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An Integrated FAHP-PROMETHEE Approach for Selecting the Best Flexible Manufacturing System

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Abstract

This paper proposes an integrated approach to the decision-making problem that combines the Fuzzy Analytical Hierarchy Process (FAHP) and the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) with the purpose of Evaluation of Flexible Manufacturing Systems with a Group Decision Support System (GDSS). The FAHP is used to determine the weights for each criterion and PROMETHEE is applied to get the final ranking and GAIA plane is used to highlight the conflicts, the similarities and independences among the criteria and the DMs. Finally, a numerical example proposed in this paper determines the most appropriate FMS alternative.

Keywords: FMS; PROMETHEE; FUZZY AHP; GAIA ANALYSIS; GDSS

Introduction

Today, the technology is expanding at an unbelievable speed. With the acceleration of the development in the field of technology, it becomes essential to take decisions more frequently for the update of the technology. Therefore, firms and organizations should consider the changes and update the information technologies so that they can create more efficient working environment and labor force and so doing, they can keep up with the technological advancements.

Competition in manufacturing environment has forced the Organizations to consider increasing the quality and responsiveness to customization, while decreasing costs. Flexible Manufacturing System (FMS) presents opportunities for manufacturers to complete their technology and profitability through a very efficient and focused approach to manufacturing effectiveness (Shang & Sueyoshi, 1995). 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 prominent factor affecting the manufacturers' conception. Other competitive factors such as flexibility, quality and customer satisfaction are drawing the equal attention. The issues such as reduction of inventories and market-response time to meet customer demands, reducing the cost of products and services to grab more market shares, etc have made it almost necessary for 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. FMS is actually an automated set of numerically controlled machine tools and material handling systems, able of performing a wide range manufacturing operations with quick tooling and instruction changeovers (Kim and Yano, 1997).

A flexible manufacturing system (FMS) consists of a group of processing work stations (usually CNC machine tools) interconnected by an automated material handling and storage system, and controlled by a distributed computer system. The reason the FMS is called flexible is that it is capable of processing a variety of different part styles simultaneously at the various work stations, and the mix of part styles and quantities of production can be adjusted in response to changing demand patterns. The evolution of flexible manufacturing systems offers great potential for increasing flexibility and changing the basis of competition by ensuring both cost effective and customized manufacturing at the same time.The decision to invest in FMS and other advanced manufacturing technology has been an issue in the practitioner and academic literature for over two decades. An effective justification process requires the consideration of many quantitative attributes and qualitative attributes (Venkata Rao, 2013).

In this study, a Group Decision Support System (GDSS) is developed to evaluate eight possible FMSs. Also an integrated approach for the decision-making problem that combines the Fuzzy Analytical Hierarchy Process (FAHP) and the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) method in conjunction with the Geometrical Analysis for Interactive Assistance (GAIA) method to capture the DMs' beliefs through a series of intuitive and analytical methods.

This paper is organized into five sections. The next section presents a review of multiple criteria paradigms in the literature. Section 3 details the proposed framework. Section 4 presents the results of a numerical example and Section 5 sums up our conclusions and future research directions.

Literature review

Elango and Meinhart (1994)0 proposed a strategic framework for selecting an FMS. Kuula (1993) presented a risk management model for FMS selection decisions using a multiple criteria decision-making approach. Tabucanon *et al.* 0 proposed a decision support system for multiple criteria machine selection for flexible manufacturing systems. The approach offered combined the analytic hierarchy process (AHP) technique with the rule-based technique for creating Expert Systems (ES). Myint and Tabucanon (1994) used AHP method and goal programming (GP) model to determine the satisfactory FMS configuration from the short-listed FMS configurations. Bayazit (2005) used AHP to implement the FMS in a tractor manufacturing plant. Also a sensitivity analysis was conducted to assess how realistic the final outcome was. Kulak and Kahraman (2005) proposed axiomatic design (AD) principles for multiple attribute comparison of advanced manufacturing systems. The comparison was made for cases of both complete and defective information. The crisp AD approach for complete information and the fuzzy AD approach for defective information were extended. Rao (2006) presented a decision-making model for FMS selection using digraphs and matrix methods. A ‘flexible manufacturing system selection index’ was proposed that evaluates and ranks flexible manufacturing systems for a given industrial application.

In another work, Rao (2007) used the TOPSIS and AHP methods in combination for evaluating flexible manufacturing systems. The analytic hierarchy process (AHP) is the most widely used scoring model that evaluates the advanced manufacturing technology alternatives by pairwise comparisons with respect to one of the criteria at a time. Wabalickis (1988) develops a justification methodology based on the AHP to evaluate the many tangible and intangible benefits of an FMS investment. Myint and Tabucanon (1994) integrate the AHP and goal programming to select the most appropriate machines for an FMS.

The PROMETHEE family of outranking methods was first introduced by Brans (1982) in the form of partial ranking of alternatives. Subsequently, the method was extended by Brans and Vincke (1985) to a full ranking approach, which is known as PROMETHEE II. A few years later, several versions of the PROMETHEE methods were developed to help with more complicated decision-making situations (Brans, and Mareschal, 2005). More specifically, the PROMETHEE method deals with ranking a finite number of alternatives based on multiple conflicting factors with inputs from a group of DMs(Macharis et al., 2004). The PROMETHEE methods have been successfully utilized to various fields, including environmental management (Briggs et al., 1990; Chou et al., 2007; Martin et al., 2003; Morais and De Almeida, 2007; Queiruga et al., 2008), hydrology and water management 0. PROMETHEE takes into account the amplitude of the deflection between the evaluations of the alternatives within each factor, removes the scaling effects completely, identifies the number of incomparabilities, prepares information on the conflicting nature of the factors, and presents sensitivity tools to test easily different sets of weights (Brans and Mareschal, 2005).

PROMETHEE GDSS, a member of the PROMETHEE family of methods, was developed to provide decision aid to a group of DMs (Machariset al., 1998). PROMETHEE GDSS is initiated with an identification of the alternatives and criteria. It is followed with an individual evaluation conducted by each Decision Maker. Finally a global evaluation is accomplished by the group to select the best alternative. Several authors have used PROMETHEE GDSS to solve a variety of multi-factor multi-person decision problems (Colson, 2000; Goletsis et al., 2003; Haralambopoulos and Polatidis, 2003; Leyva-López and Fernández-González, 2003; Raju et al., 2000). Macharis et al. 0(1998) and Behzadian et al. (2010) have provided best reviews of the PROMETHEE methodologies and their applications. In summary, most of the prior research on the selection of flexible manufacturing systems has considered AHP and PROMETHEE methods separately with individual decision making although this study has focused on the combined Fuzzy AHP and PROMETHEE method with group decision making and GAIA analysis.

An overview of the FAHP and PROMETHEE approaches

In this section, FAHP and PROMETHEE are briefly introduced. Then the hybrid approach is proposed to assist the Evaluation of Flexible Manufacturing Systems.

FAHP

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making approach and was introduced by Saaty (1977, 1994). AHP is a strong method to solve complex decision problems. Any complex problem can be disintegrated into several sub-problems using AHP in terms of hierarchical levels where each level illustrate a set of criteria or attributes related to each sub-problem. The AHP is a multi-criteria method of analysis based on an additive weighting process, in which several related attributes are represented through their relative importance. Through AHP, the importance of several attributes is obtained from a process of paired comparison, in which the relation of the attributes or categories of drivers of intangible assets are matched two-on-two in a hierarchic structure. However, the AHP method has some shortcomings (Yang and Chen, 2004). They pointed out that the AHP method is mainly used in nearly crisp-information decision applications; the AHP method creates and deals with a very unbalanced scale of judgment; the AHP method does not take into account the uncertainty associated with the mapping of human judgment to a number by natural language; the ranking of the AHP method is rather imprecise; and the subjective judgment by evaluation, improvement and selection based on preference of decision-makers have great penetration on the AHP results 0. To overcome these problems, some researchers integrate fuzzy theory with AHP method to improve the uncertainty. Hence, Buckley (1985) used the evolutionary algorithm to calculate the weights with the trapezoidal fuzzy numbers.

We consider a triangular fuzzy number (TFN) to describe a fuzzy event as denoted as (l, m, n), as shown in Fig. 3. The parameters l, m and n respectively denote the smallest possible value, the most possible value, and the largest possible value of a fuzzy event.

The general fuzzy-AHP process used in this paper is discussed as follows (Ball and Korukoğlu, 2009)

Step 1: Fuzzy synthetic extent calculation:

Let X ={x1, x2,., xn} be an object set, and U = {u1, u2,.,um} be a goal set. Using Chang's extent analysis approach, each object is taken and extent analysis for each goal is performed respectively. Therefore, *m* extent analysis values for each object can be calculated, and are denoted as:

$A_{g_i}^1, A_{g_i}^1, \ldots, A_{g_i}^m$ i=1,2,...,n (1)

Where all the $A_{g_i}^j$ (j=1,2,…,m) are triangular fuzzy numbers.

With respect to the *i* th object, the value of fuzzy synthetic extent is defined as:

$S_i = \sum_{j=1}^{m} A_{g_i}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} A_{g_i}^j\right]^{-1}$ (2)

Step2: comparison of fuzzy values:

The degree of possibility of $A_2 = (l_2, m_2, n_2) \geq A_1 = (l_1, m_1, n_1)$ is defined as:

V $(A_2 \geq A_1)$ = SUP$\left[\min\left(\mu_{A_1(x)}, \mu_{A_2(y)}\right)\right]$ (3)

When a pair (x, y) exists such that x≥y and $\mu_{A_1(x)} = \mu_{A_2(y)} = 1$

Then we have V $(A_2 \geq A_1) = 1$, Since A_1 and A_2 are convex fuzzy numbers so they are expressed as follows

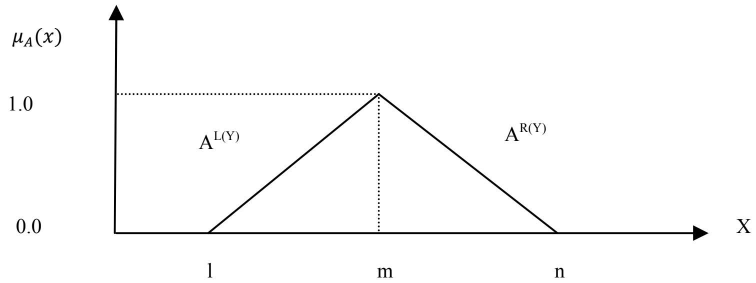

Figure 1. A Triangular fuzzy number, $\widetilde{A}$

V $(A_2 \geq A_1)$ = hgt $(A_1 \cap A_2) = \mu_{A_2}(d)$ (4)

Where d is the ordinate of the highest intersection point D between μ_{A_1} and μ_{A_2} as shown in fig4 when

$A_1 = (l_1, m_1, n_1)$ and $A_2 = (l_2, m_2, n_2)$ then $\mu_{A_2}(d)$ is computed by

$$\mu_{A_2}(d) = \begin{cases} 1 & m_2 \geq m_1 \\ 0 & l_1 \geq n_2 \\ \frac{l_1 - n_2}{(m_2 - n_2) - (m_1 - l_1)} & otherwise \end{cases} \quad (5)$$

For the comparison of A_1 and A_2, we need both the values of V $(A_1 \geq A_2)$ and V $(A_2 \geq A_1)$

Step 3: Priority weight calculation:

The degree possibility of convex fuzzy number to be greater than k convex fuzzy numbers A_i(i=1,2,…k) can be defined by:

V (A≥ $A_1, A_2, \ldots, A_k$) =V (A≥ A_1) and (A≥ A_2) and… and (A≥ A_k) (6)

V (A≥ $A_1, A_2, \ldots, A_k$) = min V (A≥ A_i) i=1,2,…,k (7)

If m (P_i) = min V $(S_i \geq S_k)$ for k=1,2,…,n; k≠I (8)

Then the weight vector is given by:

$W_p = (m(P_1), m(P_2), \ldots, m(P_n))^T$ (9)

Here P_i(i=1,2,…,n) are n elements,

Step 4: Calculation of normalized weight vector:

After normalization of W_p, we get the normalized weight vectors

W_p=$(W(P_1), W(P_2), \ldots, W(P_n))^T$ (10)

Where, W is a non-fuzzy number and it gives the priority weights of one decision alternative over another.

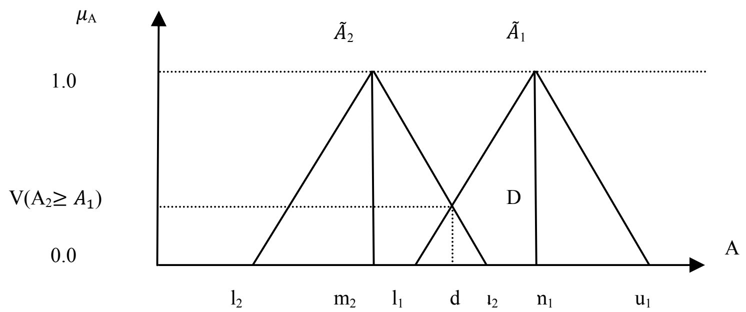

Figure 2. The intersection between $\widetilde{A}_1$ and $\widetilde{A}_2$

PROMETHEE

The PROMETHEE method was firstly proposed by Brans (1985). The method uses outranking relation between pairs of alternatives to solve problems which have a finite alternatives and are needed to be sorted considering with conflicting criteria and different units. Unlike other ranking methods which apply the same evaluation scale and preference function in the evaluation process, the PROMETHEE usually uses different preference functions to define different decision attributes according to their different features (Brans and Vincke, 1985; Podvezko and Podviezko, 2010). When a pair of alternatives (a, b) is compared, a preference function is used to express the difference between the two alternatives in terms of a preference degree range [0, 1]. Usually, two PROMETHEE methods 0 can be employed to solve the evaluation problems: PROMETHEE I and PROMETHEE II. Compared to PROMETHEE I that provide a partial ranking of alternatives, PROMETHEE II offer a complete ranking from the best alternative to the worst one. Therefore, PROMETHEE II is chosen in the hybrid decision making approach. The procedure of PROMETHEE II is constituted by four steps (Dağdeviren, 2008; Podvezko and Podviezko, 2010).

Calculating the deviations based on comparison two alternatives with respect to j the criterion:

$d_j(a,b)$=f_j(a)-f_j(b), j=1,2,…,k. (11)

Where j denotes the j th criterion k stands for the finite number of criteria.

Applying the preference function:

P_j(a,b)=$F_j[d_j(a,b)]$, j=1,2,…,k (12)

0≤ P_j ≤1, j=1,2,…,k (13)

Where P_j(a,b) expresses the preference of alternative a with regarding to alternative b on the j th criterion.

Calculating a global preference index. The overall preference index of alternative b is denoted as:

$\pi(a,b)$=$\sum_{j=1}^{k} W_j P_j(a,b)$, j=1,2,…,k (14)

Where w_j represents the weight of the criterion j.

Calculating the outranking flows. The outgoing flow Φ+ which expresses the outranking character of

Alternative a (how a dominates all the other alternatives) and the incoming flow Φ- which indicates the outranked character of alternative a (how is a dominated by all the other alternatives) can be represented as follows:

$$\emptyset^{+}(a)=\sum_{x\in A}\pi(x,a) \quad (15)$$

$$\emptyset^{-}(a)=\sum_{x\in A}\pi(a,x) \quad (16)$$

Where A denotes the alternative set.

The net flow $\Phi(a)$ which is defined by equation (17) expresses the overall preferred degree of alternative a. Higher value of $\Phi(a)$ means a better performance of alternative a.

$$\emptyset(a)=\emptyset^{+}(a)-\emptyset^{-}(a) \quad (17)$$

The hybrid decision making approach

The hybrid approach of Evaluation of Flexible Manufacturing Systems, which integrates FAHP and PROMETHEE II includes four steps, is displayed in the Fig 3:

Step 1: Data gathering:

Firstly, the FMS alternatives are obtained from brainstorming sessions within the evaluators' team. Afterwards, the criteria for FMS evaluation are determined. The decision making hierarchy structure is also established with the chosen FMS alternatives. Finally, the criteria and hierarchy structure are checked.

The proposed decision hierarchy structure contains three layers: In the first layer, the global goal of the decision making approach is confirmed as "selecting best FMS". The layer below is the decision maker layer. The criteria on the bottom of the hierarchy which is consisted by determined decision criteria.

Step 2: FAHP calculation:

In this step, the individual pairwise comparison is carried out in the FMS evaluation process. The weights of decision criteria are obtained.

Step 3: PROMETHEE calculation:

The FMS alternatives are evaluated with respect to each decision criterion to form the evaluation matrix and different preference functions are defined for different decision criteria according to their characteristics. Then, the values of outgoing/incoming flow are calculated. Finally, the complete ranking can be found.

Step 4: Decision making:

Based on above mentioned results, the final decision is made and the best FMS is chosen.

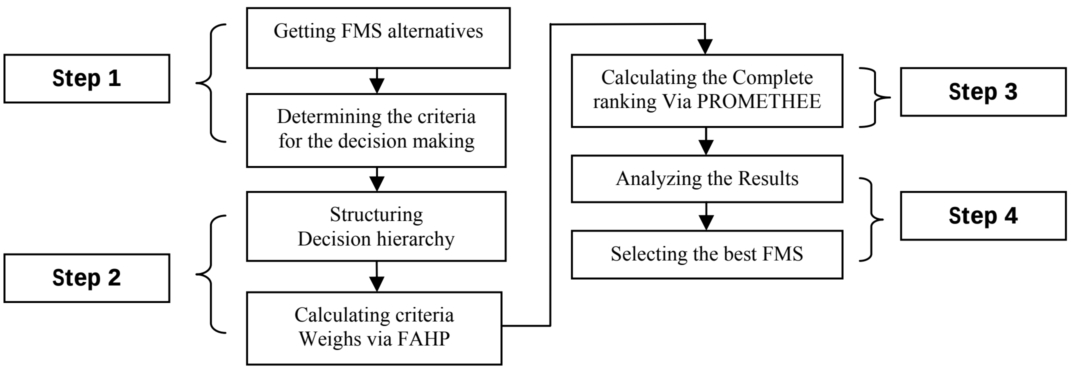

Figure 3. The hybrid decision making approach

Numerical example

Now, to demonstrate and validate the application of the proposed hybrid approach, this example presented by Karsak *et al*. (2002) is considered by a few changes. They considered eight alternative, seven criteria although the difference between this study and previous one is addition of one decision maker also we considerd decision matrices with fuzzy numbers. Five criteria were expressed objectively, and two criteria were expressed subjectively. The hybrid approach proposed in this paper determines the most appropriate FMS alternative through maximization of objectives such as reduction in labor cost, reduction in setup cost, reduction in work-in-process (WIP), increase in market response, improvement in quality, minimization of capital and maintenance cost and floor space used.

The valuation of the 'Increase in market response' criteria and 'Increase in quality' is difficult to quantify and their valuations are based upon literature reviews and brainstorm sessions within the evaluators' team. For this purpose, a 5-point qualitative scale ranging from 1 (very bad impact) to 5 (very good impact) has been applied. For other criteria ('Reduction in labor cost', 'RWP: Reduction in WIP', 'Reduction in set up cost', 'Capital and maintenance cost', Floor space used), the valuation of them was obtained quantitatively.

The hierarchical structure is shown in four levels in Fig 4. After introducing the goal in the first level, the Scenarios are divided into two main categories in the second level, namely: Decision maker1 and Decision maker2. The third level consists of some criteria that are compared by decision makers. At the bottom level, the eight alternatives are evaluated by visual PROMETHEE software (GAIA analysis).

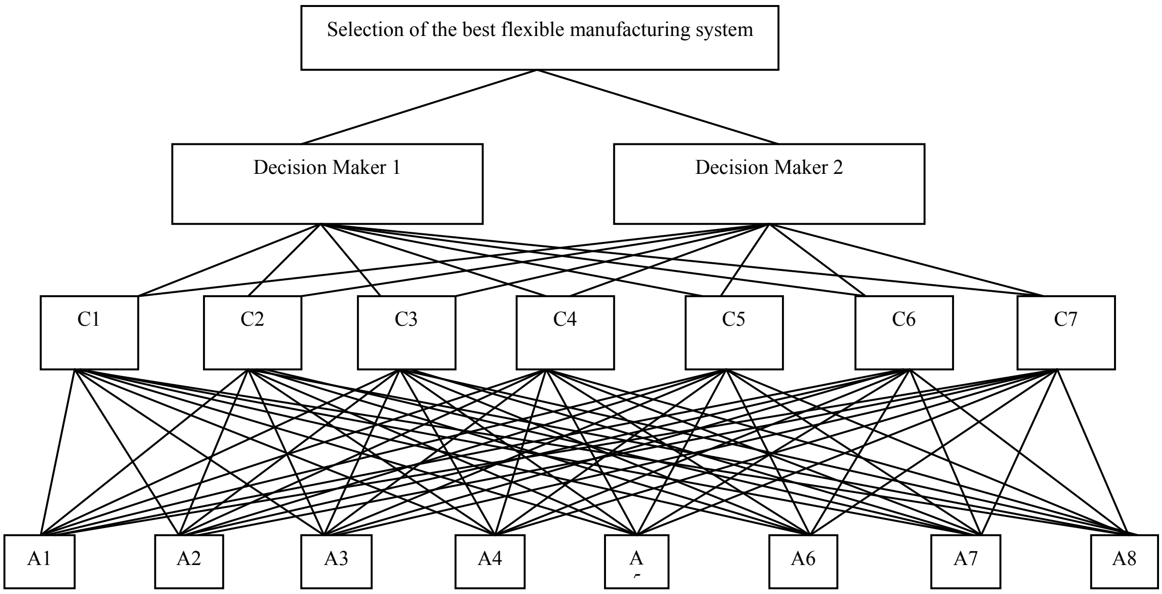

Figure 4. Hierarchy of flexible manufacturing system Selection

In this step, weights of the criteria and global weights of them are calculated. Fuzzy evaluations are performed in the pairwise comparisons by the expert team as follows: for instant, Reduction in WIP and reduction in setup cost are compared using the question ''How important are Reduction in WIP when it is compared to reduction in setup cost'' and if the answer is ''weak importance'', for this linguistic scale the triangular fuzzy number is (1, 2, 3). Two fuzzy evaluation matrices are produced in the same manner for each decision maker. The Weights of the criteria are calculated by using the fuzzy comparison values presented in Table 4.The judgment matrices of criteria or are defined by rating the relative importance of elements based on a standard scale (where 1 = equally important; 2 = weak importance; 3 = strong importance; 4 = demonstrated importance; 5 = absolute importance).

Table 1. Pairwise comparison matrix by DM1

Criteria	C1	C2	C3	C4	C5	C6	C7
C1	(1,1,1)	(1,2,3)	(2,2,3)	$(\frac{1}{4},\frac{1}{3},\frac{1}{2})$	$(\frac{1}{2},1,1)$	$(\frac{1}{3},\frac{1}{2},\frac{1}{2})$	$(\frac{1}{2},1,1)$
C2	$(\frac{1}{3},\frac{1}{2},1)$	(1,1,1)	(1,2,3)	$(\frac{1}{4},\frac{1}{2},1)$	$(\frac{1}{3},\frac{1}{3},1)$	$(\frac{1}{2},1,1)$	(1,1,1)
C3	$(\frac{1}{3},\frac{1}{2},\frac{1}{2})$	$(\frac{1}{3},\frac{1}{2},1)$	(1,1,1)	$(\frac{1}{4},\frac{1}{3},1)$	$(\frac{1}{2},\frac{1}{2},1)$	$(\frac{1}{2},1,1)$	(2,3,4)
C4	(2,3,4)	(1,2,4)	(1,3,4)	(1,1,1)	(1,1,1)	$(\frac{1}{2},\frac{1}{2},1)$	(2,2,3)
C5	(1,1,2)	(1,3,3)	(1,2,2)	(1,1,1)	(1,1,1)	$(\frac{1}{3},\frac{1}{2},1)$	(1,2,2)
C6	(2,2,3)	(1,1,2)	(1,1,2)	(1,2,2)	(1,2,3)	(1,1,1)	$(\frac{1}{3},\frac{1}{2},1)$
C7	(1,1,2)	(1,1,1)	$(\frac{1}{4},\frac{1}{3},\frac{1}{2})$	$(\frac{1}{3},\frac{1}{2},\frac{1}{2})$	$(\frac{1}{2},\frac{1}{2},1)$	(1,2,3)	(1,1,1)

The obtained weights of the criteria are calculated following the procedure presented in Section 3.1, as follow:

Table 2.Weights of the criteria obtained by DM1

	C1	C2	C3	C4	C5	C6	C7
W	0.129	0.105	0.115	0.204	0.172	0.167	0.105

Table 3. Pairwise comparison matrix by DM2

Criteria	C1	C2	C3	C4	C5	C6	C7
C1	(1,1,1)	(3,4,4)	$(\frac{1}{5},\frac{1}{4},\frac{1}{3})$	(1,3,4)	$(\frac{1}{3},\frac{1}{2},\frac{1}{2})$	(1,1,2)	(3,3,3)
C2	$(\frac{1}{4},\frac{1}{3},\frac{1}{3})$	(1,1,1)	(1,2,3)	(3,4,4)	(1,2,4)	(2,3,5)	(2,3,3)
C3	(3,4,5)	$(\frac{1}{3},\frac{1}{2},1)$	(1,1,1)	(2,3,3)	$(\frac{1}{5},\frac{1}{4},\frac{1}{3})$	$(\frac{1}{2},\frac{1}{2},\frac{1}{2})$	(1,1,1)
C4	$(\frac{1}{4},\frac{1}{3},1)$	$(\frac{1}{4},\frac{1}{4},\frac{1}{3})$	$(\frac{1}{3},\frac{1}{3},\frac{1}{2})$	(1,1,1)	(4,4,5)	(3,3,3)	$(\frac{1}{4},\frac{1}{4},\frac{1}{3})$
C5	(2,2,3)	$(\frac{1}{4},\frac{1}{2},1)$	(3,4,5)	$(\frac{1}{5},\frac{1}{4},\frac{1}{4})$	(1,1,1)	$(\frac{1}{4},\frac{1}{4},\frac{1}{3})$	$(\frac{1}{4},\frac{1}{4},\frac{1}{3})$
C6	$(\frac{1}{2},1,1)$	$(\frac{1}{5},\frac{1}{3},\frac{1}{2})$	(2,2,2)	$(\frac{1}{3},\frac{1}{3},\frac{1}{3})$	(3,4,4)	(1,1,1)	(4,4,4)
C7	$(\frac{1}{3},\frac{1}{3},\frac{1}{3})$	$(\frac{1}{3},\frac{1}{3},\frac{1}{2})$	(1,1,1)	(3,4,4)	(3,4,4)	(1,2,3)	(1,1,1)

Table 4.Weights of the criteria obtained by DM2

	C1	C2	C3	C4	C5	C6	C7
W	0.087	0.239	0.136	0.116	0.104	0.179	0.135

Table 5-Decision maker's pairwise comparison matrix

DM	DM1	DM2
DM1	(1,1,1)	(1,2,3)
DM2	$(\frac{1}{3},\frac{1}{2},1)$	(1,1,1)

Table 6. Weights of the Decision Makers

	DM1	DM2

W	0.692	0.307

In this step, the global weights of criteria are calculated.

For example the weight of C1 based on opinion of both Decision Makers is calculated as follow:

$W_{c1}= (0.129 * 0.692) + (0.087 * 0.307) = 0.116$

The other weight calculations are not given here because they follow the same procedure as discussed above.

Table 7- Global Weight

	C1	C2	C3	C4	C5	C6	C7
W (total)	0.116	0.146	0.121	0.176	0.151	0.170	0.114

In this stage, the Decision makers evaluate possible alternatives in terms of their criteria. With this information, the evaluation matrix is constructed for each scenario as follow:

Table 8-Evaluation Matrix by DM1

criteria	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
W	0.116	0.146	0.121	0.176	0.151	0.170	0.114
Action1	30.00	23.00	5.00	good	good	1500.00	5000.00
Action2	18.00	13.00	15.00	good	good	1300.00	6000.00
Action3	15.00	12.00	10.00	average	average	950.00	7000.00
Action4	25.00	20.00	13.00	good	good	1200.00	4000.00
Action5	14.00	18.00	14.00	Very bad	good	950.00	3500.00
Action6	17.00	15.00	9.00	good	average	1250.00	5250.00
Action7	23.00	18.00	20.00	average	good	1100.00	3000.00
Action8	16.00	8.00	14.00	Very bad	average	1500.00	3000.00

Table 9- Evaluation Matrix by DM2

criteria	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
W	0.116	0.146	0.121	0.176	0.151	0.170	0.114
Action1	30.00	23.00	5.00	good very	good	1500.00	5000.00
Action2	18.00	13.00	15.00	average	average	1300.00	6000.00
Action3	15.00	12.00	10.00	bad	good	950.00	7000.00
Action4	25.00	20.00	13.00	average	Very good	1200.00	4000.00
Action5	14.00	18.00	14.00	bad	good	950.00	3500.00
Action6	17.00	15.00	9.00	average	bad	1250.00	5250.00
Action7	23.00	18.00	20.00	bad	average	1100.00	3000.00
Action8	16.00	8.00	14.00	average	good	1500.00	3000.00

Then, the outgoing flow $\Phi+$, the incoming flow $\Phi-$ and the net flow $\Phi (a)$ are calculated for scenarios and shown in Table 10 and 11. These tables show the results of the net flows and the complete ranking for each DM. Each DM was able to see his evaluation and compare it with the ranking of the other DM.

Table 10- Results of PROMETHEE calculation by DM1

DM1	phi	Phi+	Phi-
Action7	0.3996	0.6251	0.2255
Action4	0.3778	0.6075	0.2297
Action1	0.1445	0.4786	0.3341
Action5	0.0691	0.4471	0.3780
Action2	-0.0520	0.4446	0.3926
Action6	-0.2052	0.3377	0.5429
Action3	-0.3669	0.2700	0.6368
Action8	-0.4709	0.2011	0.6720

Table 11- Results of PROMETHEE calculation by DM2

DM2	phi	Phi+	Phi-
Action1	0.5756	0.7641	0.1885
Action4	0.5551	0.7574	0.2023
Action7	0.2925	0.6172	0.3247
Action2	-0.0126	0.4678	0.4804
Action6	-0.2257	0.3670	0.5927
Action8	-0.2632	0.3156	0.5788
Action5	-0.4317	0.2369	0.6685
Action3	-0.4901	0.2178	0.7079

Next, we used the GAIA plane to highlight the conflicts, the similarities and independences among the criteria and the DMs. The GAIA plane is the result of a Principal Components Analysis (PCA) where a great deal of information is preserved after projection. The aim of the GAIA method is to represent on a two dimensional view as much as possible the decision-makers preferences and its implications (Brans and Mareschal, 2005).

Individual ranking and analysis

The individual evaluation and GAIA analysis for each DM are carried out in this step. The difference between alternatives can be determined as follows:

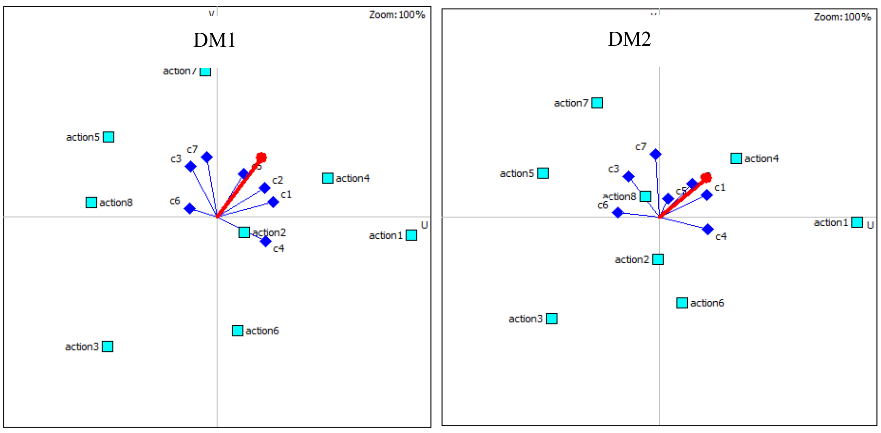

Figure 5. The GAIA plane analysis for each DM.

Notes: c1 = Reduction in labor cost (%), c2 = Reduction in WIP (%), c3 = Reduction in set up cost (%),c4 = Increase in market response, c5 = Increase in quality, c6 = Capital and maintenance cost ($1,000) and c7 = Floor space used (sq. ft.).

The length of the decision axis (red color vector) is a measure of its power in differentiating alternatives where the alternatives are represented by green points and the criteria are represented by blue vectors.

In this setting, criteria vectors expressing similar preferences on the data are oriented in the same direction, while conflicting criteria are pointing in opposite directions. For example, for DM1, the direction of the decision axis is towards action1, action4 and action7, which are the best alternatives in this decision problem. Other alternatives with opposite directions with respect to the decision axis appear the worst alternatives of action8, action3 and action6.

Table 12- Global Results of PROMETHEE Calculation

	phi	Phi+	Phi-
Action4	0.4665	0.6825	0.2160
Action1	0.3601	0.6214	0.2613
Action7	0.3460	0.6211	0.2751
Action2	0.0197	0.4562	0.4365
Action5	-0.1813	0.3420	0.5233
Action6	-0.2154	0.3524	0.5678
Action8	-0.3670	0.2583	0.6524
Action3	-0.4285	0.2439	0.6724

Next, we used the GAIA plane again but this time for the global ranking. Fig. 4 provides a visualization aid for understanding the different perceptions among the DMs as well as the performance of each alternative. The DMs are represented as vectors while the alternatives are represented as points. The direction of decision axis is towards action7, action4 and action1, which are the best alternatives, and just the direct opposite of action5, action6, action8 and action3 which is the worst alternative. Since the vectors of DM 1 and DM 2 are almost in the same direction, they possess quite similar preferences.

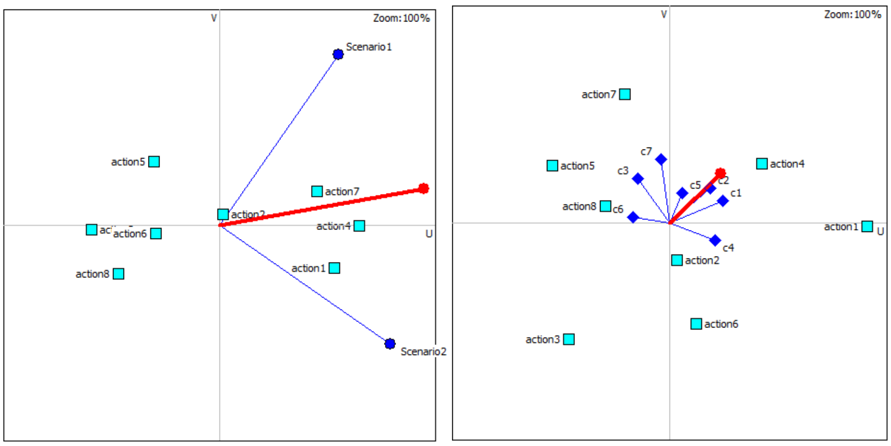

Figure 6.The GAIA plane for the global evaluation Notes: c1 = Reduction in labor cost (%), c2 = Reduction in WIP (%), c3 = Reduction in set up cost (%),c4 = Increase in market response, c5 = Increase in quality, c6 = Capital and maintenance cost ($1,000) and c7 = Floor space used (sq. ft.).

Action5, for example, performs successfullyon a number of criteria such as "Capital and maintenance cost", 'Reduction in set up cost' and 'Floor space used', and is never good or bad on the criteria such as 'Increase in quality'. This alternative also performs unsuccessfully on the criteria such as 'Increase in market response', 'Reduction in WIP' and 'Reduction in labor cost' in the opposite side.

A global PROMETHEE was then computed using Visual PROMETHEE. In this study, Action4 and Action1 with the net flows of 0.4665 and 0.3601 were preferred from a group decision-making viewpoint, respectively. The net flows for Action7, Action2, Action5 Action6 and Action8 were 0.3460, 0.0197, -0.1813, -0.2154 and -0.3670, respectively. Action3 with a net flow of -0.4285 was considered to be the worst alternative. In summary, the overall ranking of the alternatives determined through according to the framework proposed in this study was:

Action4 > Action1 > Action7 > Action2 > Action5 > Action6 > Action8 > Action3

Conclusions

The aim of this paper is to explain recommendations towards decision-makers in order to select the most appropriate flexible manufacturing system. With the selection of flexible manufacturing system, companies may have some positive results in a world of competition and globalization such as decreased the costs, time-efficiency and increased quality and increased work performance. In this paper, FAHP and PROMETHEE are integrated for selection of the best flexible manufacturing system. FAHP is a useful approach for evaluating complex multiple criteria alternatives involving subjective and uncertain judgment, thus is used for determining the weights of the criteria. PROMETHEE is one of the well-known outranking methods for multiple-criteria decision-making and can be easily used for ranking alternatives. Then PROMETHEE method is used for determining the ranking of the Flexible manufacturing systems. The integration of FAHP and PROMETHEE approaches enables experts and users to efficiently select a more suitable FMS for a specific purpose and requirements. The GAIA plane enables a graphical representation of the alternatives and criteria and helps to explore the weak and strong points of the different scenarios. To demonstrate and validate the application of the proposed hybrid approach, the numerical example is presented. In this paper eight alternatives and seven criteria are considered for selecting the best flexible manufacturing system and finally forth alternative is selected that it has the best performance among other alternatives. By using of a combined FAHP and PROMETHEE approach the best alternative is selected which results in the reduction of labor cost, work-in-process, setup cost, capital and maintenance cost, used floor space and increase in responsiveness and product quality. In future studies other multi-criteria methods can be combined to select FMSs.

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