Global Journal of Flexible Systems Management (September 2013) 14(3):125–141
DOI 10.1007/s40171-013-0038-5

ORIGINAL ARTICLE

Ranking of Flexibility in Flexible Manufacturing System by Using a Combined Multiple Attribute Decision Making Method

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Received: 21 April 2013 / Accepted: 10 June 2013 / Published online: 29 June 2013

Abstract *The flexibility in manufacturing system is required so it is called flexible manufacturing system (FMS), but in FMS, there is different flexibility, which is incorporated. So, in manufacturing system which flexibility has more impact and which is less impact in FMS is decided by combined multiple attribute decision making method, which are analytic hierarchy process (AHP), technique for order preference by similarity to ideal situation, and improved preference ranking organization method for enrichment evaluations. The criteria weights are calculated by using the AHP. Furthermore, the method uses fuzzy logic to convert the qualitative attributes into the quantitative attributes. In this paper, a multiple attribute decision making method is structured to solve this problem and concluded that production flexibility has the most impact, and programme flexibility has the least impact in FMS based on factors, which affect the flexibility in FMS by using combined multiple attribute decision making method.*

Keywords Flexible manufacturing system · Fuzzy · Multiple attribute decision making · Improved PROMETHEE · AHP · TOPSIS

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Introduction

A flexible manufacturing system (FMS) is an integrated, computer-controlled complex arrangement of automated material handling devices and numerically controlled (NC) machine tools that can simultaneously process medium-sized volumes of a variety of part types (Stecke 1983). FMS is capable of producing a variety of part types and handling flexible routing of parts instead of running parts in a straight line through machines (Chen and Ho 2005). FMS characterizes organizational culture, organizational strategy, organizational size and structure and management experience and style interact to determine the tendency of the organization to adopt FMS (Belassi and Fadlalla 1998). FMS are crucial for modern manufacturing to enhance productivity involved with high product proliferation (Dai and Lee 2012).

The word ‘flexibility’ comes from the Latin word meaning ‘bendable’. Stockton and Bateman (1995) have suggested that flexibility is the ability of a manufacturing system to:

- Change between existing part types,
- Change the operation routes of components,
- Change the operations required to process a component,
- Change production volumes, i.e. either expansion or contraction,
- Add new part types,
- Add new processes to the system.

The flexibility of a manufacturing system can be defined as the ability of the system to respond to changes either in the environment or in the system itself (Kaighobadi and Venkatesh 1994). Flexibility in manufacturing is defined as the ability to change or react with little penalty in time, effort, cost or performance (Gultekin 2012). Flexibility is one of the critical dimensions of enhancing the competitiveness of organizations. Flexibility is one of the most sought-after properties in modern manufacturing systems (Shewchuk and Moodie 1998). According to Chen and Chung (1996), flexibility refers to the ability of the manufacturing system to respond quickly to changes in part demand and part mix. Das (1996) has defined it as the ability of a system or facility to adjust to changes in its internal or external environment. Several researchers have classified flexibility under different categories. Park and Son (1988), and Son and Park (1990) have identified four types of flexibility—process, product, demand and equipment flexibility. Browne et al. (1984) have proposed eight types of flexibilities including machine flexibility, routing and expansion, etc., Azzone and Bertele's (1989) have suggested six types of flexibility: process, product, production, routing, expansion and volume flexibility. Sethi and Sethi (1990) have identified eleven types of flexibility: product, process, program, production, volume, routing, expansion, operation, machine, material handling and market flexibility.

In this paper, 15 factors which affect the flexibility in a FMS have been identified through literature along with 15 flexibilities of FMS. From literature many flexibilities and factors were extracted by a group of Industry experts and academia (taken a group of six industry experts and a group of eight academia. All six industry experts having the qualification B. Tech & M. Tech/MBA and working on the rank of A.G.M./G.M and all eight academia are Ph.D in Mechanical specialization in Manufacturing/Production) decided 15 flexibilities. They took 15 factors also to evaluate the flexibility. So, 15 flexibilities and 15 factors have been taken to evaluate the flexibility. The ranking of these flexibilities (which is defined in "Identification of Flexibility and Factors Affecting Flexibility in FMS" section below) is analyzed by combined multiple attribute decision making methods (MADMs), i.e. analytic hierarchy process (AHP), technique for order preference by similarity to ideal situation (TOPSIS) and improved preference ranking organization method for enrichment evaluations (PROMETHEE).

The proposed methods easily handle qualitative criteria involved in the decision-making process. Multi-objective techniques seem to be an appropriate tool for ranking or selecting one or more alternatives from a set of the available options based on the multiple objectives.

The purpose of the ranking of flexibility is to accord a proper attention of researchers and production managers to focus the flexibility in FMS. Olhager (1993) has proved that flexibility is usually considered to be the best step towards manufacturing excellence. The impact of flexibility and its contributing means on increasing profitability of the manufacturing system. Based on this ranking, he can conclude on which flexibility he should focus to reduce costs or increase the performance of the manufacturing system. As the flexibility increases, as a result productivity of the system increases.

The main objectives of this paper are as follows:

- To identify types of flexibility and factors affecting the flexibility in FMS.
- Find the ranking of flexibility based on factor by using combined MADMs, i.e. AHP, TOPSIS and improved PROMETHEE.
- To discuss managerial implication of this research.

In the remainder of this paper, identification of flexibility and factors affecting flexibility in a FMS through literature is presented in "Identification of Flexibility and Factors Affecting Flexibility in FMS" section. In "Combined Multiple Attribute Decision Making (MADM) Methodology Used for Ranking of Flexibility" section, an overview and use of combined MADM are given. The "Ranking of Flexibility" section gives the ranking of flexibilities using MADM. Industrial implication and conclusion are followed in "Industrial Implication" and "Conclusion" sections respectively.

Identification of Flexibility and Factors Affecting Flexibility in FMS

Several authors (Sethi and Sethi 1990; Groover 2006; Stecke et al. 1983) carried out an extensive survey of the literature on flexibility in manufacturing and identified varying types of flexibility and at least 50 different terms describing these varying types. These definitions are essentially in agreement with (Browne et al. 1984). According to the group of experts 15 flexibility were taken which are taken as alternatives used for MADM and these are defined as given below:

1. *Machine flexibility* it is defined as the capability to adapt a given machine (Workstation) in the system to a wide range of production operations and part styles. The greater the range of operations and part styles, the greater the machine flexibility.
2. *Routing flexibility* it has the capacity to produce parts through alternative work station sequences in response to equipment breakdowns, tool failures, and other interruptions at individual stations. The ability to produce a part using different process routes.
3. *Process flexibility* the ability to produce a given set of part types, each possibly using different material, in several ways. Process flexibility increases as the machine setup costs decrease.

4. *Product flexibility* the ability to change over to produce a new (set of) product(s) very economically and quickly. Product flexibility relates to the ease of new-product introduction and product modification.
5. *Volume flexibility* the ability to economically produce parts in high and low total quantities of production, given the fixed investment in the system. A higher level of automation increases this flexibility, partly as a result of both lower machine setup costs and lower variable costs.
6. *Material handling flexibility* the ability of the material-handling system to move different parts efficiently throughout the manufacturing system.
7. *Operation flexibility* the ability of a part to be produced in different ways, i.e. a number of alternative processes or ways in which a part can be produced within the system.
8. *Expansion flexibility* the ease with which the system can be expanded to increase total production quantities and capability to expand volumes as needed.
9. *Production flexibility* the range or universe of part types that can be produced without the need to purchase new equipment. The range of part types that the FMS can produce. This flexibility is measured by the level of existing technology.
10. *Programme flexibility* the ability of a system to operate unattended for additional shifts or the length of time the system can operate unattended.
11. *Market flexibility* the ease, in terms of time and/or cost, with which changes can be made within the capability envelope, i.e. long-term flexibility.
12. *Response flexibility* the ease, in terms of time and/or cost, with which changes can be made within the capability envelope, i.e. long-term flexibility.
13. *Product mix flexibility* mix flexibility is the ability to change the relative proportions of different products within an aggregate output level. The total envelope of capability or range of states which the manufacturing system is capable of achieving, i.e. short-term flexibility.
14. *Size flexibility* the component sizes that can be manufactured without requiring setups that take longer than a specific time period.
15. *Range flexibility* the total envelope of capability or range of states which the manufacturing system is capable of achieving, i.e. short-term flexibility.

Based on the literature review and discussions with the group of experts 15 factors were identified (Raj et al. 2012; Sujono and Lashkari 2007; Bayazit 2005; Groover 2006; Primrose 1996; Kaighobadi and Venkatesh 1994). These factors are considered as attributes in MADM. Descriptions of these factors are given below:

1. *Ability to manufacture a variety of products* flexibility of any production system is directly linked with the variety of products to be manufactured in that production system. More is the variety of products to be handled by a particular production system; more will be its flexibility.
2. *Capacity to handle new product* flexibility of a particular manufacturing system would be more if it is capable of handling the more number of new and unexpected products.
3. *Flexibility in the design of the production system* Bayazit (2005) had discussed that maximum utilization of equipment for job shop and medium-volume situations can be achieved by using the same equipment for a variety of parts or products.
4. *Flexible fixturing* FMS is meant for handling a variety of work part configurations. For prismatic parts, this is usually accomplished by using modular pallet fixtures in the handling system (Groover 2006).
5. *Combination of operation* Groover (2006) has discussed that production occurs as a sequence of operations. Complex parts may require dozens, or even hundreds, of processing steps. The strategy of combined operation involves performing two or more machining operations with one cutting tool.
6. *Automation* it reduces the human efforts and introduces some flexibility in the manufacturing system. For example, the use of CNC machines with the help of which human efforts can be reduced, and flexibility of the production system is enhanced.
7. *Use of automated material handling devices* material handling systems provide a key integrating function within a manufacturing system (Sujono and Lashkari 2007). Industrial robots and AGVs are used to pick and place materials from or onto the conveyors, loading and unloading the materials from machines.
8. *Increased machine utilization* it is one of the main sources of inspiration for achieving more flexibility because with a variety of parts being machined, flexibility will be enhanced. FMSs achieve a higher average utilization than a machine in a conventional batch production machine shop.
9. *Use of reconfigurable machine tool* Koren et al. (1999) defined reconfigurable manufacturing system as a system designed at the outset foe rapid changes in structure as well as in hardware and software components in order to quickly adjust production capacity and functionality within a part family in response to sudden changes in market or in regulatory requirements.
10. *Manufacturing lead time and set-up time reduction* it is closely correlated with reduced work-in-process

(WIP) is the time spent in a process by the parts. The ability of a manufacturing firm to deliver a product to the customer in the shortest possible time that time is referred to manufacturing lead time (Keong et al. 2005). Reduction in setup time and subsequently in manufacturing lead time enables the production system to produce a variety of parts at a faster rate. FMS generally employs CNC/NC machines, which have automatic tool interchange capabilities that reduce the setup time (Chang 1999).

11. *Speed of response* an FMS improves response capability to part design changes, introduction of new parts, and changes in the production schedule; machine breakdowns and cutting tool failures.
12. *Reduced WIP inventories* because different parts are processed together rather than separately in batches, WIP is less than in a batch production mode. The inventory of starting and finished parts can be reduced as well. Inventory reductions of 60–80 % are estimated. Reduced WIP may help in improving the routing flexibility.
13. *Reduction in material flow* Bayazit (2005) had found that FMS reduced nonproductive time with the use of automated material handling and storage system. Reduction in material flow also aids in the improvement of routing flexibility of the system.
14. *Quality consciousnesses* Bayazit (2005) has suggested that quality affects the flexibility as a factor in FMS. On-line inspection is generally carried out with machine vision or coordinate measuring machine. Improved inspection capabilities have resulted in the improvement of quality.
15. *Reduction in scrap* it involves the use of special-purpose equipment designed to perform one operation with the greatest possible efficiency to reduce scrap. Use of CNC machines and computer control systems has resulted in reduction of scrap.

Combined Multiple Attribute Decision Making (MADM) Methodology Used for Ranking of Flexibility

The MADM refers to an approach to problem solving that is employed to solve problems involving selected from among a finite number of alternatives. An MADM method is a procedure that specifies how attribute information is to be processed in order to arrive at a choice. MADM application is summarized in Table 1.

In this paper methodology used for ranking of flexibility are

(a) Fuzzy multiple attribute decision making method (MADM)
(b) Analytic hierarchy process (AHP)
(c) Technique for order preference by similarity to ideal situation (TOPSIS)
(d) Improved preference ranking organization method for enrichment evaluations (PROMETHEE)

Rao (2007) has defined combined multiple attribute decision making methodology for AHP, TOPSIS and Rao and Patel (2010) defined improved PROMETHEE as under.

Fuzzy MADM

Rao (2007) has consolidated the information on fuzzy MADM. Bellman and Zadeh (1970) were the first to relate fuzzy set theory to decision-making problems. Yager and Basson (1975) proposed fuzzy sets for decision making. Baas and Kwakernaak (1977) proposed a fuzzy MADM method that is widely regarded as the classic work of fuzzy MADM methods. Chen and Hwang (1992) proposed an approach to solve more than 10 alternatives, and they proposed first converts linguistic terms into fuzzy numbers and then the fuzzy numbers into crisp scores. An 11-point scale is used in the paper is shown in the Fig. 1 and crisp score is shown in Table 2.

Table 1 MADM applications found in literature

Sr. no.	Name of the authors (year)	Application
1	Chauhan and Vaish (2013)	Hard coating material selection
2	Baykasoğlu et al. (2013)	For truck selection
3	Iç (2012)	Selection of computer-integrated manufacturing technologies
4	Pei and Zheng (2012)	A novel approach to multi-attribute decision making
5	Lavasani et al. (2012)	Selecting the best barrier for offshore wells
6	Jahan et al. (2012)	Technique for materials selection
7	Xu et al. (2012)	Linguistic power aggregation operators
8	Kalbar et al. (2012)	Selection of an appropriate wastewater treatment technology
9	Daim et al. (2012)	Site selection for a data center
10	Bakhoum and Brown (2012)	Ranking of structural materials

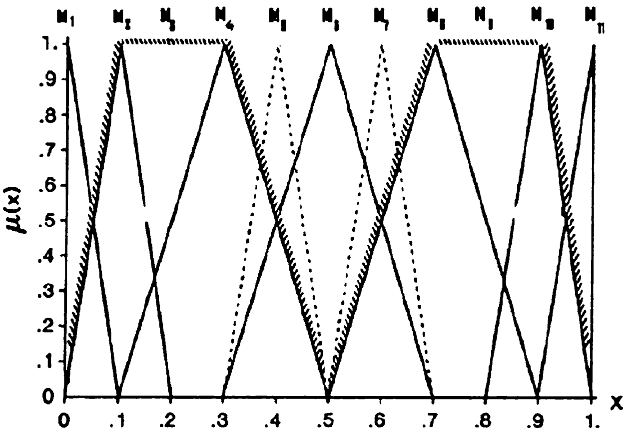

Fig. 1 Linguistic terms into their corresponding fuzzy

Table 2 Conversion of linguistic terms into fuzzy scores (11-point scale)

Linguistic term	Fuzzy no.	Crisp no.
Exceptionally low	M_1	0.045
Extremely low	M_2	0.135
Very low	M_3	0.255
Low	M_4	0.335
Below average	M_5	0.410
Average	M_6	0.500
Above average	M_7	0.590
High	M_8	0.665
Very high	M_9	0.745
Extremely high	M_{10}	0.865
Exceptionally high	M_{11}	0.955

AHP Methodology

Saaty (1980, 2000) developed AHP, which decomposes a decision-making problem into a system of hierarchies of objectives, attributes (or criteria), and alternatives. The main procedure of AHP using the radical root method (also called the geometric mean method) is as follows:

Step 1 The first step is to determine the objective and the evaluation attributes. Then develop a hierarchical structure, objective at the top level, the attributes at the middle level and the alternatives at the last level.

Step 2 Determine the relative importance of different attributes with respect to the goal or objective.

- Construct a pairwise comparison matrix using a scale of relative importance. The judgements are entered using the fundamental scale of the analytic hierarchy process (Saaty 1980, 2000). An attribute compared with itself is always assigned the value 1, so the main diagonal entries of the pairwise comparison matrix are all 1. The numbers 3, 5, 7, and 9 correspond to the verbal judgements 'moderate importance', 'strong importance', 'very strong importance' and 'absolute importance' (with 2, 4, 6, and 8 for compromise between these values). Assuming M attributes, the pairwise comparison of attribute, i with attribute j yield a square matrix $B_{M \times M}$ where a_{ij}, denotes the comparative importance of attribute, i with respect to attribute j. In the matrix, $b_{ij} = 1$ when $i = j$ and $b_{ji} = 1/b_{ij}$.

$$B_{M\times M} = \begin{array}{c} Attributes \\ B_1 \\ B_2 \\ B_3 \\ - \\ - \\ B_M \end{array} \begin{bmatrix} B_1 & B_2 & B_3 & - & - & B_M \\ 1 & b_{12} & b_{13} & - & - & b_{1M} \\ b_{21} & 1 & b_{23} & - & - & b_{2M} \\ b_{31} & b_{32} & 1 & - & - & b_{3M} \\ - & - & - & - & - & - \\ - & - & - & - & - & - \\ b_{M1} & b_{M2} & b_{M3} & - & - & 1 \end{bmatrix} \tag{1}$$

- Find the relative normalized weight (w_j) of each attribute by (i) calculating the geometric mean of the i-th row, and (ii) normalizing the geometric means of rows in the comparison matrix. This can be represented as

$$GM_J = \left[\prod_{i-1}^{M} b_{ij}\right]^{\frac{1}{M}} \tag{2}$$

and

$$w_j = GM_j / \sum_{j-0}^{M} GM_j \tag{3}$$

The geometric mean method of AHP is commonly used to determine the relative normalized weights of the attributes, because of its simplicity, ease, determination of the maximum Eigenvalue, and reduction in inconsistency of judgements.

- Calculate matrices A3 and A4 such that $A3 = A1 \times A2$ and $A4 = A3/A2$, where $A2 = [w_1, w_2, \ldots, w_j]^T$.
- Determine the maximum Eigenvalue λ_{max} that is the average of the matrix A4 Calculates the consistency index $CI = (\lambda_{max} - M)/(M - 1)$. The smaller the value of CI, the smaller is the deviation from the consistency.

Table 3 Random index (RI) values

Attributes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49	1.52	1.54	1.56	1.58	1.59

- Obtain the random index (RI) for the number of attributes used in decision making shown in Table 3 (Saaty and Tran 2007).
- Calculate the consistency ratio CR = CI/RI. Usually, a CR of 0.1 or less is considered as acceptable, and it reflects an informed judgement attribute to the knowledge of the analyst regarding the problem under study.

Step 3 Expressed the attribute values (may be qualitative or quantitative). It then normalized the values of attributes.

Step 4 The next step is to obtain the overall or composite performance scores for the alternatives by multiplying the relative normalized weight (w_j) of each attribute (obtained in step 2) with its corresponding normalized weight value for each alternative (obtained in step 3), and summing over the attributes for each alternative.

TOPSIS Methodology

The TOPSIS method was developed by Hwang and Yoon (1981). This method is based on the concept that the chosen alternative should have the shortest Euclidean distance from the ideal solution, and the farthest from the negative ideal solution. The main procedure of the TOPSIS method for the selection of the best alternative from among those available is described below:

Step 1 The first step is to determine the objective, and to identify the pertinent evaluation attributes and develop a hierarchical structure.

Step 2 This step represents a matrix based on all the information available on attributes. Such a matrix is called a decision matrix. Each row of this matrix is allocated to one alternative, and each column to one attribute. Therefore, an element d_{ij} of the decision table 'D' gives the value of the j-th attribute in original real values, that is, non-normalized form and units, for the, i-th alternative.

If the number of alternatives is M and the number of attributes in N, then the decision matrix is an M × N matrix can be represented as:

$$D_{M\times M} = \begin{array}{c} Attributes \\ D_1 \\ D_2 \\ D_3 \\ - \\ - \\ D_M \end{array} \begin{bmatrix} D_1 & D_2 & D_3 & - & - & D_N \\ d_{11} & d_{12} & d_{13} & - & - & d_{1N} \\ d_{21} & d_{22} & d_{23} & - & - & d_{2N} \\ d_{31} & d_{32} & d_{33} & - & - & d_{3N} \\ - & - & - & - & - & - \\ - & - & - & - & - & - \\ d_{M1} & d_{M2} & d_{M3} & - & - & d_{MN} \end{bmatrix} \quad (4)$$

In the case of a qualitative attribute (i.e. quantitative value is not available); a ranked value judgement on a scale is adopted by using fuzzy set theory. Once a qualitative attribute is represented on a scale then the normalized values of the attribute assigned for different alternatives are calculated in the same manner as that for quantitative attributes.

Step 3 Obtain the normalized decision matrix, R_{ij}. This can be represented as

$$R_{ij} = d_{ij} / \left[\sum_{j-1}^{M} d_{ij}^2 \right]^{1/2} \quad (5)$$

Step 4 Decide on the relative importance (i.e., weights) of different attributes with respect to the objective. It is same as step 2 in "AHP Methodology" section. A set of weights w_j (for j = 1, 2,…, M) such that $\sum w_j = 1$ may be decided upon.

Step 5 Obtain the weighted normalized matrix V_{ij}. This is done by the multiplication of each element of the column of the matrix, R_{ij} with its associated weight w_j. Hence, the elements of the weighted normalized matrix V_{ij} are expressed as:

$$V_{ij} = w_j R_{ij} \quad (6)$$

Step 6 Obtain the ideal (best) and negative ideal (worst) solutions in this step. The ideal (best) and negative ideal (worst) solutions can be expressed as:

$$V^+ = \left\{ \left(\sum_i^{max} V_{ij} / j \in J \right), \left(\sum_i^{min} V_{ij} / j \in J' \right) / \; i = 1, 2, \ldots, N \right\} = \left\{ V_1^+, V_2^+, V_3^+, \ldots, V_M^+ \right\} \quad (7)$$

$$V^- = \left\{ \left(\sum_i^{max} V_{ij}/j \in J \right), \left(\sum_i^{min} V_{ij}/j \in J' \right) / i = 1, 2, \ldots, N \right\} = \left\{ V_1^-, V_2^-, V_3^-, \ldots, V_M^- \right\} \quad (8)$$

where J = (j = 1, 2,…, M)/j is associated with beneficial attributes, and J′ = (j = 1, 2,…, M)/j is associated with non beneficial attributes.

V_j^+ indicates the ideal (best) value of the considered attribute among the values of the attribute for different alternatives. In the case of beneficial attributes (i.e., those of which higher values are desirable for the given application), V_j^+ indicates the higher value of the attribute. In the case of non-beneficial attributes (i.e., those of which lower values are desired for the given application). V_j^+ indicates the lower value of the attribute. V_j^- indicates the negative ideal (worst) value of the considered attribute among the values of the attribute for different alternatives. In the case of beneficial attributes (i.e., those of which higher values are desirable for the given application), V_j^- indicates the lower value of the attribute. In the case of non beneficial attributes (i.e., those of which lower values are desired for the given application), V_j^- indicates the higher value of the attribute.

Step 7 Obtain the separation measure. The separation of each alternative from the ideal one is given by the Euclidean distance in the following equations.

$$S_i^+ = \left\{ \sum_{J-1}^{M} \left(V_{ij} - V_j^+ \right)^2 \right\}^{0.5}, \quad (9)$$

where i = 1, 2,…N

$$S_i^- = \left\{ \sum_{J-1}^{M} \left(V_{ij} - V_j^- \right)^2 \right\}^{0.5}, \quad (10)$$

where i = 1, 2,…N

Step 8 The relative closeness of a particular alternative to the ideal solution, P_i, can be expressed in this step as follows.

$$P_i = {S_i^-} / \left(S_i^+ + S_i^- \right) \quad (11)$$

Step 9 A set of alternative is generated in the descending order in this step, according to the value of P_i indicating the most preferred and least preferred feasible solutions. P_i may also be called the overall or composite performance score of alternative A_i.

Improved PROMETHEE Methodology

The PROMETHEE method was introduced by Brans et al. (1984) and belongs to the category of outranking methods.

It may be added here that the original PROMETHEE method can effectively deal mainly with quantitative criteria. However, there exists some difficulty in the case of qualitative criteria. In the case of a qualitative criterion (i.e. quantitative value is not available); a ranked value judgment on a fuzzy conversion scale is adopted in this paper. By using fuzzy set theory, the value of the criteria can be first decided as linguistic terms, converted into corresponding fuzzy numbers and then converted to the crisp scores. The improved PROMETHEE methodology for ranking of flexibility is described below:

Step 1 The first step is to determine the objective, to identify the pertinent evaluation attributes and then shortlist the alternatives. After short listing the alternatives, prepare a decision table, including the measures or values of all criteria for the shortlisted alternatives.

Step 2 The weights of relative importance of the criteria may be assigned using the AHP method (Saaty 2000). This step is explained in step 2 of "AHP Methodology" section.

Step 3 After calculating the weights of the criteria using the AHP method, the next step is to have the information on the decision maker preference function, which he/she uses when comparing the contribution of the alternatives in terms of each separate criterion.

The preference function *(P_i)* translates the difference between the evaluations obtained by two alternatives (a1 and a2) in terms of a particular criterion, into a preference degree ranging from 0 to 1. Let $P_{i,a1a2}$ be the preference function associated with the criterion c_i.

$$P_i, a1a2 = G_i[c_i(a1) - c_i(a2)] \quad (12)$$

$$0 \leq Pi, a1a2 \leq 1 \quad (13)$$

where G_i is a non-decreasing function of the observed deviation (d) between two alternatives $a1$ and $a2$ over the criterion c_i.

Step 4 Let the decision maker have specified a preference function P_i and weight w_i for each criterion c_i (i = 1, 2, M) of the problem. The multiple criteria preference index Π_{a1a2} is then defined as the weighted average of the preference functions P_i.

$$\prod_{a1a2} = \sum_{i-1}^{M} w_i P_{i,a1a2} \quad (14)$$

Π_{a1a2} represents the intensity of preference of the decision maker of alternative a1 over alternative $a2$, when considering simultaneously all the criteria. Its value ranges from 0 to 1 (Marinoni 2005). For PROMETHEE outranking relations, the leaving flow, entering flow and the net flow for an alternative a belonging to a set of alternatives A are defined by the following equations:

$$\varphi^{+}(\mathrm{a}) = \sum_{\mathrm{x\varepsilon A}} \Pi_{\mathrm{xa}} \quad (15)$$

$$\varphi^{-}(\mathrm{a}) = \sum_{\mathrm{x\varepsilon A}} \Pi_{\mathrm{ax}} \quad (16)$$

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

$\varphi^{+}(a)$ is called the leaving flow, $\varphi^{-}(a)$ is called the entering flow and $\varphi(a)$ is called the net flow. $\varphi^{+}(a)$ is the measure of the outranking character of a (i.e. dominance of alternative an overall other alternatives) and $\varphi^{-}(a)$ gives the outranked character of a (i.e. degree to which alternative a is dominated by all other alternatives). The net flow, $\varphi(a)$ represents a value function, whereby a higher value reflects a higher attractiveness of alternative a. The net flow values are used to indicate the outranking relationship between the alternatives.

The proposed decision making framework using PROMETHEE method provides a complete ranking of the alternatives from the best to the worst one using the net flows.

Ranking of Flexibility

Ranking of Flexibility by AHP

Step 1 Objective is finding the raking of flexibility in FMS based on 15 attributes. The hierarchical structure is shown in Fig. 2 as a ranking of flexibility at the top level, 15 attributes at the second level and 15 alternatives at the third level

Step 2 Relative importance of different attributes with respect to objective is find as under:

(a) Pairwise comparison matrix using a scale of relative importance (as explained in AHP methodology) is shown in Table 4. All attributes are beneficial attributes so higher values are desired. The data given in Table 4 will be used as a matrix $A1_{15\times15}$.
(b) Calculating the geometric mean of i-th row and weights of the attributes, according to the step 2 of "AHP Methodology" section. The weights of the attributes will be used as the matrix A2. Weights of attributes are shown in Table 5.
(c) Calculate the matrix A3 and A4 i.e. shown below.
(d) Find the maximum Eigenvalue λ_{max} i.e. 17.2112 i.e. is the average of matrix A4.
(e) Find the consistency index CI = $(\lambda_{max} - M)/(M - 1) = 0.158$.
(f) Take the RI for the 15 number of attributes = 1.59.
(g) Calculate the consistency ratio (CR) = CI/RI = 0.0993.
CR = 0.0993 < 0.1
CR is less than or equal to 0.1 is acceptable.

Step 3 The attributes are expressed in linguistic term. These linguistic terms are converted into fuzzy scores as explained by the fuzzy MADM methodology. Table 6 presents the values in quantitative terms. The quantitative values of attributes are normalized and shown in Table 7.

Step 4 Obtain the overall or composite performance scores for the alternatives by multiplying the relative normalized weight (w_j) of each attribute with its corresponding normalized weight value for each alternative and summing over the attributes for each alternative. The overall or composite performance scores are shown in Table 8. And according this score ranking of flexibilities are shown in Table 9.

Fig. 2 Hierarchical structure

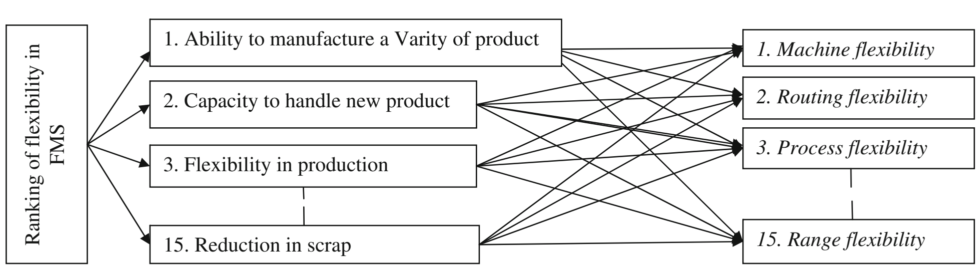

Table 4 Pairwise matrix

Sr. no.	Variables	1 Ability to manufacture a variety of product	2 Capacity to handle new product	3 Flexibility in Production	4 Flexible fixturing	5 Combination of operation	6 Automation	7 Use of automated material handling devices
1	Ability to manufacture a variety of product	1	2	3	1/3	1/3	1/3	3
2	Capacity to handle new product	1/2	1	3	1/3	2	1/3	2
3	Flexibility in Production	1/3	1/3	1	1/3	3	½	3
4	Flexible fixturing	3	3	3	1	3	3	1/3
5	Combination of operation	3	1/2	1/3	1/3	1	1/3	1/3
6	Automation	3	3	2	1/3	3	1	1/3
7	Use of automated material handling devices	1/3	1/2	1/3	3	3	3	1
8	Increase machine utilization	1/3	1/3	1/3	1/3	1/3	1/3	1/3
9	Use of reconfigurable machine tool	3	3	3	1/2	3	1/3	1/3
10	Manufacturing lead time and setup time reduction	1/3	1/3	1/3	1/3	1/3	½	1/3
11	Speed of response	1/5	1/3	1/3	1/3	1/3	1/7	1/5
12	Reduced WIP inventories	1/2	1/3	1/3	1/3	1/2	1/3	1/3
13	Reduction in material flow	1/3	1/3	1/3	1/3	1/3	1/3	1/3
14	Quality consciousness	1/3	1/3	1/3	1/3	1/3	1/3	1/3
15	Reduction in scrap	1/2	1/2	1/2	1/3	1/3	1/3	1/3

Sr. no.	Variables	8 Increase machine utilization	9 Use of reconfigurable machine tool	10 Manufacturing lead time and setup time reduction	11 Speed of response	12 Reduced WIP inventories	13 Reduction in material flow	14 Quality consciousness	15 Reduction in scrap
1	Ability to manufacture a variety of product	3	1/3	3	5	2	3	3	2
2	Capacity to handle new product	3	1/3	3	3	3	3	3	2
3	Flexibility in Production	3	1/3	3	3	3	3	3	2
4	Flexible fixturing	3	2	3	3	3	3	3	3
5	Combination of operation	3	1/3	3	3	2	3	3	3
6	Automation	3	3	2	7	3	3	3	3
7	Use of automated material handling devices	3	1/3	3	5	3	3	3	3
8	Increase machine utilization	1	1/3	1/2	1/3	2	3	2	2
9	Use of reconfigurable machine tool	3	1	1/2	3	3	3	3	3
10	Manufacturing lead time and setup time reduction	2	2	1	3	2	3	3	2
11	Speed of response	1/3	1/3	1/3	1	1/3	1/3	1/3	1/2
12	Reduced WIP inventories	1/2	1/3	1/2	3	1	1	2	2
13	Reduction in material flow	1/3	1/3	1/3	3	1	1	2	1/2
14	Quality consciousness	1/2	1/3	1/3	3	1/2	1/2	1	1/2
15	Reduction in scrap	1/2	1/3	1/2	2	1/2	2	2	1

Table 5 Weights of the attributes

Alternatives	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Weight (w)	0.086	0.085	0.078	0.136	0.067	0.121	0.096	0.035	0.095	0.053	0.019	0.037	0.030	0.027	0.035

Table 6 Fuzzy or crisp value of attributes

Attributes alternatives	1	2	3	4	5	6	7	8
1	0.865	0.665	0.665	0.5	0.59	0.5	0.41	0.59
2	0.41	0.41	0.665	0.5	0.255	0.5	0.59	0.59
3	0.665	0.5	0.59	0.59	0.5	0.5	0.41	0.59
4	0.745	0.865	0.665	0.59	0.41	0.5	0.41	0.59
5	0.41	0.41	0.41	0.5	0.5	0.59	0.59	0.5
6	0.255	0.255	0.41	0.41	0.5	0.59	0.745	0.41
7	0.335	0.255	0.41	0.5	0.41	0.5	0.41	0.41
8	0.41	0.335	0.665	0.5	0.5	0.41	0.5	0.665
9	0.665	0.59	0.59	0.59	0.5	0.665	0.59	0.665
10	0.255	0.255	0.335	0.255	0.135	0.5	0.59	0.335
11	0.5	0.59	0.5	0.335	0.255	0.665	0.135	0.255
12	0.5	0.59	0.665	0.59	0.335	0.745	0.59	0.41
13	0.59	0.5	0.665	0.5	0.5	0.59	0.5	0.5
14	0.665	0.59	0.5	0.5	0.5	0.5	0.59	0.5
15	0.5	0.5	0.59	0.5	0.41	0.5	0.59	0.41

Attributes alternatives	9	10	11	12	13	14	15
1	0.665	0.665	0.59	0.335	0.255	0.5	0.41
2	0.41	0.41	0.665	0.59	0.5	0.41	0.5
3	0.5	0.5	0.59	0.5	0.5	0.41	0.5
4	0.59	0.5	0.665	0.41	0.41	0.5	0.41
5	0.5	0.665	0.5	0.41	0.41	0.41	0.41
6	0.41	0.59	0.59	0.5	0.41	0.335	0.255
7	0.59	0.5	0.41	0.335	0.335	0.255	0.255
8	0.745	0.745	0.5	0.335	0.255	0.41	0.255
9	0.865	0.41	0.41	0.255	0.335	0.5	0.135
10	0.41	0.335	0.59	0.255	0.255	0.135	0.135
11	0.59	0.255	0.5	0.255	0.135	0.5	0.135
12	0.5	0.335	0.5	0.255	0.41	0.665	0.5
13	0.5	0.59	0.5	0.59	0.41	0.5	0.5
14	0.59	0.665	0.5	0.41	0.335	0.335	0.255
15	0.5	0.5	0.59	0.335	0.255	0.255	0.135

Ranking of Flexibility by TOPSIS

Step 1 Objective is finding the raking of flexibility in a FMS based on 15 attributes is same as discussed in AHP ranking. All attributes the beneficial attributes i.e. higher values are desired.

Step 2 The next step is to represent all the information available for attributes (as in Table 5) in a decision matrix.

Step 3 The quantitative values of attributes are normalized and shown in Table 10 as $R_{15\times15\ \text{matrix}}$.

Step 4 Relative importance matrix (i.e. weights) of different attributes with respect to the objective is taken as in "AHP Methodology" section.

Step 5 The weighted normalized matrix, V_{15x15} is calculated and is shown below in Table 11.

Step 6 The next step is to obtain the ideal (best) and negative ideal (worst) solutions. Ideal (best) and negative ideal (worst) solutions are shown in Table 12.

Step 7 The next step is to obtain the separation measures. Separation measures are shown in Table 13.

Step 8 The relative closeness of a particular alternative to the ideal solution is calculated and shown in Table 14. And according to this Ranking of flexibilities are shown in Table 15.

Table 7 Normalized value of attributes

Attributes alternatives	1	2	3	4	5	6	7	8
1	1.000	0.769	1.000	0.847	1.000	0.671	0.550	0.887
2	0.474	0.474	1.000	0.847	0.432	0.671	0.792	0.887
3	0.769	0.578	0.887	1.000	0.847	0.671	0.550	0.887
4	0.861	1.000	1.000	1.000	0.695	0.671	0.550	0.887
5	0.474	0.474	0.617	0.847	0.847	0.792	0.792	0.752
6	0.295	0.295	0.617	0.695	0.847	0.792	1.000	0.617
7	0.387	0.295	0.617	0.847	0.695	0.671	0.550	0.617
8	0.474	0.387	1.000	0.847	0.847	0.550	0.671	1.000
9	0.769	0.682	0.887	1.000	0.847	0.893	0.792	1.000
10	0.295	0.295	0.504	0.432	0.229	0.671	0.792	0.504
11	0.578	0.682	0.752	0.568	0.432	0.893	0.181	0.383
12	0.578	0.682	1.000	1.000	0.568	1.000	0.792	0.617
13	0.682	0.578	1.000	0.847	0.847	0.792	0.671	0.752
14	0.769	0.682	0.752	0.847	0.847	0.671	0.792	0.752
15	0.578	0.578	0.887	0.847	0.695	0.671	0.792	0.617

Attributes alternatives	9	10	11	12	13	14	15
1	0.769	0.893	0.887	0.568	0.510	0.752	0.820
2	0.474	0.550	1.000	1.000	1.000	0.617	1.000
3	0.578	0.671	0.887	0.847	1.000	0.617	1.000
4	0.682	0.671	1.000	0.695	0.820	0.752	0.820
5	0.578	0.893	0.752	0.695	0.820	0.617	0.820
6	0.474	0.792	0.887	0.847	0.820	0.504	0.510
7	0.682	0.671	0.617	0.568	0.670	0.383	0.510
8	0.861	1.000	0.752	0.568	0.510	0.617	0.510
9	1.000	0.550	0.617	0.432	0.670	0.752	0.270
10	0.474	0.450	0.887	0.432	0.510	0.203	0.270
11	0.682	0.342	0.752	0.432	0.270	0.752	0.270
12	0.578	0.450	0.752	0.432	0.820	1.000	1.000
13	0.578	0.792	0.752	1.000	0.820	0.752	1.000
14	0.682	0.893	0.752	0.695	0.670	0.504	0.510
15	0.578	0.671	0.887	0.568	0.510	0.383	0.270

Table 8 The overall or composite performance scores

Alternatives	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Overall or composite performance scores	0.799	0.703	0.763	0.803	0.712	0.654	0.605	0.710	0.789	0.470	0.562	0.774	0.772	0.742	0.672

Table 9 Ranking of flexibility by AHP

Ranking	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Flexibility	4	1	9	12	13	3	14	5	8	2	15	6	7	11	10

Table 10 Normalized

Attributes alternatives	1	2	3	4	5	6	7	8
1	0.4089	0.3335	0.3031	0.2586	0.3487	0.2318	0.2005	0.2997
2	0.1938	0.2056	0.3031	0.2586	0.1507	0.2318	0.2885	0.2997
3	0.3144	0.2507	0.2689	0.3052	0.2955	0.2318	0.2005	0.2997
4	0.3522	0.4338	0.3031	0.3052	0.2423	0.2318	0.2005	0.2997
5	0.1938	0.2056	0.1869	0.2586	0.2955	0.2736	0.2885	0.2540
6	0.1205	0.1279	0.1869	0.2121	0.2955	0.2736	0.3643	0.2082
7	0.1584	0.1279	0.1869	0.2586	0.2423	0.2318	0.2005	0.2082
8	0.1938	0.1680	0.3031	0.2586	0.2955	0.1901	0.2445	0.3378
9	0.3144	0.2959	0.2689	0.3052	0.2955	0.3083	0.2885	0.3378
10	0.1205	0.1279	0.1527	0.1319	0.0798	0.2318	0.2885	0.1701
11	0.2364	0.2959	0.2279	0.1733	0.1507	0.3083	0.0660	0.1295
12	0.2364	0.2959	0.3031	0.3052	0.1980	0.3454	0.2885	0.2082
13	0.2789	0.2507	0.3031	0.2586	0.2955	0.2736	0.2445	0.2540
14	0.3144	0.2959	0.2279	0.2586	0.2955	0.2318	0.2885	0.2540
15	0.2364	0.2507	0.2689	0.2586	0.2423	0.2318	0.2885	0.2082

Attributes alternatives	9	10	11	12	13	14	15
1	0.3007	0.3243	0.2793	0.2158	0.1824	0.3022	0.3025
2	0.1854	0.2000	0.3148	0.3801	0.3576	0.2478	0.3689
3	0.2261	0.2439	0.2793	0.3221	0.3576	0.2478	0.3689
4	0.2667	0.2439	0.3148	0.2641	0.2932	0.3022	0.3025
5	0.2261	0.3243	0.2367	0.2641	0.2932	0.2478	0.3025
6	0.1854	0.2878	0.2793	0.3221	0.2932	0.2025	0.1881
7	0.2667	0.2439	0.1941	0.2158	0.2396	0.1541	0.1881
8	0.3368	0.3634	0.2367	0.2158	0.1824	0.2478	0.1881
9	0.3911	0.2000	0.1941	0.1643	0.2396	0.3022	0.0996
10	0.1854	0.1634	0.2793	0.1643	0.1824	0.0816	0.0996
11	0.2667	0.1244	0.2367	0.1643	0.0965	0.3022	0.0996
12	0.2261	0.1634	0.2367	0.1643	0.2932	0.4019	0.3689
13	0.2261	0.2878	0.2367	0.3801	0.2932	0.3022	0.3689
14	0.2667	0.3243	0.2367	0.2641	0.2396	0.2025	0.1881
15	0.2261	0.2439	0.2793	0.2158	0.1824	0.1541	0.0996

Ranking of Flexibility by Improved PROMETHEE

Step 1 Objective is finding the raking of flexibility in a FMS based on 15 attributes is same as discussed in AHP ranking.

Step 2 Relative importance matrix (i.e. weights) of different attributes with respect to the objective is taken as in "AHP Methodology" section.

Step 3 The next step is to have the information on the decision maker preference function P_i, which he/she uses when comparing the contribution of the alternatives in terms of each separate criterion. The pairwise comparison of criterion 'Ability to manufacture a variety of product' gives the matrix given in Table 16. Ability to manufacture a variety of products is a beneficial criterion, and higher values are desired. Flexibility having a comparatively high value of Ability to manufacture a variety of products is said to be 'better' than the other. Another criterion is followed same as the ability to manufacture a variety of products.

Step 4 After specifying a preference function P_i and weight w_i for each criterion, the multiple criteria preference index, Π_{a1a2} is calculated.

The leaving flow, entering flow and the net flow for different alternatives are calculated and these are given in Table 17. According to this net flow ranking of flexibility is shown in Table 18.

Table 11 Weighted normalized (R_{ij})

Attributes alternatives	1	2	3	4	5	6	7	8
1	0.0352	0.0283	0.0236	0.0352	0.0234	0.0281	0.0192	0.0105
2	0.0167	0.0175	0.0236	0.0352	0.0101	0.0281	0.0277	0.0105
3	0.0270	0.0213	0.0210	0.0415	0.0198	0.0281	0.0192	0.0105
4	0.0303	0.0369	0.0236	0.0415	0.0162	0.0281	0.0192	0.0105
5	0.0167	0.0175	0.0146	0.0352	0.0198	0.0331	0.0277	0.0089
6	0.0104	0.0109	0.0146	0.0288	0.0198	0.0331	0.0350	0.0073
7	0.0136	0.0109	0.0146	0.0352	0.0162	0.0281	0.0192	0.0073
8	0.0167	0.0143	0.0236	0.0352	0.0198	0.0230	0.0235	0.0118
9	0.0270	0.0251	0.0210	0.0415	0.0198	0.0373	0.0277	0.0118
10	0.0104	0.0109	0.0119	0.0179	0.0053	0.0281	0.0277	0.0060
11	0.0203	0.0251	0.0178	0.0236	0.0101	0.0373	0.0063	0.0045
12	0.0203	0.0251	0.0236	0.0415	0.0133	0.0418	0.0277	0.0073
13	0.0240	0.0213	0.0236	0.0352	0.0198	0.0331	0.0235	0.0089
14	0.0270	0.0251	0.0178	0.0352	0.0198	0.0281	0.0277	0.0089
15	0.0203	0.0213	0.0210	0.0352	0.0162	0.0281	0.0277	0.0073

Attributes alternatives	9	10	11	12	13	14	15
1	0.0286	0.0172	0.0053	0.0080	0.0055	0.0082	0.0106
2	0.0176	0.0106	0.0060	0.0141	0.0107	0.0067	0.0129
3	0.0215	0.0129	0.0053	0.0119	0.0107	0.0067	0.0129
4	0.0253	0.0129	0.0060	0.0098	0.0088	0.0082	0.0106
5	0.0215	0.0172	0.0045	0.0098	0.0088	0.0067	0.0106
6	0.0176	0.0153	0.0053	0.0119	0.0088	0.0055	0.0066
7	0.0253	0.0129	0.0037	0.0080	0.0072	0.0042	0.0066
8	0.0320	0.0193	0.0045	0.0080	0.0055	0.0067	0.0066
9	0.0372	0.0106	0.0037	0.0061	0.0072	0.0082	0.0035
10	0.0176	0.0087	0.0053	0.0061	0.0055	0.0022	0.0035
11	0.0253	0.0066	0.0045	0.0061	0.0029	0.0082	0.0035
12	0.0215	0.0087	0.0045	0.0061	0.0088	0.0109	0.0129
13	0.0215	0.0153	0.0045	0.0141	0.0088	0.0082	0.0129
14	0.0253	0.0172	0.0045	0.0098	0.0072	0.0055	0.0066
15	0.0215	0.0129	0.0053	0.0080	0.0055	0.0042	0.0035

Table 12 Ideal (best) solutions (V^+) and ideal (worst) solutions (V^-)

Alternatives	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ideal (best) solutions (V^+)	0.0352	0.0369	0.0236	0.0415	0.0234	0.0418	0.0350	0.0118	0.0372	0.0193	0.0060	0.0141	0.0107	0.0109	0.0129
Ideal (worst) solutions (V^-)	0.0104	0.0109	0.0119	0.0179	0.0053	0.0230	0.0063	0.0045	0.0176	0.0066	0.0037	0.0061	0.0029	0.0022	0.0035

Table 13 Separation measures

Alternatives	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Separation measures (S^+)	0.0266	0.0406	0.0301	0.0270	0.0359	0.0463	0.0457	0.0393	0.0234	0.0577	0.0480	0.0310	0.0302	0.0297	0.1045
Separation measures (S^-)	0.0473	0.0362	0.0470	0.0485	0.0377	0.0375	0.0277	0.0381	0.0499	0.0223	0.0263	0.0458	0.0408	0.0446	0.0417

Table 14 The relative closeness of a particular alternative to the ideal solution

Alternatives	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
The relative closeness (P_i)	0.6403	0.4713	0.6096	0.6427	0.5123	0.4474	0.3775	0.4923	0.6806	0.2786	0.3540	0.5962	0.5748	0.6007	0.2851

Table 15 Ranking of Flexibility by TOPSIS

Ranking	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Flexibility	9	4	1	3	14	12	13	5	2	8	6	7	11	15	10

Table 16 Pairwise comparison of criterion 'Ability to manufacture a variety of product'

	Alternatives														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	–	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	0	–	0	0	0	1	1	0	0	1	0	0	0	0	0
3	0	1	–	0	1	1	1	1	0	1	1	1	1	0	1
4	0	1	1	–	1	1	1	1	1	1	1	1	1	1	1
5	0	0	0	0	–	1	1	0	0	1	0	0	0	0	0
6	0	0	0	0	0	–	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	1	–	0	0	1	0	0	0	0	0
8	0	0	0	0	0	1	1	–	0	1	0	0	0	0	0
9	0	1	0	0	1	1	1	1	–	1	1	1	1	0	1
10	0	0	0	0	0	0	0	0	0	–	0	0	0	0	0
11	0	1	0	0	1	1	1	1	0	1	–	0	0	0	0
12	0	1	0	0	1	1	1	1	0	1	0	–	0	0	0
13	0	1	0	0	1	1	1	1	0	1	1	1	–	0	1
14	0	1	0	0	1	1	1	1	0	1	1	1	1	–	1
15	0	1	0	0	1	1	1	1	0	1	0	0	0	0	–

Table 17 Leaving flow, entering flow and the net flow

Alternatives Attributes	1	2	3	4	5	6	7	8	9
1	–	0.346	0.424	0.234	0.492	0.697	0.580	0.440	0.460
2	0.217	–	0.230	0.198	0.234	0.568	0.528	0.423	0.199
3	0.238	0.522	–	0.169	0.541	0.607	0.635	0.549	0.174
4	0.307	0.549	0.390	–	0.561	0.596	0.568	0.576	0.423
5	0.284	0.336	0.270	0.337	–	0.552	0.691	0.404	0.174
6	0.284	0.337	0.270	0.374	0.152	–	0.450	0.303	0.270
7	0.030	0.215	0.095	0.000	0.095	0.317	–	0.151	0.125
8	0.279	0.277	0.384	0.346	0.288	0.595	0.641	–	0.222
9	0.513	0.625	0.432	0.414	0.636	0.636	0.799	0.649	–
10	0.096	0.000	0.096	0.096	0.019	0.000	0.115	0.236	0.019
11	0.121	0.414	0.328	0.121	0.492	0.492	0.416	0.319	0.019
12	0.445	0.617	0.407	0.279	0.568	0.663	0.713	0.616	0.310
13	0.319	0.534	0.412	0.409	0.348	0.614	0.769	0.421	0.252
14	0.163	0.386	0.329	0.216	0.344	0.568	0.583	0.455	0.144
15	0.096	0.386	0.096	0.096	0.268	0.480	0.364	0.407	0.109

Table 17 continued

Alternatives Attributes	10	11	12	13	14	15	$\varphi^{+}(a)$	$\varphi^{-}(a)$	$\varphi(a)$
1	0.734	0.852	0.477	0.440	0.432	0.561	7.169	3.392	3.777
2	0.688	0.519	0.174	0.180	0.261	0.261	4.680	5.544	−0.864
3	0.764	0.672	0.327	0.306	0.397	0.453	6.354	4.163	2.191
4	0.783	0.757	0.477	0.456	0.531	0.663	7.637	3.289	4.348
5	0.885	0.489	0.192	0.149	0.213	0.405	5.381	5.038	0.343
6	0.715	0.508	0.272	0.168	0.303	0.466	4.872	7.385	−2.513
7	0.679	0.489	0.252	0.095	0.000	0.160	2.703	7.852	−5.149
8	0.734	0.662	0.287	0.183	0.288	0.390	5.576	5.949	−0.373
9	0.786	0.703	0.363	0.681	0.465	0.655	8.357	2.900	5.457
10	–	0.233	0.019	0.115	0.019	0.000	1.063	10.606	−9.543
11	0.695	–	0.095	0.301	0.148	0.328	4.289	8.341	−4.052
12	0.795	0.678	–	0.465	0.427	0.512	7.495	3.762	3.733
13	0.885	0.653	0.278	–	0.328	0.569	6.791	4.069	2.722
14	0.764	0.575	0.373	0.415	–	0.550	5.865	3.909	1.956
15	0.699	0.551	0.176	0.115	0.097	–	3.940	5.973	−2.033

Table 18 Ranking of flexibility by improved PROMETHEE

Ranking	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Flexibility	9	4	1	12	13	3	14	5	8	2	15	6	11	7	10

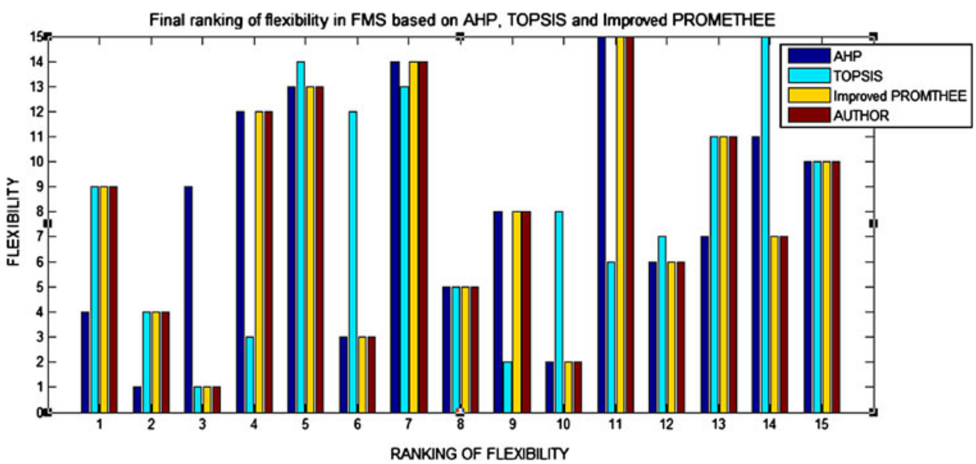

Fig. 3 Ranking of flexibility in FMS based on AHP, TOPSIS and improved PROMETHEE

Industrial Implication

Production Manager often feels handicapped in differentiating machine flexibility, process flexibility, product flexibility, operation flexibility and production flexibility. We find that Production Managers face problems in manufacturing system like how to measure the level of flexibility and how to quantify them. Researchers have not been able to develop any universally accepted technique on which the manufacturing people can rely. Though a lot of research work has been reported regarding flexibility in the FMS, yet its real-life implications are not encouraging. In this paper, we have tried to define the definitions of different flexibilities as given in the literature. In the research work, Ranking of flexibility of FMS is done by MADM and concluded that production flexibility has the most impact on FMS. It is helpful to the Production Manager for analysis this for their organization. Based on this Ranking, he can conclude on which flexibility he should focus to reduce costs or increase the performance of the manufacturing system. As the flexibility increases, as a result productivity of the system increases.

Flexibility is not a strictly defined phenomenon, and consequently any measure proposed for it will be inapplicable in many situations. Managers should study the measures carefully and modify them, or possibly reconstruct them, to best suit their needs. However, in the specific case, the type and amount of flexibility needed to be established, as well as the means for achieving that type of flexibility, focusing on the specific sales, cost and asset issues that are relevant to the company and manufacturing situation.

Conclusion

The major objective of this paper is to identify the 15 factors that significantly affect the flexibility of FMS in any industry and the main focus on the ranking of 15 flexibility which is identified in a FMS so that management may effectively deal with these flexibilities. In this paper, ranking of flexibilities is found out by a different methodology of combined MADM such as an AHP, TOPSIS, and improved PROMETHEE.

1. Ranking of flexibilities by AHP is 4-1-9-12-13-3-14-5-8-2-15-6-7-11-10.
2. Ranking of flexibilities by TOPSIS is 9-4-1-3-14-12-13-5-2-8-6-7-11-15-10.
3. Ranking of flexibilities by improved PROMETHEE is 9-4-1-12-13-3-14-5-8-2-15-6-11-7-10.

Final ranking of flexibility in a FMS based on AHP, TOPSIS and Improved PROMETHEE is 9-4-1-12-13-3-14-5-8-2-15-6-11-7-10. According to these rankings, No. 9 i.e. production flexibility has the top ranking, i.e. the most impact on FMS and No. 10 i.e. programme flexibility has lower most ranking i.e. the least impact on FMS. Ranking of flexibilities is shown in Fig. 3.

The relative importance of the outcomes is not considered, although it could be a major concern in decision making. The MADM literature indicates that several approaches are available for the formulation and analysis of problems which require the consideration of multiple attributes in the choices that have to be made. The present study applies only 15 factors for ranking of flexibility, a greater number of factors may be considered for this purpose.

Acknowledgments The authors acknowledge the anonymous referee of this paper for his or her valuable suggestions, which have helped to improve the quality of this paper.

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Key Questions

1. What are the main flexibilities in a flexible manufacturing system?
2. Which factors considered in Combined Multiple Attribute Decision Making Method for ranking of flexibilities in a flexible manufacturing system?
3. How do you convert qualitative data into quantitative data?
4. Define the weights of attributes in Combined Multiple Attribute Decision Making Method.

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