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Selection of Flexible Manufacturing System (FMS): A Synthesis of Three Multi Criteria Decision Making Approaches

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Abstract—*Globalization, flicking market requirements and modern lifestyle trends has put up tremendous challenge to manufacturing industries. The product cost is no longer the predominant factor affecting the manufacturers' perception. Flexible manufacturing is a concept that allows manufacturing systems to be built under high customized production requirement. The importance of using a Flexible Manufacturing System (FMS) to enhance firm competitiveness has been well accepted. The selection process must consider not only operational and financial aspects, but also be consistent with industry, market, organizational, and other strategic needs. This paper addresses the problem of selecting the most appropriate Flexible Manufacturing System (FMS) for a manufacturing organization. Here three multiple criteria decision making techniques VIKOR, improved PROMETHEE and ELECTRE III are used to facilitate decision making in the selection of a flexible manufacturing system (FMS). The model proposed in this paper determines the most appropriate FMS alternative through maximization of objectives. A numerical example is presented to illustrate these three multiple criteria decision making techniques for the selection of flexible manufacturing system (FMS).*

1. INTRODUCTION

In the current business scenario the competitiveness of any manufacturing industry is determined by its ability to respond quickly to the rapidly changing market and to produce high quality products at low costs. However, the product cost is no longer the predominant factor affecting the manufacturers' perception. Other competitive factors such as flexibility, quality, efficient delivery and customer satisfaction are drawing the equal attention. Manufacturing industries are striving to achieve these capabilities through automation, robotics and other innovative concepts such as just-in-time (JIT), Production planning and control (PPC), enterprise resource planning (ERP) etc. Flexible manufacturing is a concept that allows manufacturing systems to be built under high customized production requirement. The issues such as reduction of inventories and market-response time to meet customer demands, flexibility to adapt to changes in the market, reducing the cost of products and services to grab more market shares, etc have made it almost obligatory to many firms to switch over to flexible manufacturing systems (FMSs) as a viable means to accomplish the above requirements while producing consistently good quality and cost effective products. Flexible Manufacturing Systems (FMSs) present opportunities for manufacturers to improve their technology, competitiveness, and profitability through a highly efficient and focused approach to manufacturing effectiveness (Buzacott and Yao, 1986). The primary reason for implementing FMS lies in its versatility (flexibility). In general, increased flexibility enables a company to adjust more easily to changes in the market place and in customer requirements, while maintaining high quality standards for its products [1]. FMS is actually an automated set of numerically controlled machine tools and material handling systems, capable of performing a wide range manufacturing operations with quick tooling and instruction changeovers. Flexibility is an attribute that allows a mixed model manufacturing system to cope up with a certain level of variations in part or product style, without having any interruption in production due to changeovers between models. The reason, the FMS is called flexible, is that it is capable of processing a variety of different part styles simultaneously with the quick tooling and instruction changeovers. Also, quantities of productions can be adjusted easily to changing demand patterns. A flexible manufacturing system (FMS) is designed to combine the efficiency of a mass-production line and the flexibility of a job shop to produce a variety of work pieces on a group of machines (Chan, Kazerooni, & Abhary, 1997) [2].

2. RESEARCH METHODOLOGY

2.1 VIKOR Method

The VIKOR method was first proposed by Opricovic (1998) and Opricovic and Tzeng (2002) for multi-criteria optimization of complex systems with the Serbian name: VlseKriterijumska Optimizacija I Kompromisno Resenje (means multi-criteria optimization and compromise solution)

(Opricovic & Tzeng, 2004. The VIKOR procedure is divided into the following five steps:

1) Determine the best $f_j^*$and worst f_j^- values of all criterion functions. If the jth criterion function represents a merit, then

$$f_j^* = Max_i f_{ij} \ , f_j^- = Min_i f_{ij} \quad (1)$$

2) Compute the values S_i and R_i, i = 1,2,3,. . .,m, by the relations

$$S_i = \sum_{j=1}^{n} \frac{w_i(f_j^* - f_{ij})}{f_j^* - f_j^-} \quad (2)$$

$$R_i = \max \left[\frac{w_i(f_j^* - f_{ij})}{f_j^* - f_j^-}\right] \quad (3)$$

Where w_i is the weight of the jth criterion which expresses their relative importance of the criteria.

3) Compute the value Q_i, i = 1,2,3,...,m, by the relation

$$Q_i = v\left[\frac{S_i - S^*}{S^- - S^*}\right] + (1\text{-}v) \left[\frac{R_i - R^*}{R^- - R^*}\right] \quad (4)$$

Where $S^*= min_i S_i$, $S^- = max_i S_i$, $R^*= min_i R_i$, $R^- = max_i R_i$, and v is the weight of the strategy of maximum group utility, whereas (1-v) is the weight

2.2 PROMETHEE Method

PROMETHEE is developed by Brans (1982) and further extended by Brans and Vincke (1985) and Brans and Mareschal (1994). The methodology of PROMETHEE method is described below:

1) After calculating the weights, the preference function is selected. Let $P_{i,a1,a2}$be the preference function associated to the criterionc_i.

$$P_{i,a1,a2} = G_i[c_i(a1) - c_i(a2)]$$

$$0 \leq P_{i,a1,a2} \leq 1$$

Where $G_{i,}$ is a non-decreasing function of the observed deviation (d) between two alternatives a1 and a2 over the criterionc_i. In this case, the Usual Criterion is used to demonstrate the calculating processes of PROMETHEE, that is, 1 is used to replace the positive deviation and the rest is replaced with 0.

2) The multiple criteria preference index $\prod_{a1a2}$, is then defined as the weighted average of the preference functions P_i:

$$\prod_{a1a2} = \sum_{i=1}^{M} w_i P_{a1a2} \quad (5)$$

3) For PROMETHEE outranking relations, the leaving flow, entering flow and the net flow for an alternative are defined by the following equations:

$$\varphi^+(\text{a}) = \sum_{x \, \varepsilon \, A} \prod_{xa}, \quad (6)$$

$$\varphi^-(\text{a}) = \sum_{x \, \varepsilon \, A} \prod_{ax}, \quad (7)$$

$$\varphi(\text{a}) = \varphi^+(\text{a}) - \varphi^-(\text{a}) \quad (8)$$

φ^+(a) is called the leaving flow, φ^-(a) is called the entering flow andφ(a) is called the net flow. The net flow values are used to indicate the outranking relationship between the alternatives. Alternative a1 outranks a2 if φ(a1) > φ(a2) and a1 is said to be indifferent to a2 if φ(a1) = φ(a2).

2.3 ELECTRE III Method

ELECTRE model is an outranking model or method to deal with Multi Criteria Decision Making (MCDM) situations in which a finite set of alternatives should be ranked from the best to the worst. For criterion j being considered, three associated thresholds are defined which are indifference (q), preference (p), and veto(v)

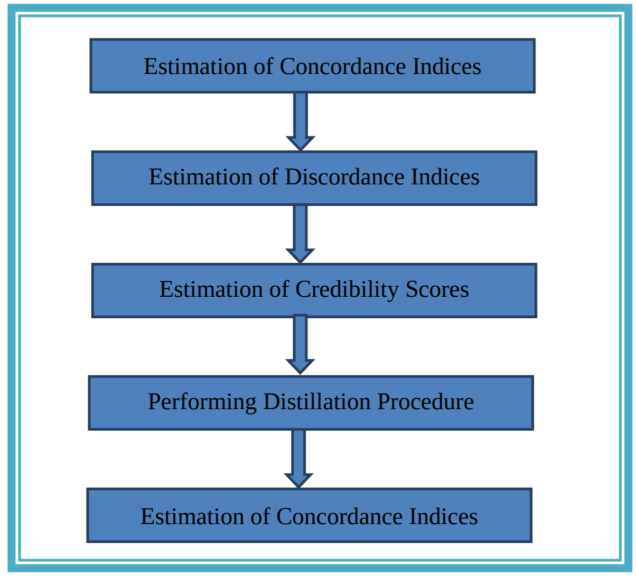

Fig. 2: Main steps of ranking using the ELECTRE III model.

The complete description of the ELECTRE III model is summarized in the following subsections.

1) Concordance index is calculated based on a weighted comparison of the performances over each criterion individually c_j(a, b) as per Eq. (9).

$$\text{C (a, b)} = \frac{1}{W} \sum_{j=1}^{n} w_j \, c_j \ (a, b) \quad (9)$$

Where; $W = \sum_{j=1}^{n} w_j$

The separate comparison indices c_j(a, b) for each criterion are calculated based on one of the following cases**:**

$$c_j(\text{A, b}) = 1 \text{ if } g_j(\text{a}) + q_j(g_j(\text{a})) \geq g_j(\text{b}) \quad (10)$$

$$c_j(\text{a, b}) = 0 \text{ if } g_j(\text{a}) + p_j(g_j(\text{a})) \leq g_j(\text{b}) \quad (11)$$

$$c_j(\text{a,b}) = \frac{g_j(\text{a}) - g_j(\text{b}) + p_j(g_j(\text{a}))}{p_j(g_j(\text{a})) - q_j(g_j(\text{a}))} \quad (12)$$

2) The veto threshold for each criterion is assigned to introduce discordance into the outranking relations. It should be noted that any outranking of b by an indicated by the concordance index can be overruled if there is any criterion for which alternative b outperforms alternative a by at least veto threshold even if all the other criteria favour the outranking of b by a as per Eq. (13).

$$g_j(\text{b}) \geq g_j(\text{a}) + v_j(g_j(\text{a})) \quad (13)$$

$$D_j(\text{a,b}) = 0 \text{ if } g_j(\text{b}) \leq g_j(\text{a}) + p_j(g_j(\text{a})) \quad (14)$$

$$D_j(\text{a,b}) = 1 \text{ if } g_j(\text{b}) \geq g_j(\text{a}) + v_j(g_j(\text{a})) \quad (15)$$

$$D_j(\text{a,b}) = \frac{g_j(\text{b}) - g_j(\text{a}) - p_j(g_j(\text{a}))}{v_j\left(g_j(\text{a})\right) - p_j(g_j(\text{a}))} \quad (16)$$

3) The degree of credibility of outranking is calculated based on concordance and discordance indices according to the one of the following two cases:

$$S(\text{a,b}) = C(\text{a,b}) \text{ if } D_j(\text{a,b}) = C_j(\text{a,b}),\ \forall_j \quad (17)$$

$$S(\text{a,b}) = C(\text{a,b}) \prod_{j \varepsilon \Psi(a,b)} \frac{1 - D_j(\text{a,b})}{1 - C(a,b)} \quad (18)$$

Where, $\Psi(a,b)$ is the set of criteria for which D_j(a,b) $> c_j$(a,b).

4) Ranking is based on a qualification score for each alternative and it is calculated as follows:
5) Set λ_0 equals to the maximum value of S(a,b) in credibility matrix (A) as per Eq. (19).

$$\lambda_0 = max_{a,b\varepsilon A} S(a,b) \quad (19)$$

A cut-off level of outranking λ_1 is defined as the largest outranking score which is just less than the maximum outranking score minus the discrimination threshold as per Eq. (20).

$$\lambda_1 = max_{\{S(a,b) < \lambda_0 - s(\lambda_0)\}} S(a,b) \quad (20)$$

Where, $s(\lambda_0)$ is the discrimination threshold at the maximum level of outranking λ_0. At initial cut-off level, a outranks b if S(a,b) is greater than the cut-off level and S(a,b) exceeds S(b,a) by more than the discrimination threshold (see Eq. (23)) satisfying the condition, given in Eq. (22).

$$s(\lambda_0) = 0.3 - 1.5\lambda_0 \quad (21)$$

$$aSb \text{ if } S(a,b) > \lambda_1 \text{ and } S(a,b) - S(b,a) > s(\lambda) \quad (22)$$

Every time a outranks b, a is given a score of +1 (strength) and b is given −1 (weakness). For each alternative, the strengths and weaknesses are added together to give a final qualification score.

3. ILLUSTRATIVE EXAMPLE

Karsak and Kuzgunkaya (2002) proposed a fuzzy multiple objective programming approaches for the selection of a flexible manufacturing system. The authors had considered eight alternative flexible manufacturing systems and seven criteria. Five criteria were expressed objectively, and two criteria were expressed subjectively. These seven criteria are Reduction of labour cost (RLC, %), Reduction in WIP (RWP, %), Reduction in setup cost (RSC, %), Increase in market response (IMR), Increase in quality (IQ), Capital and maintenance cost (CMC, $1000), Floor space used (FSU, sq. ft.)

Step 1. Data of attributes of example is given in table 1

Table 1: Data of attributes

	Criteria						
FMS	**RLC**	**RWP**	**RSC**	**IMR**	**IQ**	**CMC**	**FSU**
1	30	23	5	G	G	1500	5000
2	18	13	15	G	G	1300	6000
3	15	12	10	F	F	950	7000
4	25	20	13	G	G	1200	4000
5	14	18	14	W	G	950	3500
6	17	15	9	G	F	1250	5250
7	23	18	20	F	G	1100	3000
8	16	8	14	W	F	1500	3000

Step 2. Linguistic rating variables are converted into number values, good as 8, fair as 5 and worst as 2 and objective values are given in table 2.

Step 3. Objective values of the FMS selection criteria, which are given in table 2 are normalized. RLC, RWP, RSC, IMR, IQ are beneficial criteria and higher values are desirable. CMC and FSU are non-beneficial criteria, and lower values are desirable. The normalized values are given in table 3.

Table 2: Objective data of attributes

	Criteria						
FMS	**RLC**	**RWP**	**RSC**	**IMR**	**IQ**	**CMC**	**FSU**
1	30	23	5	8	8	1500	5000
2	18	13	15	8	8	1300	6000
3	15	12	10	5	5	950	7000
4	25	20	13	8	8	1200	4000
5	14	18	14	2	8	950	3500
6	17	15	9	8	5	1250	5250
7	23	18	20	5	8	1100	3000
8	16	8	14	2	5	1500	3000

Table 3: Normalized data of attributes

	Criteria						
FMS	**RLC**	**RWP**	**RSC**	**IMR**	**IQ**	**CMC**	**FSU**
1	1	1	0.25	1	1	0.63	0.6
2	0.6	0.56	0.75	1	1	0.73	0.5
3	0.5	0.52	0.5	0.62	0.62	1	0.43
4	0.83	0.87	0.65	1	1	0.79	0.75
5	0.47	0.78	0.7	0.25	1	1	0.85
6	0.57	0.65	0.45	1	0.62	0.76	0.57
7	0.77	0.78	1	0.62	1	0.86	1
8	0.53	0.35	0.7	0.25	0.62	0.63	1

Step 4. Relative importance of criteria is decided by decision maker and given table 4

Step 5. The weights of the attributes computed using AHP is given in table 4.

Table 4. Relative importance of criteria							
	RLC	**RWP**	**RSC**	**IMR**	**IQ**	**CMC**	**FSU**	**W_i**
RLC	-	0.5	0.665	0.5	0.335	0.335	0.665	0.14
RWP	0.5	-	0.665	0.5	0.335	0.335	0.665	0.14
RSC	0.335	0.335	-	0.335	0.255	0.255	0.5	0.10
IMR	0.5	0.5	0.665	-	0.335	0.335	0.665	0.14
IQ	0.665	0.665	0.745	0.665	-	0.5	0.745	0.19
CMC	0.665	0.665	0.745	0.665	0.5	-	0.745	0.19
FSU	0.335	0.335	0.5	0.335	0.255	0.255	-	0.10

Step 6. Now VIKOR, improved PROMETHEE and ELECTRE III are applied individually to rank the alternatives and results are compared.

VIKOR Method

1) The best $f_j^*$and worst f_j^- values of all criterion functions are determined using equation (1) and given in table 5.

Table 5: Best $f_j^*$and worst f_j^- values							
	RLC	**RWP**	**RSC**	**IMR**	**IQ**	**CMC**	**FSU**
f_j^*	1	1	1	1	1	1	1
f_j^-	0.47	0.35	0.25	0.25	0.62	0.63	0.43

2) Value of $\frac{w_i(f_j^*-f_{ij})}{f_j^*-f_j^-}$ is calculated and given in table 6.

Table 6. Value of $\frac{w_i(f_j^*-f_{ij})}{(f_j^*-f_j^-)}$							
	RLC	**RWP**	**RSC**	**IMR**	**IQ**	**CMC**	**FSU**
1	0	0	0.10	0	0	0.19	0.070
2	0.10	0.094	0.03	0	0	0.138	0.087
3	0.132	0.103	0.06	0.071	0.19	0	0.10
4	0.045	0.028	0.046	0	0	0.108	0.044
5	0.14	0.047	0.040	0.14	0	0	0.026
6	0.114	0.075	0.073	0	0.19	0.123	0.075
7	0.060	0.047	0	0.071	0	0.072	0
8	0.124	0.14	0.040	0.14	0.19	0.19	0

3) Based on the Table 6, Eq. (2), Eq. (3) and Eq. (4) values of S_i, $R_i$and Q_i are obtained for each alternative, as shown in Table 7. Here, the $Q_i$value of each alternative is calculated using each v value as v = 0.5.
S^*= 0.250, S^- = 0.824, R^*= 0.072, R^- = 0.19

Table 7: Q_i value and ranking				
	S_i	**R_i**	**Q_i**	**Rank**
1	0.360	0.19	0.596	5
2	0.449	0.138	0.452	4
3	0.656	0.19	0.854	7
4	0.271	0.108	0.170	2
5	0.393	0.14	0.413	3
6	0.656	0.19	0.712	6
7	0.250	0.072	0	1
8	0.824	0.19	1	8

Improved PROMETHEE Method

1) Contribution of the alternatives in terms of each separate criterion is compared and preference functions are calculated. 1 for the positive deviation and the rest is replaced with 0.

Table 8: Preference values related to RLC								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	-	0	0	0	0	0	0	0
2	1	-	0	1	0	0	1	0
3	1	1	-	1	0	1	1	1
4	1	0	0	-	0	0	0	0
5	1	1	1	1	-	1	1	1
6	1	1	0	1	0	-	1	0
7	1	0	0	1	0	0	-	0
8	1	1	0	1	0	1	1	-

Similarly preference values are calculated for all the criteria.

2) The multiple criteria preference index $\prod_{a1a2}$, is then defined as the weighted average of the preference functions P_i is calculated using equation (5)

Table 9: Multiple criteria preference index $\prod_{a1a2}$,											
∏	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**φ^+**	**φ^-**	**φ**	**Rank**
1	-	0.29	0.29	0.39	0.39	0.19	0.39	0.20	3.39	2.14	1.25	3
2	0.38	-	0.19	0.57	0.43	0.43	0.67	0.10	3.33	2.77	0.56	5
3	0.71	0.81	-	0.81	0.53	0.52	0.67	0.34	1.90	4.39	-2.49	7
4	0.28	0.24	0.19	-	0.39	0	0.39	0.20	4.27	1.69	2.58	2
5	0.42	0.38	0.28	0.42	-	0.28	0.48	0.24	3.17	2.50	0.67	4
6	0.57	0.57	0.29	0.86	0.72	-	0.86	0.20	2.17	4.07	-1.90	6
7	0.42	0.14	0.19	0.42	0.19	0.14	-	0	4.36	1.50	2.86	1
8	0.61	0.90	0.47	0.80	0.52	0.61	0.90	-	1.28	4.81	-3.53	8

Table 10: Criteria threshold values.

Threshold	**Value**
Indifference (q)	$0.05g_j(a)$
Preference (p)	$0.05g_j(a)$
Veto (v)	Not used

3) On the basis of the net flow values, the case companies are ranked and rank is given in table 9.

ELECTRE III Method

1) Indifference, preference and veto threshold for problem taken is given in table 10 belowPreference threshold

values and indifference threshold values are calculated and listed in table 11.

2) Concordance index, C(a,b), is calculated for each pair of alternatives according to the equation (9). The separate comparison indices c_j(a,b) used in equation (9) for each criterion are calculated according to the equation (10), (11) and (12).
Similarly it is calculated for each pair of alternatives.

3) From the values concordance index is calculated. As no veto threshold is used, so degree of credibility of outranking is equal to concordance index. Credibility index is given table 13.

4) Value of λ_0 is find out according to equation (19)
$\lambda_0 = 1$, And a cut-off level of outranking λ_1 is find out using equation (20) and (21)
$s(\lambda_0) = 0.3 – 0.15\lambda_0 = 0.15$

$\lambda_1 = 0.82$

Table 11. Preference and indifference threshold values

	RLC	RWP	RSC	IMR	IQ	CMC	FSU
1	0.05	0.05	0.0125	0.05	0.05	0.0315	0.03
2	0.03	0.028	0.0375	0.05	0.05	0.0365	0.025
3	0.025	0.026	0.025	0.031	0.031	0.05	0.0215
4	0.0415	0.0435	0.0325	0.05	0.05	0.0395	0.0375
5	0.0235	0.039	0.035	0.0125	0.05	0.05	0.0425
6	0.0285	0.0325	0.0225	0.05	0.031	0.038	0.0285
7	0.0385	0.039	0.05	0.031	0.05	0.043	0.05
8	0.0265	0.0175	0.035	0.0125	0.031	0.0315	0.05

Table 12: Separate comparison indices for 1 and 2

$g_j(1) + p_j(g_j(1))$	$g_j(2)$	$c_j(1,2)$	W	$wc_j(1,2)$
1.05	0.6	1	0.14	0.14
1.05	0.56	1	0.14	0.14
0.2625	0.75	0	0.10	0
1.05	1	1	0.14	0.14
1.05	1	1	0.19	0.19
0.6615	0.73	0	0.19	0
0.63	0.5	1	0.10	0.10
0.71				

RLC					
RWP					
RSC					
IMR					
IQ					
CMC					
FSU					
C(1,2)					

Table 13: Credibility index table

	1	2	3	4	5	6	7	8
1	1	0.71	0.71	0.61	0.61	0.71	0.61	0.80
2	0.62	1	0.81	0.43	0.67	0.76	0.33	0.90
3	0.29	0.19	1	0.19	0.47	0.48	0.33	0.66
4	0.72	0.90	0.81	1	0.61	1	0.61	0.80
5	0.58	0.62	0.72	0.58	1	0.72	0.52	0.76
6	0.24	0.38	0.71	0.14	0.28	1	0.14	0.61
7	0.58	0.86	0.81	0.58	0.81	0.86	1	1
8	0.39	0.10	0.53	0.20	0.48	0.39	0.10	1

5) Now using the eq. (22) it is find out that which alternative outranks the other alternatives and a table is made for strength, weakness and for the final score or qualification. On the basis of the qualification score, the case companies are ranked and ranking is given in table below.

Table 14: Qualification score

	Outranks	Strength	Weakness	Qualification score
1	None	0	0	0
2	8	1	2	-1
3	None	0	0	0
4	2,6	2	0	2
5	None	0	0	0
6	None	0	2	-2
7	2,6,8	3	0	3
8	None	0	5	-5

4. DISCUSSION & CONCLUSION

Comparative ranking of alternatives on the basis of VIKOR, improved PROMETHEE and ELECTRE III indicates the set {7, 4} as good alternatives. The alternatives ranked highest are 7 and 4, of which alternative 7 is the ideal according to the criteria RSC, IQ, FSU and closet to ideal according to the criteria IMR, CMC and closer to ideal according to criteria RLC and RWP. As an alternative for a final solution, alternative 7 could be considered the best compromise. To decide which method to apply, matching methods with classes of appropriate problems are needed. The validation procedures have to be developed, and application feasibility should be explored. Researchers are challenged to provide a guide for choosing the method that is both theoretically well founded and practically operational to solve real life problems.

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