Comparison of Fuzzy and Multi-Criteria Decision Making Approach to Measure Manufacturing Flexibility

Ritu Chandna, S.R. Ansari

Abstract- Manufacturing flexibility is the ability of the system to adapt to changes. Manufacturing flexibility is a difficult to quantify concept. To assist managers in better achieving a flexible enterprise, a model on the basis of fuzzy logic is purposed to provide a means of measuring how flexible an enterprise is. In this approach, the performance ratings and importance weights of different flexibility capabilities assessed by experts are expressed in linguistic terms. The fuzzy logic-based measurement of flexibility can efficiently aid managers in dealing with both ambiguity and complexity involved in flexibility measurement. The fuzzy flexibility approach is an extension of the multicriteria decision making (MCDM) approach, in order to ascertain the efficiency of this method, a comparison study of the MCDM approach with fuzzy approach is proposed. The proposed scheme is illustrated through an example.

Index Terms- Fuzzy logic, fuzzy numbers, importance weights, Manufacturing flexibility, multi-criteria decision making, performance ratings

1. INTRODUCTION

Owing to the globalization of the market, increasing demands of the customized products and rapidly changing needs of customers, the manufacturers are facing a problem of customer satisfaction and survival in the market among the various competitors. 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 (S. Treville, 2007). 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.

Operation managers must evaluate MF when making capital investment decisions and measuring performance level (Gerwin, 1993). Flexibility constitutes a strategic topic in decision making to give quick and efficient answers to the demands of the national and international markets (Pelaez, and Ruiz, 2004, Y. M. Wang et al., 2009). MF is a complex, multidimensional and difficult-to-synthesize concept (Sethi and Sethi, 1990). Since flexibility is a critical measure of the total manufacturing system (Kaplan, 1983; Son and Park, 1987) and one of the key objectives of any manufacturing system, management asks for flexibility measures to compare different systems and to evaluate performance. Also, in a business firm with a flexibility focused strategy, there is a need for flexibility evaluation which is essential to analyze competiveness and to verify effectiveness of strategy.

Thus, in embracing flexible enterprise many important questions concerning flexibility need to be asked, such as: what precisely is flexibility and how can it be measured? What factors contribute to the flexibility degree of manufacturing systems? How will companies know when they have it, as there are no simple metrics or indexes available? How and to what degree does the company's attributes affect companies' business performance? How to compare flexibility with competitiveness? If a company wants to improve flexibility, how can the company identify the principal obstacles to improvement? How to assist in achieving flexibility effectively? (Van Hop and Ruengsak, 2005). Answers to such questions are critical to the practitioners and to the theory of flexible enterprise design. Therefore, the purpose of this research is to solve some of these problems, with particular focus upon flexibility measuring using multicriteria decision making approach.

In Section 2, we review the relevant literature and identify different flexibility types in Section 3. In Section 4, basic concepts of fuzzy set theory used are given. Section 5

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represents the measurement approach and is followed by a worked through example in Section 6. Comparison study is given in Section 7. The results are shown in Section 8 whereas Section 8 provides a summary conclusion of the key contribution of the paper.

2. RELATIVE LITERATURES

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 mathematical 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 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 measuring how flexible an enterprise is. 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. This model is developed from the concept of multi-criteria decision making.

3. FLEXIBILITY-TYPES

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). In this section, different flexibility types and capabilities are defined on the basis of past research. We want to emphasis that the following flexibility attributes is by no means exhaustive and therefore new factors may be added/ amended depending on the product, industry and market characteristics.

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.

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

4. 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 book by Klir and Yuan (1995).

4.1 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 $FL_i \in FL$ can be calculated as below:

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

where $p = \{x_0, x_1, \ldots x_m\} \in [0, 10]$ 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.

4.2 Fuzzy Weighted Average

Let $R_1, R_2, \ldots, R_n$ and $W_1, W_2, \ldots W_n$ 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

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

5. 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 Eq.(2).

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

$$FPII_{ijk} = [(1, 1, 1) \ominus W'_{ijk}] \ (*) \ AC_{ijk}, \quad (3)$$

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

6. AN EXAMPLE

Suppose a committee comprised of four experts is formed to conduct the agility evaluation. After a series of activities consisting assessment of marketplace nature, competition circumstance, technology changing situation, customer requirements, social/cultural changes, products/processes complexity, criticality of relations with suppliers, and agility strategy discussion between analysts, the committee selects the criteria shown in Table 1 for evaluation.

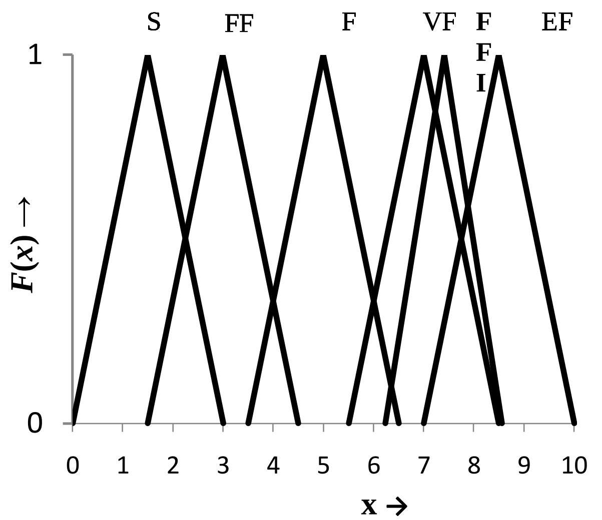

Fig. 1. Linguistic levels to match fuzzy-flexibility-index [EF (7, 8.5, 10); VF (5.5, 7, 8.5); F (3.5, 5, 6.5); FF (1.5, 3, 4.5); S (0, 1.5, 3)]

Table 1 Critical flexible-enable parameters for flexibility index evaluation.

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})
	Routing 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 different operations performed (MF_{211}) Time taken for each Operation (MF_{212}), Set up time (MF_{213}), Versatility (MF_{214}), Adjustability (MF_{215}), Output Quality & reliability (MF_{216}), Throughput from machine (MF_{217})
	Volume Flexibility (MF_{22})	Range of Volume (MF_{221}) Time required increasing or decreasing the output (MF_{222}), Cost required to increase or decrease volume 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})

The next step is to determine the appropriate preference-rating scale and to assess. Furthermore, on the basis of linguistic level bank as shown in Table 2, the linguistic assessments are approximated by fuzzy numbers as shown in Table 3 and Table 4.

Table 2 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 3 Performance ratings of flexibility parameters assigned by assessors using linguistic terms

M_{ijk}	Experts				
	E_1	E_2	E_3	E_4	E_5
MF_{111}	G	VG	VG	G	VG
MF_{112}	VG	F	VG	G	G
MF_{121}	VG	VG	E	G	G
MF_{122}	VG	VG	G	VG	VG
MF_{123}	G	F	G	G	F
MF_{124}	P	G	F	F	F
MF_{131}	G	VG	VG	VG	G
MF_{132}	E	VG	VG	G	G
MF_{133}	G	E	E	E	VG
MF_{211}	VG	G	VG	VG	VG
MF_{212}	VG	VG	G	G	VG
MF_{213}	G	P	F	F	G
MF_{214}	F	G	G	VG	G
MF_{215}	VP	P	P	F	F
MF_{216}	G	VG	G	F	G
MF_{217}	VG	G	G	G	F
MF_{221}	VG	VG	VG	VG	VG
MF_{222}	E	E	VG	VG	G
MF_{223}	VG	VG	E	G	G
MF_{231}	VG	G	G	G	VG
MF_{232}	E	VG	VG	VG	VG
MF_{241}	G	G	G	G	VG
MF_{242}	G	G	G	G	G

Table 4 Importance weights of flexibility parameters assigned by assessors using linguistic terms.

M_i	M_{ij}	M_{ijk}	Experts				
			E_1	E_2	E_3	E_4	E_5
MF_1			VH	VH	VH	H	VH
	MF_{11}		VH	H	VH	VH	VH
		MF_{111}	H	VH	VH	H	VH
		MF_{112}	H	VH	VH	H	FH
	MF_{12}		M	FH	FH	M	H
		MF_{121}	FH	M	FH	FH	M
		MF_{122}	VH	VH	FH	FH	H
		MF_{123}	FH	FH	FH	FH	FH
		MF_{124}	FH	FH	H	FH	H
	MF_{13}		VH	H	H	VH	VH
		MF_{131}	FH	H	FH	H	H
		MF_{132}	VH	VH	H	VH	VH
		MF_{133}	VH	H	H	VH	VH
MF_2			FH	H	FH	H	VH
	MF_{21}		M	FH	H	H	H
		MF_{211}	VH	VH	H	H	H
		MF_{212}	VH	H	VH	VH	VH
		MF_{213}	H	M	FH	FH	M
		MF_{214}	H	H	VH	VH	H
		MF_{215}	FL	M	FH	FH	FH
		MF_{216}	VH	H	FH	H	H
		MF_{217}	H	VH	VH	H	VH
	MF_{22}		VH	VH	VH	VH	VH
		MF_{221}	H	VH	VH	VH	VH
		MF_{222}	M	H	FH	H	VH
		MF_{223}	FH	VH	VH	VH	H
	MF_{23}		M	VH	H	VH	VH
		MF_{231}	VH	H	VH	VH	FH
		MF_{232}	VH	VH	H	VH	H
	MF_{24}		FH	H	H	H	H
		MF_{241}	VH	VH	FH	H	VH
		MF_{242}	H	FH	M	H	H

Table 5 Aggregated Performance rating and aggregated importance weight of Flexibility parameters

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

By applying mean operation one can gain the mean merit rating and mean importance weighting of flexibility-enable-factors, the results shown in Table 5. Furthermore, applying Eq (3), the mean merit ratings and mean importance

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weightings be aggregated into the FFI of the enterprise is obtained as:

FFI= [(6.55, 7.67, 8.75)(*)(0.85, 0.95, 1.0)(+) (5.85, 7.10, 8.35)(*)(0.7, 0.8, 0.9)] / [(0.85, 0.95, 1.0) (+)(0.7, 0.8, 0.9)] = (6.23, 7.41, 8.56)

Further, by applying Eq.(3) the fuzzy merit-importance indices of enable-factors are obtained as listed in Table 6.

Table 6 Fuzzy merit-importance indices of enable-factors

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

Finally, suppose a natural-language expression of flexibility-level set FL={Very Low, Low, Fairly Low, Fairly High, High, Very High} with membership functions shown in Fig. 1 are chosen for labeling. Then, by using Eq.(1), the Euclidean distance D from FFI to each member in set FL can be calculated:

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

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 Fig. 1.

7. COMPARISON STUDY

Since the fuzzy flexibility evaluation an extension of the multicriteria decision making approach, in order to ascertain the efficiency of this method, a comparison study of the MCDM approach was made by the evaluation committee. In multicriteria decision making problems, relevant alternatives are evaluated according to a number of criteria. Each criteria includes a particular ordering of the alternatives and a procedure is needed to construct one overall preference ordering. In general, suppose that a given MCDM problem is defined on n alternatives $A_1, A_2, \ldots, A_n$ and m decision criteria $C_1, C_2, \ldots, C_m$.

Furthermore, let us assume that all the criteria are benefit criteria, that is, the higher the values are, the better it is. Next suppose that w_i denotes the relative weight of importance of the criterion C_i and a_{ij} is the performance value of alternative A_j when it is evaluated in terms of criterion C_i. The most common approach to multicriteria decision problems is to find a global criteria, R_j, that is for each A_j to which the individual criteria $C_1, C_2, \ldots, C_m$ are satisfied. A frequently employed aggregating operator is the weighted average

$$R_j = \frac{\sum_{i=1}^{m} w_i a_{ij}}{\sum_{i=1}^{m} w_i}, \qquad j = 1,2,3\ldots,n \tag{4}$$

When using the MCDM approach for flexibility evaluation, the ambiguity and multiplicity within flexibility parameters were ignored. The evaluators were asked to use a scale to score the criteria directly or to use linguistic terms to assess the criteria. Subsequently, the linguistic terms were translated into a crisp scale for computing the possible-flexibility-index of the organization. In the comparison study, the team of experts used the “core” member of the fuzzy number to represent a linguistic value in the MCDM approach. For example, the triangular fuzzy number (5, 6.5, 8) was used to approximate the linguistic variable “Good,” and the core member 6.5 was adopted to represent the linguistic variable “Good” in the MCDM approach. The contrasting fuzzy numbers for approximating linguistic variables and crisp scales representing linguistic variables are listed in Table 7.

Table 7 Fuzzy numbers for approximating linguistic variables versus crisp scales representing linguistic variables

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Performance rating			Importance weighting		
Performance rating	Fuzzy number	Crisp scale	Linguistic variables	Fuzzy number	Crisp scale
Worst	(0,0.5,1.5)	0.5	Very Low	(0, .05,.15)	0.05
Very Poor	(1, 2, 3)	2	Low	(.1, .2, .3)	0.2
Poor	(2, 3.5, 5)	3.5	Fairly Low	(.2, .35, .5)	0.35
Fair	(3, 5, 7)	5	Medium	(.3, .5, .7)	0.5
Good	(5, 6.5, 8)	6.5	Fairly High	(.5, .65,.8)	0.65
Very Good	(7, 8, 9)	8	High	(.7,.8, .9)	0.8
Excellent	(8.5,9.5,10)	9.5	Very High	(.85, .95, 1)	0.95

The results were compared with those derived from the fuzzy logic-based evaluation model. From the possible-success-rating scale point of view, the results generated by both approaches seemingly lead to similar conclusions as shown in Table 8. However, the possible success rating generated by the FFI approach was expressed in terms of ranges of value [6.23–8.56]. This rating can provide an overall picture of the relevant possibility and ensure that the decision made in the subsequent selection process is not biased. Further, it allows the managers a high degree of flexibility in decision-making. In the example, the flexibility-index had a fuzzy value (6.23, 7.41, 8.56). Qualitatively, this suggests that the proposed flexibility-index is success-high and far from being a failure. However, a crisp rating of 7.41 generated by MCDM approach may imply differently or provide less rich information.

Table 8 Comparison of fuzzy logic approach and MCDM approach

Approach	Flexibility Index	Range	Linguistic labeling
Fuzzy Logic	(6.23, 7.41, 8.56)	2.33	Very flexible
MCDM	7.41		Very flexible

8. RESULTS

- The fuzzy flexibility index FFI of the manufacturing system was (6.23, 7.41, 8.56).
- By matching a linguistic label with the minimum Euclidean Distance, the flexibility index level of the manufacturing system was identified as ‘’very flexible’ as in Fig.1
- On comparing the with MCDM approach, the proposed flexibility-index is success high as the FFI approach is expressed in terms of ranges of value [6.23–8.56].

9. 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 assist in enhancing flexibility 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 nor 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 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).

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. The membership functions of linguistic variables depend on the managerial perception of the decision-maker. Thus, the decision-maker must be at a strategic level in the company in order to realize the importance, possibility and trends of all aspects, such as strategy, marketing and technology. Furthermore, competitive situations and requirements vary from company to company; hence, companies have to establish their unique membership function by fitting in with their specific environment and considerations. 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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