World Academy of Science, Engineering and Technology
International Journal of Industrial and Manufacturing Engineering
Vol:5, No:4, 2011

An MCDM Approach to Selection Scheduling Rule in Robotic Flexible Assembly Cells

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***Abstract*—**Multiple criteria decision making (MCDM) is an approach to ranking the solutions and finding the best one when two or more solutions are provided. In this study, MCDM approach is proposed to select the most suitable scheduling rule of robotic flexible assembly cells (RFACs). Two MCDM approaches, Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) are proposed for solving the scheduling rule selection problem. The AHP method is employed to determine the weights of the evaluation criteria, while the TOPSIS method is employed to obtain final ranking order of scheduling rules. Four criteria are used to evaluate the scheduling rules. Also, four scheduling policies of RFAC are examined to choose the most appropriate one for this purpose. A numerical example illustrates applications of the suggested methodology. The results show that the methodology is practical and works in RFAC settings.

***Keywords*—**AHP, TOPSIS, Scheduling rules selection

I. Introduction

ROBOTIC Flexible Assembly Cells (RFACs) are systems composed of industrial robot(s), assembly stations and an automated material handling system, all controlled by a central computer[1, 2]. The potential benefits of RFAC are the flexibility to assemble a variety of products, as well as ease to modify and reconfigure [3]. In contrast, the difficulties of RFAC are the need for complex a scheduling policy to prevent collisions between robots and other equipments in the cell [4]. Research dealing with scheduling proble m in RFAC, has been carried out by Lee and Lee [5], Jiang et al. [6], Basran et al. [7], Dell Valle and Camacho [8], Nof and Drezner [9], Lin et al. [10], Pelagagge et al. [11], Sawik [12], Rabinowitz et al. [13], Glibert et al. [14], Hsu and Fu [15] and Brussel et al. [16]. All previous research work presented above described technique to scheduling RFACs for assembly of single-product.

In our previous study [17, 18], scheduling RFACs for concurrent assembly of multi-products has been proposed. In last study [18], four scheduling rules are implemented. Also, four criteria to evaluate the scheduling results are suggested.

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The scheduling results showed that making a decision of the best scheduling rule based on multi criteria is a considerably complex task, as shown in Fig. 1. This study does not describe how to select the most suitable scheduling rule.

A suitable scheduling rule selection is a crucial activity for any manufacturing system, the reason being that a good scheduling rule can positively affect the productivity. Additionally, the proper scheduling rule can enhance utilisation and flexibility of the system.

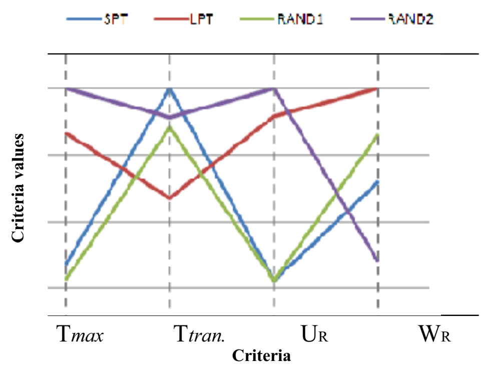

Fig. 1 Sensitivity analysis of scheduling rules with criteria

In general, scheduling rule selection problem implies that a set of rules should be evaluated and ranked according to different criteria, which are conflicting with each other. Accordingly, scheduling rule selection is considered as a multi-criteria decision-making (MCDM) problem.

The aim of this paper is to propose a methodology to select the best scheduling rule of RFACs, using MCDM method. This paper is organised as follows: MCDM methods are described in section II. In section III, the proposed methodology is introduced. A numerical example is provided in section IV. Conclusion and further research are presented in section V.

II. MCDM Method

Several methods have been proposed to solve MCDM problems. The most well known methods are TOPSIS [19], AHP [20], Electre [21], Promethee [22] and SMART [23]. There is no universally accepted MCDM method, but some methods are more suitable than others to solve particular decision problems [24].

In the literature, several studies have combined AHP with TOPSIS to solve different decision making problems. For example, Lin et al. [25] used AHP and TOPSIS to improve customer-driven product design process. Shyjith et al. [26] combined AHP-TOPSIS for the selection of maintenance strategy for a textile industry. Athawale and Chakraborty [27] applied AHP and TOPSIS to solve the conveyor belt material selection problem, also Chakladar and Chakraborty [28] developed methodology based on TOPSIS and AHP to select the most appropriate non-traditional machining processes. Accordingly, a combined AHP with TOPSIS has attracted significant attention to solve many industrial problems.

AHP (Analytic Hierarchy Process) method was originally developed by Saaty [19]. AHP is well-known MCDM method, which is assisting the decision maker to set criteria priorities. AHP consists of three main stages: Constructing pair-wise comparison matrix, synthesize judgments and check for consistency [29].

A. Construct a Pair-Wise Comparison Matrix

The matrix of pair-wise comparisons is constructed from $i \times j$ elements, Where i, j are the number of criteria (n), as follow:

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1j} \\ a_{21} & 1 & \cdots & a_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{ij} \end{bmatrix} \quad (1)$$

In the matrix, a_{ij} represents the value of comparative of *i* criterion with respect to j criterion. $a_{ij} = \frac{1}{a_{ji}}$ and $a_{ij} = 1$ when $i = j$. The comparisons between each criterion are made using fundamental scale of Saaty, which is represent on a nine point scale, as shown in table I.

TABLE I
PAIR WISE COMPARISON IN AHP PREFERENCE [19]

Definition	Intensity of importance
Equally important	1
Moderately more important	3
Strongly more important	5
Very strongly more important	7
Extremely more important	9
Intermediate values	2,4,6,8

B. Synthesize Judgments

Synthesize judgments represent a procedure of calculating the weight of each criterion. This procedure involves three steps.

1) Sum the values of the elements in each column of pair-wise comparison matrix A.
2) Divide each element pair-wise comparison matrix by its column total to obtain the normalized pair-wise comparison matrix.
3) Calculate average of elements in each row in the normalized matrix A, which is represented the weight of each criterion.

C. Check for Consistency

Check for consistency is described as a key to check the inconsistency of the subjective values of the matrix A, by calculating consistency ratio (*CR*). If *CR* is less than or equal 0.10, the values of subjective judgment is acceptable. If CR is more than 0.10, subjective judgment is unacceptable and need to be altering. *CR* can be calculated using the following steps:

1) Compute the maximum eigenvalue (λ_{max}). λ_{max} can be computed by calculate the consistency value (CV) of each raw using equation 2, then divided the summation of CV by n to obtain λ_{max} as shown in equation 3.

$$CV_i = \frac{\left(\sum_{j=1}^{n} a_{ij} \times w_j\right)}{w_j} \quad \forall\, i; i = 1,2,\ldots.n \quad (2)$$

$$\lambda_{max} = \frac{\sum_{i=1}^{n} CV_i}{n} \quad (3)$$

2) Calculate the consistency index (*CI*) using the following equation.

$$CI = (\lambda_{max} - n)/(n-1) \quad (4)$$

3) Divided consistency index (*CI*) by random index (RI) to get CR, as follow. The value of RI depends on n. RI values corresponding with n is listed in table II.

TABLE II
THE VALUE OF RANDOM INDEX RELATING TO MATRIX SIZE

n	1	2	3	4	5	6	7	8
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method was initially presented by Hwang and Yoon [19]. TOPSIS is one of the common methods used to solve multiple-criteria decision-making (MCDM) problems. The basic idea of TOPSIS method is that the selected alternative should have close to the best of ideal solution and farthest from the worst one [25, 26]. The procedural steps of TOPSIS are stated as follows [19]:

A. Construct Decision Matrix

The first step of the TOPSIS method is to build the $\mathbf{m \times n}$ decision matrix *DM.*

$$\begin{array}{c} \\ DM = \end{array} \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{matrix} C_1 & C_2 & \cdots & C_n \end{matrix} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \end{array} \quad (5)$$

Where *i* is criterion index (*i = 1 . . . m*); j is alternative index (*j = 1 . . . n*). $C_1, C_2, \ldots, C_n$ are denoted the criterion: and $A_1, A_2, \ldots, A_m$ are denoted the possible alternative. The elements x_{ij} of matrix are represented the values of criteria i with respect to alternative j.

B. Calculate Normalized Decision Matrix

The normalized values r_{ij} of the normalized decision matrix are computed using the following equation:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad \forall j \tag{6}$$

C. Construct Weighted Normalized Decision Matrix

Assign set of weight for each criteria W= ($w_1, w_2, \ldots, w_l$), then multiply each element of each column of the normalized decision matrix by its assigned weight. The new matrix $V = v_{ij} = [w_j r_{ij}]$ is defined as follow:

$$V = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \cdots & w_j r_{1j} \\ w_1 r_{21} & w_2 r_{22} & \cdots & w_j r_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ w_1 r_{i1} & w_2 r_{i2} & \cdots & w_j r_{ij} \end{bmatrix} \tag{7}$$

D. Identify Ideal and Non-Ideal Solutions

The ideal (A^+) and the non-ideal (A^-) solutions are defined by the equations given below.

- Ideal solutions

$$A^+ = \{(\max_i v_{ij} \mid j \in J), (\min_i v_{ij} \mid j \in J')\} = \{v_1^+, v_2^+, \ldots, v_n^+\} \tag{8}$$

- Non-ideal solutions

$$A^- = \{(\min_i v_{ij} \mid j \in J'), (\max_i v_{ij} \mid j \in J)\} = \{v_1^-, v_2^-, \ldots, v_n^-\} \tag{9}$$

Where J is associated with the beneficial attributes and J' is associated with the non-beneficial attributes.

E. Calculate The Separation Measure

Separation (S^+, S^-) of each alternative from the ideal solution (A^+) and non-ideal (A^-) solution can be calculated as follow:

$$S^+ = \sqrt{\sum_{j=1}^{n} \left(v_j^+ - v_{ij}\right)^2}, \qquad \text{for } i = 1, \ldots, m \tag{10}$$

$$S^- = \sqrt{\sum_{j=1}^{n} \left(v_j^- - v_{ij}\right)^2}, \qquad \text{for } i = 1, \ldots, m \tag{11}$$

F. Calculate The Relative Closeness of Ideal Solution

The relative closeness of alternative A_i with respect to the ideal solution A^+ is computed by the equations given below.

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-}, \qquad i = 1, \ldots, m \tag{12}$$

G. Rank The Preference Order

A set of alternatives can be ranked in descending order according to the value of C_i. The larger value denotes the better the performance of the alternative.

III. Proposed Methodology

The proposed methodology for the scheduling rule selection problem composed of three main stages: (1) problem definition, (2) AHP computation and (3) TOPSIS computation. In the first stage, alternatives scheduling rules and the criteria to be used in evaluation are presented. Additionally, the decision hierarchy is constructed. After forming a hierarchical tree known as a decision hierarchy, criteria used in scheduling rule selection are assigned weights using AHP computation stage. In this stage, pair-wise comparison matrix is created, based on the judgement of decision-maker, which determines the values of this matrix. Then, the relative weight of each criterion is computed based on the pair-wise comparison matrix. After that, the decision-maker examines the values of criteria weights. In the last stage, scheduling rules alternatives are analysed and ranked using TOPSIS method. Subsequently, the most suitable scheduling rule is selected according to the ranking of the alternatives. Schematic of the proposed methodology is depicted in fig. 2.

IV. Numerical Example

In this section, a numerical example is proposed in order to demonstrate the usefulness of the combined AHP and TOPSIS methods for selecting the most suitable scheduling rule of RFAC. Three stages are considered: problem definition, AHPP method and TOPSIS method, which are mentioned in fig. 2.

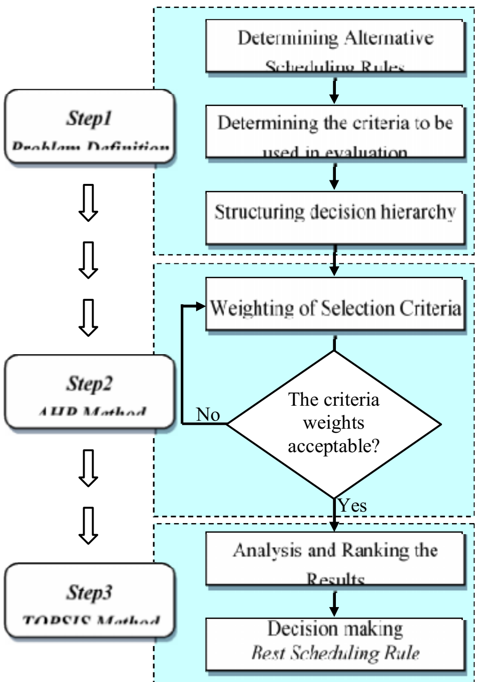

Fig. 2 Schematic of proposed methodology

A. Problem Definition

In this study, four alternatives scheduling rules are considered, namely short processing time (SPT), long processing time (LPT), random (RAND1) and random (RAND2). In addition, two main criteria are used, namely time-based measures and utilisation-based measures. The first criteria are divided into two sub-criteria: scheduling length (T_{max}) and total transportation time (γ_l). The second one is divided also into two sub-criteria: utilisation rate (U_R) and workload rate (W_R). The data concerning alternatives scheduling rules and evaluation criteria are presented in table III, which is reported in our previous study [18].

TABLE III
DECISION MATRIX

Criteria	T*max* (Sec)	T*tran.* (Sec)	UR	WR
Max/Min	Min	Min	Max	Max
SPT	296	67	62%	79%
LPT	266	73	71%	85%
RAND1	300	69	62%	82%
RAND2	257	68.5	72.5%	74%

After determining the alternative scheduling rules and the criteria to be used in evaluation, a decision hierarchy tree can be described simply by four levels. The first level represents the goal of the decision problem which is described as "Selection of the best Scheduling Rule". The criteria are on the second level. The sub-criteria are represented at the third level of the hierarchy. The alternatives are on the last level of the hierarchy which are denoted on the decision options, as shown in fig. 3.

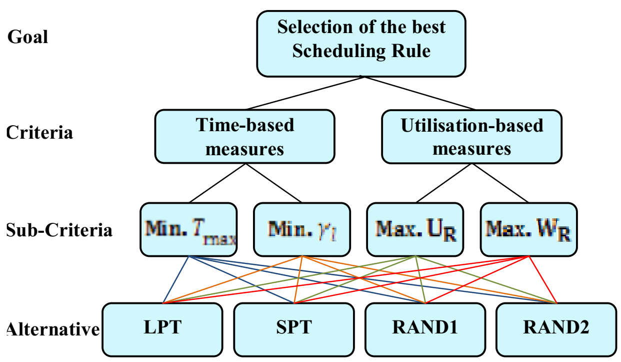

Fig. 3 The decision hierarchy of scheduling rule selection

B. AHP Method

When constructing the hierarchical tree for scheduling rule selection problem, the criteria to be used in this study are assigned weights, by construct pairwise comparison matrix, using AHP. The judgement of decision maker is determined the values of this matrix, using the scale, listed in Table II. For example, experience indicates that the criterion T_{max} and W_R are important when weigh against U_R, hence, a value 3 and 2 are assigned when pairwise comparing $T_{max} \rightarrow U_R$ with and $W_R \rightarrow U_R$ respectively. The $U_R \rightarrow T_{max}$ and $U_R \rightarrow W_R$ are placed inverse values 1/3 and 1/2 respectively. The values of the diagonal positions in the matrix are equal 1, as shown in table IV.

TABLE IV
PAIR WISE COMPARISON MATRIX

Criteria	T*max*	T*tran.*	UR	WR
T*max*	1	2	3	1
T*tran.*	1/2	1	2	1
UR	1/3	1/2	1	1/2
WR	1	1	2	1

After applying the last two stages as mentioned in AHP method, the normalised weights of criteria obtained from AHP calculations are shown in fig. 4.

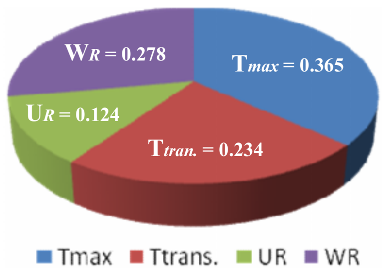

Fig. 4 Weights of criteria obtained from AHP calculations

According to step C in section AHP, the results of λ_{max}, CI, RI and CR are provided in table V. The value of CR is 0.02, which is less than the maximum allowable value (0.10). As a result, the decision process can be continued and the values of weights are consistent.

TABLE V
RESULTS OBTAINED FROM AHP METHOD

λ_{max}	CI	RI	CR
4.045	0.015	0.9	0.02

C. TOPSIS method

After assigned weight to each criterion, scheduling rules alternatives are ranked using TOPSIS method. This method is implemented according to the procedures listed in section II.

1) Construct decision matrix using equation (5), as shown in table VI.
2) Calculate normalized decision matrix listed in table VII using equation (6).
3) Construct weighted normalized decision matrix using equation (7), as shown in table VIII.
4) Identify ideal (A^+) and the non-ideal (A^-) solutions by the equations (8, 9) as follow:

$$A^+ = \{0.197, 0.121, 0.067, 1.147\}$$
$$A^- = \{0.169, 0.111, 0.057, 1.128\}$$

5) Calculate the separation measure using the equations (10, 11) and, as shown in table IX.
6) Calculate the relative closeness of ideal solution listed in table IX, using equation (12).

TABLE VI
DECISION MATRIX

Alternative	T_{max}	$T_{tran.}$	U_R	W_R
SPT	0.003	0.015	62%	79%
LPT	0.004	0.014	71%	85%
RAND1	0.003	0.014	62%	82%
RAND2	0.004	0.015	72.5%	74%

TABLE VII
THE NORMALIZED DECISION MATRIX

Alternative	T_{max}	$T_{tran.}$	U_R	W_R
SPT	0.469	0.517	0.462	0.493
LPT	0.522	0.474	0.529	0.531
RAND1	0.463	0.502	0.462	0.512
RAND2	0.541	0.506	0.541	0.462

TABLE VIII
WEIGHTED NORMALIZED DECISION MATRIX

Alternative	T_{max}	$T_{tran.}$	U_R	W_R
SPT	0.171	0.121	0.057	0.137
LPT	0.191	0.111	0.066	0.147
RAND1	0.169	0.117	0.057	0.142
RAND2	0.197	0.119	0.067	0.128

TABLE X
SEPARATION MEASURE AND RELATIVE CLOSENESS COEFFICIENT

Alternative	S1	S2	C
SPT	0.030	0.013	0.311197
LPT	0.012	0.030	0.713385
RAND1	0.031	0.015	0.333676
RAND2	0.019	0.031	0.614983

7) Finally, rank the preference order. The final ranking of the scheduling rules is LPT - RAND2 - RAND1 - SPT in descending order of preference. LPT is observed to be the superior scheduling rule for RFAC, while SPT is the worst one on this numerical example, as show in fig. 4.

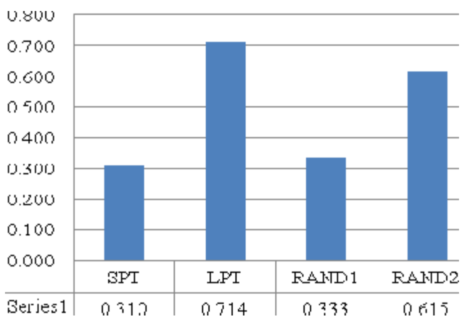

Fig. 5 The final ranking of scheduling rules

V. CONCLUSION

This paper describes the process of selecting the most suitable scheduling rule of RFACs. The process is based on two MCDM approaches, namely, AHP and TOPSIS, which are combined in proposed methodology to find the best scheduling rule alternatives relating to identified criteria. AHP is used to assign weights of the evaluation criteria, and TOPSIS method is employed to achieve final ranking of scheduling rules.

In this study, the criteria values based on the decision maker's experience. In reality, some criteria have uncertain value which is difficult to be measured accurately. In such situation, fuzzy logic can be applied not just to overcome this difficulty, but also consider the real-life situations of the system.

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