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An AHP Approach to Evaluate the Manufacturing Flexibility in Manufacturing Organizations

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Abstract

Flexibility is considered as an important aspect to solve the problem of environmental turbulence and uncertainty. Organizations need to be flexible in order to survive under highly uncertain environments. There are many instances of failures due to inability of organizations to adapt to market pressure. Different researchers working in this area have different opinions about the definition and dimensions of manufacturing flexibility The objective of this paper is to understand and explicate the interaction between various dimensions of manufacturing flexibility and to analyze them using analytical hierarchy process (AHP). The results of the study reveal the relative importance and contribution of each dimension of manufacturing flexibility in making an organization flexible.

Introduction

Expanding global competition, rapidly changing markets and technology, increasing complexity and uncertainty are creating a new competitive environment. As a result of this highly volatile and turbulent dynamism, a firm faces an unpredictable environment characterized by very fast changes in technologies, aggressive variations in customer demand and intense fluctuations in supply of materials (Yang and Li, 2011). Organizations must adapt to market pressure and competitors' innovations with increasing speed to deliver both efficiency and effectiveness. From a combined business and functional strategy viewpoint, competitiveness and profitability call for improved organizational adaptability and more flexible and advanced systems (relative to manufacturing, engineering, supply chain, information and process technology, etc.) to improve manufacturing competence. The manufacturing organizations have also experienced an unprecedented degree of change in the recent times, involving drastic changes in management approaches, product and process technologies, customer expectations, supplier attitudes as well as competitive behavior.

The basic competitive priorities generally considered by academician and professionals are quality, delivery, price and flexibility. However, the past decade has witnessed an increased interest in flexibility, which bestows on a firm the ability to respond promptly to market opportunities and changing technologies and most likely to continue with ever increasing changes in the marketplace. The investigation of strategic choice of aligning flexibility development with the external environment that manufacturing manager's face, considering uncertainties in demand, material supply, competition and new product technology, indicates the need of matching the

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manufacturing flexibility with environmental uncertainty to ensure profit and sales performance (Chang *et al.*, 2002). Manufacturing flexibility has been heralded as a major competitive weapon for manufacturing organizations operating in increasingly uncertain environments and turbulent markets. It has been considered in the literature that manufacturing flexibility has the capability to provide organizations with the ability to change levels of production rapidly, to develop new products more quickly and more frequently, and to respond more rapidly to competitive threats.

Manufacturing Flexibility

Manufacturing flexibility, the focus of the study, is defined as the ability of the system to adjust to environmental changes/ market fluctuations and process requirements with little penalty in time, effort, cost or performance. (Gerwin, 1993; D'Souza and Williams, 2000; Koste and Malhotra, 1999; Barad and Sipper, 1988). Manufacturing flexibility can be viewed as a multi-dimensional concept rather than as an independent variable that can be defined and measured in isolation. It is considered as the strategic element of business, along with price (cost), quality, and dependability. Priorities assigned to each of these factors determine how an organization positions itself relative to its competitors.

A great deal of research in defining various types of flexibilities in manufacturing has occurred over the last two decades. Despite this, there is no general agreement on how to define flexibility. At the outset, this is due to the multidimensional nature of flexibility and the various views of flexibility that result: flexibility has been viewed and studied as a physical property, an attribute of decision making, an economic indicator, and a strategic tool. Understanding the constituent dimensions of manufacturing flexibility and their interrelationships would be of value to the firms whose competitive strength depends on flexible manufacturing. Its dimensions addressed in the literature mainly include equipment flexibility, material flexibility, routing flexibility, material handling flexibility, program flexibility, mix flexibility, volume flexibility, modification flexibility, new product flexibility, delivery flexibility and market flexibility.

Table 1: Taxonomy of Flexibility

Operational Flexibilities (Machine/Shop level)	Equipment flexibility	The ability of a machine to switch among different flexibilities types of operations without prohibitive effort
	Material flexibility	The ability of equipment to handle variations in key dimensional and metallurgical properties of inputs
	Routing flexibility	The ability to vary machine visitation sequences for processing a part
	Material handling flexibility	The ability of the material handling system to move material effectively through the plant
	Program flexibility	The ability of equipment to run unattended for long periods of time
Tactical Flexibilities (Plant level)	Mix flexibility	The ability of a manufacturing system to switch flexibilities between different products in the product mix
	Volume flexibility	The ability of the manufacturing system to vary aggregate production volume economically
	Expansion flexibility	The ability to expand capacity without prohibitive effort
	Modification flexibility	The ability of the manufacturing process to customize products through minor design modifications
Strategic Flexibilities (Firm Level)	New product flexibility	The ability of the manufacturing system to introduce and manufacture new parts and products
	Market flexibility	The ability of the manufacturing system to adapt to or influence market changes

The development of a generic categorization is likely to remain elusive in the previous research as manufacturing flexibility manifest itself in many forms at various levels in an organization. Yilmaz and Davis (1987) have examined manufacturing flexibility through different dimensions of time. Carlson (1989) goes on to distinguish three types of flexibility: operational (short term), tactical (medium term) and strategic (long term).

Narasimhan and Das (1999) suggested taxonomy of flexibility as operational flexibilities, tactical flexibilities and strategic flexibilities (Table 1)

Operational flexibility corresponds to built-in procedures that permit a large range of responses to operational variables including sequencing and scheduling. While tactical flexibilities relate to the embodiment in technological and organizational routines of responses in how to deal with changes in rates of production, product mix over the course of a business cycle, strategic flexibilities are external in application and relates to how the organization is positioning itself with respect to future challenges and opportunities. D'Souza and Williams (2000) categorized manufacturing flexibility as external and internal driven dimensions. This study focuses on the generalization of hierarchical taxonomy of manufacturing flexibilities based on the insights of the available literature.

Volume flexibility, corresponds to the ability of manufacturing system to be operated profitable (in the short term) with various amount of volume for several products without incurring negative effects (e.g. time delays, changes in performance outcomes) when switching from one operation to another (Sethi and Sethi, 1990, Koste and Malhotra, 1999, Hyun and Ahn, 1992). However, the issues related to ease of producing minor alterations in product design to meet customization or differentiation requests have been addressed by modification flexibility (Gerwin, 1993). Modification flexibility is useful for product and market differentiation efforts and overall market share growth. Delivery flexibility further strengthens the capabilities of manufacturing system to respond to or influence market changes & enables the rapid delivery of innovativeness, customized products for new market creation (Narasimhan and Das, 2000).

Analytical Hierarchy Process

Saaty (1980, 1982, 1986, 1990), Saaty and Vergas (1982), Saaty and Kearns (1985) describe and elaborate on the process.

Table 2: Three Phases used in AHP (Saaty 1980)

Intelligence Phase	
Discuss a preliminary problem in order to :	obtain an enriched, consensual view of the problem
Design Phase	
Discuss an initial list of alternatives in order to :	obtain a revised list of alternatives;
	obtain an initial set of objectives/criteria.
Discuss an initial set of objectives in order to :	obtain a revised set of objectives/criteria.
Choice Phase	
Structure one or more AHP models in order to:	obtain common (group) Expert Choice model(s) along with judgments.

AHP provides improved results over other well-known scoring approaches since the criteria weights or priorities established by the AHP are not based on arbitrary scales, but a ratio scale for human judgments is used (Golden et al., 1989), Basic methodology to be used in AHP mainly consist of three phases as given by (Saaty 1980), namely intelligence phase, design phase and Choice phase, which have been briefly explained in Table 2

Describing Model Structure and Formulation of Hierarchy

Identification of the important attributes requires a thorough analysis of the problem. For current study, the selection of attributes has been determined through literature survey and discussions which were held with experts during industrial visits. Eight factors have been indentified and their description is given in Table 3.

Table 3: Description of the Attributes Chosen

S. No.	Flexibility Dimension	Abbreviation
1	Machine Flexibility	MCF
2	Material Handling Flexibility	MHF
3	Process Flexibility	PRF
4	Part Mix Flexibility	PMF
5	Volume Flexibility	VLF
6	Routing Flexibility	RTF
7	Expansion Flexibility	EXF
8	Operation Flexibility	OPF

The decision hierarchy is formulated by breaking down the problem into a hierarchy of decision elements and is given in Figure 1. In this, we have taken manufacturing flexibility as a goal, nine attributes (MCF, MHF, PRF, PMF, VLF, RTF, EXF, OPF) and two alternatives (Flexible and Inflexible)

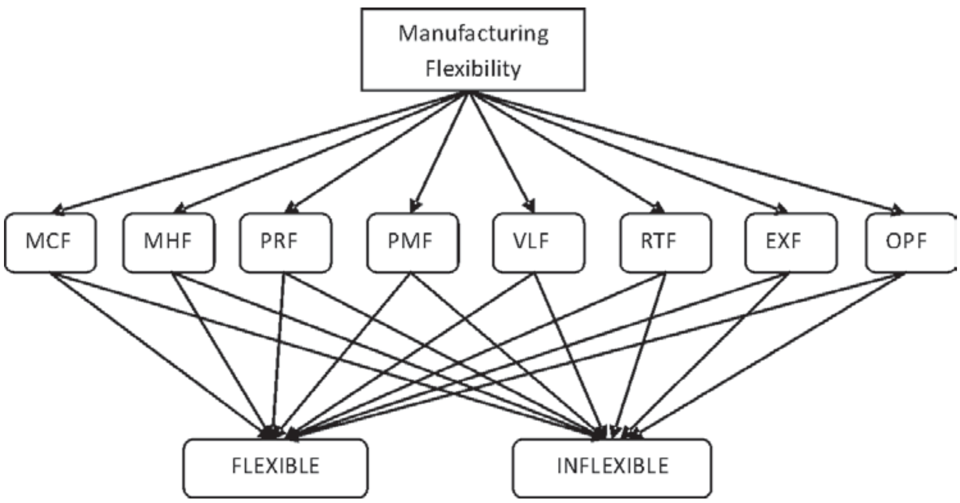

Figure 1: AHP Model Formulated

Paired Comparison

Paired comparison is based on the idea that a complex issue can be effectively examined if it is hierarchically decomposed into its parts. The elements are compared with each other, thus providing an opportunity for a pair-wise comparison for evolving the structure into an nxn reciprocal judgment matrix. In the matrix, one begins with an element on the left and compares how much more important it is than an element on top. When compared with itself, the ratio is one. When compared with another element, if it is more important than that element, an integer value, as discussed below, is used. If, however, it is less important, then reciprocal of the previous integer value is used. In either case, reciprocal value is entered in the transpose position of the matrix. Thus, only n (n-1)/2 judgments are considered where n is the total number. The respondent is to concentrate on only two elements at a time. A scale of 1 to 9 is used for giving judgment value according to the following guidelines:

= 1 if i and j are equally important.

= 3 if i is weakly more important than j.

= 5 if i is strongly more important than j.

= 7 if i is very strongly more important than j.

= 9 if i is absolutely more important than j.

Value of 2, 4, 6 and 8 are used to compromise between two judgments.

Table 4: Pair-wise Comparison Matrix

	MCF	MHF	PRF	PMF	VLF	RTF	EXF	OPF
MCF	1.00	3.00	5.00	5.00	2.00	3.00	5.00	2.00
MHF	0.33	1.00	2.00	3.00	1.00	1.00	3.00	2.00
PRF	0.20	0.50	1.00	2.00	0.33	0.33	1.00	0.25
PMF	0.20	0.33	0.50	1.00	0.25	0.33	2.00	1.00
VLF	0.50	1.00	3.00	4.00	1.00	2.00	2.00	2.00
RTF	0.33	1.00	3.00	3.00	0.50	1.00	2.00	3.00
EXF	0.20	0.33	1.00	0.50	0.50	0.50	1.00	1.00
OPF	0.50	0.50	4.00	1.00	0.50	0.33	1.00	1.00
Total	3.27	7.67	19.50	19.50	6.08	8.50	17.00	12.25

After a pair-wise comparison matrix is obtained, the next step is to get the value of normalized matrix. Normalized matrix can be obtained by dividing each entry in the column by the sum of entries in column in pair-wise comparison matrix. The normalized value r_{ij} is calculated as:

$$r_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$$

Further, the approximate priority weight (W1, W2,…….Wj) for each attribute is obtained as shown in Table 5

$$W_j = \frac{1}{n} \text{ X } \sum_{i=1}^{n} a_{ij}$$

Table 5: Normalized Matrix along with Priority Weights

	MCF	MHF	PRF	PMF	VLF	RTF	EXF	OPF	Weight
MCF	0.31	0.39	0.26	0.26	0.33	0.35	0.29	0.16	0.29
MHF	0.10	0.13	0.10	0.15	0.16	0.12	0.18	0.16	0.14
PRF	0.06	0.07	0.05	0.10	0.05	0.04	0.06	0.02	0.06
PMF	0.06	0.04	0.03	0.05	0.04	0.04	0.12	0.08	0.06
VLF	0.15	0.13	0.15	0.21	0.16	0.24	0.12	0.16	0.17
RTF	0.10	0.13	0.15	0.15	0.08	0.12	0.12	0.24	0.14
EXF	0.06	0.04	0.05	0.03	0.08	0.06	0.06	0.08	0.06
OPF	0.15	0.07	0.21	0.05	0.08	0.04	0.06	0.08	0.09

Checking for Consistency

The weight ages of the features are obtained by calculating the Eigen Vector weights for the judgment matrix. An index of consistency is calculated to provide information on how serious is violations of numerical and transitive consistency. The results could be used to seek additional information and re-examine the data used in constructing the scale in order to improve consistency.

The consistency index (CI) is = $(\lambda_{max} - n) / (n-1)$ where n is the number of elements being compared and λ_{max} is the largest Eigen value of the judgment matrix. Dividing CI by the random consistency number for the same size matrix, consistency ratio CR can be obtained (CR = CI/RI). The value of CR should be around 10% or less to be acceptable. In some cases, a maximum value of 20% may be tolerated. If CR is not within this range, participants should study the problem and revise their judgment.

The average consistencies for different order random matrices are given below (Saaty and Kearns, 1985).

Table 6: Random Consistency Index (RI)

Size of matrix	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.42	1.45	1.49

Table 7: Results of Consistency Test

Maximum Eigen Value (λ_{max})	C.I.	R.I.	C.R.
8.5408	0.07725	1.42	0.0544

Priority Weights for Alternatives with Respect to Attribute

The chances of an organization to be flexible increase only if attributes (sub-objectives) present are strong. Priority weights are used for measuring the preference of the alternative (flexible or inflexible) with respect to an attribute. Thus, if the presence of one attribute is strong in the organization, it is more likely to improve flexibility, as compared to the other attribute which is present but weak. For priority weights, the weight evaluation of each alternative is multiplied in the matrix of evaluation rating by vector of attribute weight and summing over the entire attribute. Table 8 summarizes the result of evaluating the possible outcome flexibility, with respect to each of eight attributes.

For the prediction weight for flexibility of organization:

Decision Index of Flexibility = 0.75 X 0.29 + 0.85 X 0.14 + 0.34 X 0.06 + 0.25 X 0.06 + 0.75X 0.17 + 0.84 X 0.14 + 0.75 X 0.06 + 0.75 X 0.09 = 0.729 or 72.9%

Thus Decision Index of Inflexibility = 1 - 0.729 = 0.271 or 27.1%

The above calculations show that all the attributes of strategic flexibility contribute 72.9% towards flexibility of the organization.

Table 8: Priority Weights for Sub-objectives

		Flexible	**Inflexible**	**Weight**
MCF	Flexible	1	3	0.75
	Inflexible	1/3	1	0.25
MHF	Flexible	1	6	0.85
	Inflexible	1/6	1	0.15
PRF	Flexible	1	1/2	0.34
	Inflexible	2	1	0.66
PMF	Flexible	1	1/3	0.25
	Inflexible	3	1	0.75
VLF	Flexible	1	3	0.75
	Inflexible	1/3	1	0.25
RTF	Flexible	1	5	0.84
	Inflexible	1/5	1	0.16
EXF	Flexible	1	3	0.75
	Inflexible	1/3	1	0.25
OPF	Flexible	1	3	0.75
	Inflexible	1/3	1	0.25

Conclusion

Using the AHP approach, the study is able to identify and emphasize the important criteria and attributes, for achieving the manufacturing flexibility in manufacturing organizations. From the literature on manufacturing flexibility, it can be established that manufacturing flexibility is a multidimensional concept. It can also be seen that out of various dimensions, machine flexibility, material handeling flexibility, volume flexibility and routing flexibility play a major role in managing manufacturing flexibility. The obtained results are quite significant and promising, and reveal that all the attributes (dimensions) chosen contribute significantly towards flexibility of an organization.

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