Selection of Lubricant in Machining using Multiple Attribute Decision Making Technique

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The main objective of this work is to select a best suitable lubricant from among a number of lubricants available for machining of alloy steel with tungsten carbide insert tool by using multiple attribute decision making technique. The selection procedure of right lubricant is based on the PROMETHEE method. The manufacturing organization has to select right manufacturing methods, product and process designs, manufacturing technologies, materials, lubricants, machinery and equipment. The selection decisions become more complicated as the decision makers in the manufacturing environment have to choose a best possible option by considering large number of alternatives based on a set of conflicting criteria. To aid these selection processes, various multiple attribute decision making methods are now available. Preference ranking organization method for enrichment evaluation is one of the technique which helps to find out the best solution among available options. The factors affecting the lubricant selection are first identified and that are cutting force during machining, surface roughness, rate of tool wear and temperature at work tool interface. The aim of multiple attribute decision making technique is to combine different measures in to a single lubricant matrix which helps to select best suitable lubricant and rank the lubricants for alloy steel machining operation.

1. Introduction

To meet the needs and challenges, manufacturing industries have to select best suitable manufacturing processes, designs of products, manufacturing tools, work piece and tool materials, machinery and equipment, etc. As many factors affects the process the selection decisions are complicated decision making and even more challenging today (Rao 2007).

In most of the machining processes because of the heat and friction generated there is a chance to damage the cutting tool and surface of the work piece. To overcome the effects of the friction, heat generated and to remove fine metal particles away from the cutting zone normally lubricants or sometimes cutting fluids are used in industries. It is very much important to provide proper lubricant to reduce the friction and to remove the heat generated as fast as possible. It is also important to maintain proper cutting conditions while machining, because it affects the surface quality of the parts. Machining with high cutting velocity, high feed rate and high depth of cut also increases the possibility of large amount of heat generation and high cutting temperature. This heat and temperature will result poor dimensional accuracy and will affect the surface homogeneity by inducing residual stresses and sub surface cracks.

The use of lubricant or cutting fluid during the machining can serve many useful purposes like increase in tool life, improving surface finish, cooling of the cutting tool at higher speeds, easy chip handling and removal etc. On the other side the chemical ingredients of the cutting fluid creates some environmental problems and health problems to the operator. (Byrne and Schlote 1993) And also the cost of providing lubrication covers the major part of total manufacturing cost. (Klocke and Eisenblatter 1997).

It is necessary to find out some alternative solution for this. The alternative can be lubrication using solid lubricant (Reddy and Rao 2006, Deshmukh and Basu 2006) minimum quantity lubrication (Varadrajan *et al.* 2002).

In a manufacturing environment, the decision makers need to select the most suitable AMS while assessing a wide range of alternative options based on a set of conflicting attributes/criteria. To help and guide the decision makers, there is a need for simple, systematic, and logical approaches or mathematical tools that can consider a large number of selection attributes and candidate alternatives. The objective of any selection procedure is to identify the appropriate selection attributes and obtains the best decision in conjunction with the real-time requirements.

This paper presents one such simple, systematic and logical method, called PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations). A lot of applications of PROMETHEE in various fields of science and technology can be found in the literature (Behzadian *et al.* 2009). However, only a few applications are found in the field of manufacturing such as, scheduling (Duvivier *et al*. 2007, Roux *et al.* 2008) manufacturing system selection (Anand and Kodali 2008). Rao R.V. and Patel B.K. (2009) applied AHP and PROMETHEE for cutting fluid selection, manufacturing programme, end of life scenario and rapid prototyping process selection.

2. The PROMETHEE method

The PROMETHEE method was introduced by Brans *et al.* (1984) and belongs to the category of outranking methods. The PROMETHEE proceeds to a pair wise 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, which he/she uses when comparing the contribution of the alternatives in terms of each separate criterion.

Step I: 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 II:
(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 (Rao 2007) or decision maker can make own preference for weightage of attributes.

Step III: After calculating the weights of the criteria using AHP method, the next step is to have the information on the decision maker preference function, which he/she uses 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 to 1. Let Pi,a1a2 be the preference function associated to the criterion c_i.

$$P_{i,\,a1a2} = G_i\,[\,c_i\,(a1) - c_i(a2)\,] \qquad (1)$$

$$0 < Pi,\, a1a2 < 1$$

Where Gi is a non-decreasing function of the observed deviation (d) between two alternatives a1 and a2 over the criterion ci. In order to facilitate the selection of a specific preference function for a criterion, six basic types were proposed. These include ‘usual function’, ‘U-shape function’, ‘V-shape function’, ‘level function’, ‘linear function’, and ‘Gaussian function’.

Preference 'usual function' is equal to the simple difference between the values of the criterion c_i for alternatives a1 and a2.

Let the decision maker have specified a preference function Pi and weight wi for each criterion ci (i=1, 2 . . . M) of the problem. The multiple criteria preference index Πa1a2 is then defined as the weighted average of the preference functions Pi:

$$\Pi_{a1a2} = \sum_{i=1}^{M} w_i P_{i,\, a1a2} \tag{2}$$

Πa1a2 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.

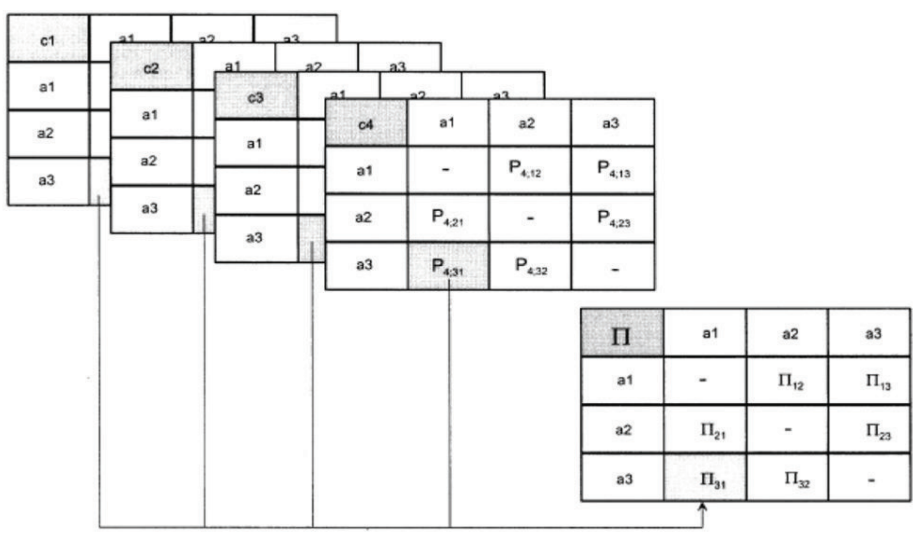
For PROMETHEE outranking relations, the leaving flow, entering flow and the net flow for an alternative a belonging to a set of alternatives A are defined by the following equations:

$$\varphi^{+}(a) = \sum_{x \varepsilon A} \Pi_{xa} \tag{3}$$

$$\varphi^{-}(a) = \sum_{x \varepsilon A} \Pi_{ax} \tag{4}$$

$$\varphi(a) = \varphi^{+}(a) - \varphi^{-}(a) \tag{5}$$

φ+ (a) is called the leaving flow, φ- (a) is called the entering flow and φ (ai) is called the net flow. φ+ (a) is the measure of the outranking character of a (i.e. dominance of alternative a overall other alternatives) and φ- (a) gives the outranked character of a (i.e. degree to which alternative a1 is dominated by all other alternatives). The net flow, φ (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 (Rao and Patel 2009). For an example, the schematic calculation of the preference indices for a problem consisting of three alternatives and four criteria is given in Figure 1.



$$\Pi_{31} = \sum_{i=1}^{4} w_i P_{i,31}$$

Figure 1. Preference indices for a problem consisting of three alternatives and four criteria. (Rao and Patel 2009)

3. Details of experiment work

In order to select a best suitable lubricant from among a number of lubricants available for machining, an alloy steel rod En-31 was turned on lathe machine with tungsten carbide insert tool. The details about the tool, cutting velocity, depth of cut and various lubricant selected during turning operation is given in table I below. To measure the value of chip interface temperature (Tc), tool wear rate (Tw), cutting force (Fc) and surface roughness (Ra) the experiments are carried out on ferrous material at cutting speed V m/min, depth of cut d mm, feed f mm/rev and tool nose radius r mm. In this operation dry, wet and minimum quantity of lubricant (graphite, boric acid powder mixed with SAE-40 base oil by weight) were used.

Table 1. Experimental conditions

Machine tool	10 HP lathe machine
Work specimen material	En-31 steel alloy
Process parameters	Cutting speed V=112m/min Feed f=0.10 mm/rev Depth of cut d=0.4 mm Tool nose radius R=0.8 mm
Lubricants	(i) Dry (no lubricant)
	(ii) Wet (soluble oil mixed with water in the ration of 1:20)
	(iii) Minimum quantity lubrication (a) 10% graphite + SAE-40 base oil (b) 10% boric acid + SAE-40 base oil (c) 15% graphite + SAE-40 base oil (d) 15% boric acid + SAE-40 base oil (e) Pure SAE-40 base oil

In this experiment a commercial alloy steel work piece En-31 of length 500 mm and diameter 50 mm is machined on heavy duty lathe machine. The application of the material includes roller bearings, boll bearings, mandrels, spindles, knurling tools, molding dies etc. The chemical composition of the material is as shown below.

Table 2. Chemical composition of work piece

Composition	**C**	**Si**	**Mn**	**Cr**	**S**	**P**
Wt %	0.95-1.2	0.10-0.35	0.30-0.75	1.0-1.6	0.040	0.040

The cutting temperature is measured by using tool-work thermocouple. Measurement of cutting force is carried out by lathe dynamometer of strain gauge type. The surface roughness measuring instrument was used to find the value of surface roughness and the tool wear is measured by single pan balance. To find accurate value of tool wear each experiment is repeated three times. The experimental results are shown in table 3.

Table 3. Lubricants and parameter values

Sr No.	**Lubricant**	**Tc (°C)**	**Fc (N)**	**Tw (mg/min)**	**Ra (μm)**
1	Dry	410	240	0.330	12.60
2	Wet	385	219	0.316	10.85
3	10% graphite + SAE-40 base oil	358	224	0.268	10.70
4	10% boric acid + SAE-40 base oil	318	150	0.242	10.38
5	15% graphite + SAE-40 base oil	374	216	0.278	10.66
6	15% boric acid + SAE-40 base oil	322	148	0.238	10.36
7	Pure SAE-40 base oil	369	225	0.329	10.74

The table shows average of three experiments for each parameter. The various steps of the PROMETHEE method can be apply as below.

Step I
The objective is to select right lubricant among the all available lubricants and value of parameter measured. For all considered parameters Chip-tool interface temperature, cutting force, tool wear and surface roughness the lower value is desirable since all are non-beneficial attributes. Because as the value of temperature increases it tends to increase in surface roughness of work piece. The higher value of cutting force results higher power consumption of machine.

Step II
The weight of different parameter can be calculated by using various methods. i.e. AHP
The weights considered are W_1= 0.6938, W_2=0.1392, W_3=0.1225 and W_4=0.0444

Step III
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 lubricant whereas the 'worse' alternative lubricant receives a value 0. All the attributes is a non-beneficial criterion and lower values are desired. The lubricant having a comparatively low value of attribute is said to be 'better' than the other.

Table 4. Resulting preference indices as well as leaving, entering and net flow values.

	1	2	3	4	5	6	7	$\varphi^+(a)$	φ	Rank
1	-	0	0	0	0	0	0	0	-5.9994	7
2	0.9999	-	0.1392	0	0	0	0.1225	1.2616	-3.3370	6
3	0.9999	0.8607	-	0	0.8163	0	0.9999	3.6768	1.3482	3
4	0.9999	0.9999	0.9999	-	0.9999	0.6938	0.9999	5.6933	5.3812	1
5	0.9999	0.9999	0.1836	0	-	0	0.3061	2.4895	-1.0204	5
6	0.9999	0.9999	0.9999	0.3061	0.9999	-	0.9999	5.3056	4.6118	2
7	0.9999	0.7382	0	0	0.6938	0	-	2.4319	-0.9961	4
$\varphi^-(a)$	5.9994	4.5986	2.3226	0.3061	3.5099	0.6938	3.4283			

Results

From the results it is clear that 10% boric acid mixed with SAE-40 base oil by weight is the best lubricant for the turning of En-31 alloy steel for the parameter measured. The above ranking can change if the user gives some other importance value for the attribute considered. Here 10% and 15% boric acid mixed with SAE-40 base oil is having close value for ranking. Turning with 10% boric acid offers minimum value of chip-tool interface temperature and cutting force.

4. Conclusion

A methodology based on a PROMETHEE method is suggested for the selection of best lubricant for turning of En-31 alloy steel material by considering chip-tool interface temperature, cutting force, tool wear and surface roughness. It is found that 10% boric acid mixed with SAE-40 base oil by weight is the best lubricant as compare to the other combination of lubricant considered.

The method is general decision making methods and can consider any number of quantitative selections attributes simultaneously and offers more objective and simple selection approaches. This technique can be used for any type of selection problem involving any number of selection attributes.

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