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Full Length Research Paper

Multi-criteria decision making using fuzzy logic approach for evaluating the manufacturing flexibility

S. R. Ansari[1], P. K. Mittal[2] and Ritu Chandna[2]*

[1]Department of Mathematics, H. N. B. Garhwal University, Srinagar (Garhwal), India.
[2]Department of Mathematics and R&D, Graphic Era University, Dehradun, Uttarakhand, India.

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Manufacturing flexibility is the ability of a manufacturing system to cope with environmental changes effectively and efficiently. Most operation managers cannot provide exact numerical values to express opinions based on human perception due to ill defined and ambiguity of flexibility assessment. However, fuzzy logic provides a useful tool to deal with problems in which the phenomena are imprecise and vague. The purpose of this study is to measure the flexibility of manufacturing system based on multi-criteria decision making using fuzzy logic approach. In this approach, the performance ratings and importance weights of different flexibility capabilities assessed by experts are expressed in linguistic terms. Fuzzy performance-importance index of each flexibility capability is also devised to help managers identify the main adverse factors and calls for managers to institute an appropriate action plan to improve the flexibility level. An example is also used to illustrate the approach developed.

Key words: Manufacturing flexibility, fuzzy logic, multi-criteria decision, performance rating, importance weights.

INTRODUCTION

Manufacturing flexibility (MF) is an effective way to face up to the uncertainties of the rapidly changing environment and it is defined as the ability to absorb various disturbances which occur in production systems, as well as the ability to incorporate and exploit new technological advances and work practices. Although there have been tremendous efforts to define the meaning of manufacturing flexibility (Sethi and Sethi, 1990; Sarker et al., 1994; Beach et al., 2000; Golden and Powell, 2000; Vokurka and O'Leary-Kelly, 2000), the flexibility concept still remains incomplete or too abstract for operational applications.

Measurement of manufacturing flexibility imparts a great deal of insight at both the strategic and operational levels of a firm that equips managers to deal with current problems such as shrinking product life cycles, fierce market competition, and the ever-increasing demand for product variety (Gerwin, 1993). Nevertheless, several frameworks have been suggested for its measurement such as entropy (Chang et al., 2001; Shuiabi et al., 2005), graph theory (Kochikar and Narendran, 1992), Petri nets (Barad and Sipper, 1988) together with other mathe-matical programming approaches that are often difficult for operations managers to interpret (Gupta and Goyal, 1989; Parker and Wirth, 1999, Gupta, 1993; Bernardo and Mohamed, 1992). However, these techniques do not record and utilize human knowledge and perceptions about flexibility in its measurement. Moreover these methods fail in putting together the various dimensions of flexibility and do not identify the adverse factors for improving flexibility levels. Most operation managers cannot provide exact numerical values to express opinions based on human perception: more realistic measurement uses linguistic assessments instead of numerical values (Beach et al., 2000; Gerwin, 1993; Herrera et al., 2000; Vokurka and O'Leary-Kelly, 2000). After Zadeh (1965) introduced fuzzy set theory to deal with vague problems, linguistic labels have been used in approximate reasoning within the framework of fuzzy set

*Corresponding author. E-mail: rituchandna15@gmail.com.

Abbreviations: MF, Manufacturing flexibility; **FFI,** Fuzzy-flexibility-index; **FPII,** fuzzy performance-importance index.

theory (Zadeh, 1975) to handle the ambiguity in evaluating data and the vagueness of linguistic expression. Using fuzzy concepts, evaluators can use linguistic terms to assess the indicators in a natural language expression and each linguistic term can be associated with a membership function. Tsourveloudis and Phillis (1998), Van Hop and Ruengsak (2005), Wang and Chuu (2004), Beskese et al. (2004); Das and Caprihan (2007) are some of the attempts that have revealed several advantages of using fuzzy models for measuring flexibility elements in terms of expressing imprecise data pervading real-world problems.

However, the above models for fuzzy flexibility measurement simply focus on fuzzifying existing flexibility elements instead of incorporating other possible underlying elements and also do not identify the principal adverse factors of flexibility to institute appropriate amending measures early on to enhance flexibility more effectively.

From this review, to assist managers in better achieving a flexible enterprise, a model on the basis of fuzzy logic is purposed to provide a means of both measuring how flexible an enterprise is and identifying the principal obstacles to improve the flexibility level. By referring to the factors proposed in previous studies together with the approach used by Lin et al. (2005), an alternate framework for manufacturing flexibility measurement have been exploited in this paper. In this approach, the performance ratings and importance weights of different flexibility capabilities assessed by experts are expressed in linguistic terms.

Then appropriate fuzzy numbers are used to present the linguistic values, and a simple fuzzy arithmetical operation is employed to synthesize these fuzzy numbers into one fuzzy number, which is called the fuzzy-flexibility-index (FFI). Also, the FFI is matched with appropriate linguistics, thereby enabling the flexibility level to be expressed in linguistic terms. After that the fuzzy performance-importance index (FPII) of each flexibility capability is devised to help managers identify the main adverse factors and calls for managers to institute an appropriate action plan to improve the flexibility level. This model is developed from the concept of multi-criteria decision making.

FLEXIBILITY TYPES AND CAPABILITIES

Manufacturing flexibility is a vague notion, exhibiting a polymorphism that makes quantification a difficult exercise. For the sake of analysis, flexibility has been categorized into several distinct types. Many reviews have considered definitions of MF, requests for MF, classificatory dimensions of MF, measurement of MF, choices for MF, and interpretations of MF (Beach et al., 2000; Gupta and Goyal, 1989; Gupta, 1993; Sarker et al., 1994; Sethi and Sethi, 1990; Vokurka and O'Leary-Kelly, 2000; Koste et al., 2004; Upton, 1994).

Product flexibility

Product flexibility is the ability to change over to produce a new set of products economically.

Operational flexibility

It refers to the capability of producing a part in different ways by changing the sequence of the operations which were originally scheduled.

Routing flexibility

Routing flexibility is the ability of a production system to manufacture a part using alternative routes in the system.

Process flexibility

Process flexibility describes the ability to change over in order to produce a given set of part patterns with different batch sizes.

Machine flexibility

It deals with the ease of making changes among operations required to produce a number of products.

Volume flexibility

Volume flexibility describes the ability to operate profitably at different production volumes.

Expansion flexibility

Expansion flexibility describes the capability to expand a system's capacity with minimal effort.

Labor flexibility

Labor flexibility is the ease of moving personnel around various departments within an organization.

BASIC CONCEPT OF FUZZY SET THEORY

For the purpose of application, the basic properties of fuzzy set theory needed in this study are introduced.

Additional discussion can be found in Klir and Yuan (1995).

Euclidean distance method

The Euclidean distance method consists of calculating the Euclidean distance from the given fuzzy number to each of the fuzzy numbers representing the natural-language expressions set.

Suppose the natural-language expression set is flexibility level (FL). Then the distance between the fuzzy number fuzzy-flexibility-index (FFI) and each fuzzy number member FL_i Є FL can be calculated as:

$$d(FFI, FL_i) = \left\{\sum_{x \in p}\left(f_{FFI}(x) - f_{FL_i}(x)\right)^2\right\}^{1/2} \quad (1)$$

Where p = {x_0, x_1, . . . x_m) C [0, 10] so that $0 = x_0 < x_1 < \ldots\ldots < x_m = 10$. To simplify, let p = {0, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8, 8.5, 9, 9.5, 10}. Then, the distance from the FFI to each of the members in the set FL can be calculated.

Fuzzy weighted average

Let R_1, R_2,…., R_n and W_1, W_2,…W_n denote, respectively, the fuzzy ratings and the fuzzy importance weights of the criteria. The fuzzy weighted average of R_i and W_i is defined as:

$$Y = \sum_{i=1}^{n} W_i R_i \Big/ \sum_{i=1}^{n} W_i \quad \ldots\ldots\ldots(2)$$

Rank fuzzy numbers

Since fuzzy numbers do not always yield a totally ordered set as real numbers do, it is very difficult to rank fuzzy numbers for prioritizing. To resolve this problem, many fuzzy numbers ranking methods that can be used to compare fuzzy numbers have been developed (Chen and Hwang 1992). In terms of the effectiveness for calculating, the fuzzy numbers ranking method using fuzzy mean and spread is adopted here. According to the fuzzy mean and spread method a triangular fuzzy number M = (l, m and u), and let DV be the defuzzification value of the M; then DV can be computed as:

$$DV = (l + 2m + u)/4 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

FUZZY FLEXIBILITY EVALUATION (FFE) APPROACH

The fuzzy flexibility evaluation (FFE) framework is composed of two major parts. The first part is the business operation environments' evaluation and flexibility capabilities' identification. The purpose of the business environment survey is to collect and analyze the flexibility drivers which are the changes in the business environment that drive a company to reconsider the company's position, strategy and process and in sequence maybe used to reset new strategies when running their business and building flexibility capabilities. The company's flexibility capabilities are the vital abilities that would provide the required strength to make appropriate responses to changes taking place in its business, so that flexibility capabilities will provide for flexibility measuring of a company. The second part of the framework is to evaluate flexibility capabilities and synthesize the ratings and the weights to obtain an FFI of a flexible enterprise and to match the FFI with an appropriate flexibility level and to make an improvement analysis. The main step description of the model developed from the concept of fuzzy multi-criteria decision making is given as follows:

Aggregate ratings and weighting to gain fuzzy- flexibility index and fuzzy merit-importance index of enable-factor

Suppose a committee of m analysts conducts the flexibility assessment and n flexible-enable attributes for flexibility assessment, then fuzzy-flexibility-index (FFI) represents the integrated merit of the flexibility-enable attributes of the enterprise is given by Equation 2.

Consequently, for each flexibility element capability *ijk*, the fuzzy performance-importance index $FPII_{ijk}$, is defined as:

$$FPII_{ijk} = [(1, 1, 1) \ominus W'_{ijk}] \otimes AC_{ijk}, \quad \ldots\ldots\ldots(4)$$

Where W_{ijk} is the fuzzy importance weight of the flexibility element capability *ijk*.

Translate FFI into linguistic flexibility term

Several methods for matching the membership function with linguistics terms have been proposed (Eshragh and Mandani, 1979; Schmucker, 1985).

There are basically three techniques: (1) Euclidean distance method, (2) successive approximation, and (3) piecewise decomposition. It is recommended that the Euclidean distance method be utilized because it is the most intuitive form of human perception of proximity (Guesgen and Albrecht, 2000). In this case the natural-language expression set FL = {Extremely Flexible [EF], Very Flexible [VF], Flexible [F], Fairly Flexible [FF], Slowly [S]} is selected for labeling, and the linguistics and corresponding membership functions are shown in Figure 1.

Then, by using the Euclidean distance method, the Euclidean distance D from the FFI to each member in set FL is calculated by Equation 1.

Rank fuzzy merit- importance index of enable-factors

Since fuzzy numbers do not always yield a totally ordered set as real numbers do, all the FPIIs must be ranked. All FPII can be defuzzified by using Equation 3 and can be ranked. This will help to analyze and identify the principal obstacles to improvement and enhance flexibility level.

AN ILLUSTRATIVE EXAMPLE

The FFE approach is demonstrated with a hypothetical an example: Manufacturing flexibility is the ability of a manufacturing system to

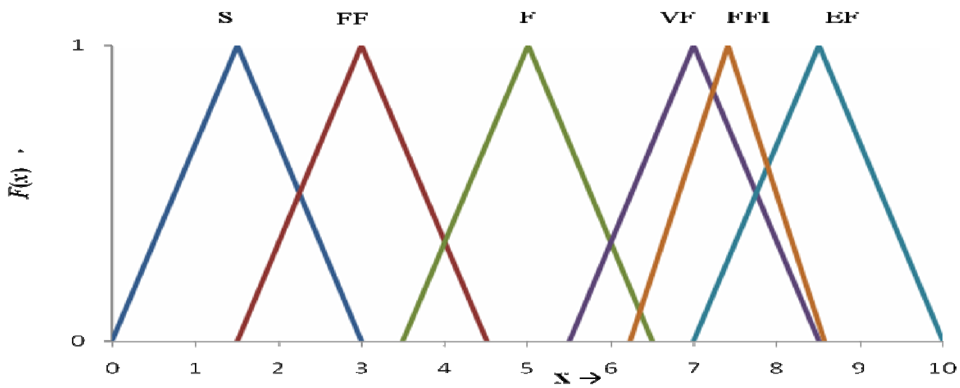

Figure 1. Linguistic levels to match fuzzy-flexibility-index [EF (7, 8.5, 10); VF (5.5, 7, 8.5); F (3.5, 5, 6.5); FF (1.5, 3, 4.5); S (0, 1.5, 3)].

Table 1. Flexibility capabilities for flexibility index evaluating in manufacturing system.

1- Grade index	2- Grade index	3- Grade index
Product flexibility (MF_1)	Operational flexibility (MF_{11})	No. of production sequence with minimal switching costs (MF_{111}), No. of Production Sequence with minimal switching times (MF_{112})
	Material handling flexibility (MF_{12})	Rerouting factor (MF_{121}) Load variety (MF_{122}) Transfer speed (MF_{123}) No. of connected elements (MF_{124})
	Sequence flexibility (MF_{13})	Operation Commonality (MF_{131}) Substitutability (MF_{132}) Average no. of machines to process different part type operations (MF_{133})
Process flexibility (MF_2)	Machine flexibility (MF_{21})	No. of diff operations performed (MF_{211}), Time taken for each Operation (MF_{212}), Set up time (MF_{213}), Versatility (MF_{214}), Adjustability (MF_{215}), Output quality and reliability (MF_{216}), Throughput from machine (MF_{217})
	Volume flexibility (MF_{22})	Range of volume (MF_{221}) Time required to increase or decrease the output (MF_{222}), Cost required to increase or decrease the volume of output (MF_{223})
	Expansion flexibility (MF_{23})	Modularity index (MF_{231}) Expansion ability (MF_{232})
	Labor flexibility (MF_{24})	Training level (MF_{241}) Job rotation (MF_{242})

cope with environmental changes effectively and efficiently. Suppose a committee comprised of few experts is formed to conduct the flexibility evaluation. After a series of activities consisting assessment of marketplace nature, competition circumstance, technology changing situation, customer requirements, social/cultural changes, product/process complexity, critically of relations with

Table 2. Aggregated performance rating and aggregated importance weight of flexibility capabilities.

MF_i	MF_{ij}	MF_{ijk}	W_i	W_{ij}	W_{ijk}	R_{ijk}
MF_1	MF_{11}	MF_{111}	VH	VH	VH	VG
		MF_{112}			H	G
	MF_{12}	MF_{121}		FH	FH	VG
		MF_{122}			H	VG
		MF_{123}			FH	G
		MF_{124}			FH	F
	MF_{13}	MF_{131}		VH	H	VG
		MF_{132}			VH	VG
		MF_{133}			VH	E
MF_2	MF_{21}	MF_{211}	H	H	H	VG
		MF_{212}			VH	VG
		MF_{213}			FH	F
		MF_{214}			H	G
		MF_{215}			FH	P
		MF_{216}			H	G
		MF_{217}			VH	G
	MF_{22}	MF_{221}		VH	VH	VG
		MF_{222}			H	VG
		MF_{223}			VH	VG
	MF_{23}	MF_{231}		VH	VH	G
		MF_{232}			VH	VG
	MF_{24}	MF_{241}		H	VH	G
		MF_{242}			H	G

criticality of relations with suppliers and flexibility discussion between analysts, the committee selects the criteria shown in Table 1 for evaluation.

The next step is to determine the appropriate linguistic scale to assess the performance ratings and importance weights of the flexibility capabilities. Furthermore, on the basis of linguistic level bank as shown in Table 3, the linguistic assessments of performance ratings and importance weights of the flexibility capabilities as shown in Table 2 are approximated by fuzzy numbers.

Then, by using the formulas in Equation 2, the fuzzy index of the flexibility 2-grade-capability MF_{ij} is obtained. For example, the fuzzy index of the flexibility 2-grade capability, information management flexibility MF_{11}, is calculated as:

$$MF_{11} = [(0.85, 0.95, 1.0) \otimes (7, 8, 9) \oplus (0.7, 0.8, 0.9) \otimes (5, 6.5, 8)] / [(0.85, 0.95, 1.0) \oplus (0.7, 0.8, 0.9)] = (6.10, 7.31, 8.53)$$

Applying the same Equation, other fuzzy indexes of flexibility 2-grade-capabilities MF_{ij} and the flexibility 1-grade-capabilities MF_i are obtained as listed in Table 4.

Furthermore, aggregate fuzzy ratings with fuzzy weights to obtain a FFI of the manufacturing system. FFI is an information fusion, which consolidates the fuzzy ratings and fuzzy weights of all of the factors that influence flexibility. FFI represents overall enterprise flexibility. Enterprise flexibility increases with increasing FFI. Thus, the membership function of FFI is used to determine the flexibility level.

Finally, applying Equation 2 again, the FFI of the manufacturing system is calculated as:

$$FFI = [(6.55, 7.67, 8.75) \otimes (0.85, 0.95, 1.0) \oplus (5.85, 7.10, 8.35) \otimes (0.7, 0.8, 0.9)] / [(0.85, 0.95, 1.0) \oplus (0.7, 0.8, 0.9)] = (6.23, 7.41, 8.56)$$

Further match the FFI with an appropriate flexibility level. Once the FFI has been obtained, to identify the level of flexibility, the FFI can be further matched with the linguistic label whose membership function is the same as (or closest to) the membership function of the FFI from the natural-language expression set of flexibility label (FL). In this case the natural-language expression set FL = {Extremely Flexible [EF], Very Flexible [VF], Flexible [F], Fairly Flexible [FF], Slowly [S]} is selected for labeling, and the linguistics and corresponding membership functions are shown in Figure 1. Then, by using the Euclidean distance method, the Euclidean distance D from the FFI to each member in set FL is calculated by Equation 1:

D(MF, EF) = 2.3017, D(MF, VF) = 0.7366, D(MF, F) = 1.9336, D(MF, FF) = 1.9336, D(MF, S) = 1.6549.

Table 3. Fuzzy numbers for approximating linguistic variable values.

Performance-rating		Importance-weighting	
Linguistic variable	**Fuzzy number**	**Linguistic variable**	**Fuzzy number**
Worst (W)	(0, 0.5, 1.5)	Very Low (VL)	(0, 0.05, 0.15)
Very Poor (VP)	(1, 2, 3)	Low (L)	(0.1, 0.2, 0.3)
Poor (P)	(2, 3.5, 5)	Fairly Low (FL)	(0.2, 0.35, 0.5)
Fair (F)	(3, 5, 7)	Medium (M)	(0.3, 0.5, 0.7)
Good (G)	(5, 6.5, 8)	Fairly High (FH)	(0.5, 0.65, 0.8)
Very Good (VG)	(7, 8, 9)	High (H)	(0.7, 0.8, 0.9)
Excellent (E)	(8.5, 9.5, 10)	Very High (VH)	(0.85, 0.95, 1)

Table 4. Fuzzy index of each grade of flexibility dimensions.

MF_i	MF_{ij}	R_i	R_{ijk}
MF_1	MF_{11}	(6.55, 7.67, 8.75)	(6.10, 7.31, 8.53)
	MF_{12}		(5.64, 6.94, 8.27)
	MF_{13}		(7.53, 8.53, 9.34)
MF_2	MF_{21}	(5.85, 7.10, 8.35)	(5.13, 6.45, 7.79)
	MF_{22}		(7, 8, 9)
	MF_{23}		(6, 7.25, 8.5)
	MF_{24}		(5, 6.5, 8)

Thus, by matching a linguistic label with the minimum D, the flexibility index level of the manufacturing system can be identified as ‘‘very flexible’’, as shown in Figure 1.

Finally, by applying Equation 4 the fuzzy merit- importance indices of enable-factors are obtained as listed in Table 5. Although the flexibility index level of manufacturing system is ‘‘very flexible’’ (according to the evaluation), there were obstacles within the organization which could have impacted the flexibility of the manufacturing system. In order to identify the principal obstacles for improving flexibility level, a fuzzy performance importance index (FPII) of flexibility element capability, which combines the performance rating and importance weight of each flexibility element capability, represents an effect which will contribute to the flexibility level of an organization. The lower the FPII of a factor is, the lower the degree of contribution for this factor. Thus, the score of the FPII of a factor is used for identifying the principal obstacles.

Then, by using the formulas in Equation 4, the FPIIs of each flexibility element capability are obtained and defuzzified by applying Equation 3, the results are listed in Table 5.

For example, the FPII of the perfect degree enterprise information system MF_{111}, is calculated as:

$$FPII_{111} = [(1, 1, 1) \ominus (1, 0.95, 0.85)] \otimes (7, 8, 9) = (0, 0.4, 1.35)$$

On the basis of experts’ knowledge/ experience, the assessment committee set a scale (suppose 0.5) as the management threshold. As shown in Table 5, three capabilities have a lower performance than the others, namely: (1) Throughput from machine, (2) Modularity index and (3) Training level.

Furthermore, according to this identification, managers can select appropriate flexibility providers from Table 1 to improve the adverse factors and to implement better flexibility level.

RESULTS

1. The fuzzy flexibility index FFI of the manufacturing system was (6.23, 7.41, 8.56).
2. By matching a linguistic label with the minimum Euclidean distance, the flexibility index level of the manufacturing system was identified as ‘‘very flexible’.
3. Three capabilities had a lower performance than the others, namely: (1) Throughput from machine, (2) Modularity index, and (3) Training level.

DISCUSSION AND CONCLUSION

Flexibility has recently emerged as a key competitive priority in the present – day manufacturing environment. Manufacturing flexibility is an effective way to face up to the uncertainties of the rapidly changing environment and it is the ability to absorb various disturbances which occur in production systems, as well as the ability to incorporate and exploit new technological advances and work practices. However, in embracing MF there are many important questions to be asked concerning flexibility, such as: how to measure the flexibility of a company? How to identify the principal adverse factors for improving the flexibility level? How to assist in enhancing flexibility

Table 5. Fuzzy performance- importance indexes of 23 flexibility capabilities.

Flexibility capability	Aggregated fuzzy performance rating	(1, 1, 1)-W'_{ijk}	Fuzzy performance-importance index FPPI	Ranking score
MF_{111}	(7, 8, 9)	(0, 0.05, 0.15)	(0, 0.4, 1.35)	0.5375
MF_{112}	(5, 6.5, 8)	(0.1, 0.2, 0.3)	(0.5, 1.3, 2.4)	1.375
MF_{121}	(7, 8, 9)	(0.2, 0.35, 0.5)	(1.4, 2.8, 4.5)	2.875
MF_{122}	(7, 8, 9)	(0.1, 0.2, 0.3)	(0.7, 1.6, 2.7)	1.65
MF_{123}	(5, 6.5, 8)	(0.2, 0.35, 0.5)	(1.0, 2.275, 4.0)	2.3875
MF_{124}	(3, 5, 7)	(0.2, 0.35, 0.5)	(0.6, 1.75, 3.5)	1.9
MF_{131}	(7, 8, 9)	(0.1, 0.2, 0.3)	(0.7, 1.6, 2.7)	1.65
MF_{132}	(7, 8, 9)	(0, 0.05, 0.15)	(0, 0.4, 1.35)	0.5375
MF_{133}	(8.5, 9.5, 10)	(0, 0.05, 0.15)	(0, 0.475, 1.5)	0.6125
MF_{211}	(7, 8, 9)	(0.1, 0.2, 0.3)	(0.7, 1.6, 2.7)	1.65
MF_{212}	(7, 8, 9)	(0, 0.05, 0.15)	(0, 0.4, 1.35)	0.5375
MF_{213}	(3, 5, 7)	(0.2, 0.35, 0.5)	(0.6, 1.75, 3.5)	1.9
MF_{214}	(5, 6.5, 8)	(0.1, 0.2, 0.3)	(0.5, 1.3, 2.4)	1.375
MF_{215}	(2, 3.5, 5)	(0.2, 0.35, 0.5)	(0.4, 1.225, 2.5)	1.3375
MF_{216}	(5, 6.5, 8)	(0.1, 0.2, 0.3)	(0.5, 1.3, 2.4)	1.375
MF_{217}	(5, 6.5, 8)	(0, 0.05, 0.15)	(0, 0.325, 1.2)	0.4625
MF_{221}	(7, 8, 9)	(0, 0.05, 0.15)	(0, 0.4, 1.35)	0.5375
MF_{222}	(7, 8, 9)	(0.1, 0.2, 0.3)	(0.7, 1.6, 2.7)	1.65
MF_{223}	(7, 8, 9)	(0, 0.05, 0.15)	(0, 0.4, 1.35)	0.5375
MF_{231}	(5, 6.5, 8)	(0, 0.05, 0.15)	(0, 0.325, 1.2)	0.4625
MF_{232}	(7, 8, 9)	(0, 0.05, 0.15)	(0, 0.4, 1.35)	0.5375
MF_{241}	(5, 6.5, 8)	(0, 0.05, 0.15)	(0, 0.325, 1.2)	0.4625
MF_{242}	(5, 6.5, 8)	(0.1, 0.2, 0.3)	(0.5, 1.3, 2.4)	1.375

more effectively? Measurement of flexibility is difficult due to the multidimensionality and vagueness of the concept of flexibility and therefore the conventional assessment approaches cannot suitably or effectively be applied. Thus, in this paper a knowledge-based framework based on concept of multi criteria decision making and fuzzy logic for the measurement of manufacturing flexibility has been proposed. The evaluation procedure include: identifying flexibility capabilities, selecting linguistic variables for assessing and interpreting the values of the linguistic variables, fuzzy rating and fuzzy weights integrating, fuzzy index labeling, and defuzzifying FPII in order to identify the main adverse factors which can influence flexibility achievement. In addition, an example is given to illustrate the use of this method, which demonstrates the method can provide the analyst more convincing results.

The measurement framework proposed in this paper appears to have the following advantages. Firstly, it is adjustable by the user and enables analysts' linguistic assessment which may involve uncertainty. Managers can establish their own unique membership function by fitting in with their specific environment and consideration. Secondly this method can give the analyst relatively realistic and informative information. The FFI is expressed in a range of values. This provides an overall picture about the possible flexibility of an organization and ensures that the decision made in selection will not be biased. As an example of this study, the flexibility index has a fuzzy value (6.23, 7.41, 8.56). Finally this method can systematically identify the weak factors within an organization and provide the means for a manager to formulate a comprehensive plan for improvement. Therefore, the method can be further used in self-assessment.

Moreover, despite the above benefits for using fuzzy-logic for the measurement of flexibility, this approach has some limitations and it does not focus on finding an optimal design but only addresses flexibility level measurement. An objective of future research can be to investigate the influence of more rules on the value of flexibility and to develop a programming model subject to company constraints.

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