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Research Article

An Improved Efficacy Coefficient Method for Machine Selection in Flexible Manufacturing Cell

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Abstract: The aim of this study is to propose a new method for selecting the desirable machine, which is a key step of the manufacturing process. The task of machine selection is to select the desirable machine from a set of candidate machines for some application based on given evaluation attributes. The machine selection problem is actually a multi-attribute decision making problem and thus the new proposed method is developed on the basis of efficacy coefficient method combining with coefficient of variation method. Finally, a practical case study proves that the proposed machine selection method is effective and feasible.

Keywords: Coefficient of variation method, efficacy coefficient method, machine selection, multi-attribute decision making

INTRODUCTION

To meet the extremely competitive international markets environment, manufac-turing companies worldwide are forced to undergo transformation processes in order to improve their ability to succeed with their products. In this perspective, the selection of the best appropriate machine tool is often crucial but very difficult to achieve (Aloini *et al*., 2014). The task of machine selection is to select the best desirable machine from a set of candidate machines for some application based on given several evaluation attributes. The machine selection problem is actually a Multi-Attribute Decision Making (MADM) problem and many MADM methods have been developed to the application of machine selection for some specific application. For example, Aloini *et al*. (2014) developed the TOPSIS method for solving packaging machine selection problem in which the selection attributes are expressed with intuitionistic fuzzy set. Moon *et al*. (2002) developed a 0-1 integer programming model for the machine tool selection problem on the aid of genetic algorithm. Yurdakul (2004) and Durán and Aguilo (2008) developed the AHP method to the machine selection problem respectively with the environment of crisp numbers and triangular fuzzy numbers. Flexible Manufacturing Cell (FMC) is a group of machines, working together to perform a set of functions on a particular part or product, with the added capability of being conveniently changeable to other parts or products (Rao, 2013). Jahromi and Moghaddam (2012) proposed a novel 0-1 integer programming model for solving a problem of dynamic machine-tool selection in a flexible Manufacturing System (FMS) environment.

FMCs have received great attention in today's dynamic manufacturing environment and the research of the machine selection problem under FMC environment is also received great interest by many schloars. There are many evaluation attributes of machine selection in a FMC environment, such as purchasing cost, machine type, number of machines required, productivity, production output requirements, product quality, task and operating preference, interrelation among operating processes, type of control and accuracy of the machine, number of available AGVs, etc. (Wang *et al*., 2000). Many MADM methods are developed for this selection problem, such as AHP method (Yurdakul, 2004), fuzzy goal-programming approach (Chan *et al*., 2005), digraph and matrix methods (Rao, 2006).

Efficacy coefficient method was the mathematical formula for the efficacy coefficient and expressed the contribution of variables to a system in progress process (Yang and Gao, 2006). Efficacy coefficient method has been applicated in many fields, such as sustainable development capacity of logistics industry (Yu, 2013), assessment of gas explosion disaster risk (Li *et al*., 2013).

Coefficient of Variation (CV) method: In machine selection process, weights of evaluation factors are very important for final evaluation results. Coefficient of variation method is an objective weighting method, which has widely been applied in many fields. Then this study will develop a new machine selection method based on efficacy coefficient method combining with coefficient of variation method.

MATERIALS AND METHODS

System efficacy coefficient was determined by all subsystem efficacy coefficients which were transformed into nondimensional indexes through a certain functional relation and carried to calculate comprehensive weight and made as comprehensive index. The bigger the system efficacy coefficient was, the better the comprehensive performance of evaluation object was (Wang *et al*., 2011).

This section will develop the efficacy coefficient method to the machine selection problem in a FMC environment and the specific calculation steps are given as follows (Zhan *et al*., 2009):

Step 1: Identify the goal: Find out all possible the candidate machines (alternatives), selection attributes and its measures for the given application.

Step 2: Establish the MADM decision matrix: The solving the machine selection problem, we begin with constructing decision matrix. Let $X = \{x_1, x_2, \ldots, x_m\}$ be a set of alternative (candidate machines) and $O = \{o_1, o_2, \ldots, o_n\}$ be a set of decision attributes or criteria. Let x_{ij} be the performance of alternative x_i ($i = 1,2,\ldots,m$) on the attribute o_j($j = 1, 2, \ldots, n$). Then the machine selection problem can be expressed with the decision matrix form $A = (x_{ij})_{m\times n}$. In the machine selection process, different attribute often has different important degree, thus we assume $w = (w_1, w_2, \ldots, w_n)$ is the attribute (index) weight vector and w_j($j = 1, 2, \ldots, n$) denotes the important degree of the attribute o_j.

Step 3: Determining index threshold: Different index exists optimal level X+ and inferior level X^- in a certain range:

$$X^+ = (x_1^+, x_2^+, \ldots, x_n^+), \text{ where } x_j^+ = \max_{1\le i\le m}\{x_{ij}\}$$

$$X^- = (x_1^-, x_2^-, \ldots, x_n^-), \text{ where } x_j^- = \max_{1\le i\le m}\{x_{ij}\}$$

Step 4: Normalize the decision matrix into $R = (r_{ij})_{m\times n}$.

If the jth-attribute is the-larger-the-better attribute, then:

$$r_{ij} = \frac{x_{ij} - x_j^-}{x_j^+ - x_j^-}$$

If the jth attribute is the-smaller-the-better attribute, then:

$$r_{ij} = \frac{x_j^+ - x_{ij}}{x_j^+ - x_j^-}$$

Step 5: Determine weights of subsystem index using coefficient of variation (CV) method: CV method is an objective weighting method, which has widely been applied in many fields, such as water quality evaluation (Liu and Zou, 2012), portfolio problem (Zhao *et al*., 2015) and comprehensive evaluation of agricultural water conservancy infrastructure (Ning *et al*., 2014). The weights can be obtained using CV method as follows (Men and Liang, 2005):

$$w_j = \frac{\delta_j}{\sum_{j=1}^{n}\delta_j}, \quad j = 1,2,\ldots,n$$

where,

$$\delta_j = \sigma_j / x_j, \quad \sigma_j = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(x_{ij} - \bar{x}_j)^2}, \quad \bar{x}_j = \frac{1}{m}\sum_{i=1}^{m}x_{ij}$$

Step 6: Compute efficacy coefficient of each index as follows:

$$d_{ij} = r_{ij} \times 40 + 60$$

where, $i = 1,2,\ldots,m$ and $j = 1,2,\ldots,n$.

Step 7: Compute comprehensive efficacy coefficient D_i ($i = 1, 2,\ldots, m$) of each alternative:

$$D_i = \prod_{j=1}^{n} d_{ij}^{w_j}, \quad i = 1,2,\ldots,m$$

Step 8: Rank all alternatives according to the values of efficacy coefficient D_i ($i = 1, 2,\ldots, m$) with the rule.

The larger of efficacy coefficient D_i is, the better of the alternative x_i is.

RESULTS AND DISCUSSION

This example is taken from Wang *et al*. (2000), which is a real case of a FMC including two CNC milling machines, one CNC lathe and one robot for material handling. In this problem the factory manager had decided to purchase some machine facilities after sufficient discussion and complete evaluation. After putting different purchasing constraints on the total purchasing cost and the specifications of milling machine, lathe machine and the robot, suitable machines of FMC were composed into ten possible alternatives. The evaluation attributes are Total purchasing cost (dollars) (o_1), Total floor space (m^2) (o_2), Total machine number (o_3), Productivity* (mm/min) (o_4). Here, o_4 is the benefit attribute and others are cost attribute (Table 1).

Table 1: Decision matrix for machine group selection in an FMC

	Evaluation attribute values					Evaluation attribute values			
No.	o_1	o_2	o_3	o_4	No.	o_1	o_2	o_3	o_4
1	581818	54.49	3	5500	6	543030	74.46	4	5600
2	595454	49.73	3	4500	7	522727	75.42	4	5800
3	586060	51.24	3	5000	8	486970	62.62	4	5600
4	522727	45.71	3	5800	9	509394	65.87	4	6400
5	561818	52.66	3	5200	10	513333	70.67	4	6000

Table 2: Normalized decision matrix for machine group selection in an FMC

	Evaluation attribute values					Evaluation attribute values			
No.	o_1	o_2	o_3	o_4	No.	o_1	o_2	o_3	o_4
1	0.1257	0.7045	1.0000	0.5263	6	0.4832	0.0323	0	0.5789
2	0	0.8647	1.0000	0.0000	7	0.6704	0.0000	0	0.6842
3	0.0866	0.8139	1.0000	0.2632	8	1.0000	0.4308	0	0.5789
4	0.6704	1.0000	1.0000	0.6842	9	0.7933	0.3214	0	1.0000
5	0.3101	0.7661	1.0000	0.3684	10	0.7570	0.1599	0	0.7895

Table 3: The values of efficacy coefficient of each index

	Evaluation attribute values					Evaluation attribute values			
No.	o_1	o_2	o_3	o_4	No.	o_1	o_2	o_3	o_4
1	65.0278	88.17910	100.0000	81.0526	6	79.32970	61.2925	60.0000	83.15790
2	60.0000	94.58770	100.0000	60.0000	7	86.81580	60.0000	60.0000	87.36840
3	63.4637	92.55470	100.0000	70.5263	8	100.0000	77.2333	60.0000	83.15790
4	86.8158	100.0000	100.0000	87.3684	9	91.73190	72.8576	60.0000	100.0000
5	72.4022	90.64290	100.0000	74.7368	10	90.27950	66.3952	60.0000	91.57890

The specific calculation steps of the proposed method are given as follows:

Step 1: The attribute weights obtained by CV method are respectively given as follows:

$$w_1 = 0.1379, w_2 = 0.3643,$$
$$w_3 = 0.3032, w_4 = 0.1947$$

Step 2: The normalized decision matrix are shown in Table 2 and the efficacy coefficient of each index are given in Table 3.

Step 3: The comprehensive efficacy coefficient D_i of each alternative are calculated as:

$D_1 = 86.4083$, $D_2 = 82.6818$, $D_3 = 85.3099$, $D_4 = 95.5245$, $D_5 = 87.1952$, $D_6 = 66.9648$, $D_7 = 67.9285$, $D_8 = 75.2134$, $D_9 = 75.4205$, $D_{10} = 71.5154$

Step 4: Then the ranking order is 4-5-1-3-2-9-8-10-7-6, which is the same as the one obtained in Rao (2013) by using improved OWA method.

CONCLUSION

For the machine selection problem, we develop a new selection method named efficacy coefficient method for solving it. This new selection method is easy to perform and can be easily accept by engineers. A case study is used to validate the application of the proposed method and the example shows that the proposed method is effective and feasible. The proposed method can also extend to other applications, such as robot selection, investment selection and material selection problems.

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