DEVELOPMENT OF A COMPONENT BASED MACHINING CENTER SELECTION MODEL USING AHP

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ABSTRACT

Machining centers are widely used in manufacturing companies all over the world. Since investments in machining centers are long-term and expensive, selection of the most appropriate machining center is an important decision for manufacturing companies. There are a great deal of efforts spent in developing crisp and fuzzy multi criteria decision making (MCDM) models that use technical specifications provided by the machining center manufacturers such as, axis size, power, spindle speed, tolerance, repeatability, cutting tool change time, number of cutting tools along with other economical and commercial factors. However, the technical specifications are directly taken from machining center manufacturers' catalogues without checking their correctness, adequacies or ability to represent the areas that are used to measure. In such a case, one can not be sure whether the outcomes are sound or not without a detailed check of technical specifications, which can only be performed after actual usage of the machine itself. To overcome all such problems, an Analytic Hierachy Process (AHP) model that evaluates the machining center components is developed in this paper. It should be noted that, the differences in machining center components are the causes of the differences in technical specification values of machining centers. The new component-based AHP model is then compared with a MCDM model that uses technical specification values.

Keywords: Machining Center Selection, Analytic Hierarchy Process (AHP), Machining Center Components.

1. Introduction

The machining centers are gaining acceptance in manufacturing industries. However, their selection is becoming more difficult with the increased number of available types and models. In the literature, there are various models developed to help manufacturing companies in machining center selection problems. For example, Vasilash (1997) developed a computer program called "machining center selector" which obtains a feasible set of machining centers by searching the data base and eliminating unsuitable ones. In other studies, Sun (2002) presents a machining center selection methodology that uses Data Envelopment Analysis and Georgakellos (2005) proposes a scoring model that incorporates technical and commercial characteristics of machines. In the literature, Multi Criteria Decision Making (MCDM) methods especially Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) are also used in selection of machining centers (Arslan et al., 2002; Lin and Yang, 1996; Çimren et al., 2004; Oeltjenbruns et al., 1995; Yurdakul, 2004; İç and Yurdakul, 2009; Ayağ and Özdemir, 2011).

The developed selection models in the literature commonly use technical specification values of machining centers such as table size, axis movement, power, spindle speed, axis speed, tool number, machine size, work piece size, finish tolerances (İç and Yurdakul, 2009; Ayağ and Özdemir, 2011). The specification values used in the models are taken from machining center manufacturers' catalogues. However, some specification values such as accuracy, repeatability, axis velocity are

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difficult to measure and their values tend to vary under changing conditions. To the best knowledge of the authors, a study that checks the accuracy of specification values provided by the machining center manufacturers is not available in the literature. It is clear that any error or misinformation in these values will directly affect the ranking results. Instead of using specification values, the components, which are the sources of the differences in the technical specification values, can be incorporated in a multi criteria machining center selection model. With such a model the machining centers are ranked according to the component types they possess avoiding any error or misinformation in the technical specification values provided in machining center builders' catalogues. This paper aims to develop such a model using AHP, which is the the most preferred approach in machining center selection literature since it is simple, easy to use, and capable of forming a hierarchical decision structure. In the following sections, the component based AHP model is developed and then compared with an AHP model that uses technical specifications.

2. Component types used in machining centers and development of the component based AHP model

Guides, spindle/bearing, feed drive and structure are the four components that are critical in determining a machining center's performance. To determine performance of a machining center five criteria, namely stiffness, damping capacity, thermal stability, speed capacity and accuracy are selected in this study. The selection criteria and the components are linked together in the developed AHP decision hierarchy to calculate ranking scores of machining centers (Figure 1). However, it is necessary to determine the performance level provided by different component types used in machining centers at each criterion and the component types used in machining centers before calculation of the ranking scores of machining centers. Types of the four components and their performance levels at the selection criteria are summarized in Table 1. The component types used in various machining centers are also provided in Table 2.

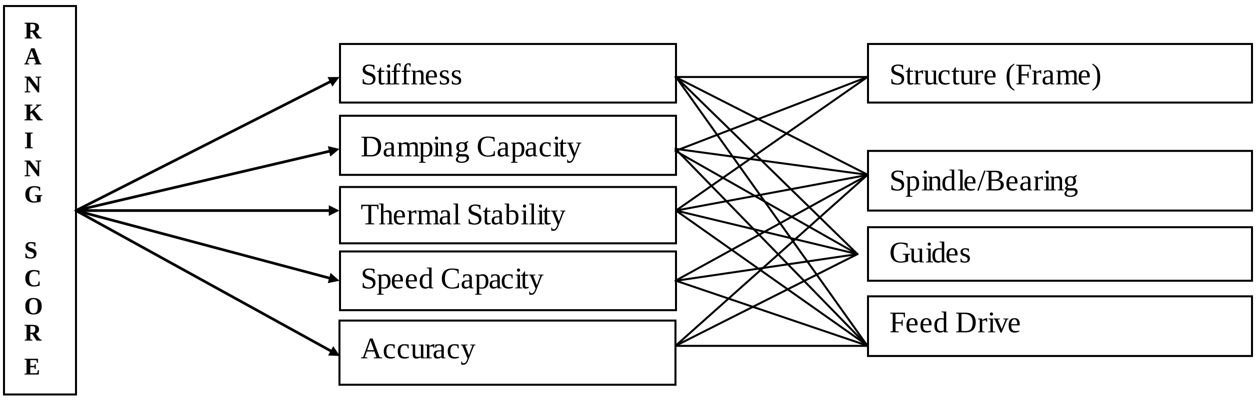

Figure 1. The AHP decision hierarchy

As a first step in obtaining ranking scores of machining centers using the AHP decision hierarchy, the performance scores of machining centers at each component are determined between zero and one based on their component types given in Table 2 and provided in Table 3. In Table 3, the lowest and highest assignable scores are '0' and '1' respectively whereas the average performance receives '0.5' score. Then, the importance weights of components at each criterion and the importance weights of selection criteria are calculated using the AHP approach. Calculation of the importance weights of selection criteria is illustrated in Table 4. The last column of the normalized pairwise comparison matrix provides the weights of selection criteria (Wabalickis, 1987; Cheng and Li, 2001). Once the weights are calculated using the AHP approach, the ranking score of each machining center can be calculated as illustrated in Table 5.

3. Comparison of component-based AHP model

The ranking results of the component-based AHP model are then compared with the selection model (MACSEL-MAchining Center SELection) using Spearman's rank correlation test and presented in Table 6 for three specific cases named as 'mass','flexible','sensitive'.

Table 1. Component types used in machining centers and their performance level (Irath and Romero, 2005; Tlusty, 2000)

Component Name	**Interaction/ Functions**	**Component Types**	**Performance Level at Selection Criteria**
Guides	Feed Motion-Work piece Surface	Box	High stiffness, high friction, low speed, high wear, good damping capacity, difficult maintenance and repair.
		Linear-Ball Bearing	Good stiffness, very low friction, very high speed, high accuracy, good damping capacity, very easy maintenance and repair
		Linear-Cylindirical Bearing	High stiffness, low firiction, high speed, very high accuracy, very good damping capacity, easy maintenance and repair
		Hydrostatic	Very high loading capacity, no wear, very low friction, difficult and expensive maintenance and repair
Spindle/ Bearing	Tool-Workpiece Motion	Ball Bearing	High speed, good accuracy, low friction
		Angular Contact Ball Bearing	High speed (requires cooling system), high accuracy, high loading capacity, high friction.
		Cylindirical Bearing	Good speed capacity, high accuracy, high stiffnes, very high loading capacity, high damping capacity, high friction.
		Hybrid Bearing	Very fast speed, high accuracy, high damping capacity.
Feed Drive	Table and Head Stock Motion	Ball-Screw-Single Nut	High speed, very good accuracy, low friction, low heating.
		Ball-Screw-Double Nut	Quite good speed, very good accuracy (with proper cooling system), very high stiffness, high damping capacity, high heat.
		Ball-Screw-Fixed both end/or Preloaded	Quite good speed, very good accuracy (if a cooling system is used), very high stiffness, high damping capacity, very high heating.
		Linear Motor	Very high speed, very low friction, high accuracy, high positioning, very easy or no maintenance.
Structure	Frame for the Machining Center's Components.	Cast-Iron	Cheap and easy to build structure, good damping capacity.
		Special Design or Special Materials Used	Better heat dissipation; It is possible to build structures such as symmetric, bridge type, extra column feeder or double column that provide increased stiffness, thermal stability and damping capacity.

Table 2. Component types used in the selected twenty machining centers

	MARK	**MODEL**	**Guides**	**Spindle/Bearing**	**Feed Drive**	**Structure**
1	MAZAK	FH8800	Linear Guide	Ball Bearing, Chiller Unit	Ball Screw	Mehanite Casting
2	MAZAK	VTC200B	Linear Guide	Ball Bearing	Ball Screw	Mehanite Casting, Cooling System
3	MAZAK	NXS510CHS	Linear Guide	Ball Bearing, Chiller Unit	Ball Screw	Mehanite Casting, Cooling System
4	OKUMA	MA550VB	Slide and Roller Way	Ball Bearing, Oil-Air Lubrication	Ballscrew Cooling System	Mehanite Casting
5	OKUMA	MB56VA	Linear Guide	Ball Bearing and TAS-S Design	Ball Screw	TAS-S-Construction
6	OKUMA	MCV3016	Linear Guide	Ball Bearing, Cooling System	Ball Screw	Mehanite Casting
7	EXCEL	PMC10T24	Linear Guide	Ball Bearing	Ball Screw Supported Both End	Mehanite Casting
8	MILLTRONICS	VM25	Linear Guide	Hybrit Bearing	Ball Screw-x2 Anchored	Cast Iron
9	MILLTRONICS	VM30	Linear Guide	Triplex Ball Bearing	Ball Screw-x2 Anchored	Cast Iron
10	EAGLE	VMC1300	Z-Axis:Box Way; X- and Y-axis:Linear Guide	P4 Grade-Angular Contact Ball Bearing	Ball Screw is Supported Both End and Preloaded	Cast Iron
11	CHALLENGER	VM1000	Box Way	Ball Bearing, Oil Chiller	Double nut and preload Ball Screw Used	Mehanite Casting
12	CHALLENGER	VMC1300	Box Way	Ball Bearing, Oil Chiller	Double nut and preload Ball Screw Used	Mehanite Casting
13	FADAL	VMC4020	Box Way, Friction Free Design	Hybrit Bearing, Oil-Air Lubrication	Ball Screw	Cast Iron
14	FADAL	VMC4525	Box Way, Friction Free Design	Ball Bearing, Cooling System	Ball Screw	Cast Iron
15	FADAL	VMC3020	Box Way, Friction Free Design	Ball Bearing, Cooling System	Ball Screw	Cast Iron
16	HYUNDAI	SPT V25	Linear Guide	Ball Bearing, Chiller Unit	Ball Screw	Bridge
17	HYUNDAI	SPT V32/405	Linear Guide	Ball Bearing, Chiller Unit	Ball Screw	Bridge
18	HYUNDAI	SPT V800	Linear Guide	Hybrit Bearing	Ball Screw is Supported Both End and Preloaded	Mehanite Casting
19	MATSUURA	HMAX500	Linear Guide	Hybrit Bearing	Double Ball Screw and Ballscrew cooling system	Bridge type design
20	MORISEIKI	NH8000DCG	Linear Guide-DCG, Cooling System	Ball Bearing, Oil Chiller	DCG, and Ballscrew cooling system	DCG and Heat Symetry Design

TAS-S: Themo Active Stabilize-Spindle; DCG: Driven of Center of the Gravity

Table 3. Performance scores of the twenty machining centers at five selection criteria

No	Mark	Model	STIFFNESS				DAMPING				TERMAL STABILITY				ACCURACY			SPEED CAPACITY		
			A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	A	B	C
1	MAZAK	FH8800	0.7	0.4	0.4	0.5	0.7	0.4	0.7	0.8	0.7	0.9	0.4	0.7	0.7	0.6	0.4	1.0	0.9	0.4
2	MAZAK	VTC200B	0.7	0.4	0.4	0.5	0.7	0.4	0.7	0.8	0.7	0.7	0.4	0.5	0.7	0.4	0.4	1.0	0.7	0.4
3	MAZAK	NXS510CHS	0.7	0.4	0.4	0.5	0.7	0.4	0.7	0.8	0.7	0.9	0.4	0.5	0.7	0.6	0.4	1.0	0.9	0.4
4	OKUMA	MA550VB	0.8	0.4	0.4	0.5	0.8	0.4	0.7	0.8	0.8	0.8	0.6	0.5	0.8	0.5	0.6	1.0	0.8	0.6
5	OKUMA	MB56VA	0.7	0.4	0.4	0.6	0.7	0.6	0.7	0.9	0.7	1.0	0.4	0.7	0.7	0.7	0.4	1.0	0.9	0.4
6	OKUMA	MCV3016	0.7	0.4	0.4	0.5	0.7	0.4	0.7	0.8	0.7	0.8	0.4	0.4	0.7	0.5	0.4	1.0	0.7	0.4
7	EXCEL	PMC10T24	0.7	0.4	0.5	0.5	0.7	0.4	0.8	0.8	0.7	0.7	0.5	0.4	0.7	0.4	0.5	1.0	0.7	0.3
8	MILLTRONICS	VM25	0.7	1.0	0.5	0.4	0.7	0.8	0.8	0.8	0.7	1.0	0.4	0.4	0.7	1.0	0.5	1.0	1.0	0.3
9	MILLTRONICS	VM30	0.7	0.5	0.5	0.4	0.7	0.5	0.8	0.8	0.7	0.6	0.4	0.4	0.7	0.5	0.5	1.0	0.6	0.3
10	EAGLE	VMC1300	0.8	0.5	0.6	0.4	0.6	0.5	0.8	0.7	0.4	0.6	0.5	0.3	0.6	0.5	0.6	0.6	0.6	0.3
11	CHALLENGER	VM1000	0.9	0.4	0.6	0.6	0.4	0.4	0.8	0.9	0.2	0.8	0.3	0.4	0.5	0.5	0.5	0.4	0.8	0.3
12	CHALLENGER	VMC1300	0.9	0.4	0.6	0.6	0.4	0.4	0.8	0.9	0.0	0.8	0.3	0.4	0.4	0.5	0.5	0.0	0.8	0.3
13	FADAL	VMC4020	0.9	1.0	0.4	0.4	0.4	0.8	0.7	0.7	0.2	0.9	0.4	0.3	0.5	1.0	0.4	0.4	1.0	0.4
14	FADAL	VMC4525	0.9	0.4	0.4	0.4	0.4	0.4	0.7	0.7	0.2	0.8	0.4	0.3	0.5	0.5	0.4	0.4	0.5	0.4
15	FADAL	VMC3020	0.9	0.4	0.4	0.4	0.4	0.4	0.7	0.7	0.2	0.8	0.4	0.3	0.5	0.5	0.4	0.4	0.5	0.4
16	HYUNDAI	SPTV25	0.7	0.4	0.4	0.8	0.7	0.4	0.7	0.9	0.7	0.9	0.4	0.5	0.7	0.6	0.4	1.0	0.9	0.4
17	HYUNDAI	SPTV32/405	0.7	0.4	0.4	0.8	0.7	0.4	0.7	0.9	0.7	0.9	0.4	0.5	0.7	0.6	0.4	1.0	0.9	0.4
18	HYUNDAI	SPTV800	0.7	1.0	0.6	0.5	0.7	0.8	0.8	0.8	0.7	1.0	0.5	0.4	0.7	1.0	0.6	1.0	1.0	0.3
19	MATSUURA	HMAX500	0.7	1.0	0.8	0.9	0.7	0.8	0.8	0.9	0.7	1.0	0.6	0.5	0.7	1.0	0.7	1.0	1.0	0.6
20	MORISEIKI	NH8000DCG	0.9	0.4	0.8	1.0	0.8	0.4	0.8	1.0	0.8	0.9	0.7	0.7	0.8	0.8	0.9	1.0	0.9	0.6

A:Guides, **B:**Spindle/Bearing **C:**Feed Drive **D:**Structure

Table 4. Calculation of the importance weights of selection criteria

	Pairwise-comparison matrix					Normalized Matrix						Row Sum of the Normalized Matrix	Importance Weights of Criteria
	TS	A	DC	SC	S								
Thermal Stability (TS)	1.00	2.00	4.00	2.00	5.00	0.41	0.49	0.35	0.36	0.31	1.92	3.83	**0.38**
Accuracy (A)	0.50	1.00	3.00	2.00	4.00	0.20	0.24	0.26	0.36	0.25	1.32	2.64	**0.26**
Damping Capacity (DC)	0.25	0.33	1.00	0.33	2.00	0.10	0.08	0.09	0.06	0.13	0.46	0.91	**0.09**
Speed Capacity (SC)	0.50	0.50	3.00	1.00	4.00	0.20	0.12	0.26	0.18	0.25	1.02	2.03	**0.20**
Stiffness (S)	0.20	0.25	0.50	0.25	1.00	0.08	0.06	0.04	0.04	0.06	0.29	0.59	**0.06**
Sum:	2.45	4.08	11.50	5.58	16.00							10.00	1.00

CI=0.028; CR=0.031

Table 5. Calculation of the MORISEIKI NH8000DCG's ranking score

Selection Criteria	**Components**	**Performance Score**	**Importance Weights of Component**	**Importance Weights of Selection Criteria**	**Global Weight**
Stiffness	Guides	0.9	**0.46**	**0.06**	0.024
	Spindle/Bearing	0.4	**0.07**		0.002
	Feed Drive	0.8	**0.31**		0.015
	Structure	1.0	**0.16**		0.009
Damping Capacity	Guides	0.8	**0.46**	**0.09**	0.034
	Spindle/Bearing	0.4	**0.07**		0.003
	Feed Drive	0.8	**0.31**		0.023
	Structure	1.0	**0.16**		0.014
Thermal Stability	Guides	0.8	**0.16**	**0.38**	0.048
	Spindle/Bearing	0.9	**0.46**		0.159
	Feed Drive	0.7	**0.31**		0.083
	Structure	0.7	**0.07**		0.019
Accuracy	Guides	0.8	**0.57**	**0.26**	0.120
	Spindle/Bearing	0.8	**0.10**		0.021
	Feed Drive	0.9	**0.33**		0.079
Speed Capacity	Guides	1.0	**0.57**	**0.20**	0.115
	Spindle/Bearing	0.9	**0.33**		0.061
	Feed Drive	0.6	**0.10**		0.012
RANKING SCORE:					**0.841**

Details of the cases and MACSEL which uses only specification values in its ranking procedure are presented in İç and Yurdakul (2009). The Spearman's rank correlation test calculates the statistical significance values of the differences in the rankings (Z) which are provided in the last row of Table 6. If 0.05 significance level of α which corresponds to 1.645 as the critical Z value is selected, it can be observed that all three Z values (1.973, 2.163 and 2.255) are higher than 1.645. The higher values tells us that there is no statistical significance between the ranking results of the two approaches.
Table 6. Ranking results of the selected twenty machining centers

MACHINING CENTER		CASE 1: Mass production			CASE 2: Flexible production			CASE 3: Sensitive production		
		Component Based AHP Ranking Scores	Ranking		Component Based AHP Ranking Scores	Ranking		Component Based AHP Ranking Scores	Ranking	
			Component Based AHP	MACSEL		Component Based AHP	MACSEL		Component Based AHP	MACSEL
MAZAK	FH8800	0.704	7	2	0.685	9	2	0.612	8	4
MAZAK	VTC200B	0.644	13	8	0.668	14	12	0.534	16	12
MAZAK	NXS510CHS	0.698	10	4	0.684	10	5	0.606	11	7
OKUMA	MA550VB	0.744	5	6	0.758	3	4	0.632	7	14
OKUMA	MB56VA	0.728	6	10	0.696	6	6	0.665	6	6
OKUMA	MCV3016	0.662	12	9	0.672	12	20	0.564	12	5
EXCEL	PMC10T24	0.665	11	16	0.675	11	17	0.556	13	15
MILLTRONICS	VM25	0.746	4	15	0.719	5	8	0.759	4	16
MILLTRONICS	VM30	0.631	14	18	0.671	13	9	0.551	14	18
EAGLE	VMC1300	0.569	16	14	0.564	15	14	0.543	15	13
CHALLENGER	VM1000	0.536	17	20	0.482	17	15	0.519	17	20
CHALLENGER	VMC1300	0.463	20	17	0.374	20	16	0.502	18	19
FADAL	VMC4020	0.576	15	19	0.513	16	18	0.670	5	17
FADAL	VMC4525	0.507	18	5	0.463	18	7	0.498	19	11
FADAL	VMC3020	0.507	18	7	0.463	18	11	0.498	19	9
HYUNDAI	SPTV25	0.702	8	12	0.688	7	13	0.610	9	8
HYUNDAI	SPTV32/405	0.702	8	11	0.688	7	10	0.610	9	10
HYUNDAI	SPTV800	0.769	3	13	0.733	4	19	0.783	2	2
MATSUURA	HMAX500	0.808	2	3	0.792	2	3	0.822	1	3
MORISEIKI	NH8000DCG	0.841	1	1	0.824	1	1	0.764	3	1
Spearman's rank correlation coefficient (r_s)			r_s	0.453			0.496			0.517
Statistical significance value (Z)			Z	*1.973*			*2.163*			*2.255*

Although the ranking results are not statistically different from each other, the differences in machining centers' rankings increase up to 15 and the average difference in the rankings of the twenty machining centers is 4.5. For example, HYUNDAI SPT800 is ranked third in CASE 1 and fourth in CASE 2 by component based AHP model whereas it is ranked thirtenth in CASE 1 and ninetenth in CASE 2 by MACSEL out of the twenty machining centers. The results show that completely different rankings are provided by the two models for HYUNDAI SPT800. The reason for the differences can be explained by the special components described in HYUNDAI SPT800's catologue. It is revealed in the catologue that HYUNDAI SPT800's spindle component is 'rigidly supported at three points by two sets of cylindrical roller bearing and one set of angular contact bearings and the spindle bearings are grease packed to minimize heat generation and hydraulic fluid that circulates in the headstock is cooled by the chiller unit' (Hyundai Heavy Industries Co.Ltd., 2007). Similarly HYUNDAI SPT800's structure is described as a 'single casting and the mounting surfaces of the X and Z axess linear bearings are machined in the same set-up for extremely high precision' (Hyundai Heavy Industries Co. Ltd., 2007). The component based AHP model captures the special components of HYUNDAI SPT800 by assigning high performance scores in HYUNDAI SPT800's row (No 18) in Table 3. However, the technical specification values can not capture the described machining performance of HYUNDAI SPT800 with the given accuracy values which are close to other machining centers' values. The real performance of the HYUNDAI SPT800 can be determined by not technical specification values but by its components. This example illustrates the advantages of using components instead of technical specification values in ranking machining centers especially when they will be used in special conditions such as 'heavy duty machining' or 'using continuously long time durations'.

4.Conclusion

The component based AHP model provides an alternative approach to the selection models that use technical specification values and it is especially recommended, when the machining center will be used under heavy conditions such as machining heavy workparts for long time durations. It should be noted in using an AHP model is that the success of the ranking results is sensitive to the correct selection of weighting numbers in filling pairwise comparison matrix. The pair wise importance values are assigned subjectively; and hence their correctness depends on the users' knowledge and familiarity with the conditions and production type of the machining center usage.

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