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SOME DIMENSIONS OF FLEXIBILITY IN FMS

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ABSTRACT

Today's dynamic market has forced the manufacturing managers to take interest in flexibility which bestows on an industry to respond promptly to market opportunities and changing technologies. The development of capabilities to be flexible rests on the mandate of top management. It helps industries to manage market uncertainties and tends to enhance manufacturing performance. This paper aims to look into the research done regarding flexibility in the context of FMS and its implication in real life cases.

Keywords: FMS; flexibility; implications

Introduction

Manufacturers are, nowadays, faced with the necessity to produce more customized products of higher quality and lower cost within a shorter time frame (Fry and Smith, 1988). Manufacturers of discrete parts face increasing demands for small-to- medium sized lots of customized products, requiring a production process, which can provide flexibility as well as economies (Kouvelis, 1991). Consequently, the adoption of FMS to respond quickly, smoothly and cheaply to as yet unknown changes in product markets and production technology is becoming a recent trend in manufacturing industries (Chen and Chung, 1996).

Flexibility is one of the critical dimensions of enhancing the competitiveness of organizations. Technological developments and market demands are forcing the organizations towards more flexibility. As a result, process flexibility is fast becoming a major priority for many organizations. Flexibility is one of the most sought-after properties in modern manufacturing systems (Shewchuk and Moodie, 1998). Stockton and Bateman (1995) have reported that flexibility is the ability of a manufacturing system quickly and economically to:

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

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In addition to above areas, flexibility enables the manufacturing companies to cope with the uncertainty that often surrounds the actions of competitors and the market. The flexibility of a manufacturing system is, therefore, an essential characteristic to be considered while designing and operating the same.

Flexibility and its Types

The flexibility issue is rooted in the evolutionary process of product design and redesign; key to this process is the event of change. The relation between the concept of change and product evolution leads to a definition of flexibility (Rajan et al., 2005). There have been numerous attempts to define and measure flexibility e.g. Sethi and Sethi, (1990); Chen and Chung, (1996); Das, (1996) and Tsubone and Horikawa, (1999) etc. Different authors have defined flexibility in their own ways. Some of these definitions are given in table 1:

Table 1: Definitions of flexibility

S. No.	Authors	Year	Definition
1	Chen and Chung	1996	Flexibility refers to the ability of the manufacturing system to respond quickly to changes in part demand and part mix.
2	Das	1996	Flexibility is defined as the ability of a system or facility to adjust to changes in its internal or external environment.
3	Tsubone and Horikawa	1999	Flexibility is the ability of a system to adapt quickly to any changes in relevant factors such as product, process, workload or machine failure.

Several authors have introduced different types of flexibilities. The identified flexibility types typically refer to different elements and attributes of a production facility such as machine, product, processing, operation, routing, capacity, expansion, design and system (Das, 1996). Some types of flexibility and their definitions as reported by (Buzacott (1982); Browne et al. (1984); Park and Son (1988); Azzone and Bertele's (1989); Son and Park (1990); Sethi and Sethi (1990) and Stockton and Bateman (1995)) are given in Table 2:

Table 2: Types of flexibility

Sr. no.	Type of flexibility	Definition
1	Machine Flexibility	It refers to the various types of operations that the machine can perform without requiring a prohibitive effort in switching from one operation to another.
2	Routing Flexibility	The ability of the manufacturing system to manufacture a product by alternate routes through the system.
3	Process Flexibility	The set of product types that the system can produce without major setups.
4	Product Flexibility	The ease with which new products can be added or substituted for existing products.
5	Volume Flexibility	The ability of the manufacturing system to be operated economically at different overall output levels.
6	Material handling	The ability of the material-handling system to move part types efficiently through the system
7	Operation	The ability of a part to be produced in different ways
8	Expansion	The ease and capability to expand volumes as needed
9	Production	The universe of part types that can be produced without the need to purchase new equipments
10	Programme	The ability of a system to operate untended for additional shifts
11	Market	The ability of a manufacturing system to adapt to changing market environments
12	Manufacturing	The ability to cope with the changing circumstances or instability caused by the environment
13	Product mix	The ability to produce several products at one manufacturing facility without incurring a major cost penalty.
14	Size	The component sizes that can be manufactured without requiring set-ups that take longer than a specific time period
15	Range flexibility	The total envelope of capability or range of states which the manufacturing system is capable of achieving,
16	Response flexibility	The ease, in terms of time and/or cost, with which changes can be made within the capability envelope

Using the definitions of Sethi and Sethi (1990) the value of flexibility has been considered at three levels i.e. basic level, system level and at the aggregate level. Flexibility at the basic level includes: machine flexibility, material handling system flexibility and operation flexibility. Flexibility at the system level includes: product flexibility, routing flexibility, process flexibility, volume flexibility and expansion flexibility and flexibility at the aggregate level includes program flexibility, production flexibility and market flexibility.

Several researchers have classified flexibility into various categories

Buzacott (1982) have classified into two categories: job and machine flexibility. Park and Son (1988) and Son and Park (1990) have defined four types of flexibility- product, process, equipment and demand flexibility. Azzone and Bertele's (1989) have defined six types of flexibility: Routing, process, product, production, volume and expansion flexibility. Sethi and Sethi (1990) have defined eleven types: machine flexibility, material handling system flexibility and operation flexibility, product flexibility, routing flexibility, process flexibility, volume flexibility and expansion flexibility, program flexibility, production flexibility and market flexibility.

Survey of Research in Flexibility Measurement

While it is helpful to understand the fundamental concept of flexibility, it is essential to have flexibility measurements developed so that firms can better benefit from utilizing manufacturing flexibility. Without the development of flexibility measurements and consequently, a better understanding of the relationship between different flexibility levels and system performance improvement, it could be quite difficult for firms to position manufacturing as one of their competitive priorities (Chen and Chung, 1996).

A flexibility measure is a formula, algorithm, methodology or the like, for generating a value for a given flexibility type under given condition. For example, a measure of routing flexibility could be the average quantity of alternate machine routes possible for the set of products considered. Given a flexibility type, multiple measures may be possible. Stockton and Bateman (1995) have reported that there are currently a variety of methods of measuring the individual types of flexibility that contribute to the production range flexibility of a manufacturing system. It can be seen from the following list of examples of methods used to measure machine flexibility, that these involve using differing "units of measure":

- Number of different operations a machine can perform without requiring more than a specified amount of effort.
- Opportunity of the machines within the system to add value to raw materials.
- Rate at which a machine becomes obsolete when new products are introduced.
- Extent of variations in dimensional properties of the input stock the machines can handle.

Chen and Chung (1996) have suggested that while machine flexibility is fundamental for process and product flexibility, routing flexibility is necessary for volume flexibility. In other words, machine and routing flexibility are required for most of the other types of flexibility. They have discussed alternative measures for the assessment of machine flexibility and routing flexibility, which are as follows:

(A) Machine Flexibility Measurement

Machine flexibility is the capability of a machine to perform different operations required by a set of parts (part types) without requiring a prohibitive effort in switching from one operation to another. Each part type is characterized by a sequence of operations, which must be performed on the part type. Operations include steps such as metal cutting, drilling, reaming, boring, heat treating etc. Machine flexibility can be measured in two ways:

1. Unweighted machine flexibility of machine *j* relative to operation set , $(UMF_j(W))$
2. Weighted machine flexibility of machine *j* relative to an operation set W, $(WMF_j(W))$

Table 3: Formulae for machine flexibility measurement

Sr. No.	Formula	Index	Meaning of symbols
1	$UMF_j(\Omega) = \mu_j / \lvert\Omega\rvert$	1 = fully flexible 0 = low flexibility	μ_j = Total no. of operations $\lvert\Omega\rvert$ = operation set
2	$WMF_j(\Omega) = \sum w_i e_{ji}$	1 = fully flexible 0 = low flexibilty	w_i=wight of importance for operation i (e.g. frequency or demand value of the operation required to complete a set of part types) e_{ji}=machine-operation efficiency coefficient(value of e_{ji} lies between 0 and 1)

As indicated in above table, a zero value of $UMF_j(\Omega)$ indicates that the machine is not capable of performing any of the required operations and with $UMF_j(\Omega) = 1$, machine j can perform all of the required operations.

(B) Routing Flexibility Measurement

Routing flexibility of a manufacturing system is its capability to process a given set of part types using more than one route (i.e. alternate routing). In the situation where each part type must be processed with exactly one route (i.e. fixed routing) due to technological and capacity constraints such as processing requirements, flexibility of the machines which make up the system, material handling, etc., the system is considered to have no routing flexibility. Routing flexibility can also be measured in two ways:

1. Potential routing flexibility relative to a part type set π, $PRF(\pi)$
2. Actual routing flexibility relative to a part type set π, $ARF(\pi)$

Table 4: Formulae for routing flexibility measurement

Sr. No.	Formula	Index	Meaning of symbols
1	$PRF(\pi) = \sum r_h / H$	1 = No flexibility n = High flexibility	$\sum r_h$ = total number of flexible routes H = number of part types
2	$ARF(\pi) = \sum a_h / H$	1 = No flexibility n = High flexibility	$\sum a_h$ = Total number of actual routes H = number of part types

Chen and Chung (1996) have illustrated the capability and applicability of the above-proposed measures with examples. They also conducted an experiment to investigate FMS performance with various levels of flexibility. The results of their study indicate the following:

1. Flexibility improves system performance at a decreasing rate.
2. Routing policy and operating conditions have critical effects on the magnitude of performance improvement.

Tsubone and Horikawa (1999) have compared the above two types of flexibility, machine flexibility and routing flexibility, in terms of manufacturing performance in various shop environments. They conducted a simulation-based investigation to analyze the impact of these types of flexibility on the average flow time of parts under various job flow pattern conditions, which characterize the shop nature from a random job shop to a flow shop, operation time variance, setup time and shop lead.

Hutchinson and Sinha (1989) have used a decision theoretic approach in developing a model to assist a decision maker in evaluating the cost-flexibility tradeoff. They developed an improved numerical method to more accurately calculate the net present values. The model is based on the choice between two alternatives: a flexible manufacturing system (FMS) and a transfer line (TL). Using the standard deviation of demand as ameasure of uncertainty, flexibility is shown to have economic value. They have also examined the sensitivity of the model with respect to several parameters of interest.

Stockton and Bateman (1995) have proposed the use of "probability" as the standard unit of measure for all flexibility types, i.e. each flexibility type will be defined in terms of "the probability of an event being able to take place". For example, they have considered a manufacturing system having four CNC machines which can perform seven number of maximum operation. But at present, only five operations are being done on these four machines. Hence, *Machine flexibility p[D]*: the probability that a part selected at random, could in terms of the operations required, be processed within the FMS.

Maximum possible score = 4 x 7 = 28

FMS score, i.e. number of Ys = 5

Machine flexibility $p[D] = 5/28 = 0.18$

Similarly, they have proposed the methods to measure other types of flexibility:

Size flexibility p[A]: the probability that a part selected at random, could in terms of its size, be processed within the FMS.

Shape flexibility p[B]: The probability that a part selected at random, could in terms of its shape, be processed within the FMS.

Materials flexibility p[C]: the probability that a part selected at random, could in terms of its materials, be processed within the FMS.

Material handling flexibility p[E]: the probability that a material-handling route through the FMS, selected at random, could be possible.

Process flexibility p[F]:The probability that a component selected at random, could in terms of its physical characteristics, be processed within the FMS.

Routeing flexibility p[G]: the probability that a process route selected at random could be possible within the FMS.

Production range flexibility p[H]: the probability that a component selected at random could be processed within the FMS.

Discussion

From the above discussion, it is clear that a lot of efforts have been put by different authors in defining and measuring flexibility. But in spite of this, many problems are generally faced in industries. First problem is with the definition of flexibility. Though many definitions have been used in the literature, but there is no agreement on one general definition of flexibility. This creates a lot of confusion in the minds of production managers in real-life situations. The second problem in the domain of flexibility issue is its measurement and quantification. No clear-cut methodology is available to practicing managers for measuring the flexibility of a system (Raj et al., 2007). Sethi and Sethi (1990) reported that at least 50 terms exist for various types of flexibilities studied. Sethi and Sethi (1990) have identified from the literature 21 methods of measuring process flexibility, 11 methods of measuring routeing flexibility, 11 methods of measuring product flexibility and seven methods of measuring material handling flexibility. Some authors have noted that the lack of standardization in the terminology about flexibility matters in the literature makes it difficult to compare different authors' classification (Raj et al., 2007).

There are three basic short comings regarding attempts to develop flexibility term for manufacturing:

1. Terms have been based on different perspectives of what constitutes a manufacturing system and its environment.
2. In defining flexibility types and measures, researchers have had different ideas as to what information is required and the corresponding level of detail necessary to specify such information.
3. Finally, as no formal mechanism for articulating flexibility type definitions and measures exists, the terms often are incomplete, imprecise and insufficient in their level of detail to be clearly understood.

Conclusion

Though a lot of research work has been reported in the literature regarding flexibility in context of flexible manufacturing systems yet its real-life implications are not much encouraging. There are certain factors regarding different resources in FMS which inhibit to achieve the desired level of flexibility in the system e.g. (i) machine tools have limited capacity for tool storage, (ii) robots are designed or selected for a definite range of parts, (iii) AGVS have well defined load carrying capacity, and they can be dispatched and routed through a fixed path and (iv) fixtures are highly rigid. Production managers often feel handicapped in differentiating process flexibility, product flexibility, operation flexibility, machine flexibility and production flexibility. In such an environment, there is an utmost need to develop models for the measurement and quantification of flexibility based on simple inputs such as variety of parts and availability of different resources. It will help the production managers to understand the concept of flexibility and its measurement on the shop floor level.

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