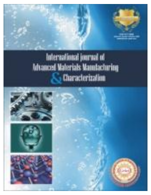

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Machinability Index Evaluation using AHP and PROMTHEE Method

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A B S T R A C T

The manufacturing sector frequently face the problem of assessing a wide range of alternative options, and selecting one based on a set of conflicting criteria.This paper presents a methodology to evaluate the machinability of work materials for a given machining operation using Preference Ranking Organisation Method for Enrichment Evaluations (PROMETHEE).The method is improved in the present work by integrating with analytic hierarchy process AHP. A universal machinability index is proposed that evaluates and ranks work materials for a given machining operation. The index is obtained from a universal machinability junction, obtained from the universal machinability attributes. The procedure is illustrated by means of an example.

Introduction

In general, the process of manufacturing a product consists of several phases such as product design, process planning, machining operations and quality control. The study of machinability can be related especially to process planning and machining operations. The machinability aspect is of considerable importance for production engineers to know in advance the machinability of a work material so that the processing can be planned in an efficient manner. In the process of product design, material selection is important for realizing the design objective and for reducing the production costs. The machinability of engineering materials, owing to its marked influence on production costs, has to be taken into account in the product design; although it will not always be a criterion considered top priority in the process of materials selection.

Machinability is influenced by a number of variables, such as the inherent properties or characteristics of the work materials, cutting tool material, tool geometry, the nature of tool engagement with the work, cutting conditions, type of cutting, cutting fluid, and machine tool rigidity and its capacity [1–4]. These variables are the machining process input variables and independent of the machining process. On the other hand, the machining process output is marked by dependent process variables, such as tool life, cutting forces, specific power consumption, processed surface finish, dimensional accuracy, temperature generated, noise, vibration, and chip characteristics. The dependent process variables are the functions of process input variables and refer to the performance of work material during machining operation in terms of technical and economic consequences, and are directly related to machining operations, and hence to machinability. Thus, these are considered as the pertinent variables to represent the machinability of a given work material for a given machining operation.

In manufacturing industries some manufacturers consider tool life as the most important criterion to evaluate the machinability, while others consider processed surface finish as the dominant factor. Some researchers have evaluated the machinability of different work materials, considering any one of the machining process output variable only [5–13]. Depending on the techno-economic needs of a process, a variable may have a primary or secondary role in the machinability evaluation. However, a realistic estimation of the machinability can be carried out only by considering all the pertinent machining process output variables and their interrelations.

The selection procedures suggested by other researchers [14–17] have considered a number of machining process output variables, with these variables being examined with respect to the work material properties and characteristics. Work materials have been evaluated in terms of their performance with respect to each machining process output variable separately. Then, the final decision regarding selection of

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work material is made in a subjective manner, in light of the overall performance.

Even though a good amount of research work was carried out in the past on machinability, there is a need for a simple, systematic and logical scientific method or mathematical tool to guide user organizations in taking a proper machinability selection decision. The objective of a machinability selection procedure is to identify the machinability selection attributes and obtain the most appropriate combination of machinability selection attributes in conjunction with the real requirement. Thus, efforts need to be extended to determine attributes that influence machinability selection, using a simple logical approach, to eliminate unsuitable machinability to strengthen the existing machinability selection procedure. This is considered in this paper using an analytic hierarchy process method.

Promethee methodology

The PROMETHEE method was introduced by Brans et al. (1984) and belongs to the category of outranking methods. Like all outranking methods, PROMETHEE proceeds to a pairwise comparison of alternatives in each single criterion in order to determine partial binary relations denoting the strength of preference of an alternative $a1$ over alternative $a2$. In the evaluation table, the alternatives are evaluated on different criteria. The implementation of PROMETHEE requires additional types of information,namely information on the relative importance or the weights of the criteria considered and information on the decision maker preference function, when comparing the contribution of the alternatives in terms of each separate criterion. It may be added here that the original PROMETHEE method can effectively deal mainly with quantitative criteria.

The analytic hierarchy process (AHP) is a powerful and flexible decision making process to help people set priorities and make the best decision when both tangible and non tangible aspects of a decision need to be considered. By reducing complex decisions to a series of one-on-one comparisons, then synthesizing the results, AHP not only helps decision makers arrive at the best decision, but also provides a clear rationale that it is the best. The combined PROMTHEE and AHP procedure helps to evaluate and rank any given set of machinability alternatives in a more comprehensive way rather than when applying individual methods.

The Methodology

The Methodology presented in this paper for decision making in machinability using improved PROMETHEE method is described below:

Step1:
Identify the selection criteria for the considered decision making problem and short-list the alternatives on the basis of the identified criteria satisfying the requirements.

Step 2:
(1) After short-listing the alternatives, prepare a decision table including the measures or values of all criteria for the short-listed alternatives.
(2) The weights of relative importance of the criteria may be assigned using analytic hierarchy process (AHP) method [18,19]. The steps are explained below .

Find out the relative importance of different criteria with respect to the objective. To do so, one has to construct a pair-wise comparison matrix using a scale of relative importance. The judgments are entered using the fundamental scale of the AHP. A criterion compared with it is always assigned the value 1 so the main diagonal entries of the pair-wise comparison matrix are all 1. The numbers 3, 5, 7, and 9 correspond to the verbal judgments 'moderate importance', 'strong importance', 'very strong importance', and 'absolute importance' (with 2, 4, 6, and 8 for compromise between the previous values).

a. Find the relative normalised weight (Wi) of each criterion by (i) calculating the geometric mean of ith row and (ii) normalising the geometric. This can be represented as

$$GM_i = \left\{ \prod_{j=1}^{N} a_{ij} \right\}^{1/N} \qquad (1)$$

and

$$W_j = GM_i \Big/ \sum_{i=1}^{N} GM_i \qquad (2)$$

The geometric mean method of AHP is used in the present work to find out the relative normalized weights of the attributes because of its simplicity and easiness to find out the maximum Eigen value and to reduce the inconsistency in judgments.
b. Calculate matrix A3 and A4 such that A3=A1×A2 and A4=A3 / A2, where A2=[W1, W2, ..., WN]^T.
c. Find out the maximum Eigen value λmax that is the average of matrix A4.
d. Calculate the consistency index CI=(λmax − N) /(N − 1). The smaller the value of CI, the smaller is the deviation from the consistency.
e. Obtain the random index (RI) for the number of attributes used in decision making.
f.Calculate the consistency ratio CR=CI/RI.Usually, a CR of 0.1 or less is considered as acceptable and it reflects an informed judgment that could be attributed to the knowledge of the analyst about the problem under study.

Step:3
The next step is to have the information on the decision maker preference function, when comparing the contribution of the alternatives in terms of each separate criterion. The preference function (Pi) translates the difference between the evaluations obtained by two alternatives ($a1$and $a2$) in terms of a particular criterion, into a preference degree ranging from 0 to1.Let $Pia1a2$ be the preference function associated to the criterion ci.

$$Pia1a2 = G_i[c_i(a1) - c_i(a2)] \qquad (3)$$

$$0 \leq P_{i,a1a2} \leq 1 \qquad (4)$$

Where Gi is a non-decreasing function of the observed deviation (d) between two alternatives$a1$ and $a2$over the criterion c_i
Let the decision maker have specified a preference function Pi and weight wi for each criterion c_i(i=1, 2, . . . , M) of the problem. The multiple criteria preference index $\prod a1a2$ is then defined as the weighted average of the preference functions Pi:

$$\prod_{a1a2} = \sum_{i=1}^{M} w_{iP_{ia1a2}} \quad (5)$$

$\prod a1a2$represents the intensity of preference of the decision maker of alternative a1 over alternative a2, when considering simultaneously all the criteria. Its value ranges from 0 to 1. This preference index determines a valued outranking relation on the set of actions.

For PROMETHEE outranking relations the leaving flow, entering flow and the net flow for an alternative a belonging to a set of alternatives A are defined by the following equations:

$$\varphi^{+}(a) = \sum_{x \in A} \prod xa \quad (6)$$

$$\varphi^{-}(a) = \sum_{x \in A} \prod ax \quad (7)$$

$$\varphi(a) = \varphi^{+}(a) - \varphi^{-}(a) \quad (8)$$

$\varphi^{+}(a)$is called the leaving flow,$\varphi^{-}(a)$ is called the entering flow and $\varphi(a)$ is called the net flow.$\varphi^{+}(a)$is the measure of the outranking character of 'a' and $\varphi^{-}(a)$ gives the outranked character of 'a'. The net flow,$\varphi(a)$ represents a value function, whereby a higher value reflects a higher attractiveness of alternative 'a'.The net flow values are used to indicate the outranking relationship between the alternatives. For example, for each alternative a, belonging to the set A of alternatives,$\prod a1a2$ is an overall preference index of $a1$over $a2$, taking into account all the criteria$\varphi^{+}(a)$ and $\varphi^{-}(a)$. Alternative $a1$ outranks $a2$ if $\varphi^{+}(a) > \varphi^{-}(a)$and $a1$ is said to be indifferent to $a2$ if$\varphi(a1) = \varphi(a2)$.

The proposed decision making framework using PROMETHEE method provides a complete ranking of the alternatives from the best to the worst one using the net flows.A computer program is developed in the present work in C language that can be used for improved PROMETHEE calculations given in Annexure-I.

Example

Konig and Erinski [17] had used the results of turning data [18] of nonferrous and ferrous alloys machined with HM tools. The results are given in Table 1.

Step 1:The problem considering three criteria and six alternative work material is shown in Table 1. The three criteria used to evaluate the six short-listed alternatives included One hour cutting speed (HC), Specific cutting force (SF) and Cutting power (CP)

Table1:Quantitative data of the machinability attributes

Work material	One hour cutting speed (m/min)	Specific cutting force (N/mm^2)	Cutting power input (KW)
W1	710	400	28
W2	900	415	38
W3	1630	440	59
W4	1720	235	43
W5	120	1150	8
W6	160	1750	19

W1:GK-AlSi10Mg (aluminium-silicon die-cast alloy); W2: GK-AlSi6Cu4 (aluminium-silicon die-cast alloy); W3:GK-AlMg5 (aluminium-magnesium die-cast alloy); W4: GK-MgAl9Zn (magnesium-aluminium die-cast alloy); W5: GG26 (grey cast iron with lamellar graphite); and W6: C35 (low carbon steel).
Cutting conditions: dry, tool material – K10, feed – 0.175 mm/rev, and depth of cut – 2 mm

Step2:The weights of relative importance of the criteria may be assigned using analytic hierarchy process (AHP) method as explained in Section 2. Let the user makes the following assignments:

$$\begin{array}{cc} & Attribute \quad HC \quad SF \quad CP \\ B2 = & \begin{array}{c} HC \\ SF \\ CP \end{array} \begin{bmatrix} 1 & 5 & 5 \\ 1/5 & 1 & 1 \\ 1/5 & 1 & 1 \end{bmatrix} \end{array}$$

Once again, it may be added that, in actual practice, these values of relative importance can be judiciously decided by the experts depending on the requirements. The assigned values in this paper are for demonstration. The normalized weights of each attribute are: WHC =0.714286; WSF = 0.142857, and WCP = 0.142857. The value of λmax is 3.0 and CR = 0.0, and there exists absolute consistency in the judgments made.

Step 3:After calculating the weights of the criteria using AHP method, the next step is to have the information on the decision maker preference function, when comparing the contribution of the alternatives in terms of each separate criterion. Let the decision maker use the preference 'usual function' for all criteria. If two alternatives have a difference d≠0 in criterion c_i, then a preference value ranging between 0 and 1 is assigned to the 'better' alternative cutting fluid whereas the 'worse' alternative cutting fluid receives a value 0. If d = 0, then they are indifferent which results in an assignment of 0 to both alternatives. The pairwise comparison of criterion cutting speed gives the matrix given in Table 2. Cutting speed is a beneficial criterion and higher values are desired.

Table 2. Preference values P resulting from the pairwise comparisons of alternative with respect to criterion cutting speed.

	W1	W2	W3	W4	W5	W6
W1	-	0	0	0	1	1
W2	1	-	0	0	1	1
W3	1	1	-	1	0	0
W4	1	1	1	-	1	1
W5	0	0	0	0	-	0
W6	0	0	0	0	1	-

Table 3. Resulting preference indices as well as leaving, entering and net flow values

Work Material	$\varphi^{+}(a)$	$\varphi^{-}(a)$	$\varphi(a)$	RANK
W1	2.428	2.571	-0.14	4
W2	2.857	2.142	0.714	3
W3	3.142	1.857	1.285	2
W4	4.425	0.571	3.857	1
W5	0.587	4.142	-3.28	6
W6	1.285	3.714	-2.42	5

The leaving flow, entering flow and the net flow values for different alternatives are calculated using Equations (6)–(8) and the resulting preference indices are given in Table 5. The ranking of machinability index is 4-3-2-1-6-5. Based on the net flow values given in Table 5, it is clear that the machinability index designated as 4 is the best choice and 5 is the last choice among the work materials considered. The above results match well with the experimental results and observations presented by Konig and Erinski [17].

Conclusions

A methodology based on a combined PROMTHEE and AHP method is suggested which helps in machinability evaluation of work materials for a given machining operation. Machinability selection index evaluates and ranks materials and this leads to selection of a suitable material for a given engineering application.

The proposed method is a general method and can consider any number of quantitative and qualitative material selection attributes simultaneously and offers a more objective and simple material selection approach. Further, the suggested methodology can be used for any type of selection problem involving any number of selection attributes. The proposed method also helps in selecting the best work–tool combination for a given machining operation.

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