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ROBOT SELECTION FOR A FLEXIBLE MANUFACTURING SYSTEM WITH AHP AND TOPSIS METHODS

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ABSTRACT

Manufacturing companies need robots to perform material-handling tasks in a flexible manufacturing system. Selection of a robot is one of the most difficult problems in today's manufacturing environment. This problem has become more challenging recently due to increasing specifications and complexity of the robots. This study aims to solve a robot selection problem for material handling task in a flexible manufacturing system. For this reason, two Multi-Criteria Decision Making methods, AHP (Analytical Hierarchy Process) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), are used to select the most convenient robot among three alternatives for a given industrial application.

Keywords: AHP, Multi-Criteria Decision Making, Robot Selection, TOPSIS.

1. INTRODUCTION

The recent growths of information technology and engineering sciences have been the key reason for the increased utilization of robots in different advanced manufacturing systems [1]. Robots with different capabilities and specifications are available for a wide range of applications and can be programmed to keep a constant speed and a predetermined quality when performing a task repetitively [2]. Robots perform repetitious, difficult, and hazardous tasks with precision, and can improve quality and productivity dramatically if applied properly [2, 3]. Therefore, manufacturers prefer to use robots in many industrial applications where repetitive, difficult or hazardous tasks need to be performed, such as assembly, machine loading, materials handling, spray painting, and welding. To improve product quality and increase productivity, robot selection has always been an important issue for manufacturing companies [2]. Selection of a robot for a specific industrial application is one of the most challenging problems in real time manufacturing environment. It has become more and more complicated due to increase in complexity, advanced features and facilities that are continuously being incorporated into the robots by different manufacturers [4]. Manufacturing environment, product design, production system and cost involved are some of the most influencing factors that directly affect the robot selection decision. The decision maker needs to identify and select the best suited robot in order to achieve the desired output with minimum cost and specific application ability [4]. Various quantitative methods have been proposed and applied to select the most suitable robot among a number of alternatives [3]. This paper attempts to solve the robot selection problem using two multi-criteria decision- making (MCDM) methods, AHP and TOPSIS, for a given industrial application.

2. AHP

AHP is a decision-making tool that can help describe the general decision operation by decomposing a complex problem into a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives [5]. The top level of the hierarchy denotes the goal of the problem, and the intermediate levels denote the factors of the respective upper levels. Meanwhile, the bottom level contains the alternatives or actions considered when achieving the goal. AHP permits factors to be compared, with the importance of individual factors being relative to their effect on the problem solution [6]. The AHP comprises six major steps [7]:

1. Define the unstructured problem.
2. Decompose the problem into a hierarchical structure.
3. Employ pairwise comparisons.
4. Find the maximum eigenvalues and eigenvectors in order to estimate the relative weights of the decision elements. After a comparison matrix has been formed, the priority of the element can be compared by the computation of eigenvalues and eigenvectors with the following formula, where w is the eigenvector, the weight vector, of A, and λmax is the largest eigenvalue of A: $A \cdot w = \lambda_{\max} \cdot w$
5. Check the consistency property of the matrix.
6. Aggregate the relative priorities of the decision elements to obtain an overall rating for decision alternatives.

3. TOPSIS

TOPSIS is one of the major techniques in dealing with Multiple Criteria Decision Making (MCDM) problems [8]. It is a practical and useful technique for ranking and selection of a number of externally determined alternatives through distance measures [9]. The underlying logic of TOPSIS method is to define the positive-ideal solution (PIS) and the negative-ideal solution (NIS) [10]. The optimal alternative is the one which the shortest distance from the positive solution and the farthest distance from the negative solution [10], and preference order is ranked according to their relative closeness combining two distance measures [8]. Suppose an MCDM problem that has *m* alternatives, $A_1, \ldots, A_m$ and *n* decision criteria, $C_1, \ldots, C_n$. Each alternative is assessed with respect to the *n* criteria. All the performance ratings assigned to the alternatives with respect to each criterion form a decision matrix denoted by $X = (x_{ij})_{m\times n}$. Let $W = (w_1, w_2, \ldots, w_n)$ be the relative weight vector about the criteria, satisfying $\sum_{j=1}^{n} w_j = 1$. In general, the criteria can be classified into two types: benefit and cost. The benefit criterion means that a higher value is better while for the cost criterion is valid the opposite [11]. The TOPSIS method can be summarized as follows:

__Step 1:__ Normalize the decision matrix $X = (x_{ij})_{m\times n}$ using the equation below.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, i = 1, 2, \ldots, m; \quad j = 1, 2, \ldots, n, \qquad (1)$$

$$\sum_{j=1}^{n} w_j = 1$$

The normalized decision matrix R, $R = [r_{ij}]_{mxn}$, represents the relative rating of the alternatives.

__Step 2:__ After normalization, we calculate the weighted normalized decision matrix $P = [p_{ij}]_{mxn}$ with $i = 1, \ldots, m$, and $j = 1, \ldots, n$ by multiplying the normalized decision matrix by its associated weights. The weighted normalized value p_{ij} is calculated as:

$$p_{ij} = w_i x r_{ij} \text{ with } i = 1, \ldots, m, \text{ and } j = 1, \ldots, n. \qquad (2)$$

__Step 3:__ Identify the positive ideal solutions A^+ (benefits) and negative ideal solutions A^- (costs) as follows:

$$A^+ = (p_1^+, p_2^+, \ldots, p_m^+) \qquad (3)$$

$$A^- = (p_1^-, p_2^-, \ldots, p_m^-) \qquad (4)$$

where

$$p_j^+ = \left(\max_i p_{ij}, j \in J_1; \min_i p_{ij}, j \in J_2\right)$$

$$p_j^- = \left(\min_i p_{ij}, j \in J_1; \max_i p_{ij}, j \in J_2\right)$$

where J_1 and J_2 represent the criteria benefit and cost, respectively.

__Step 4:__ Calculate the Euclidean distances from the positive ideal solution A^+ and the negative ideal solution A^- for each alternative A_i, respectively as follows:

$$d_i^+ = \sqrt{\sum_{j=1}^{n} (d_{ij}^+)^2} \quad (5)$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} (d_{ij}^-)^2} \quad (6)$$

where

$d_{ij}^+ = p_j^+ - p_{ij}$, with $i = 1, \ldots, m$.
$d_{ij}^- = p_j^- - p_{ij}$, with $i = 1, \ldots, m$.

Step 5: Calculate the relative closeness ξ_i for each alternative A_i with respect to positive ideal solution as given by:

$$\xi_i = \frac{d_i^-}{d_i^+ + d_i^-}. \quad (7)$$

Step 4: Rank the alternatives according to the relative closeness. The best alternatives are those that have higher value ξ_i and therefore should be chosen because they are closer to the positive ideal solution [11].

4. INDUSTRIAL APPLICATION

Application was carried out at a metal cutting workshop of a tractor factory. A flexible manufacturing cell was examined. It was decided the selection of a new robot to perform material handling tasks. After initial selection, three robots R1, R2 and R3 were chosen for further evaluation. Thus, the robot selection problem consists of three main criteria and eight sub-criteria. These criteria are as follows and the hierarchy shown in Figure 1: **Cost (C):** maintenance cost **(C1)**, insurance **(C2)**, purchase cost **(C3), Flexibility (F):** capacity **(F1)**, part size **(F2)**, velocity **(F3), Programming (P):** programming easiness **(P1),** error feedback **(P2)**. This study uses a combination of methods, TOPSIS and AHP. These methods have been used to evaluate criteria. First of all, the weights or relative importance of the considered criteria are calculated using AHP method. Next, TOPSIS method has been applied to solve robot selection problem. The results of the calculations are shown in Table 1, Table 2, Table 3 and Table 4, respectively.

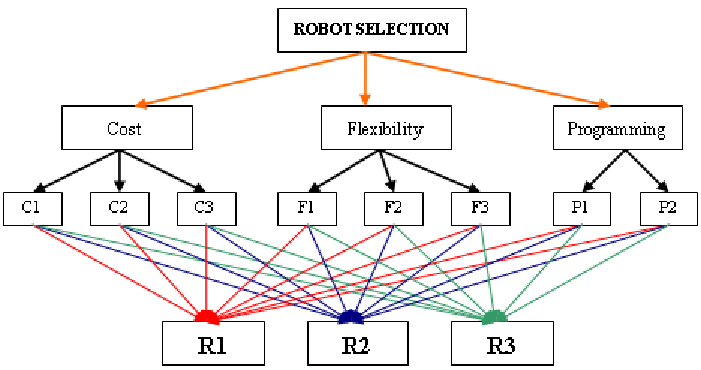

Figure 1. Hierarchical structure.

5. CONCLUSIONS

The aim of this paper is to solve the robot selection problem using two multi-criteria decision- making (MCDM) methods, AHP and TOPSIS, for a given industrial application. Firstly, the weights of the considered criteria are calculated using AHP method. Secondly, TOPSIS method has been applied to solve robot selection problem. According to the calculations, the ranking order of three robots is ***R2***, ***R3*** and ***R1*** for the problem.

Table 1. Priorities of criteria and sub-criteria.

Criteria	Priorities of criteria	Sub-criteria	Local priorities of sub-criteria	Global priorities of sub-criteria
C	0,6196	C1	0,1932	0,1197
		C2	0,0833	0,0516
		C3	0,7235	0,4483
F	0,2243	F1	0,6333	0,1420
		F2	0,2605	0,0584
		F3	0,1062	0,0238
P	0,1560	P1	0,7500	0,1170
		P1	0,2500	0,0390

Table 2. Preference degree of the alternatives.

	Local preference degree of the alternatives		
Sub-criteria	**R1**	**R2**	**R3**
C1	0,5390	0,2973	0,1638
C2	0,6196	0,2243	0,1560
C3	0,5390	0,1638	0,2973
F1	0,5889	0,2519	0,1593
F2	0,4905	0,3119	0,1976
F3	0,4905	0,3119	0,1976
P1	0,6230	0,1373	0,2395
P2	0,5390	0,1638	0,2973

Table 3. Positive ideal solutions A^+ and negative ideal solutions A^-.

A^+	0,0308	0,0119	0,1153	0,1267	0,0467	0,0190	0,1070	0,0330
A^-	0,1013	0,0472	0,3793	0,0343	0,0188	0,0077	0,0236	0,0100

Table 4. d_i^+, d_i^- values and relative closeness for each alternative.

Alternatives	d_i^+	d_i^-	ξ_i
R1	0,2756	0,1301	**0,3207**
R2	0,1172	0,2706	**0,6978**
R3	0,1511	0,1885	**0,5551**

6. REFERENCES

[1] Rao R.W., Patel B.K., Parnichkun M.: Industrial Robot Selection Using A Novel Decision Making Method Considering Objective and Subjective Preferences, Robotics and Autonomous Systems, 59, 367-375, 2011,

[2] Kumar R., Garg R.K.: Optimal selection of robots by using distance based approach method, Robotics and Computer-Integrated Manufacturing, 26, 500-506, 2010,

[3] Parkan C., Wu M.L.: Decision-making and performance measurement models with applications to robot selection, Computers & Industrial Engineering, 36, 503-523, 1999,

[4] Chatterjee P., Athawale V.M., Chakraborty S.: Selection of industrial robots using compromise ranking and outranking methods, Robotics and Computer-Integrated Manufacturing, 26, 483-489, 2010,

[5] Sharma M.J., Moon I., Bae H.: Analytic hierarchy process to assess and optimize distribution network, Applied Mathematics and Computation, 202, 256-265, 2008,

[6] Chang C.W., Wu C.R., Lin C.T., Lin H.L.: Evaluating digital video recorder systems using analytic hierarchy and analytic network processes, Information Sciences, 177, 3383-3396, 2007,

[7] Chung S.H., Lee A.H.I., Pearn W.L.: Product Mix Optimization for Semiconductor Manufacturing Based on AHP and ANP Analysis, Int. J. Adv. Manuf. Technol., 25, 1144-1156, 2005,

[8] Jiang J., Chen Y.W., Chen Y.W., Yang K.W., TOPSIS with fuzzy belief structure for group belief multiple criteria decision making, Expert Systems with Applications, 38, 9400-9406, 2011,

[9] Tan C.: A multi-criteria interval-valued intuitionistic fuzzy group decision making with Choquet integral-based TOPSIS, Expert Systems with Applications, 38, 3023-3033, 2011,

[10] Park J.H., Park I.Y., Kwun Y.C., Tan X.: Extension of the TOPSIS method for decision making problems under interval-valued intuitionistic fuzzy environment, Applied Mathematical Modelling, 35, 2544-2556, 2011,

[11] Krohling R.A., Campanharo V.C.: Fuzzy TOPSIS for group decision making: A case study for accidents with oil spill in the sea, Expert Systems with Applications, 38, 4190-4197, 2011.