A DECISION SUPPORT SYSTEM FRAMEWORK FOR MACHINE SELECTION

L. Nyanga[1*] , A.F. Van der Merwe[2], S Matope[3] and M.T. Dewa[4]
[1,2,3,4] Department of Industrial Engineering
University of Stellenbosch, South Africa
[1] inyanga@sun.ac.za
[2]andrevdm@sun.ac.za
[3]smatope@sun.ac.za
[4]mncee2009@gmail.com

ABSTRACT

Selecting the right machinery to machine a part is a multi criteria decision making problem which is crucial in production planning. The process becomes more complex and tedious when one has to choose from a variety of machines available in an online registry. This paper investigates this decision making process with the objective to increase machine utilisation for small, medium and micro enterprises. A real time information based decision support system is necessary to assist the decision maker. A decision support system framework for machine selection for a manufacturing agent is proposed based on the Analytical Hierarchy Process (AHP). A human expect uploads parameters for a part that has to be machines. Based on these parameters, suitable machines are sought for from an online machine registry and ranked according to their capability to produce the desired part.

* Corresponding Author

1 INTRODUCTION

Globalisation has opened up competition for manufacturing companies from competitors both locally and abroad. This has necessitated a change in the manufacturing strategies the companies are using in order to remain competitive. Most of the manufacturing companies are moving towards being more agile and lean hence they are implementing distributed manufacturing systems. This creates an opportunity for Small to Medium Enterprises (SMEs) as they most of the time they specialise on certain manufacturing operations which other companies can subcontract them to do. The biggest problem the SMEs face is limited financial resources which results in them failing to own high value machinery they would want to use. An e-manufacturing framework has been developed to enable the SMEs to increase machine utilization and manufacturing capabilities by sharing manufacturing resources. Selection of machinery to machine a part is a Multi Criteria Decision Making problem. The complexity of the problem is increased when the choices of machinery become dynamic as is the case in the proposed framework. In this paper we present a methodology for machine selection to be used by a manufacturability agent which is part of an e-manufacturing system [1]. The rest of the paper is structured as follows. Section 2 contains related literature, section 3 discusses the proposed framework and section 4 discusses the decision making methodology. The paper finally ends with a conclusion.

2 RELATED LITERATURE

2.1 Multi-Criteria Decision-Making

Multiple Criteria Decision-Making (MCDM) refers to making decisions in the presence of multiple and usually conflicting objectives. It is divided into Multi-Objective Decision-Making (MODM) and Multi-Attribute Decision-Making (MADM) [2]. MODM consists of a set of conflicting goals that cannot be satisfied simultaneously whilst MADM deals with the problem of choosing an alternative from a set of candidate alternatives which are characterized in terms of some attributes.[3]. To solve a MCDM problem a decision tree is constructed using the criteria relevant to a particular decision and the weighting/scoring of the criteria and the alternatives for each different criterion. Several MCDM methods have been developed in literature with Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) being the mostly widely used methods [2, 4, 5, 6, 7, 8, 9, 10].

2.2 Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a multi-criteria decision-making approach which was introduced by Saaty [11, 12]. It uses well-defined mathematical structure of consistent matrices and their Eigen vector to generate weights on the selection criteria [13, 14, 15]. To make decisions with AHP the following steps should be followed [16]:

1) The problem should be defined.
2) A decision hierarchy with the goal of the decision at the top followed by objectives from a broader perspectives, then intermediate level criteria is developed from the top level down to the alternatives.
3) A set of pair wise comparison matrices is developed with each element on an upper level used to compare the elements in the level immediately below it.
4) The priorities of the comparison the criteria in the upper level is used to weigh the criteria in the lower level immediately under it.

2.2.1 *Problem definition*

The facilitator sits with the decision-maker(s) to structure the problem and develop a hierarchical structure of the criteria which enables users to focus on specific criteria and sub-criteria when allocating the weights. Brugha [17], Saaty and Forman [18] have developed a complete guideline to structure a problem hierarchically and compiled hierarchies in different applications. To avoid large differences when decision making involves a large number of elements, the elements should be clustered [19], [20], [21]. According to Lin and Yang [22] it is best that each hierarchy does not contain more than seven elements otherwise the elements should be clustered, then divided into an additional hierarchy.

2.2.2 *Pair wise comparison*

A pair wise comparison matrix is developed using a scale of numbers that indicates how many times more important or dominant one element is over another element, with respect to the criterion or property to which they are compared as shown in Table 1. The development of the matrix is discussed in section 4.1.1.

Table 1: Fundamental scale of absolute numbers [14]

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

2.2.3 *Determination of priorities*

The priorities of each element can be determined by finding the Eigen vector of the pairwise comparison matrix. This can be achieved by raising the matrix to large powers and summing each row and dividing each by the total sum of all the rows [16]. In our approach we use the approximation of the priorities by adding each row of the matrix and dividing by their total. Once the priorities have been found the Principal Eigen value can be obtained from the summation of products between each element of Eigen vector and the sum of columns of the reciprocal matrix.

2.2.4 *Consistency checks*

The degree of consistency in the judgement of the priorities is measured by Consistency Ratio (CR). To calculate CR the Consistency Index (CI) should be derived using the following formula [11]:

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (1)$$

Where λ_{max} is the Principal Eigen value of the pair wise comparison matrix and n is the dimension of the matrix.

Consistency Ratio is then given by

$$CR = \frac{CI}{RI} \quad (2)$$

Where CI is the Consistancy Index and RI is the Random Consistency Index given in Table 2. If the value of Consistency Ratio is smaller or equal to 10%, the inconsistency is acceptable. If the Consistency Ratio is greater than 10%, we need to revise the subjective judgment.

Table 2: Random indices [11]

n	3	4	5	6	7	8	9	10
RI	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

According to Ishizaka and Labib [23] several other consistency measures close to Saaty's have been developed [24, 25, 26, 27]. Saaty's consistency measure has also been criticised for allowing contradictory judgements [28, 29] and also rejecting reasonable judgements [30] but it is still the most used measure.

2.2.5 *Application of AHP in machine selection*

From the literature several methods of applying AHP in machine selection have been proposed. Arslan et al [6], Yurdakul and Ic [31], Ic and Yudakul [32], Wang and Chin [1] and Ayag, Z. and O¨zdemir [33] have developed models that use the technical data of machines obtained from catalogues to select machinery. Yusuf et al [5] uses components of a machine. Lin and Yang [22] developed a model for machine selection in a Flexible Manufacturing System (FMS). Oeltjenbruns et al [34] developed a model that explores different planning alternatives ranging from extending the life of existing machinery to total system and to evaluate these alternatives through economical and technological criteria replacement with a new manufacturing. Most of the models proposed in literature are used for the selection of machinery when purchasing machinery. To the authors' best knowledge, a study that links machine selection to the part to be machined is not available in the literature. In our proposed framework the parameters of the part to be machined are linked to the parameters of the machines available.

3 MACHINE SELECTION FRAMEWORK

In the selection of machinery three factors are considered to ensure that a manufacturer remains competitive. These are the quality of products, cost of production and delivery time as shown in Figure 4. With machines being able to do a variety of operations, the selection of machinery which can be used to machine a part becomes a multi criteria decision making problem, hence AHP methodology has been adopted. The objective of the application of AHP is to select the suitable machine for machining a part from an online registry. In this paper we regard capability as the quality factor since the objective is to select a machine capable to manufacture a part. Cost and time factors will be discussed in subsequent papers.

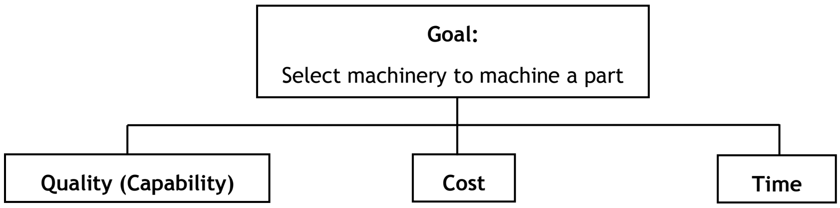

Figure 1: Machine selection top hierarchy

3.1 Decision Criteria

The objective is decomposed into a 4 level hierarchy of decision making criteria. The top level of the hierarchy is shown in Figure 4 and the second level is shown in Figure 5. The second level of the hierachy consists of productivity, flexibility and conformance to specification given for a product. Productivity sub criterion has to do with the rate at which the machine produces products. It contains the following machine attributes maximum spindle speed (MS), maximum power (MP), number of spindles (NS) and rapid traverse (RT). Flexibility sub criteria have to do with minimizing the number of set ups on the machine. It contains the number of axis on a machine (NA), swivelling range of the rotary table (RA), number of tools in the tool magazine (NT) and the control mechanism (CM) on the machine (i.e. CNC, NC or manual). The specifications sub criteria contains tolerances the machine can achieve (T), work envelope for the largest part that can be machined on the machine (WE), quality certification and references the company has (QC). The quality certificates a company has and references can also be used as an indication of whether the company will be able to produce a part with the desired quality. From a survey conducted most of the manufacturers indicated that they prefer working with companies they have previously done business with and those refereed to them by friends and other customers.

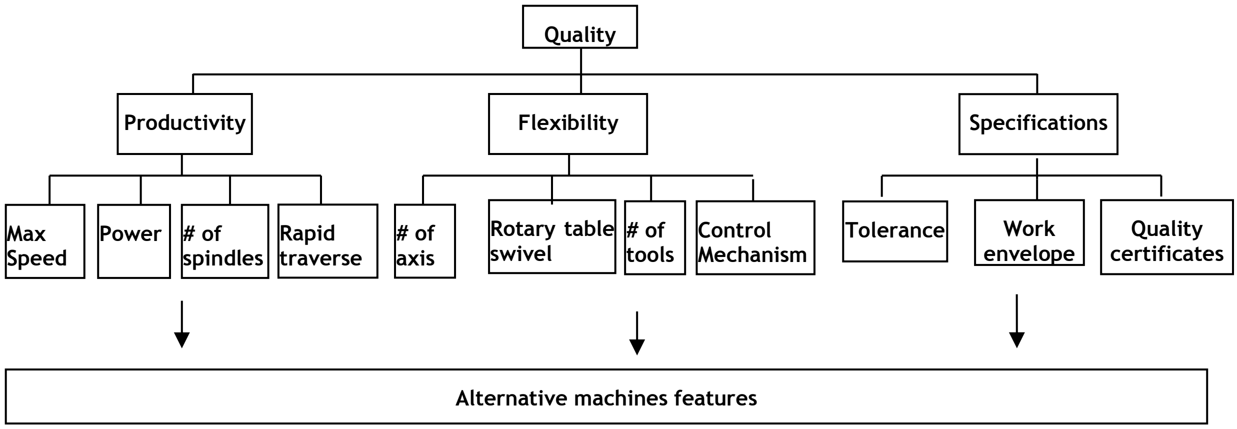

Figure 2: Quality priority

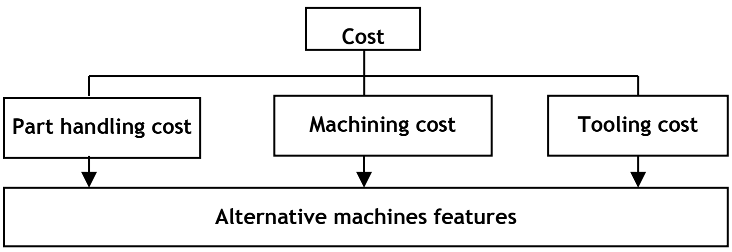

Figure 3: Cost factors

Production costs in Figure 6 are considered before the overall costs of subcontracting a machine. This enables that the benefits gained from using the machinery which might be rejected from the first glance if subcontracting costs are considered at an early stage of decision making. The objective is to select a machine with the minimum cost but maximum benefits. The time priority in Figure 7 ensures that parts are machined within the required time.

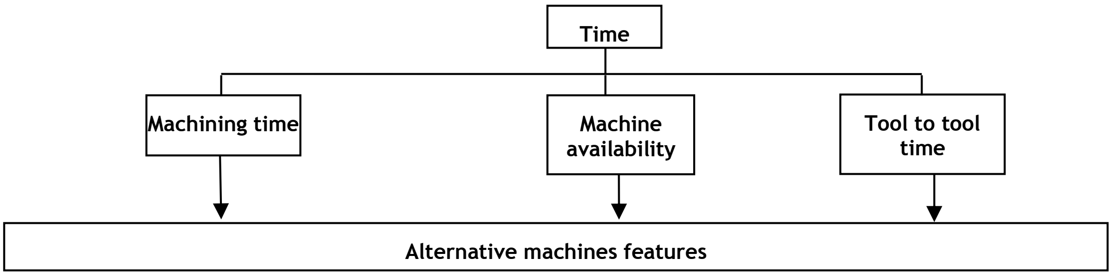

Figure 4: Time factors

4 METHODOLOGY FOR DECISION MAKING

The methodology proposes to rank the machinery from the best suitable machine at the top to the worst suitable machine at the bottom. A human expect inputs the required specifications for the part they want to machine. In the first stage of decision making the machines which do not meet the required specifications are filtered out. For those machines that are left the next step is to perform a pair wise comparison of the criteria and sub criteria to determine their ranking. Due to the large number of machines that one may have to choose from and the different number of alternatives when each search is done, it may be difficult to compare the alternative rankings. Instead of comparing the weights on the alternatives we adopt the approach by Çimren et al [35] where the weights of the decision criteria are used in ranking the machinery.

4.1 Machine ranking

In order to rank the machine each criteria ranking is determined by the following steps.

4.1.1 *Pair wise comparisons*

The decision maker enters relationships between the general criteria i.e. quality, cost and time. A half matrix where the relationships of the criteria on the rows are compared to the criteria on the columns is developed. Questions asked are in the following format:

If quality is on the row and flexibility on the column the question is asked as "*How important is the quality of the product to the production time?*" The answers to the question are given in the scale 1-9 (refer Table 1). If the criterion on the row is less important to the one on the column the inverse of the scale in table is given.

For a scenario where quality (Q) has extreme importance compared to cost (C), quality has strong importance to time (T) and the cost has very strong importance to time the pair wise comparisons are shown in Table 3.

Table 3: Pairwise comparisons

	Q	**C**	**T**
Q	1	9	7
C		1	1/7
T			1

4.1.2 *Pair-wise comparison matrix*

The pair wise comparison matrix is completed by the putting the inverse of the scales for the inverse relationships as shown in Table 4.

Table 4: Pairwise comparison matrix

	P	F	S
P	1	9	7
F	1/9	1	1/7
S	1/7	7	1

4.1.3 *Priority determination*

The pair-wise comparison matrix is normalised by dividing the values in each column by the column sum as shown in Table 5. To determine the priorities of each criterion, the normalised principal Eigen vector is obtained by averaging across the rows.

Table 5: Normalised pairwise comparison matrix

	Q	C	T	Priority
Q	0.80	0.60	0.69	0.70
C	0.09	0.07	0.01	0.06
T	0.11	0.47	0.10	0.23
Sum	1.25	15.00	10.14	

From Table 5, quality is considered as most important, followed by time and then lastly the cost. The priority ranking for quality ($Q_{p)}$, cost (C_p) and Time (T_p) are 0.70, 0.06 and 0.23 respectively. Ideally the sum of the priorities (Q_P+C_P+T_P) = 1.

$$\lambda_{max} = 1.25 * 0.72 + 15 * 0.063 + 10.14 * 0.22 = 4.016$$

$$CI = \frac{4.016 - 3}{2} = 0.51$$

$$CR = \frac{0.51}{0.58} = 0.88 = 0.9\% < 10\%$$

Since $CR < 10$ the judgement can be accepted hence we move on to the sub criteria priority ranking.

4.1.4 *Sub criteria priority ranking*

Calculate the priority ranking for the sub criteria using the steps 1 to 5. For example for productivity the pair wise matrix can be developed as shown in Table 6:

Table 6: Productivity sub criteria priority ranking

	MS	MP	NS	RT
MS	1	9	7	5
MP	1/9	1	7	7
NS	1/7	2	1	1/5
RT	1/5	1/7	5	1

The priority ranking for maximum spindle speed (MS), maximum power (MP), number of spindles (NS) and rapid traverse (RT) will be 0.57, 0.26, 0.04 and 0.12 respectively and CR is 7.4%.

Using the same method shown section 4.1.1 to 4.1.3 the priority ranking for the flexibility and specifications sub criteria is calculated. The priority ranking for number of axis, swivelling range of the rotary table, number of tools and control mechanism in the flexibility sub criteria are found to be 0.59, 0.18, 0.17 and 0.06 respectively with CR = 7.7%. The priority ranking for tolerance, work envelope and quality certificates in the specifications sub criteria are found to be 0.68, 0.09 and 0.23 respectively with CR = 6.5%.

4.1.5 *Calculate machine attribute contribution*

A part with specifications shown in Table 7 is used to illustrate how machine attribute contributions for machines with specifications given in Table 8. The specifications given in Table 8 contribute to the quality criteria. The attribute ranking for each machine attribute in sub criteria is calculated using the method illustrated in sections 4.1.1 to 4.1.4.

Table 7: Part specifications

MS	P	NS	Rapid Traverse			NA	RA	NT	CM	T	Work Envelope			QC
			X	Y	Z						X	Y	Z	
5000	10	1	45	45	40	3	90	10	CNC	0.01	50	30	20	ISO 9000, SABS

Table 8: Available Machines

Co	Mac ID	Type	MS	P	NS	R Traverse			NA	RA	NT	CM	T	Traverse			QC
						X	Y	Z						X	Y	Z	
A	M01	HMC	10000	29	1	45	45	40	5	130	42	CNC	0.008	800	800	550	2
A	M05	HMC	5000	15	1	23	23	7	3	45	20	CNC	0.05	780	780	400	2
B	CM2	VMC	1500	11	1	2.7	2.3	1.3	3	0	1	M	0.1	880	360	300	1
B	CM6	UMC	15000	20	1	45	45	40	5	130	42	CNC	0.008	800	800	550	1
C	DA4	VMC	1500	7.5	1	2.7	1.8	1	3	0	1	M	0.1	780	280	400	2
C	SA2	HMC	18000	20	1	45	45	40	5	130	42	CNC	0.008	800	800	550	2

The contribution of each attribute on the machine is calculated using Equations 3 and 4. For attributes with a single value the attribute contribution is given by

$$f(x) = \frac{Machine\ attribute}{Required\ part\ attribute} \qquad \textbf{(3)}$$

For attributes with a range of values the attribute contribution is given by the triangular distribution

$$f(x) = \begin{cases} 0 & for\ x < a\ and\ b \\ \frac{2(x-a)}{(b-a)(c-a)} & for\ a \leq x \leq c \\ \frac{2(b-a)}{(b-a)(c-a)} & for\ c < x \leq b \end{cases} \qquad \textbf{(4)}$$

Where x is the part attribute, a minimum value of the attribute on the machine, b is the maximum value of the machine attribute and c is the median between the maximum and minimum machine attributes.

The machine attribute for the quality criteria are shown in Table 9. The overall contribution for each machine attribute is calculated by multiplying the machine attribute ranking by the machine attribute contribution and is shown in Table 10. The machine contributions for cost and time criteria are summarised in Table 11.

Table 9: Machine attribute contribution

Co	Type	MS	P	NS	RT			NA	RA	NT	CM	T	Traverse			QC
					X	Y	Z						X	Y	Z	
A	HMC	2	2.9	1	1	1	1	1.67	1.44	4.2	1	1.25	16	26.67	27.5	1
A	HMC	1	1.5	1	0.51	0.51	0.18	1	0.5	2	1	0.2	15.6	26	20	1
B	VMC	0.3	1.1	1	0.06	0.051	0.033	1	0	0.1	0	0.1	17.6	12	15	0.5
B	UMC	3	2	1	1	1	1	1.67	1.44	4.2	1	1.25	16	26.67	27.5	0.5
C	VMC	0.3	0.75	1	0.06	0.04	0.025	1	0	0.1	0	0.1	15.6	9.333	20	1
C	HMC	3.6	2	1	1	1	1	1.67	1.44	4.2	1	1.25	16	26.67	27.5	1

Table 10: Overall quality machine attributes contribution

Co	Type	MS	P	NS	RT	NA	RA	NT	CM	T	Traverse	QC
A	HMC	1.15	0.76	0.04	0.12	0.98	0.26	0.73	0.06	0.86	1.41	0.23
A	HMC	0.57	0.40	0.04	0.02	0.59	0.09	0.35	0.06	0.14	1.37	0.23
B	VMC	0.17	0.29	0.04	0.00	0.59	0.00	0.02	0.00	0.07	1.06	0.11
B	UMC	1.72	0.53	0.04	0.12	0.98	0.26	0.73	0.06	0.86	1.41	0.11
C	VMC	0.17	0.20	0.04	0.00	0.59	0.00	0.02	0.00	0.07	0.82	0.23
C	HMC	2.06	0.53	0.04	0.12	0.98	0.26	0.73	0.06	0.86	1.41	0.23

Table 11: Overall cost and time machine attribute contribution

Co	Mach ID	Type	Cost			Time		
			Part handling cost	Machining cost	Tooling cost	Machining time	Machine availability	Tool to Tool time
A	M01	HMC	0.1243	0.0020	0.0043	0.2556	0.1969	0.0387
A	M05	HMC	0.1243	0.0030	0.0086	0.1534	0.1181	0.0249
B	CM2	VMC	0.2072	0.0075	0.0103	0.0767	0.0656	0.0058
B	CM6	UMC	0.2072	0.0040	0.0065	0.1917	0.1181	0.0387
C	DA4	VMC	0.2072	0.0067	0.0129	0.0639	0.0622	0.0058
C	SA2	HMC	0.2072	0.0020	0.0052	0.2556	0.1477	0.0387

4.1.6 *Calculate the overall machine attribute score*.

The overall attribute score is given by multiplying the priority scores of the general criteria, sub-criteria and the attribute contribution.

$$Overall\ score = General\ criteria\ priority * Subcriteria\ priority * attribute\ contribution \quad (5)$$

The overall machine attribute scores for quality, cost and time are shown in Table 12 and Table 13 respectively.

Table 12: Overall quality machine attribute score

Co	Type	MS	P	NS	RT	NA	RA	NT	CM	T	Traverse	QC
A	HMC	0.5718	0.3813	0.0221	0.0595	0.0443	0.0117	0.0329	0.0026	0.1297	0.2137	0.0345
A	HMC	0.2859	0.1972	0.0221	0.0104	0.0266	0.0041	0.0157	0.0026	0.0208	0.2084	0.0345
B	VMC	0.0858	0.1446	0.0221	0.0019	0.0266	0.0000	0.0008	0.0000	0.0104	0.1603	0.0173
B	UMC	0.8577	0.2630	0.0221	0.0595	0.0443	0.0117	0.0329	0.0026	0.1297	0.2137	0.0173
C	VMC	0.0858	0.0986	0.0221	0.0015	0.0266	0.0000	0.0008	0.0000	0.0104	0.1247	0.0345
C	HMC	1.0292	0.2630	0.0221	0.0595	0.0443	0.0117	0.0329	0.0026	0.1297	0.2137	0.0345

Table 13: Overall cost and time machine attribute score

Company	Machine ID	Type	Cost			Time		
			Part handling cost	Machining cost	Tooling cost	Machining time	Machine availability	Tool to Tool time
A	**M01**	HMC	0.01	0.0001133	0.00024	0.05787	0.0445704	0.0088
A	**M05**	HMC	0.01	0.00017	0.00049	0.03472	0.0267422	0.0056
B	**CM2**	VMC	0.01	0.0004249	0.00058	0.01736	0.0148568	0.0013
B	**CM6**	UMC	0.01	0.0002266	0.00036	0.0434	0.0267422	0.0088
C	**DA4**	VMC	0.01	0.0003777	0.00073	0.01447	0.0140748	0.0013
C	**SA2**	HMC	0.01	0.0001133	0.00029	0.05787	0.0334278	0.0088

4.1.7 *Determine Machine ranking*

The overall machine rank is calculated by summing up all the overall attribute scores. The machines are ranked in ascending order of the machine ranks. The machine with the highest machine rank is more suitable to machine the part hence it appears first. From the example given the most suitable machine to machine the part is SA2 from company C.

Table 14: Machine total score

Company	Machine ID	Type	Total Score
C	SA2	HMC	1.95555679
B	CM6	UMC	1.74578927
A	M01	HMC	1.62287843
A	M05	HMC	0.90304234
B	CM2	VMC	0.51599939
C	DA4	VMC	0.44759253

5 CONCLUSION

Machine selection is defined as a Multi Criteria Decision Making problem with the objective of selecting the best suitable machine for machining a part. The paper presents a decision support system framework for the machine selection for a manufacturing agent. When a part is uploaded on an online registry the part features are compared with the machines that have been uploaded to filter out the machines that do not have the required specifications. The AHP methodology is then implemented to determine the machine ranking and its suitability to machine a given part. The proposed methodology enables the application of

AHP methodology in an environment with a large or dynamic number of alternatives. The framework will be implemented inform of a manufacturability agent.

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