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AN APPLICATION OF INTEGRATED MULTI CRITERIA DECISION MAKING (AHP/COPRAS) MODEL FOR RANKING AND SELECTION OF FLEXIBLE MANUFACTURING SYSTEM

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ABSTRACT

The aim of the present work is to propose an integrated multi criteria decision making (MCDM) methodology for ranking selection of flexible manufacturing system. The proposed model is based on Analytical hierarchy process (AHP) method and COmplex PRoportional ASsessment (COPRAS) method. AHP method is used to determine the relative normalized weights of FMS selection criteria and COPRAS method is employed to find FMS utility index of each FMS alternatives. Furthermore, all FMS alternatives are ranked and arranged in the descending order according to FMS utility index value and FMS alternative is selected as best candidate for a given application whose FMS utility index value is the highest or ranked first. One numerical application of FMS selection problem presented to demonstrate and validate the applicability integrated multi criteria decision making AHP/COPRAS method for effective ranking and selection of flexible manufacturing system.

Key words: *Multi Criteria Decision Making, FMS, AHP Method, COPRAS Method.*

1. Introduction

A Flexible Manufacturing Systems (FMSs) are characterized as an integrated, computer-controlled complex arrangement of automated material handling devices and computer numerically controlled (CNC) machine tools that can simultaneously process medium-sized volumes of a variety of part types [1]. The use of FMS in manufacturing industries provides better inventory control, high quality product, decrease in labour cost, reduce production time and increase the productivity. Hence, nowadays manufacturing industries are doing investments in FMS. Moreover, there is a need of effective evaluation and justification for investing and selecting appropriate FMS. Selection of the FMS not depends only on the cost alone but it also depends on the other factors known as attributes like floor space requirements, flexibility, number of workers required, throughput time, etc,[2]. To address this issue of selection of appropriate flexible manufacturing systems, various mathematical model and research methodologies are proposed with considering case studies, empirical research, analytical and simulation modeling

In the past decade, enormous work reported for selection of FMS using MCDM method. Talluri et al. [3] presented a nonparametric stochastic procedure for FMS evaluation with DEA. Chan et al. [4] developed an intelligent decision support tools to aid the design of flexible manufacturing systems which uses simulation and AHP. Karsak and Tolga [5] proposed a fuzzy multi-criteria decision-making procedure for evaluating advanced manufacturing system investments. Both economic evaluation criterion and strategic criteria were considered for selection. Karsak and Kuzgunkaya [6] proposed a fuzzy multiple objective programming approach for the selection of an FMS. Tseng [7] proposed a game theoretical model for selection of flexible manufacturing technologies. Bayazit [8] used AHP to implement FMS in a tractor manufacturing plant. Kulak and Kahraman [9] proposed axiomatic design (AD) principles for multiple attribute comparison of advanced manufacturing systems. Rao [10] presented a decision-making model for FMS selection using graph theory and matrix approach (GTMA) method. Rao [11] presented combined (TOPSIS and AHP) multiple attribute decision making method for evaluating flexible manufacturing systems. Liu [12] presented a DEA/AR approach for selection of flexible manufacturing systems. Rao and Parnichkun [13] presented combinatorial mathematics-based decision-making method for selection of flexible manufacturing system. Chuu [14] presented fuzzy multiple attributes group decision making with multiple fuzzy information for selecting the advanced manufacturing technology.

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The literature study reveals that in the most of the reported work, researchers applied fuzzy decision support system, axiom design principle, Data Envelop Analysis (DEA), Graph theory and matrix approach (GTMA), and multi attribute decision making methods (MADM) such as Analytical hierarchy process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method, etc. for the justification, evaluation, and selection of FMS.

This paper presents AHP/COPRAS model for the selection of appropriate FMS system for a given industrial application. The proposed model is integration of AHP method and COPRAS method. AHP method is used to determine relative normalized weights of FMS selection criteria and COPRAS method is employed for ranking and selection of FMS alternatives.

2. Methodology Review

Multi criteria decision making (MCDM) is the special branch of operation research which deals to make decisions in the presence of multiple criteria. Mostly, MCDM is classified as multi objective decision making (MODM) method and multi attribute decision making (MADM) method. In addition, MODM method deals with solving design related problems in which decision maker have to select optimal valued of the decision variables with satisfying the objective functions and constraints while MADM method are widely used to solve selection problems in which the best alternative is selected from the given list of finite and pre-determined list of alternatives. The present study considered the selection problem and it's solved using well known MADM method. The general procedure for solving MADM problem is shown in Fig. 1.

Many MADM methods are reported in the literature for selection, evaluation, and ranking of alternative in decision making problem [10, 15,16,17,18]. The present study considered the AHP method and COPRAS method for solving FMS selection problem.

The Analytical Hierarchy Process (AHP) is a potential decision making tool developed by Saaty [17]. AHP is particularly useful for evaluating complex multi-attribute alternatives involving subjective or objective criteria.

In the present study, AHP method is used only for the determination of relative normalized or subjective weight (W_j) of FMS selection attributes. A determination of subjective weight is started with the constructing the pair-wise decision matrix according to the judgments taken by decision maker for assigning relative importance between attributes using a scale of relative importance suggested by Saaty[17].

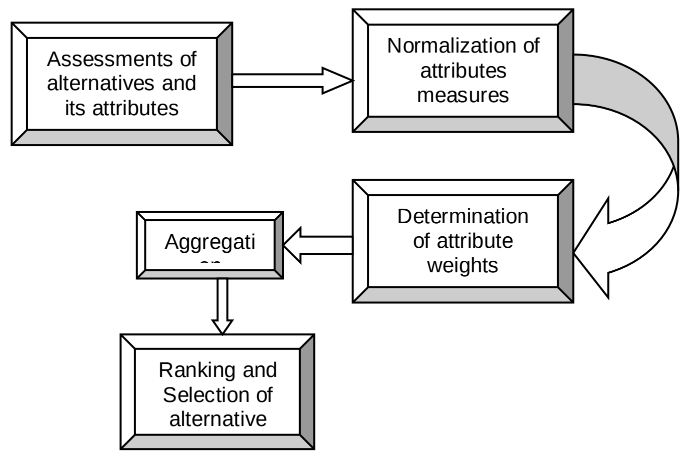

Fig. 1 MADM Methodology

A COPRAS method is well known MADM method developed by Zavadskas et al. [18] and widely used for the civil engineering application [18,19]. Hence, in this study COPRAS method is used first time for selection of FMS.

3. Integrated MCDM Method (AHP/COPRAS MODEL)

This section describes the proposed integrated AHP/COPRAS model as MADM method for selection of appropriate FMS. The main steps of the proposed model are described below.

Step-1: Define the problem

This step is associated with to define the objective and identification of all the possible alternatives and its attributes. Let A = {A_i for i = 1,2,3,…m} be a set of FMS alternative, C = {C_j for j =1,2,3,…,n } be a set of decision criteria or attributes of FMS selection problem, W = {W_j for j =1,2,3,…,n } be a set of weight of criteria C_j, and Q_{ij} is the performance of alternative A_i when it examined with criteria C_j. the FMS selection attributes are mostly categories into two way; qualitative (subjective value) attributes and quantitative (objective value) attributes.

Step-2: Formulate the decision matrix

The formulation of the decision matrix is an important step for solving any MADM problem. In the decision matrix all the performance measure of attributes (Q_{ij}) are represented into quantitative form or in numerical value (x_{ij}) as shown in Table 1. If the performance or measures of attributes are in qualitative form, i.e. linguistic term, then it is required to convert the linguistic terms into crisp score using fuzzy conversion scale. In the present study, 11-point scale is adopted to convert the linguistic terms into crisp value proposed by Venkatasamy and Agrawal [20] as shown in Table 2.

Table 1: Decision Matrix

Alternatives	Criteria			
	C_1	**C_2**	**…..**	**C_n**
A_1	x_{11}	x_{12}	…..	x_{1n}
A_2	x_{21}	x_{22}	…..	x_{2n}
:	:	:	:	:
:	:	:	:	:
A_m	x_{m1}	x_{m2}	…..	x_{mn}

Table 2: Crisp Value of FMS Selection Attributes[20]

Linguistic terms of FMS Selection Attribute	Fuzzy Number	Crisp Value of FMS Selection Attribute
Exceptionally low	M1	0.045
Extremely low	M2	0.135
Very low	M3	0.255
low	M4	0.335
Below average	M5	0.410
Average	M6	0.500
Above average	M7	0.590
High	M8	0.665
Very high	M9	0.745
Extremely high	M10	0.865
Exceptionally high	M11	0.955

Step-3: Formulate the normalized decision matrix

In this step all the attribute measures are normalized to convert attribute data into compatible form in range of zero to one. This all normalized attribute measures are represented in the matrix form known as normalized decision matrix as shown in Eq. (1).

$$\bar{X} = \begin{matrix} A_1 \\ A_2 \\ \cdots \\ A_m \end{matrix} \begin{bmatrix} \bar{x}_{11} & \bar{x}_{12} & \cdots & \bar{x}_{1n} \\ \bar{x}_{21} & \bar{x}_{22} & \cdots & \bar{x}_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \bar{x}_{m1} & \bar{x}_{m2} & \cdots & \bar{x}_{mn} \end{bmatrix} \quad (1)$$

In this $\left[\bar{X}\right]_{M\times N}$ matrix, value of $\bar{x}_{ij}$ is calculated using Eq. (2).

$$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{j=1}^{m} x_{ij}} ; \forall i, j \quad (2)$$

Step-4: Formulate pair-wise comparison matrix

A pair-wise comparison matrix is formulated to determine relative normalized weights of FMS selection attributes. A pair wise comparison matrix is constructed using a 9-pointt scale of relative importance as shown in Table 3. Let, there are m attributes are involved in the decision making, the pair wise comparison of attribute i with attribute j yields a square matrix $A1_{m\,xm}= [r_{ij}]_{m\times m}$, where a_{ij} denotes the comparative importance of attribute i with respect to attribute j. In the matrix, $r_{ij} = 1$ when i = j and $r_{ji} = 1/r_{ij}$. Finally, a pair-wise comparison matrix is presented as shown in Eq.(3).

$$A1_{mxm} = \begin{matrix} C1 \\ C2 \\ C3 \\ - \\ - \\ Cm \end{matrix} \begin{bmatrix} 1 & r_{12} & r_{13} & -- & -- & r_{1m} \\ r_{21} & 1 & r_{23} & -- & -- & r_{2m} \\ r_{31} & r_{32} & 1 & -- & -- & r_{3m} \\ -- & -- & -- & 1 & -- & -- \\ -- & -- & -- & -- & 1 & -- \\ r_{m1} & r_{m2} & r_{m3} & -- & -- & 1 \end{bmatrix} \quad (3)$$

Table 3: Scale of Relative Importance [17]

Scale	Importance	Meaning for Attributes
1	equal importance	Two attributes are equally important
3	moderate importance	One attribute is moderately important over the other
5	strong importance	One attribute is strongly important over the other
7	very importance	One attribute is very important over the other
9	absolute importance	One attribute is absolutely important over the other
2,4,6,8	compromise importance between 1,3,5,7 and 9	

Step-5: Determination of relative normalized weight

The estimation of attributes weight plays an important role in MADM approach due to complexity and uncertainty of real world decision making problems. A relative normalized weight of each FMS selection attributes are calculated using Eq. (4) and Eq.(5).

$$GM_j = \left[\prod_{j=1}^{m} r_{ij}\right]^{\frac{1}{m}} \quad (4)$$

$$W_j = \frac{GM_j}{\sum_{j=1}^{m} GM_j} \quad (5)$$

If the judgment matrix or comparison matrix is inconsistent then judgment should be reviewed and improved it to obtain the consistent matrix. Hence, consistency test will be carried out using following steps.

- Calculate matrices; A3 = A1 x A2 and A4 = A3 / A2, Where; A1= $[r_{ij}]_{m\times m}$, A2 = $[W_1, W_2, ..,W_j]^T$
- Calculate Eigen value λ_{max} (average of matrix A4)
- Calculate the consistency index: CI = $(\lambda_{max} - m) / (m - 1)$
- Calculate the consistency ratio: CR = CI/RI, select value of random index (RI) according to number of attributes used in decision-making [17].
- If CR < 0.1, considered as acceptable decision, otherwise judgment of the analyst about the problem under study.

Step-6: Formulate the weighted normalized decision matrix

Now, the weighted normalized matrix (D_{ij}) is constructed by the multiplication of each normalized value of FMS selection attribute measures with its associated weight Wj. In addition, the weighted normalized decision matrix is represented as shown in Eq.(6).

$$D_{ij} = \begin{matrix} A_1 \\ A_2 \\ : \\ A_m \end{matrix} \begin{bmatrix} W_1 \cdot \bar{x}_{11} & W_2 \cdot \bar{x}_{12} & ... & W_m \cdot \bar{x}_{1n} \\ W_1 \cdot \bar{x}_{21} & W_2 \cdot \bar{x}_{22} & ... & W_m \cdot \bar{x}_{2n} \\ : & : & : & : \\ W_1 \cdot \bar{x}_{m1} & W_2 \cdot \bar{x}_{m2} & ... & W_m \cdot \bar{x}_{mn} \end{bmatrix} \quad (6)$$

Step-7: Compute maximizing normalized indices (α_{+i}) and minimizing normalized indices (β_{-i}).

In this step, sums of maximizing indexes (α_{+i}) value of each FMS alternative are computed for those attribute values whose larger values are more preferable and sums of minimizing indexes (β_{-i}) value of each FMS alternative are computed for those attribute values whose lower values are more preferable using Eq.(7).

Table 4: Date of FMS Selection Attributes [2]

Ai	C1	C2	C3	C4	C5	C6	C7	C8
FMS-1	8	Average	Excellent	75	15	High	100	570
FMS-2	10	Very High	Average	75	35	Very High	200	320
FMS-3	6	Average	Very High	90	28	Average	150	400
FMS-4	12	High	High	70	25	Average	90	290
FMS-5	15	Excellent	High	85	37	Very High	200	310

C1: Total Cost (in 10lacks Rs), C2: Flexibility, C3: Quality improvement, C4: Space requirement ($100ft^2$), C5:% Reduction in labour cost, C6: Market Adoptability, C7: WIP, C8: Throughput time (minutes).

$$\alpha_{+i} = \sum_{j=1}^{m} D_{+ij} \quad \text{and} \quad \beta_{-i} = \sum_{j=1}^{m} D_{-ij} \quad (7)$$

Step-8: Determine the minimal value of minimizing normalized indices β_{-I};

$$\beta_{-min} = \min_{i} \beta_{-i}; \quad (8)$$

Step-9: Determine the significance of each alternative

In this step relative weight or significance of each FMS alternative is computed based on maximizing indexes values and minimizing indexes values:

$$S_i = \alpha_{+i} + \frac{\beta_{-min} \sum_{i=1}^{n} \beta_{-i}}{\beta_{-i} \cdot \sum_{i=1}^{n} \frac{\beta_{-min}}{\beta_{-i}}} \quad (9)$$

Step-10: Compute FMS utility index (η)

FMS utility index η is computed by comparing FMS alternative with the most efficient FMS alternative using Eq. (10). FMS alternative with the greater value of Si is considered as efficient FMS alternative.

$$\eta_i = \frac{S_i}{S_{max}} \times 100\% \quad (10)$$

Step-11: Ranking and Selection of FMS alternative

After calculation of the FMS utility index η, FMS alternatives are ranked according to descending or ascending order to facilitate the managerial interpretation of the results. Pick up FMS alternative with leading position in the ranking as potential candidates.

4. A Case Study

To demonstrate and validate proposed method, one FMS selection case study is considered which is previously examined by Maniya and Bhatt [2] using Grey relational Analysis (GRA) method. The detail calculation explained below for selection of FMS using AHP/COPRAS method.

Step-1: The aim of the present study is to select appropriate FMS for a given industrial application. This example includes five FMS alternatives and eight FMS selection attributes such as Total cost, Flexibility, Quality improvement, Space requirement, Reduction in labour cost, Market Adoptability, WIP, and Throughput time. We considered the total cost, space requirement, throughput time, and WIP as non-beneficial and reduction in labour cost, market adoptability, flexibility, and quality improvement as beneficial attributes. The data of FMS selection attributes are given in Table 4.

$$
\begin{array}{c} \textbf{Attributes} \\ \\ \\ X_{n\times m} = \\ \\ \\ \end{array}
\begin{array}{c} \\ FMS-1 \\ FMS-2 \\ FMS-3 \\ FMS-4 \\ FMS-5 \end{array}
\begin{array}{c} \begin{array}{cccccccc} C1 & C2 & C3 & C4 & C5 & C6 & C7 & C8 \end{array} \\
\begin{bmatrix} 8 & 0.5 & 0.865 & 75 & 15 & 0.665 & 100 & 570 \\ 10 & 0.745 & 0.5 & 75 & 35 & 0.745 & 200 & 320 \\ 6 & 0.5 & 0.745 & 90 & 28 & 0.5 & 150 & 400 \\ 12 & 0.665 & 0.665 & 70 & 25 & 0.5 & 90 & 290 \\ 15 & 0.865 & 0.665 & 85 & 37 & 0.745 & 200 & 310 \end{bmatrix} \end{array} \qquad (11)
$$

Step -2: In this step a decision matrix is formulated by converting qualitative data into quantitative data. In the present study 11- point scale is adopted to convert the qualitative data in to quantitative data. Finally, the decision matrix is represented as shown in Eq.(11).

Step-3: A normalized FMS selection matrix is formulated using Eq.(1) and it is presented in the tabular format as shown in Table 5.

Table 5: A Normalized FMS Selection Decision Matrix

A_i	C1	C2	C3	C4	C5	C6	C7	C8
FMS-1	0.1569	0.1527	0.2515	0.1899	0.1071	0.2108	0.1351	0.3016
FMS-2	0.1961	0.2275	0.1454	0.1899	0.2500	0.2361	0.2703	0.1693
FMS-3	0.1177	0.1527	0.2166	0.2279	0.2000	0.1588	0.2027	0.2126
FMS-4	0.2353	0.2031	0.1933	0.1772	0.1786	0.1585	0.1216	0.1535
FMS-5	0.2941	0.2641	0.1933	0.2152	0.2643	0.2361	0.2703	0.1640

Step-4 and Step 5: A relative normalized weight of each FMS selection attribute is computed by assigning a relative importance between FMS selection attributes using AHP method. In this study we consider the same relative importance between FMS selection attributes and same relative normalized weight as same of Maniya and Bhatt [2]. Let, the decision maker prepare the following pair-wise comparison matrix to determine relative normalized weight of FMS selection attributes.

Table 6: A Pair-Wise Comparison Matrix [2]

	C_j	C1	C2	C3	C4	C5	C6	C7	C8
	C1	1	1	1	7	5	1	5	3
	C2	1	1	5	7	7	1	5	5
A1	**C3**	1	1/5	1	5	4	1	5	5
	C4	1/7	1/7	1/5	1	1/3	1/5	1/2	1/2
	C5	1/5	1/7	1/4	3	1	1/5	1	1
	C6	1	1	1	5	5	1	3	3
	C7	1/5	1/5	1/5	2	1	1/3	1	1
	C8	1/3	1/5	1/5	2	1	1/3	1	1

The relative normalized weight of each FMS selection attributes are: W_{c1} = 0.2034, W_{c2} = 0.2764, W_{c3} = 0.1653, W_{c4} =0.028, W_{c5} =0.047, W_{c6} = 0.183, W_{c7} = 0.0483, W_{c8} = 0.0483.

Step-6: A weighted normalized decision matrix is constructed as explained in section 3. This weighted normalized decision matrix is shown in Table 7.

Table 7: A Weighted Normalized FMS Selection Decision Matrix

Alternative	C1	C2	C3	C4	C5	C6	C7	C8
Max. or Min of C_j	Min	Max	Max	Min	Max	Max	Min	Min
FMS-1	0.0319	0.0422	0.0416	0.0053	0.0050	0.0386	0.0065	0.0146
FMS-2	0.0399	0.0629	0.0240	0.0053	0.0118	0.0432	0.0131	0.0082
FMS-3	0.0240	0.0422	0.0358	0.0064	0.0094	0.0290	0.0098	0.0102
FMS-4	0.0479	0.0561	0.0320	0.0050	0.0084	0.0290	0.0059	0.0074
FMS-5	0.0598	0.0730	0.0320	0.0060	0.0124	0.0432	0.0131	0.0079

Step-7 to Step-11: The results of calculations of Step-7 to Step-11 are summarized in Table 8. A result of proposed model shows that FMS-5 is the first choice, FMS-2 is the second choice, and FMS-3 is the third choice, FMS-1 is the fourth choice and FMS-4 is the last choice using AHP/COPRAS.

The alternative flexible manufacturing systems are arranged in the descending order of their FMS utility index. This can be arranged as: FMS-5 > FMS-2 > FMS-3 > FMS-1 > FMS-5.

Table 8: A Results of AHP/COPRAS Model for Selection of FMS

Alternative (A_i)	Total sum of Maximizing normalized indices (α_{+i})	Total sum of Minimizing normalized indices (β_{+i})	Alternative's significance (S_i)	FMS utility index (η_i)	Rank
FMS-1	0.1274	0.05832	0.1988	95.32	4
FMS-2	0.1419	0.06643	0.2046	98.09	2
FMS-3	0.1164	0.05032	0.1992	95.50	3
FMS-4	0.1255	0.06611	0.1885	90.38	5
FMS-5	0.1606	0.08683	0.2086	100	1

4.1 Result comparison

Now, to validate the results obtained using integrated proposed AHP/COPRAS model are compared with the published results of FMS selection example using grey relational analysis (GRA) method. A result comparison is shown in Table 9.

Table 9: A Result Comparison

	Proposed method		GRA method [2]	
Alternative	FMS utility index	Rank	GRA grade	Rank
FMS-1	95.32	4	0.5811	3
FMS-2	98.09	2	0.5471	4
FMS-3	95.50	3	0.5335	5
FMS-4	90.38	5	**0.6365**	**1**
FMS-5	**100**	**1**	0.5892	2

A result comparison clearly indicates that both the method suggest the different FMS selection alternative for a given industrial application. The proposed methodology suggests FMS-5 is an optimal choice and GRA method suggested FMS-4 is an optimal choice while proposed method suggests that FMS-4 is the last choice, even supposing weighage of all the FMS selection criteria are same. Hence, it is difficult for the decision makers to decide that which alternative is an optimal choice for the given industrial application. If one can observe the attribute measures of FMS selection alternatives shown in Table 4. FMS -5 has higher flexibility, good amount of reduction in labour cost and higher market adoptability compare to FMS -4 while cost of FMS-5 is slightly higher compare to FMS-4.

But this higher cost is justified looking to the other FMS selection attributes measures such as flexibility, reduction in labour cost and market adoptability. This discussion clearly confirms that the results obtained using proposed AHP/COPRAS method is more authentic, consistent and more effective compare to GRA method.

5. Conclusion

The proposed MADM method, COPRAS with integration of AHP is an effective tool for the selection of appropriate flexible manufacturing system. The ranking of FMS alternatives depends on attribute weights and on value of the considered attributes. The proposed integrated MADM method can be applied for any types of multi attribute decision making problems.

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