dots, [\min_{j=n;i=1,\dots,m} v(i,j)]\}$$

$$= \{ V^-_1 , V^-_2 , \dots, V^-_n \} \quad (9)$$

TOPSIS considers the distances of each alternative from both the ideal and negative-ideal solutions. These distances are calculated from equations 10 and 11.

$$S_i^* = [\sum_{j=1}^{n} (v (i, j) - V_1^*)^2]^{1 / 2} \quad (10)$$

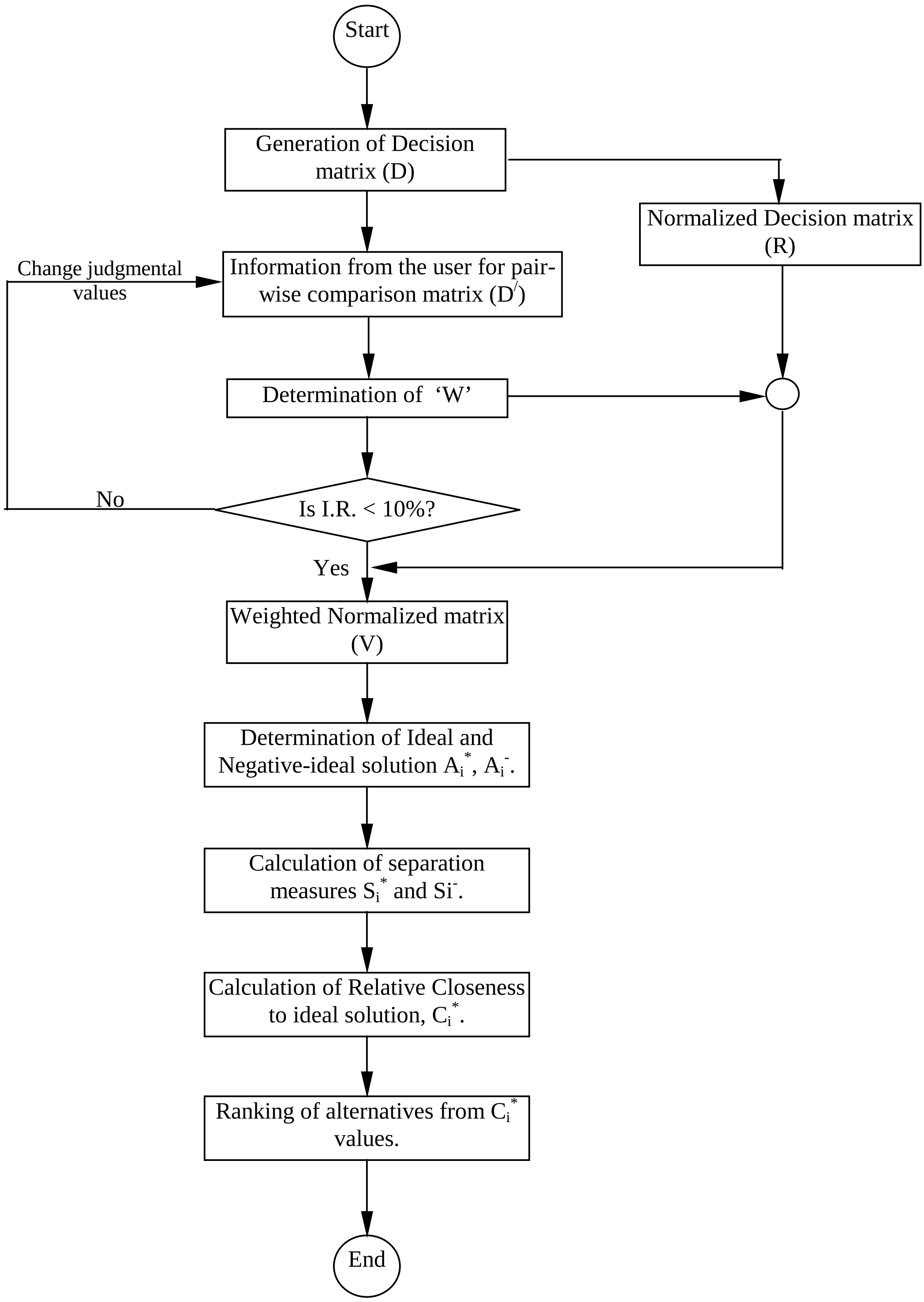


Fig. 2 The TOPSIS algorithm

$$S_i^- = [\sum_{j=1}^{n} (v(i,j) - V_1^-)^2]^{1/2} \qquad (11)$$

The relative separation measures (equation 12) are then calculated to find the level of importance of each alternative.

$$C_i^* = S_i^- / (S_i^* + S_i^-) \qquad (12)$$

The merit of importance of the alternatives is based on the descending values of C_i^*.

MACHINING PROCESS SELECTION PROBLEM

Twelve different conventional and non-conventional machining processes are chosen for the example problem. The different alternatives are designated as

MP_1, MP_2, MP_3, MP_4, ..., MP_{12}. Six attributes are considered for each machining process. The attributes are as follows:

X_1: Geometry of the feature,

X_2: The dimensions of the said geometry,

X_3: Mechanical properties of workpiece,

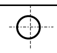
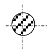
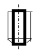
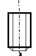
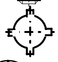
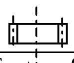
X_4: Dimensional tolerances,

X_5: Surface finish,

X_6: The effects of a machining process on the surface integrity of the workpiece.

Geometry of the feature is an important factor. Various types of geometry can be manufactured with these twelve machining processes. A code of some basic geometry patterns is thus suggested in Table 3.

Table-3: Code of some basic geometry patterns

Geometry Pattern	Symbols	Codes
Circular hole		1
Square hole		2
External diameter of solid		3
Internal thread		4
External thread		5
External spline		6
Internal spline		7
Profile (convex / concave)		8
Barrel		9
Gear		10

Some of the effects of machining processes on the surface integrity of the workpiece are shown in Table 4. Codes, ranging from Arabic numerals 1 to 6, are suggested for this problem. The decision matrix 'D' and the pair-wise comparison matrix 'D$^{/}$' are shown in Table 6 and Table 7 respectively.

Table-4: Points to be given on the effects of machining processes on the surface integrity of the workpiece

Effects on workpiece material	Points
Stress developed (Thermal, Fatigue, etc.)	1
Surface cracks	2
Undulated surfaces due to excessive heat generation	3
Internal cracks	4
Undesirable changes in the microstructure of material	5
Changes in shape / size due to excessive heat generation during machining operation	6

Table-5: Factors influencing the machining process selection problem

Attributes	Factors	Unit of Factors	Range of Attribute values
X_1	Geometry	---	1 – 10
X_2	Dimensions	mm	2 – 20
X_3	Mechanical Properties of W/P	BHN	180 – 230
X_4	Tolerances	μm	0.05 – 20
X_5	Surface Finish	μm	0.02 – 10
X_6	Effects on surface integrity	---	1 – 6

Table-6: The Decision Matrix, D

	X_1	X_2	X_3	X_4	X_5	X_6
MP_{01}	3	18	200	0.05	4.00	6
MP_{02}	10	15	180	0.07	0.08	1
MP_{03}	5	18	190	1.00	1.00	3
MP_{04}	1	20	185	10.0	0.07	3
MP_{05}	7	14	230	8.00	6.00	5
MP_{06}	9	12	195	15.0	0.09	2
MP_{07}	4	16	190	12.0	0.06	1
MP_{08}	2	18	205	15.0	2.00	1
MP_{09}	8	15	220	0.09	8.00	6
MP_{10}	6	18	230	10.0	0.02	4
MP_{11}	3	20	200	15.0	7.00	1
MP_{12}	1	12	210	20.0	10.0	2

Table-7: The Pair-wise comparison Matrix, D$^{/}$

	X_1	X_2	X_3	X_4	X_5	X_6
X_1	1.00	1.00	0.43	0.67	0.43	0.40
X_2	1.00	1.00	0.43	0.67	0.43	1.50
X_3	2.33	2.33	1.00	1.50	2.33	1.00
X_4	1.50	1.50	0.67	1.00	0.67	2.00
X_5	2.33	0.43	0.67	1.50	1.00	0.67
X_6	2.50	0.67	1.00	0.50	1.50	1.00

RESULTS AND DISCUSSION

An interactive computer code has been generated in C language that runs on a PC under the Microsoft disc operating system using a Turbo C Compiler to enable the user to select the welding process to fit best for the user for the particular application that the user wants.

Finally, the machining processes are ranked in descending order of C^*_i values (Table 8).

Table-8: TOPSIS ranking

Ranking	Machining Processes	C^*_i values
1	MP_{12}	0.642
2	MP_{05}	0.567
3	MP_{11}	0.529
4	MP_{09}	0.528
5	MP_{06}	0.423
6	MP_{01}	0.414
7	MP_{08}	0.399
8	MP_{10}	0.396
9	MP_{04}	0.322
10	MP_{07}	0.319
11	MP_{02}	0.229
12	MP_{03}	0.224

The solution through TOPSIS gives a solution that is not only closest to the hypothetically best (i.e., ideal solution) but which is also the farthest from the hypothetically worst (i.e., negative-ideal solution). In other terms, consideration the separation measure values the chosen alternative has the shortest Euclidean distance from the ideal solution and the farthest from that of the negative-ideal solution.

FUTURE POSSIBILITIES

The TOPSIS methodology combines two types of information from decision-maker (DM). 'D' matrix comprises of the values full of certainty, whereas '$D^/$' matrix comprises of judgmental values dependent on DM's choice. The values of '$D^/$' matrix are highly uncertain and may be under risk as it involves a huge amount of capital investment. TOPSIS may become more practicable if the level of uncertainty in pair-wise comparison matrix is considered. The uncertainty in '$D^/$' matrix may be approximated by introducing maximin and simple additive weighting method using membership function of the fuzzy set theory.

CONCLUSION

Selection of a particular machining process is an important task when the attributes of the processes are conflicting in nature and they have incommensurable units. TOPSIS makes it possible in selecting the machining process to fit best for the user for a particular application. The methodology presented in this paper may provide a strong decision support to the manufacturing engineers. Utility of this type of decision support lies in providing information articulation, practicability and immense value in managerial understanding. The TOPSIS methodology has some advantages. They are – easy accessibility, easy communicability and user interface.

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