An Integrated AHP Approach in SCM for Machine Tool Selection

Rajveer Singh[1]* Sandeep Singhal[2] and Rakesh Kumar Phanden[3]
[1]M.Tech Scholar, Mechanical Engineering Department, NIT Kurukshetra, INDIA
[2]AssociateProfessor, Mechanical Engineering Department, NIT Kurukshetra, INDIA
[3]Associate Professor, Mechanical Engineering Department, M. M. University, Mullana, INDIA

Abstract- **Proper selection of equipments justifies labor saving, improved product quality and production rate with enhanced overall productivity. Present study highlights a logical procedure to select the tools in terms of various aspects as expense, operability, reliability, flexibility, service quality, tool capacity, and maximum tool diameter by analytical hierarchy process (AHP) method. The analytical hierarchy process is used in machine tool selection as a potential decision making method. The primary requirement of AHP is to make a matrix of the variables for their paired comparison . There are lot of AHP processes, but here only the two of them i.e. additive normalization method (AN) and geometric mean method (GM) are being used by analyzing the machine tools in mechanical workshop of National Institute of Technology (NIT) Kurukshetra with respect to micro and macro variables. The AHP procedure can be implemented manually or automatically. The results derived while solving the equipment selection problem highly corroborates with those as obtained by past researchers.**

Keywords -Machine tool selection; Multi-criteria decision making; Analytical Hierarchy Process; Supply Chain Management.

1. INTRODUCTION

A computer numerical control (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 advantages of selecting a proper machine tool lie not only in increased production and delivery, but also in improved product quality, increased product flexibility and enhanced overall productivity. In this paper authors selects the machine tools for applying the supply chain management concept using AHP method [1]. Therefore, according to the supply chain management, customers utmost satisfaction has become the main objective of the organization which has forced the companies/ industry to adopt effective and efficient strategies to fulfill the demands of the customers. Supply chain management is considered a strategic approach to achieve the ultimate objective i.e. customer satisfaction. It is essential for an organization to run supply chain smoothly and efficiently to fulfill customer demands timely and accurately [2]. Advanced information technology and improved information infrastructures have made an increasingly viable machine tool selection, implementing supply chain management. Decision-making techniques are very useful for study of supply chain management. In order to maintain a competitive position in the global market, organizations have to follow strategies to achieve shorter lead times, reduced costs and higher quality. Therefore machine tool selection play a key role in achieving corporate competitiveness and as a result of this, selecting the right tools constitutes critical component of these new strategies [3]. In these new strategies, authors are using the AHP method. The AHP is a decision- aiding method

Developed by Saaty (1980) and is often referred to eponymously as the Saaty method [4-7]. It focuses on quantifying relative Eigen values for a given setoff alternatives on a ratio scale [8]. The analytical hierarchy process as a potential decision making method is used in machine tool selection. The AHP decided with the behavior of decision-maker [9]. The strength of this approach lies in organizing tangible and intangible factors in a systematic way and provides a structured yet relatively simple solution to the decision making problem [10]. The objective of this paper is to integrate AHP approach in SCM for machine tool selection. The paper will briefly review the concepts and application of the multiple criterion decision analysis. This paper also presents a logical and systematic procedure to evaluate the CNC machines[11], in terms of system specifications and cost by using the techniques for order preference by similarity to ideal AHP method. The primary need of AHP is to construct a matrix of the variables for their pair-wise comparison, and then the priority weights for different criteria are determined using AHP method which are subsequently used for arriving at the best decision regarding selection of the proper CNC machine tool using AHP method [12].

2. SUPPLY CHAIN MANAGEMENT

Supply chain is a network of autonomous or semi- autonomous business entities collectively responsible for procurement, manufacturing and distribution activities associated with one or more families of related products. A supply chain is a network of facilities that procure raw materials, transform them into intermediate goods and then final products and deliver products to customers through a distribution system. Now some other researchers also define the supply chain management (SCM) a network of facilities and distribution options that perform the functions of procurement of materials, transformations of these materials into finished product and the distribution of these products to customers [13-16]. The given procedure describes the concept of SCM through the network between supplier, manufacturing unit, transport, and distribution centre. In this network all shows points in the field of SCM are connecting to each other to fulfill the customer demands in an efficient manner. Supply chain management is the process of planning, implementing and controlling the operations of supply chain as efficient as possible. Supply chain management spreader of all movement and storage of raw materials, work in process inventory and finished goods from point of origin to point of consumption. This explains the relationship between various aspects as plan, implementation of plan, and verification of plan and then evaluates them efficiently by the application of supply chain management. The supply chain management may be integrated with process planning and scheduling function of manufacturing system [17-19].

3. MULTI-CRITERIA DECISION ANALYSIS (MCDA)

The elements of the problems are numerous and the interrelationships among the elements are extremely complicated. Relationship between elements of a problem may be highly nonlinear and changes in the elements may not be related by simple proportionality. Therefore the human value and judgment system are integral elements of CNC machines problems [20-24]. Therefore the ability to make sound decisions is very important to the success of a process for machine tool selection. Multiple-criteria decision making (MCDM) approaches are major parts of decision theory and analysis. Author seeks to take explicit account of more than one criterion in supporting the decision process. The aim of MCDM methods is to help decision-makers to learn about the problems that they face , to learn about their own and other parties personal value systems, to learn about organizational values & objectives and exploring these in the context of the problem to guide them in identifying a preferred course of action[25-30].According to Belton MCDA is useful in circumstances which necessitate the consideration of different course of action , which cannot be evaluated by the measurement of simple, single dimension. [31] Published a comprehensive survey of multiple attribute decision making methods and applications.

4. THE ANALYTICAL HIERARCHY PROCESS (AHP)

The analytic hierarchy process (AHP) was developed by Saaty (1980) and is often referred to eponymously, as the Saaty method. In the past research [32], compared AHP and a simple multi- attribute value(MAV), as two of the multiple-criteria approaches. A number of criticisms have erupted at AHP over the years. According [29] prescribed the approach in order to elicit the weights of the criteria by means of a ratio scale. [4] Developed the following steps for applying the AHP.

Step1: Specify the problem and evaluate its goal.

Step2: Lay down the hierarchy from the top (the objective from a decision- makers view point) through the mid levels (criteria on which subsequent levels depend) to the lowest level which usually accommodate the set of options.

Step3: Evolve a set of paired comparison of matrices (size nxn) for each of the bottom levels with one matrix for every constituent in the level promptly above by adopting the comparative scale measurement shown in Table 1. The paired comparisons are done in terms of which constituent influences the other.

Table 1: Paired comparison of scale for AHP preferences

Intensity of importance	Definition	Explanation
9	Especially preferred	The conformation advising one over the other is of excessive possible validity
8	Very strongly to especially	When agreement is needed
7	Very strongly preferred	Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice

6	Strongly to very strongly	When agreement is needed
5	Strongly preferred	Experience and judgment strongly favor one over the other
4	Moderately to strongly	When agreement is needed
3	Moderately preferred	Experience and judgment slightly favor one over the other
2	Equally to moderately	When agreement is needed
1	Equally preferred	Two factors contribute equally to the objective.

Step 4: There are m / (m-1) judgment needed to construct the set of matrix in step 3. Complementary are automatically allocate in every paired comparison

Step 5: Hierarchical incorporate is now utilized to weigh the Eigen vectors by the weights of the standard and the summation is taken overall weighted Eigen vector ingress correlating to those in the next bottom level of the hierarchy.

The weightages of the features are obtained by calculating the Eigen vectors weights for the judgment matrix. The yields normalization matrix A_w, Eigen vector 'c' is initiate out by splitting the summation of all the ingresses in rows 'i' with 'm' no. of constituents of normalization matrix. After computing A_w and c, then calculate the AC as given below in the following forms.

Here, **C** = Eigen vector, **J**=column, **Aw**= Yield normalized matrix**, I =**Row = Number of elements of normalized matrix

$$Aw = \begin{bmatrix} \frac{a_{11}}{\sum a_{i1}} & \frac{a_{11}}{\sum a_{i2}} & \cdots\cdots & \frac{a_{1m}}{\sum a_{im}} \\ \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots \\ \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots \\ \frac{a_{m1}}{\sum a_{i1}} & \frac{a_{m2}}{\sum a_{i2}} & \cdots\cdots & \frac{a_{mm}}{\sum a_{im}} \end{bmatrix} \quad (1)$$

$$c = \begin{bmatrix} c_1 \\ c_2 \\ \cdots \\ \cdots \\ \cdots \\ \cdots \\ \cdots \\ c_m \end{bmatrix} = \begin{bmatrix} \dfrac{\frac{a_{11}}{\sum a_{i1}} + \frac{a_{12}}{\sum a_{i2}} + \cdots \frac{a_{1m}}{\sum a_{im}}}{m} \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ \dfrac{\frac{a_{11}}{\sum a_{i1}} + \frac{a_{12}}{\sum a_{i2}} + \cdots \frac{a_{1m}}{\sum a_{im}}}{m} \end{bmatrix} \quad (2)$$

Step6: In this step authors assemble the pair-wise comparisons and then the consistency is resolved by applying the Eigen value λmax.

$$Ac = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ a_{m1} & a_{m2} & \cdots & a_{mm} \end{bmatrix} \times \begin{bmatrix} c_1 \\ c_2 \\ \cdots \\ \cdots \\ c_m \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ \cdots \\ \cdots \\ x_m \end{bmatrix} \quad (3)$$

Now, consistency index (CI) is determined as follows

$$CI = \left(\frac{\lambda_{\max} - m}{m-1} \right) \quad (4)$$

Where m = Size of matrix

$$\lambda_{\max} = \frac{1}{m} \quad \frac{\sum ithentryin AC}{ithentryin AC} \qquad (5) \qquad \lambda_{\max} = \frac{1\sum X_i}{mC_i}$$

Consistency of Judgment can be evaluated by proceeding the consistency ratio (CR) of consistency index (CI) with the proper value as given in Table 2.

Table 2: Random consistency index (RCI)

Matrix size	1	2	3	4	5	6	7	8	9	10
Random consistency	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

By determining proper value of random consistency index (RCI), for a matrix size using Table 2 , author finds RCI and compute the consistency ratio, CR , as shown.

$$CR = \frac{CI}{RI} \qquad (6)$$

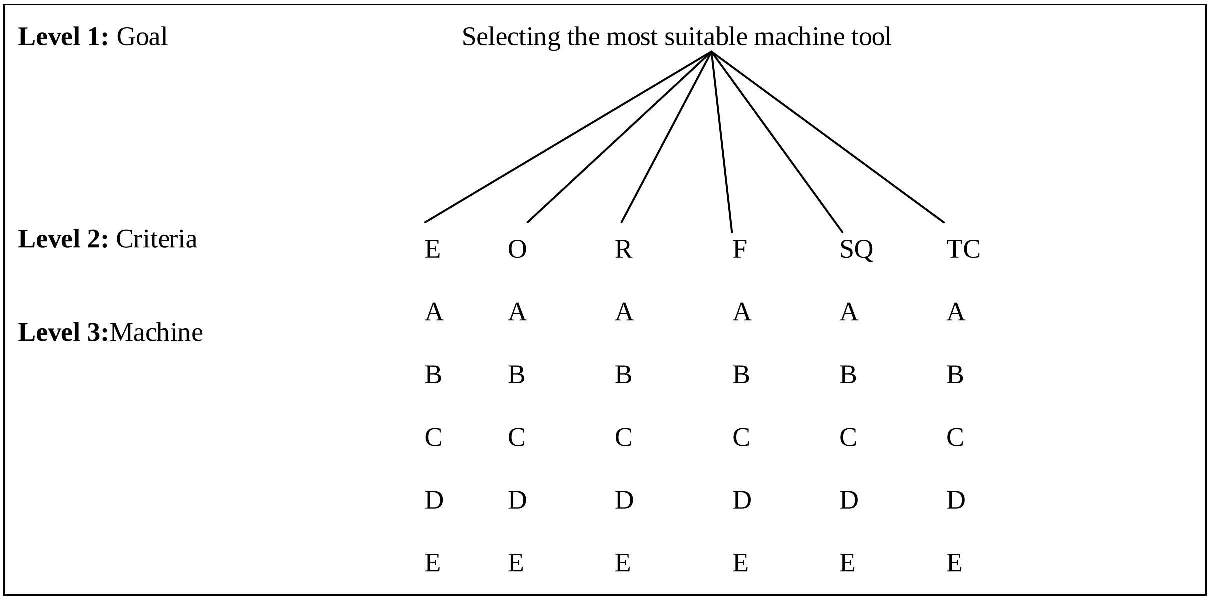
The CR is adequate, if the value of consistency ratio is more than 10% or 0.10, the given judgment matrix is unacceptable and inconsistent and if it is less, then judgment matrix is consistent and acceptable.

Step7: Steps 3-6 are accomplish for each of elevation in the hierarchy.

5. RESULT AND DISCUSSION

Here the analysis is done to evaluate the best CNC machines (Lathes) in terms of specifications and cost at the operational level. Selecting the best CNC machines on the basis of performance and efficiency, we select the most appropriate machine tool as per the authors' expectations. The evaluation of CNC machines is based on the AHP method. It aims in identifying a homogenous set of good systems, by critically analyzing each machine. The use of AHP method is to discriminate between the good systems and bad systems. These good systems can be further evaluated for the selection of the best system amongst them 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 [33].

The technical features (output) on which the performance of a CNC machine depends are operability, reliability, flexibility, service quality, tool capacity, and therefore to simplify calculations, these factors are used in machine tool selection [34-38]. By following the AHP procedure, the hierarchy of the problem is depicted in the figure 3, on the basis of three levels as goal, criteria, and machine. On the basis of these levels authors are arranged machines according the criteria that are taking in the machine tool selection. The hierarchies of machine tools are doing by selecting the best machine on the basis of their manufacturing performance. The arrangement that is discussed in this case study is shown in figure below:



E = Expense, O = Operability, R = Reliability, F= Flexibility, SQ= Service quality, TC= Tool capacity

A, B, C, D, E is machine on which tools are selected

Figure 1: Hierarchy of the machine tool example

The hierarchy as above is sequenced manually or automatically by the AHP software, and as per the expert choice.

Step-1: Arranging the pair-wise comparison and then computing the Eigen vector for a criterion such as Expense.

Step-2: Calculating the Consistency ratio (CR), λmax and Consistency index (CI).

Step-3: choosing proper value of the random consistency index (RCI).

Step-4: Scanning the consistency of the paired comparison matrix to evaluate the decision-makers comparisons were consistent or not.

5.1 Additive Normalization Method (ANM)

The calculations for these items are explained further. Synthesizing the pair-wise comparison matrix is performed by dividing each element of the matrix by its column total. For example, the value 0.08 in Table 4 is obtained by dividing 1(from Table 3) by 12.5, the sum of the column items in the Table 3 (1+3+2+6+1/2).

Table 3: Paired comparison of matrix for Expense

E	A	B	C	D	E
A	1	1/3	1/2	1/6	2
B	3	1	2	1/2	4
C	2	1/2	1	1/3	3
D	6	2	3	1	7
E	1/2	1/4	1/3	1/7	1

The priority vector in Table 4 can be obtained by finding the row averages. For example, the priority of machines A with respect to the criterion 'Expense 'in Table 4 is calculated by dividing the sum of the rows (0.08 + 0.082 + 0.073 + 0.078 + 0.118) by the numbers of machines (columns) , i.e. 5 in order to obtain the value 0.086 . The priority

Vector for Expense, indicated in Table 4 as shown.

Table 4: Incorporated matrix for Expense

E	A	B	C	D	E	Priority vector
A	0.08	0.082	0.073	0.078	0.188	0.086

B	0.24	0.245	0.293	0.233	0.235	0.249
C	0.16	0.122	0.146	0.155	0.176	0.152
D	0.48	0.489	0.439	0.466	0.412	0.457
E	0.04	0.061	0.049	0.066	0.059	0.055
						$\sum = 0.999$

λ_{max} = 5.037, CI= 0.00925, RI = 1.12, CR = 0.0082 < 0.1, Consistent and acceptableNow, calculating the consistency ratio as given below:

$$0.086\begin{bmatrix}1\\3\\2\\6\\1/2\end{bmatrix}+0.249\begin{bmatrix}1/3\\1\\1/2\\2\\1/4\end{bmatrix}+0.152\begin{bmatrix}1/2\\2\\1\\3\\1/3\end{bmatrix}+0.457\begin{bmatrix}1/6\\1/2\\1/3\\1\\1/7\end{bmatrix}+0.055\begin{bmatrix}2\\4\\3\\7\\1\end{bmatrix}=\begin{bmatrix}0.431\\1.259\\0.766\\2.312\\0.276\end{bmatrix}$$

Now dividing all elements of the weighted sum matrices by their respective priority vector element as $\frac{0.431}{0.086}=5.012, \frac{1.259}{0.249}=5.056, \frac{0.766}{0.152}=5.039, \frac{2.312}{0.457}=5.059, \frac{0.276}{0.055}=5.018$

Further authors compute the average of these values to obtain λmax.

$$\lambda_{max}=\left(\frac{5.012+5.056+5.039+5.059+5.018}{5}\right)=5.037$$

Now, author finds the consistency index (CI), as follows.

$$CI=\left(\frac{\lambda_{max}-m}{m-1}\right) = \left(\frac{5.037-5}{5-1}\right)=0.00925$$

Selecting the appropriate value of random consistency ratio, RI, for a matrix size of five using Table 2, author find RI = 1.12. Author then calculate the consistency ratio, CR

$$CR=\frac{CI}{RI} = \frac{0.00925}{1.12}=0.0082$$

As per calculation the CR value is less than 0.1 or 10%, the judgments are consistent and acceptable.

Similarly, the pair-wise comparison matrices and priority vectors for remaining criteria can be found as shown in Tables 5 – 9 respectively.

Table 5: Paired comparison of matrix for Operability

O	A	B	C	D	E	Priority vector
A	1	6	3	2	7	0.425
B	1/6	1	1/4	1/2	3	0.088
C	1/3	4	1	1/3	5	0.178
D	1/2	2	3	1	7	0.268
E	1/7	1/3	1/5	1/7	1	0.039
						$\sum = 0.998$

λ_{max} = 5.32, CI = 0.08, RI = 1.12, CR= 0.071< 0.1 or 10%, Consistent and acceptable

Table 6: Paired comparison of matrix for Reliability

R	A	B	C	D	E	Priority vector

A	1	7	1/3	2	8	0.269
B	1/7	1	1/5	1/4	4	0.074
C	3	5	1	4	9	0.461
D	1/2	4	1/4	1	6	0.163
E	1/8	1/4	1/9	1/6	1	0.031
						∑= 0.998

λ_{max}= 5.38, CI= 0.095, RI = 1.12, CR = 0.085< 0.1 or 10%, Consistent and acceptable

Table 7: Paired comparison of matrix for Flexibility

F	A	B	C	D	E	Priority vector
A	1	1/2	1/4	2	5	0.151
B	2	1	1/3	5	7	0.273
C	4	3	1	4	6	0.449
D	1/2	1/5	1/4	1	2	0.081
E	1/5	1/7	1/6	1/2	1	0.045
						∑ = 0.999

λ_{max}= 5.24, CI = 0.059, RI= 1.12, CR = 0.053< 0.1 or 10%, Consistent and acceptable

Table 8: Paired comparison of matrix for service quality

SQ	A	B	C	D	E	Priority vector
A	1	1/6	1/8	2	3	0.084
B	6	1	1/4	5	7	0.264
C	8	4	1	9	9	0.556
D	1/2	1/5	1/9	1	2	0.057
E	1/3	1/7	1/9	1/2	1	0.038
						∑ = 0.999

$\lambda_{max=}$ 5.28, CI= 0.071, RI= 1.12, CR = 0.063< 0.1 or 10 %, Consistent and acceptable

Table 9: Paired comparison of matrix for Tool capacity

TC	A	B	C	D	E	Priority vector
A	1	1/5	1/3	3	3	0.144
B	5	1	5	6	6	0.537
C	3	1/5	1	2	2	0.173
D	1/3	1/6	1/2	1	2	0.084
E	1/3	1/6	1/2	1/2	1	0.062
						∑ = 0.999

λ_{max} = 5.40, CI = 0.10, RI = 1.12, CR = 0.089 < 0.1 or 10%, consistent and acceptable

Now pair-wise comparison is applied for the decision alternatives and the authors also use the same pair- wise comparison procedure to set priority for all six criteria in terms of importance of each in contributing to the overall goal of machine tool selection. Table 10 shows the pair-wise comparison matrix and priority vector for the six criteria.

Table 10: Paired comparison of matrix for the six criteria (E, O, R, F, SQ, and TC)

E	O	R	F	SQ	TC	Priority vector
1	2	3	6	6	5	0.372
1/2	1	3	6	6	5	0.293
1/3	1/3	1	4	4	3	0.156
1/6	1/6	1/4	1	2	1/2	0.053
1/6	1/6	1/4	1/2	1	1/4	0.039
1/5	1/5	1/3	2	4	1	0.087
						∑ = 1.00

λmax= 6.31, CI = 0.062, RI = 1.24, CR = 0.05 < 0.1 or 10%, consistent and acceptable

New step is to combine the criterion priorities and the priorities of each decision alternative relative to each criterion in order to develop an overall priority ranking of the decision alternative which is termed as the priority matrix (Table 11). The overall priorities of machines on the basis of the given alternatives as expense , operability, reliability , flexibility , service quality , tool capacity are done manually or automatically by expert choice and software in an efficient manner[39-43]. The calculations for finding the overall priority of machines are done on the basis of these alternatives to select the best or efficient machine tool. The machine tool can be select by AHP method simply and in most efficient manner.

The overall priorities of the machines on basis of the given alternatives are shown in Table 11.

Table 11: Priority matrix for machine tool

	E	**O**	**R**	**F**	**SQ**	**TC**	**Overall Priority vector**
A	0.086	0.425	0.269	0.151	0.084	0.144	0.222
B	0.249	0.088	0.074	0.273	0.264	0.537	0.201
C	0.152	0.178	0.461	0.449	0.556	0.173	0.241
D	0.457	0.268	0.163	0.081	0.057	0.084	0.288
E	0.055	0.039	0.031	0.045	0.038	0.062	0.046
							$\sum = 0.998$

Here, E = 0.372, O = 0.293, R = 0.156, F = 0.053, SQ = 0.039, TC = 0.087 (Priority vector of the factors that are used to select the efficient machine tool).

Now, the calculation for overall priority of the machine tool is given below.

Overall priority of ***machine A***

[0.372 (0.086) + 0.293 (0.425) + 0.156 (0.269) + 0.053 (0.151) + 0.039 (0.084) + 0.087 (0.144)] = 0.222

Overall Priority of ***machine B***

[0.372 (0.249) + 0.293(0.088) + 0.156(0.074) + 0.053(0.273) + 0.039(0.264) + 0.087(0.537)] = 0.201

Overall priority of **machine C**

[0.372(0.152) + 0.293(0.178) + 0.156(0.461) + 0.053(0.449) + 0.039(0.556) + 0.087(0.173)] = 0.241

Overall priority of ***machine D***

[0.372(0.457) + 0.293 (0.268) + 0.156(0.163) + 0.053(0.081) + 0.039(0.057) + 0.087(0.084)] = 0.288

Overall priority of ***machine E***

[0.372(0.055) + 0.293(0.039) + 0.156(0.031) + 0.053(0.045) + 0.039(0.038) +0.087(0.062)] = 0.046

For machine tool selection purpose, the machines are now ranked in order of overall priorities, as D, C ,A ,B, and E (D>C>A>B>E) , and indicating that the D machine is the best machine for best tool selection at NIT Kurukshetra mechanical workshop, and E is the least preferred.

6. CONCLUSIONS

This is crystal clear and understandable that selecting an appropriate machine tool for a given manufacturing application involves a huge number of considerations and the use of AHP method has been perceived to be entirely competent and also computationally facile to determine and analyze proper machine tool from a given set of a alternatives. This work also lays down the measures of the considered criteria with their relative importance in order to arrive at the final ranking of the alternatives CNC machines . Thus, this popular MCDA 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, an AHP methodology may be developed to aid the decision makers. The paper has granted the AHP as an effective decision – making method that permits the deliberation of numerous consideration of multiple criteria.

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