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A TOPSIS Method-based Approach to Machine Tool Selection

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Abstract

Due to highly competitive global market, the organizations are now forced to focus more on increasing productivity while decreasing cost by right selection of machine tools. Proper selection of machine tool justifies labor saving, improved product quality and increased production rate with enhanced overall productivity. Evaluation and selection of a machine tool is a complex decision-making problem involving multiple conflicting criteria. This paper presents a logical procedure to evaluate the CNC machines in terms of system specifications and cost by using TOPSIS method. The results derived while solving the CNC machine selection problem highly corroborate with those as obtained by the past researchers.

Keywords
Machine tool selection, Multi-criteria decision-making, Analytic hierarchy process, Technique for order preference by similarity to ideal solution.

1. Introduction
A CNC machine is considered as cost effective equipment that can be used to perform repetitious, difficult and unsafe manufacturing tasks with high degree of accuracy. Selection of proper machine tool is one of the important issues for achieving high competitiveness in the global market. The main advantage of selecting a proper machine tool lies not only in increased production and delivery, but also in improved product quality, increased product flexibility and enhanced overall productivity. Improper selection of a machine tool may cause problems affecting productivity, flexibility and process capability. Evaluation and selection of a machine tool is a complex decision-making problem involving multiple conflicting criteria, such as capital cost, machining diameter and length, spindle speed, tool capacity, flexibility, safety and compatibility. As a result, the problem of machine tool selection should be carefully studied before a large capital investment is made. This paper presents a logical and systematic procedure to evaluate the computer numerical control (CNC) machines [1] in terms of system specifications and cost by using the technique for order preference by similarity to ideal (TOPSIS) method, which is observed to be quite capable of solving such type of multi-criteria decision-making (MCDM) problems. The priority weights for different criteria are determined using analytic hierarchy process (AHP) method and subsequently, these weights are used for arriving at the best decision regarding selection of the proper CNC machine using TOPSIS method.

2. Literature Review
Past researchers have already solved the machine tool selection problem for different manufacturing facilities using various mathematical models, heuristics and MCDM techniques. Atmani and Lashkari [2] developed a production planning model for solving the machine tool selection and operation allocation problem in flexible manufacturing system (FMS). The model determines the optimal machine tool combination and assigns the operations of the part types to the machines, while minimizing the total cost of processing, material handling and machine set-up. Rai et al. [3] and Mishra et al. [4] applied fuzzy goal-programming technique to model the problem of machine tool selection and operation allocation. A genetic algorithm (GA)-based approach and a random search optimization methodology are adopted respectively to optimize the proposed models. Yurdakul [5] proposed a model linking the machine alternatives to manufacturing strategies for machine tool selection. The evaluation of machine tool alternatives is solved considering strategic implications of the machine tool selection decision using AHP and analytic network

process (ANP) methods. Chan et al. [6] and Chan and Swarnkar [7] applied fuzzy goal programming approach to solve the machine tool selection and operation allocation problems of FMS. The models are optimized using artificial immune system and ant colony optimization (ACO) based approaches respectively. Ayağ and Özdemir [8] proposed a fuzzy AHP based approach to evaluate the alternative machine tools. Cost-benefit analysis is carried out using both the fuzzy AHP score and procurement cost for each alternative, and computer software is developed to make all calculations of the fuzzy AHP easier and quicker while incorporating a data-driven user interface and related database. Ayağ and Özdemir [9] developed an intelligent approach for machine tool selection problem using fuzzy ANP to improve the imprecise ranking of an organization's requirements which are based on conventional ANP. A preference ratio (PR) analysis is adopted while using the results of the fuzzy ANP and investment costs of the alternatives. Durán and Aguilo [10] proposed a fuzzy-AHP based approach for selecting machine tools. It is reported that adoption of fuzzy numbers allows the decision makers to achieve a better estimation of flexibility regarding the overall importance of attributes and alternatives. Önüt et al. [11] presented a fuzzy TOPSIS based methodology for evaluation and selection of vertical CNC machining centers for a manufacturing unit. Yurdalul and İç [12] evaluated the benefits of using fuzzy numbers as a substitute of crisp numbers in a TOPSIS method based machine tool selection model. It is concluded that as the vagueness and imprecision increases in a decision-making problem, fuzzy numbers should be preferred to crisp numbers. Thus, from the review of the past researches, it is observed that the MCDM methods are quite suited and appropriate for solving the machine tool selection problem for a given manufacturing application. In this paper, the most suitable CNC machine is selected using TOPSIS (technique for order preference by similarity to ideal) method, which is an efficient MCDM tool for solving such type of complex decision-making problems in manufacturing domain.

3. TOPSIS Method

The procedural steps of TOPSIS method are enlisted as below [13]:

Step 1: Determine the objective and identify the pertinent evaluation criteria.

Step 2: Construct a decision matrix based on all the information available for the criteria. Each row of the decision matrix is allocated to one alternative and each column to one criterion. Therefore, an element, m_{ij} of the decision matrix shows the performance of i^{th} alternative with respect to j^{th} criterion.

Step 3: Obtain the normalized decision matrix, D_{ij} using the following equation:

$$D_{ij} = m_{ij} \Bigg/ \left[\sum_{j=1}^{M} m_{ij}^2 \right]^{1/2} \qquad (1)$$

Step 4: a) Decide on the relative importance of different criteria with respect to the objective by constructing a pair-wise comparison matrix using the scale of relative importance of AHP [14]. In this judgment process of assigning values, a criterion when compared with itself is always assigned a value of 1. The remaining values of relative importance in the pair-wise comparison matrix can be decided from 1 to 9 depending on the requirements. Assuming there are M criteria, the pair-wise comparison of i^{th} criterion with respect to j^{th} one yields a square matrix, A_1 where a_{ij} denotes the comparative importance of i^{th} criterion with respect to j^{th} one. In this matrix, $a_{ij} = 1$ when $i = j$ and $a_{ij}=1/a_{ji}$.

b) Find the relative normalized weight (w_j) of each criterion by (i) calculating the geometric mean of i^{th} row, and (ii) normalizing the geometric mean of rows in the comparison matrix. This can be represented using the following equations:

$$GM_j = \left[\prod_{j=1}^{M} a_{ij} \right]^{1/M} \qquad (2)$$

$$w_j = GM_j / \sum_{j=1}^{M} GM_j \qquad (3)$$

c) Calculate the matrices, A_3 and A_4 such that $A_3 = A_1 x A_2$ and $A_4 = A_3/A_2$, where

$$A_2 = [w_1, w_2, ..., w_M]^T.$$

d) Determine the maximum eigenvalue (λ_{max}) which is average of matrix A_4.

e) Calculate the consistency index as CI = (λ_{max} – M)/(M – 1). The smaller the value of CI, the smaller is the deviation from consistency.

f) Calculate the consistency ratio, CR = CI/RI, where RI is the random index value obtained by different orders of the pair-wise comparison matrices. Usually, a CR of 0.1 or less is considered as acceptable, indicating the unbiased judgments made by the decision makers.

Step 5: Obtain the weighted normalized matrix, V_{ij}.

$$V_{ij} = w_j D_{ij} \tag{4}$$

Step 6: Obtain the ideal (best) and the negative ideal (worst) solutions using the following equations:

$$V^+ = \left\{ \left(\sum_i^{\max} V_{ij} \Big/ j \in J \right), \left(\sum_i^{\min} V_{ij} \Big/ j \in J' \right) / i = 1,2,..., N \right\} \tag{5}$$

$$V^- = \left\{ \left(\sum_i^{\min} V_{ij} \Big/ j \in J \right), \left(\sum_i^{\max} V_{ij} \Big/ j \in J' \right) / i = 1,2,..., N \right\} \tag{6}$$

where, $J = (j = 1,2,..., M)/j$ is associated with beneficial attributes and $J' = (j = 1,2,..., M)/j$ is associated with non-beneficial attributes.

Step 7: Obtain the separation measures. The separations of each alternative from the ideal and the negative ideal solutions are calculated by the corresponding Euclidean distances, as given in the following equations:

$$S_i^+ = \left\{ \sum_{j=1}^{M} \left(V_{ij} - V_j^+ \right)^2 \right\}^{0.5}, i = 1,2,..., N \tag{7}$$

$$S_i^- = \left\{ \sum_{j=1}^{M} \left(V_{ij} - V_j^- \right)^2 \right\}^{0.5}, i = 1,2,..., N \tag{8}$$

Step 8: The relative closeness of a particular alternative to the ideal solution is computed as follows:

$$P_i = S_i^- \Big/ \left(S_i^+ + S_i^- \right) \tag{9}$$

Step 9: A set of alternatives is arranged in the descending order, according to P_i value, indicating the most preferred and the least preferred solutions.

4. Illustrative Example

Sun [1] applied data envelopment analysis (DEA) to evaluate 21 CNC machines (lathes) in terms of system specifications and cost at the operational level. The evaluation of CNC machines is based on the combination of the Banker, Charnes and Cooper (BCC) model and cross-efficiency method of DEA. It aims at identifying a homogenous set of good systems, by measuring, for each machine, the pure technical efficiency through the BCC model. The use of cross-efficiency evaluation is to discriminate better between the good systems and bad systems. These good systems can be further evaluated for the selection of the best system in the decision-making process. The main input and output measures for assessing the CNC machines are considered to be the purchase cost and technical specifications. The capital cost of a CNC machine, quoted in New Taiwanese Dollar (NT$), is the only input parameter. The technical features (output) on which the performance of a CNC machine depends are work capacity, machine body, spindle and tool turret. Work capacity is measured by the maximum machining diameter (mm) and machining length (mm). The machine body is measured by rapid traverse rates (m/min) of the X-axis and Z-axis. Rapid traverse rates of the X and Z-axes reflect the positioning capability of a turning centre. The spindle is measured by spindle speed range (rpm). Spindle speed is the number of revolutions that a spindle can make in one minute and it allows a machine to maintain a constant cutting speed regardless of the part diameter. The tool turret is measured by the tool capacity. The fewer is the number of tools in the turret, the more is the time required to change the tools as selected for use in a particular program. Thus, seven criteria, i.e. capital cost (CC) spindle speed range (SS), tool capacity (TC), rapid traverse rate of X-axis (TX), rapid traverse rate of Z-axis (TZ), maximum machining diameter (MD) and maximum machining length (ML) are considered that affect the ability of a CNC machine to perform various manufacturing operations. In this example, the most suitable CNC machine is selected for small-size shell production from the available alternatives using TOPSIS method. Among the seven criteria, CC, TX and TZ are the non-beneficial attributes as their lower values are desirable; on the other hand, SS, TC, MD and ML are the beneficial attributes because their higher values are always preferable. Table 1 shows the criteria values for 21 alternative CNC machines (lathes).

Table 1: Quantitative information for 21 CNC lathes [1]

Sl. No.	CNC Lathe	CC	SS	TC	TX	TZ	MD	ML
1	YANG ML-5A	1200000	5590	8	24	24	205	350
2	YANG ML-25A	1550000	3465	8	20	20	280	520
3	YCM TC-15	1400000	5950	12	15	20	250	469
4	VTURN 16	1100000	5940	12	12	15	230	600
5	FEMCO HL-15	1200000	5940	12	12	16	150	330
6	FEMCO WNCL-20	1500000	3465	12	6	12	260	420
7	FEMCO WNCL-30	2600000	3960	12	12	16	300	625
8	EX-106	1320000	4950	12	24	30	240	340
9	ECOCA SJ20	1180000	4480	8	24	24	250	330
10	ECOCA SJ25	1550000	3950	12	15	20	280	460
11	ECCOA SJ30	1600000	3450	12	15	20	280	460
12	TOPPER TNL-85A	1200000	3465	8	20	24	264	400
13	TOPPER TNL-100A	1350000	2970	8	20	24	264	400
14	TOPPER TNL-100AL	1400000	2970	12	24	30	300	600
15	TOPPER TNL-85T	1350000	3465	12	30	30	264	350
16	TOPPER TNL-100T	1450000	2970	12	20	24	300	400
17	TOPPERTNL-120T	1520000	2475	12	20	24	300	400
18	ATECH MT-52S	1376000	4752	12	20	24	235	350
19	ATECH MT-52L	1440000	4752	12	20	24	235	600
20	ATECH MT-75S	1824000	3790	10	12	20	300	530
21	ATECH MT-75L	1920000	3790	10	12	20	300	1030

As all these criteria considered for selecting the proper CNC machine are having different units and dimensions, their values are first normalized using Eqn. (1). In order to determine the relative normalized weight of each criterion affecting the CNC machine selection decision, a pair-wise comparison matrix, as shown in Table 2, is developed using AHP method. The criteria weights are obtained as w_{CC} = 0.1148, w_{SS} = 0.1808, w_{TC} = 0.1884, w_{TX} = 0.1197, w_{TZ} = 0.1148, w_{MD} = 0.1546 and w_{ML} = 0.1268. The value of CR is calculated as 0.0847 which is less than the allowed value of CR (= 0.1), indicating the fact that there is a good consistency in the judgments made by the decision maker while assigning values in the pair-wise comparison matrix. Now the values in the normalized decision matrix and the criteria weights are multiplied using Eqn. (4) to yield the weighted normalized matrix, as given in Table 3. The ideal (best) and the negative ideal (worst) solutions are now calculated using Eqns. (5) and (6) respectively, and those are shown in Table 4. Using Eqns. (7) and (8), the separation measures of each alternative CNC machine from the ideal and the negative ideal solutions are computed, as given in Table 5.

Table 2: Pair-wise comparison matrix

Criteria	CC	SS	TC	TX	TZ	MD	ML
CC	1	1	1	1/2	1	1/2	1
SS	1	1	1	1	1	3	2
TC	1	1	1	1	2	2	2
TX	2	1	1	1	1/2	1/3	1
TZ	1	1	1/2	2	1	1/2	1/2
MD	2	1/3	1/2	3	2	1	1
ML	1	1/2	1/2	1	2	1	1

Table 3: Weighted normalized matrix

Sl. No.	CNC Lathe	CC	SS	TC	TX	TZ	MD	ML
1	YANG ML-5A	0.0199	0.0519	0.0299	0.0333	0.0268	0.0262	0.0194
2	YANG ML-25A	0.0257	0.0322	0.0299	0.0278	0.0223	0.0358	0.0288
3	YCM TC-15	0.0232	0.0552	0.0449	0.0208	0.0223	0.0320	0.0260
4	VTURN 16	0.0182	0.0551	0.0449	0.0167	0.0167	0.0294	0.0332
5	FEMCO HL-15	0.0199	0.0551	0.0449	0.0167	0.0179	0.0192	0.0183
6	FEMCO WNCL-20	0.0249	0.0322	0.0449	0.0083	0.0134	0.0332	0.0233
7	FEMCO WNCL-30	0.0431	0.0368	0.0449	0.0167	0.0179	0.0383	0.0346
8	EX-106	0.0219	0.0460	0.0449	0.0333	0.0335	0.0307	0.0188
9	ECOCA SJ20	0.0196	0.0416	0.0299	0.0333	0.0268	0.0320	0.0183
10	ECOCA SJ25	0.0257	0.0367	0.0449	0.0208	0.0223	0.0358	0.0255
11	ECCOA SJ30	0.0265	0.0320	0.0449	0.0208	0.0223	0.0358	0.0255
12	TOPPER TNL-85A	0.0199	0.0322	0.0299	0.0278	0.0268	0.0337	0.0222
13	TOPPER TNL-100A	0.0224	0.0276	0.0299	0.0278	0.0268	0.0337	0.0222
14	TOPPER TNL-100AL	0.0232	0.0276	0.0449	0.0333	0.0335	0.0383	0.0332
15	TOPPER TNL-85T	0.0224	0.0322	0.0449	0.0416	0.0335	0.0337	0.0194
16	TOPPER TNL-100T	0.0240	0.0276	0.0449	0.0278	0.0268	0.0383	0.0222
17	TOPPER TNL-120T	0.0252	0.0230	0.0449	0.0278	0.0268	0.0383	0.0222
18	ATECH MT-52S	0.0228	0.0441	0.0449	0.0278	0.0268	0.0300	0.0194
19	ATECH MT-52L	0.0239	0.0441	0.0449	0.0278	0.0268	0.0300	0.0332
20	ATECH MT-75S	0.0302	0.0352	0.0374	0.0167	0.0223	0.0383	0.0293
21	ATECH MT-75L	0.0318	0.0352	0.0374	0.0167	0.0223	0.0383	0.0570

Table 4: Ideal and negative ideal solutions

V^+	0.0182	0.0552	0.0449	0.0083	0.0134	0.0383	0.0570
V^-	0.0431	0.0230	0.0299	0.0416	0.0335	0.0192	0.0183

Table 5: Separation measures

CNC	1	2	3	4	5	6	7	8	9	10	11
S_i^+	0.0511	0.0455	0.0356	0.0270	0.0443	0.0418	0.0394	0.0514	0.0525	0.0405	0.0430
S_i^-	0.0392	0.0330	0.0494	0.0558	0.0516	0.0487	0.0438	0.0375	0.0343	0.0400	0.0383
CNC	12	13	14	15	16	17	18	19	20	21	
S_i^+	0.0505	0.0529	0.0488	0.0592	0.0507	0.0535	0.0468	0.0367	0.0390	0.0281	
S_i^-	0.0330	0.0303	0.0361	0.0308	0.0351	0.0341	0.0379	0.0402	0.0401	0.0543	

Table 6: Relative closeness values

CNC	1	2	3	4	5	6	7	8	9	10	11
P_i	0.4346	0.4205	0.5813	0.6740	0.5382	0.5386	0.5264	0.4215	0.3952	0.497	0.4713
CNC	12	13	14	15	16	17	18	19	20	21	
P_i	0.3949	0.3637	0.4249	0.3427	0.4086	0.3894	0.4478	0.5229	0.5073	0.6587	

Table 6 shows the relative closeness value of each alternative CNC machine, which is calculated using Eqn. (9). Now, the alternative CNC machines are arranged in descending order according to their relative closeness values. From Table 6, it is observed that the CNC lathe 4 (VTURN 16) is the best choice. The final ranking of the CNC machines is 4-21-3-6-5-7-19-20-10-11-18-1-14-8-2-16-9-12-17-13-15, which almost matches with the results as obtained by Sun [1].

5. Conclusions

It is quite clear that selection of a proper machine tool for a given manufacturing application involves a large number of considerations. The use of TOPSIS method is observed to be quite capable and computationally easy to evaluate and select the proper machine tool from a given set of alternatives. This method uses the measures of the considered criteria with their relative importance in order to arrive at the final ranking of the alternative CNC machines (lathes). Thus, this popular MCDM method can be successfully employed for solving any type of decision-making problems having any number of criteria and alternatives in the manufacturing domain. As a future scope, a fuzzy TOPSIS based methodology may be developed to aid the decision makers to take decisions in presence of imprecise and incomplete data.

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