Evaluation of Operational Flexibility for a Manufacturing Organization

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Abstract

Flexibility in the context of an organization is the ability of it to respond and cope with uncertainties. These uncertainties can be both internal as well as external. Therefore, it has become very critical to manage and effectively react to several uncertainties posed by today's changing environment. Operational flexibility is a formative approach to meet the demand of a customer during a changing environment. The research focuses on operational flexibility at a micro-level in the context of an Indian manufacturing organization, 'XYZ'. By referring to past literature and experts' opinion, 7 main and 28 sub-attributes have been established as the parameters for measuring the operational flexibility index. The study is an approach to evaluate operational flexibility through the fuzzy logic approach. The research concludes that the organization is found to be 'very flexible' in its routine operations.

Keywords
flexibility, operational flexibility, attributes, fuzzy set theory, Euclidean distance.

1. Introduction
Patel et al. (2017), reviewed flexibility in the context of a manufacturing organization, as an amalgamation of 3 sub-divisions of flexibility- operational, organizational and supply chain flexibility. Operational flexibility has distinct dimensions that may vary in importance across environments (Stevenson and Spring 2007) and are crucial to be adopted by organizations to respond to changes and uncertainties. Operational flexibility is described as a short-term flexibility potential pertaining to everyday operations (Johnson et al. 2003), or a routine activity maneuvering capacity that constitutes maintenance of these routines based upon existing structures and goals of an organization (Volberda 1997). Operational flexibility is particularly critical for a manufacturing organization as it integrates fluctuating demand and supply based on an uncertain working environment. Therefore, operations managers need to ensure that an organization is capable to adapt to potential threats of uncertainty. For example, the COVID-19 pandemic is one such example that unfolded the importance of flexibility in routine operations.

The research explores operational flexibility and examines it empirically for an Indian manufacturing organization 'XYZ' based in northern India by implementing a fuzzy approach. The name of the organization is kept confidential. Beach et al. (2000) reasons that the employment of the fuzzy set theory approach deals with ambiguity and dubious complications; Zadeh (1965) et al. provided linguistic labels that have been employed with approximate reasoning within the framework of fuzzy theory. Implementation of fuzzy approach enables evaluators to use simple and understandable linguistic terms to evaluate attributes. As a distinct membership function is associated with each of these linguistic terms, a calculation to establish a fuzzy index is carried out (Ansari and Mittal 2010).

1.1 Objectives

The approach used by Lin et al. (2006); Patel et al. (2017) has been adopted to establish a framework for evaluation of operational flexibility for an Indian manufacturing organization in this paper. The following research objectives are formulated for the study:

- To analyze operational flexibility in context of a manufacturing organization 'XYZ' and identify attributes and sub-attributes through literature review and experts' opinion.
- To evaluate the operational flexibility index using fuzzy set theory and determining flexibility level for the organization, based on the responses recorded for the study.
- To propose recommendations for the organization to improve the level of operational flexibility in their routine operations.

2. Literature Review

Operational flexibility is the ability of an organization to respond to threats posed by changing environments while incorporating changes in its routine operations (Yu et al. 2015). This process involves a formative approach to meet the demand of a customer during an uncertain business or market environment. It is the ability to improve demand fulfillment with simultaneous reduction in conversion costs that are incurred by an organization. (Narsalay 2015). This is followed by responding to uncertainty (internal and external) associated with operational changes in a reactive or a proactive manner. Patel et al. (2017) identified 5 main-attributes of operational flexibility. These are material handling flexibility, automation, labor, machine, and process flexibility. However, based on consensus among industry experts from a manufacturing organization, it is noted that these 5 attributes are not enough to evaluate operational flexibility. Thus, two more attributes, expansion and routing flexibility are added to analyze and evaluate operational flexibility in this study. Therefore, a total of 7 attributes are finalized for the study of evaluation of operational flexibility in a manufacturing organization.

2.1 Attributes and Sub-Attributes

To analyze and evaluate operational flexibility, it is important to categorize and list the most important main attributes regarded as characteristics inherent to it. Furthermore, sub-attributes inherent to main attributes must be listed to conceptualize a model for operational flexibility in a manufacturing organisation. These main and sub-attributes serve as the parameters to evaluate the level of operational flexibility in an organization (Lin et al. 2006).

2.1.1 Material Handling Flexibility

Material handling flexibility is the interchangeable capability of the movement of parts of an organization's routine operations. Therefore, this undeniably depends upon the configuration management system of an organization. Uncertainties may force operations managers to strategically readjust paths (Nayak et al. 2010), for e.g., in case of an expansion and design effective material control (Aized 2010). As machines operate on different tasks, machine handling flexibility brings modularity in the movement of products in an efficient manner.

2.1.2 Labor Flexibility

An organization must invest in labor under uncertain demand. An effective way to handle this is, the anticipation of deployment framework appropriate to labor flexibility, following the realization of the demand (Francas et al. 2011). It is also the ability to administer movement of the workforce around several departments within an organization without complications (Ansari and Mittal 2010). Labour flexibility can be achieved by regulating working schedules and policies (Antonietti et al. 2017) which is also a compelling measure to ensure labor flexibility. Labor flexibility ensures the execution of a variety of tasks economically while simultaneously increasing the productivity of operations within an organization. Worker training skills is a practical solution to ensure skill training in various areas peculiar to the company such as processes, operating mechanisms, culture, etc. (Valverde et al. 2000). Process-oriented worker training skills particularly concentrates on acquiring skills to operate on different pieces of machinery (Sawhney 2013). Whereas skill-based pay (Beltran-Martín et al. 2008) is a measure to associate a rewards system to labor flexibility in order to increase productivity and loyalty in an organization.

2.1.3 Automation Flexibility

The Manufacturing sector have started to move towards the implementation of industry 4.0. Moreover, automation has made today's manufacturing systems more reliable and efficient. The advantage of implementing automation flexibility in routine operations is that it allows the production of a variety of part types in small batch sizes through a series of combinations around technology (Browne et al. 1984). Programmable automation enables changeovers in routine operations without complications. It safeguards the ability to compose new codes to enhance the functioning of mechanical changeovers (Miller et al. 2007).

2.1.4 Machine Flexibility

Machine flexibility allows the performance of ample operations in machines both effectively and economically. It is the ability to perform necessary changes to a given set of machine parts (Chandra and Tombak 1992). Thus, manufacturing systems must have machines designed to handle varying volumes of production (Tao et al. 2017). This also allows the manufacture of products of varying quality (Sethi 1990) i.e., output quality. The system is able to use multiple machines to execute replicated operations on a part (Golda et al. 2018). Regulating the process of producing new products by implementing and incorporating quick changes across machinery operations (Moslemipour et al. 2012; R Rajesh 2020) can help achieve and establish machine flexibility to a great extent as well as encounter the problem of fluctuating demand.

2.1.5 Process Flexibility

Process flexibility is the ability to systematically design and manage process management systems within an organization. This can be achieved by offering customers, a range of product lines (Schmenner and Tatikonda 2005) and constructively develop sequences to infer productivity for better flexibility (Lafou et al. 2016). This can be accomplished by a synchronized system of sequence in operations (Vital-Soto et al. 2020). Minimizing the need for duplicate machines (Awwad et al. 2007) and complementing factory network (Yu 2015) can lift the effective usage and efficiency of shared machinery and infrastructure respectively.

2.1.6 Expansion Flexibility

Expansion flexibility is the capability to expand the capacity of an arrangement without facing a great deal of difficulty hence with, minimal effort (Ansari and Mittal 2010). Capacity management can considerably mitigate uncertainties related to expansion. Integration of manufacturing and marketing decisions helps track behaviors of end customers directly through channel partners and broader tracking of industry trends (Narsalay 2015). Therefore, this collectively administers capacity and capability needs in response to volatile markets or markets needs in general. On the other hand, direct and indirect costs (Sethi 1990) and speed of expansion (Carter 1986) also affect the establishment of expansion flexibility.

2.1.7 Routing Flexibility

The number of alternative routes to export or import the products safely accounts for routing flexibility in an organization (Kumar et al. 2008) Flexible routing is established by effective and well-thought routing strategies that define the path of the route while stating the destination as well as the type of routing (static/dynamic), between the origin and destination (Mohammadi et al. 2020). Therefore, it is important to establish support systems, capable of keeping production going during repairs (Koren 2010) and redundancy in machines (Sethi 1990). Moreover, effective handling of breakdown (Chan 2001), periodically updated system control software (Custodio and Machado 2020) and machines are versatile (Buzacott and Yao 1985) prompt routing flexibility.

3. Conceptual Model for Operational Flexibility in a Manufacturing Organization

A comprehensive conceptual model of operational flexibility in a manufacturing organization developed for this study is given in Figure 1. This model is developed based on the assessment of main and sub-attributes of operational flexibility. This model is then further used to evaluate operational flexibility level in a manufacturing organization considered for this research. It consists of 7 main-attributes and a total of 28 sub-attributes assessed from literature as well as expert consultation and opinion. These are listed with their indices in Table 1.

Table 1. Operational flexibility attributes for measuring flexibility index

Main Attributes	**Index**	**Sub-attributes**	**Index**
Material handling flexibility	A_1	Reconfiguration efficiency	A_{11}
		Material control	A_{12}
		Buffer sizes	A_{13}
		Ergonomically designed equipment	A_{14}
Labor flexibility	A_2	Worker training skills	A_{21}
		Policies	A_{22}
		Convincing hours (or) working schedules	A_{23}
		Assessment based payment system	A_{24}
Automation flexibility	A_3	Programmable automation	A_{31}
		Industrial Internet of Things (IIOT)	A_{32}
		Customization of process	A_{33}
		Scalability in design	A_{34}
Machine flexibility	A_4	machines designed to handle varying volumes of production	A_{41}
		Usage of multiple machines to execute replicated operation on a part	A_{42}
		Machines that produce new products/goods by incorporating minimal changes	A_{43}
		Output quality	A_{44}
Process flexibility	A_5	Production management	A_{51}
		Sequence of operations	A_{52}
		Efficiency of shared machines	A_{53}
		Factory network	A_{54}
Expansion flexibility	A_6	Integration of manufacturing and marketing decisions	A_{61}
		Easiness in layout	A_{62}
		Direct and indirect cost	A_{63}
		Speed of expansion	A_{64}
Routing flexibility	A_7	Effective handling of breakdowns	A_{71}
		System control software	A_{72}
		Redundancy in machines	A_{73}
		Versatility in machines	A_{74}

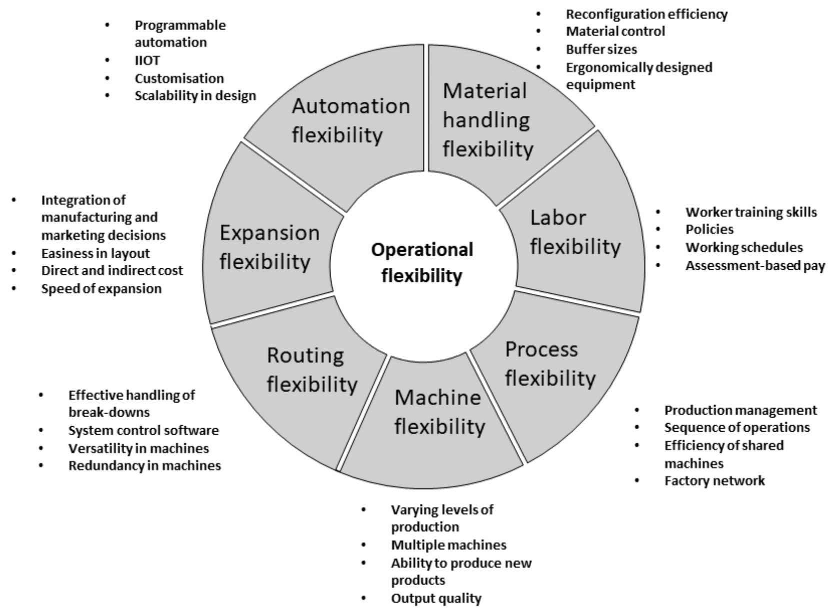

Figure 1. The model of operational flexibility in a manufacturing organization

4. Fuzzy Method for Evaluation of Operational Flexibility: A Research Methodology

The research methodology carried out in this study is as follows:

- Identification of main attributes and sub-attributes through literature review and opinions of experts.
- Assigning performance ratings and importance weights to attributes and main attributes using linguistic labels in natural expression through experts' opinion.
- Approximation and calculation of linguistic labels using fuzzy numbers.
- Deduction of fuzzy flexibility index at an attribute level.
- Subsequent determination operational flexibility index (Ansari and Mittal 2010) for the organization.
- Determination of Euclidean Distance.
- Matching a linguistic label with minimum distance 'D'.
- Derivation of operational flexibility level for the organization.

The conceptual framework for evaluation of operation is depicted in Figure 2.

Figure 2. A conceptual framework for evaluation of flexibility at an operational level

The survey to record responses from industry experts of the organization ‘XYZ’ was executed in the form of a questionnaire. Therefore, performance rating (R) and importance weights (W) for identified attributes were assigned based on the linguistic terms. Each of these linguistic terms/labels was assigned a corresponding fuzzy number, adopted from past research (Lin et al. 2006). These linguistic terms with their corresponding notations and associated fuzzy numbers (Patel et al. 2017) are given in Table 2.

Table 2. Linguistic terms and corresponding notations and fuzzy numbers

Performance Rating (R)			Importance weighting (W)		
Linguistic variable	Notation	Fuzzy Number	Linguistic variable	Notation	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	(0.85,0.95,1.0)

Experts assessed the performance of the sub-attributes finalized this study and estimated the relative importance of these sub-attributes and main-attributes in the context of the organisation ‘XYZ’.
The responses were recorded and are provided in Table 3 and Table 4.

Table 3. Performance ratings and Weights associated with sub-attributes assigned by experts using a linguistic expression

A_i	A_{ij}	**Assigned ratings of sub-attributes by experts using linguistic terms**				**Assigned weights of sub-attributes by experts using linguistic terms**			
		E1	**E2**	**E3**	**E4**	**E1**	**E2**	**E3**	**E4**
A_1	A_{11}	F	G	G	F	FH	H	FH	H
	A_{12}	VG	G	G	G	H	H	VH	H
	A_{13}	G	G	G	F	H	H	H	H
	A_{14}	G	G	G	G	H	H	H	H

A_2	A_{21}	VG	VG	G	G	VH	VH	H	H
	A_{22}	VG	G	G	G	VH	H	H	H
	A_{23}	G	G	G	VG	H	H	VH	H
	A_{24}	G	G	F	G	FH	H	H	H
A_3	A_{31}	G	F	F	G	H	FH	FH	FH
	A_{32}	VG	G	G	G	VH	VH	H	H
	A_{33}	F	F	G	F	FH	FH	H	H
	A_{34}	G	F	G	G	H	H	H	FH
A_4	A_{41}	VG	VG	G	VG	VH	VH	VH	H
	A_{42}	VG	VG	G	G	VH	H	H	FH
	A_{43}	G	G	G	F	H	H	H	FH
	A_{44}	E	E	VG	VG	VH	H	H	H
A_5	A_{51}	VG	VG	E	E	H	H	H	VH
	A_{52}	E	E	VG	E	VH	VH	VH	VH
	A_{53}	G	G	VG	G	H	H	VH	VH
	A_{54}	VG	G	VG	VG	H	H	H	VH
A_6	A_{61}	G	F	G	G	FH	M	M	FH
	A_{62}	G	F	F	G	FH	M	M	FH
	A_{63}	F	G	F	F	FH	M	FH	FH
	A_{64}	G	G	G	VG	H	H	H	H
A_7	A_{71}	G	G	F	G	H	H	FH	FH
	A_{72}	G	VG	G	G	H	VH	VH	H
	A_{73}	F	G	F	G	FH	M	FH	FH
	A_{74}	VG	G	G	G	H	H	H	VH

Table 4. Weights assigned to main attributes by experts by using linguistic expression

A_i	**Assigned weights of sub-attributes by experts using linguistic terms**			
	E1	**E2**	**E3**	**E4**
A_1	H	H	H	VH
A_2	H	VH	H	H
A_3	FH	FH	FH	H
A_4	H	H	FH	H
A_5	H	VH	VH	VH
A_6	H	M	M	M
A_7	FH	H	H	H

4.3 Calculation of Average Ratings and Weights of Sub-Attributes

'R_{ij}' is defined as the average performance rating (R) while 'W_{ij}' is defined as the average importance weight (W) assigned to the 'j_{th}' sub-attribute falling under the 'i_{th}' categorization of the main attribute. Average ratings and importance weights in Table 5. These are calculated based on the expression adopted by the works of (Lin et al. 2006).

$$R_{ij} = \frac{R_{ij1} + R_{ij2} + R_{ij3} + \cdots + R_{ija}}{a} \quad (1)$$

$$W_{ij} = \frac{W_{ij1} + W_{ij2} + Wij3 + \cdots + W_{ija}}{a} \quad (2)$$

For an instance, (R_{ij}) and (W_{ij}) of a sub-attribute accredited as 'A_{12}' i.e., 'material control' is calculated as in the following example. Here, 'a' in the expression is the number of accessors approached for this study.
The average rating and average weight can be calculated as:

$$R_{ij} = \frac{\mathrm{VG} + \mathrm{G} + \mathrm{G} + \mathrm{G}}{4} \tag{3}$$

$$R_{12} = \frac{[(7,8,9) + (5,6.5,8) + (5,6.5,8) + (5,6.5,8)}{4} \tag{4}$$

$$W_{ij} = \frac{\mathrm{H} + \mathrm{H} + \mathrm{VH} + \mathrm{H}}{4} \tag{5}$$

$$W_{12} = \frac{[(0.7,0.8,0.9) + (0.7,0.8,0.9) + (0.85,0.95,1.0) + (0.7,0.8,0.9)}{4} \tag{6}$$

Table 5. Average fuzzy ratings and weights of sub-attributes

A_i	A_{ij}	W_{ij}	R_{ij}
A_1	A_{11}	(0.60,0.73,0.85)	(4.5,6.13,7.75)
	A_{12}	(0.74,0.84,0.93)	(5.50,6.88,8.25)
	A_{13}	(0.70,0.80,0.90)	(4.5,6.13,7.75)
	A_{14}	(0.70,0.80,0.90)	(5,6.5,8)
A_2	A_{21}	(0.78,0.88,0.95)	(6,7.25,8.5)
	A_{22}	(0.74,0.84,0.93)	(5.5,6.88,8.25)
	A_{23}	(0.74,0.84,0.93)	(5.5,6.88,8.25)
	A_{24}	(0.65,0.76,0.88)	(4.5,6.13,7.75)
A_3	A_{31}	(0.55,0.69,0.83)	(4,5.75,7.50)
	A_{32}	(0.78,0.88,0.95)	(5.50,6.88,8.25)
	A_{33}	(0.60,0.73,0.85)	(3.50,5.38,7.25)
	A_{34}	(0.65,0.76,0.88)	(4.50,6.13,7.75)
A_4	A_{41}	(0.81,0.91,0.98)	(6.50,7.63,8.75)
	A_{42}	(0.69,0.80,0.90)	(5.50,6.88,8.25)
	A_{43}	(0.65,0.76,0.88)	(5.50,6.88,8.25)
	A_{44}	(0.74,0.84,0.93)	(7.38,8.38,9.25)
A_5	A_{51}	(0.74,0.84,0.93)	(7.75,8.75,9.50)
	A_{52}	(0.85,0.95,1)	(8.13,9.13,9.75)
	A_{53}	(0.78,0.88,0.95)	(5.50,6.88,8.25)
	A_{54}	(0.74,0.84,0.93)	(6.50,7.63,8.75)
A_6	A_{61}	(0.40,0.73,0.85)	(4.5,6.13,7.75)
	A_{62}	(0.40,0.58,0.75)	(4,5.75,7.5)
	A_{63}	(0.45,0.61,0.78)	(3.5,5.38,7.25)
	A_{64}	(0.70,0.80,0.9)	(5.5,6.88,8.25)
A_7	A_{71}	(0.60,0.73,0.85)	(4.5,6.13,7.75)
	A_{72}	(0.78,0.88,0.95)	(5.50,6.88,8.25)
	A_{73}	(0.45,0.61,0.78)	(4,5.75,7.50)
	A_{74}	(0.74,0.84,0.93)	(5.88,7.25,8.5)

4.1 Calculation of Operational Fuzzy Flexibility Index (FFI) at Main-Attribute Level

Fuzzy numbers are consolidated into one index through the fuzzy arithmetic operation. This index is known as the fuzzy index. As the objective of the study is to calculate operational flexibility index, this fuzzy index is termed as FFI (Ansari and Mittal 2010) i.e., fuzzy flexibility index.

The operational flexibility index is obtained by calculating FFI at an attribute level. This is denoted as. ‘FFI_i’. Fuzzy flexibility index at attribute level is calculated for every attribute identified for the study where, ‘FFI_i’ is the flexibility of the ‘ith’ attribute. The expression for calculation of FFI_i adopted by (Vinodh and Vimal 2012) is used for this study. FFI_i is calculated for all 7 attributes. It is given in Table 6.

$$\frac{\sum_{k=1}^{n}(W_{ij} * R_{ij})}{\sum_{k=1}^{n} W_{ij}} \tag{7}$$

Table 6. Operational flexibility index at the attribute level

E_i	W_i	FI_i
E1	(0.74,0.84,0.93)	(4.90,6.42,7.94)
E2	(0.78,0.88,0.95)	(5.41,6.80,8.20)
E3	(0.55,0.69,0.83)	(4.46,6.08,7.71)
E4	(0.65,0.76,0.88)	(6.26,7.46,8.63)
E5	(0.78,0.88,0.95))	(6.99,8.11,9.07)
E6	(0.40,0.58,0.75)	(4.53,6.10,7.71)
E7	(0.65,0.76,0.88)	(5.11,6.57,8.03)

4.2 Determination of Operational Flexibility Index for the Organization

The expression for calculation of FFI adopted by (Vinodh and Vimal 2012) is given as:

$$\frac{\sum_{i=1}^{l}(W_i * FFI_{\mathrm{i}})}{\sum_{i=1}^{l} W_i} \tag{8}$$

Therefore, FFI for the organization ‘XYZ’ is calculated as (5.48,6.85,8.21). The labeling of the fuzzy flexible index (Patel et al 2017.) is given in Table 7.

Table 7. Labeling of fuzzy flexible index

Linguistic term	fuzzy number
Extremely flexible	(7,8.5,10)
Very flexible	(5.5,7,8.5)
Flexible	(3.5,5,6.5)
Fairly flexible	(1.5,3,4.5)
Slowly becoming flexible	(0.1.5,3)

4.3 Determination of Euclidean Distance

The fuzzy flexibility index determined is matched by a linguistic term for the purpose of obtaining operational flexibility level for the organization. The method of determination of euclidean distance had been employed to match a linguistic label with FFI obtained in the study. Euclidean distance method helps to determine a relevant perspective of humans on proximity (Vinodh et al. 2013). The set FL = {extremely n flexible (FA), very flexible (VF), flexible (F), fairly (F), slowly (S)} indicates labeling of the level of flexibility in natural expression. In this method, the least distance (D) is calculated between FFI and a corresponding set in FL. The expression for calculation of (D) used in this study is adopted by (Vinodh and Devadasan 2011) which is as follows:

$$\left\{\sum_{x\epsilon p}\left[f_{FFI}(x) - f_{FL}(x)\right]^2\right\}^{1/2} \tag{9}$$

Subsequently, a linguistic label was matched with the minimum Euclidean distance. This led to indicate a fuzzy flexible index for operational flexibility. It has been concluded as **'very flexible'** at the operational level for the manufacturing organization considered for this study. The linguistic label for corresponding Euclidean distance (Vinodh et al. 2013) is given in Table 8.

Table 8. Linguistic labeling of Euclidean distance

Euclidean Distance	Numerical Value
D (FFI, EF)	2.8700
D (FFI, VF)	0.3271
D (FFI, F)	3.2042
D (FFI, FF)	6.6653
D (FFI, SF)	9.2626

5. Conclusion

A manufacturing organization must deal with changes in its operations to breakout from threats posed by uncertainties and changing environments. Therefore, it is very crucial to incorporate flexibility for an organization in its routine operations. To empirically determine the level of operational flexibility in a manufacturing organization, the fuzzy logic approach is used. This approach is used to eliminate problems associated with vagueness complexities in the study. A conceptual model has been developed and seven important enablers of operational flexibility have been established. The first step for this study is established by collecting ratings and weights of attributes and sub-attributes consolidated through literature and industry experts' opinions. Flexibility Index has been computed. The organization is found to be 'very flexible' by employing the Euclidean distance method to obtain operational flexibility level. The study is based on evaluation of flexibility in manufacturing organization. However, it can be extended to a series of other organizations of different sectors of economy. The study focuses and evaluates operational flexibility of an organization. Following this, it can be extended to other notions of flexibility such as organizational and supply chain flexibility. This method can help an organization to identify and monitor weaker areas in its operations that help determine flexibility. Following the study, it is evidently drawn that operations managers of the organization need to establish and improve material handling flexibility, labor flexibility and automation flexibility. This improvement can be done by focusing on a pool of factors explained in the study.

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