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Manufacturing Flexibility: Its Need, Type, and Effects

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Abstract

Now in the present days, when manufacturing industry is facing very competitive and challenging environment, with growing difficulty, and high levels of customisation. The unexpected events, so called disturbances invariably affect the overall performance of manufacturing system. Which can be controlled by incorporating manufacturing flexibility dimensions with respect to design, operation, and management of manufacturing system. In this presentation, an attempt has been made to through some light on manufacturing flexibility, its' type, classification, measures, and effect on the performance of manufacturing system.
Keywords: *Manufacturing Flexibility Dimensions.*

1. Introduction

In simple terms a manufacturing system (MS) is a combination of man, machines, material handling devices, and power source. In present era of manufacturing the effectiveness of any MS is not only based on cost, quality, and other performance measures but it is also shifting towards time based performance measures [1]. A typical MS transforms raw material into a desired shape and size consistently. There are number of unexpected events making this transformation process more complex. These unexpected events can be categorized into two categories based on their source of origination in the literature[2]:

- Disturbances originated within system boundary: resource unavailability, machine break down, etc.
- Disturbances originated from outside system boundary: variation in demand, product dimension, etc.

Despite increasing automation of MS, the human element is still an essential component[3] for any manufacturing system. Chung[4] demonstrated that success in the implementation of advanced manufacturing technology largely depends on human resource related issues. Hence, disturbances originated due to human factor should be handled very carefully. Both categories of disturbances invariably affect the overall performance of any MS. To handle these unexpected disturbances the managers should consider / practice the concept of flexibility in design, operation, and management of MS [5]. In literature, plethora of work (theoretical, simulation based, and empirical) is reported on manufacturing flexibility (flexibility), its' dimensions, need, and effect on manufacturing system performance, etc. The presentation aims towards need, types, and effects of flexibility dimensions on the performance of manufacturing system.

2. Manufacturing Flexibility

Numerous authors tried to capture the essence of manufacturing flexibility and formulated number of definitions, some of them can be found in literature [2, 5, 8-10]. Still there is a lack of general agreement on definitions of flexibility[11]. Shewchuk & Moodie[11] found over seventy terms on flexibility, its' types and measures in the literature. Sethi and Sethi [5], in their popular survey of literature reported at least fifty terms exist for the various types of flexibilities studied. They also observed that flexibility is a complex, multidimensional, and hard-to capture concept, even several terms refer to the same flexibility type in many cases, and the definitions for flexibility types often are imprecise and conflicting, even for identical terms[9,11]. It is observed that researchers must agree that, in simplest terms:

"Flexibility is the ability to deal with change"

Change is the universal law of nature. Response of an organization to the change has a major stake in deciding the fate of the organization. That's why dealing with change is most crucial. While dealing with change, the use of inherent knowledge of experience within as well as outside the system will be highly beneficial and must be utilized. This inherent knowledge must be documented for further reference.

2.1 Flexibility Dimensions: Numerous categories and dimensions of flexibility are reported in literature. In 1984, Browne et.al[12] identified eight types of flexibility, while in 1990; Sethi and Sethi [5] envisioned the concept of eleven flexibility types, while in 2000, Vokurka and O'LearyKelly[13] observed four additional types of flexibility to be important in the context of MS. Earlier to Vokurka and O'Leary-Kelly[13], in 1991, Ramasesh and Jaykumar[14] already came up with the theory that flexibility can be in several different forms e.g.

machine, operation, routing, material handling, process, program, product, volume, expansion, labour, and material flexibilities. The definition for each of these fifteen flexibility dimensions is envisioned in Table 1. Table 2 represents the flexibility type required to handle a particular category of disturbances[19].

2.2 Measures of Various Flexibility Types: A number measurement schemes for flexibility dimension are there [5, 12, 14-20]. Gupta (1993) speculates that the cause of “so many different measurement schemes” and “lack of universal acceptance of any one scheme” is the fact that any measurement of flexibility must, because of its nature, be user or situation specific. Still the scheme of measurement of various flexibility dimensions adapted from Chen and Adam [15] is given in table 3.

2.3 Classification of Various Flexibility Dimensions: number of classification schemes for flexibility types has been given time to time on the basis of different attributes of it. Some of them are quoted below:

Taking inspiration from Pelaez-Ibarrondo and Ruiz-Mercader [21], and Koste and Malhotra[16] the ten flexibility types has been segregated as per the level where it is usually performed namely level of shop floor, plant, and individual / resource as shown in Table 4.

A classification based on management perspective is detailed in table 5.

Mandelbaum (1978) classify various flexibility dimensions into two main contexts action flexibility, where outside intervention is required before the system can respond to change, and State flexibility, where a system's capacity to respond to change is contained within the system [19]. Whereas Frazelle (1986) categorise flexibility in terms of its long and short term strategic effects [19].
Later Carlsson (1989), categorised flexibility as being either Type I or Type II as per the economic considerations [19]. In 1994, Upton, categorised flexibility as external e.g. volume, variety etc, and internal flexibility e.g. Process, Material handling etc [19].

2.4 Linkage Between Eleven Flexibility Types: Earlier a linkage among his eight flexibility dimensions is given by Browne et al [12]. In 1990, Sethi and Sethi [5] prescribed the linkage among eleven flexibility dimensions, the same is reproduced in figure 1.

3. Effect of Flexibility on Manufacturing System Performance

It is well accepted that introduction of flexibility improves the performance of a manufacturing system. A plethora of literature (both empirical / simulation and modelling based) is available on the effect of manufacturing flexibility. Some of them is tabulated in table 6.

4. Conclusions

In the light of above discussion the following conclusions can be made:

- It is also observed flexibility dimension could not work in isolation. It has an impact on other flexibility dimension(s) too. A firm may benefit more from a good mix of various flexibility dimensions rather an exclusive use of a single type of flexibility. From the literature [1, 23,31-34], it is clear that up to a particular level of flexibility, the system performance increases with the increase in degree of flexibility. Increase in degree of flexibility beyond this threshold value, deterioration in system performance starts and makes it even worse. It would be beneficial to study the impact of different degrees of a particular flexibility dimension on the system performance in isolation as well as in a group of all / major flexibility dimension(s).

- Estimation of the impact a given flexibility dimension on system performance as well as on other flexibility dimensions will be useful for both the design and operation of FMS. Return on investment is one of the basic and foremost criteria for adoption of any newer technology. For identifying conditions & opportunities, for which flexibility can drive the maximum benefits, Prioritisation of various flexibility dimensions on the basis of effect on the system performance is required.

- It seems that it is a reactive concept, not proactive. Though, a number of studies are available, still the need of an exhaustive, systematic and updated study is there.

Table 1 Definitions of fifteen flexibility types / dimensions

S.NO.	Flexibility Dimension	Definition
1	Machine [5,12,13,15, 16,18]	Machine’s ability to perform a range of operations without incurring any major setup
2	Process	System’s ability to

	[5,13,15,17-19]	produce a given set of part types in different ways possibly with different material
3	Operations [5,9,12,13,15,16,18]	Ability to produce a component / product by interchanging the order of processes
4	Product [5,12,13,15, 18]	System's ability to substitute, change over or add new (set of) part(s), efficiently
5	Routing [5,12,13,15, 16,18]	System's ability to have number of alternative paths within the system, by which a part could be made
6	Volume [5,12,13,15-18]	System's ability to operate at range of different output levels economically
7	Production [5,9,12,13,15,18] (Product mix)	System's ability to produce a plethora of products without adding new equipment
8	Expansion [5,12,13,15, 16,18]	Ease at which capacity and capability of the system may be enhanced
9	Material Handling [5,9,13,16-18]	Capability of Material handling system to move and position different parts throughout the MS
10	Program [1,13,18]	Capability of system to operate / run unattended for a long period of time
11	Market [5,13,18]	Adaptability and responsiveness to the changing market environment
12	Automation [5]	Level at which flexibility is incorporated in the automation /computerization of manufacturing technologies
13	New Design [5]	Ability to design and introduce new product into the system well before time
14	Delivery [5]	Responsiveness of the system towards changes in delivery requests
15	Labour [5,9,14,16,18,22]	Multitasking ability of labour/ man power i.e. within the MS without sacrificing the efficiency

Table 2: Disturbance and required flexibility dimension to handle it

Disturbances		Description	Required Flexibility
Inside	Human Factor	Absenteeism, Lack of training, etc	Labour, Program, Automation
	Others	Machine breakdown, Information flow, etc	Machine, Material Handling, Routing, Operations, Process
Outside		Consumer, Demand, Competitor, Society, Government Regulation & Policies etc	Production, Delivery, Volume, Labour, Market, Expansion, New Design

Table 3: Various flexibility types and their measures

Flexibility Type	Measure
Machine Flexibility	Time to replace worn-out or broken cutting tools, time to change tools in tool magazine to produce a different subset of the given part types, time to assemble or movement ofthe new fixtures required.
Process Flexibility	Number of part types that can simultaneously be processed without using batches.
Product Flexibility	Time required to switch from one part mix to another, not necessarily of the same part types.
Routing Flexibility	Robustness of the FMS when breakdowns occur the production rate does not decrease dramatically and parts continue to be processed.

Volume Flexibility	The smallest volume can be for all part types with the FMS that still being run profitably.
Expansion Flexibility	The magnitude of the FMS can become.
Operation Flexibility	The number of alternate operation orders for each part type that the FMS can accommodate.

Table 4: Flexibility dimensions classified on the basis of management perspective

Nature	Definition	Example
Strategic: Long Term	Ability of a system to respond to: market changes, changes in strategy, new product introduction and basic design changes	Market, New product
Tactical : Mid Term	Ability to operate at varying rates, to handle a variety of parts of known basic design, to accept random, minor changes and to convert the plant for alternative use	Part-mix, Volume
Operational: Short Term	Ability to reset and readjust between known production tasks, to permit a high degree of variation in sequencing and scheduling, etc	Routing, Operation, Material Handling

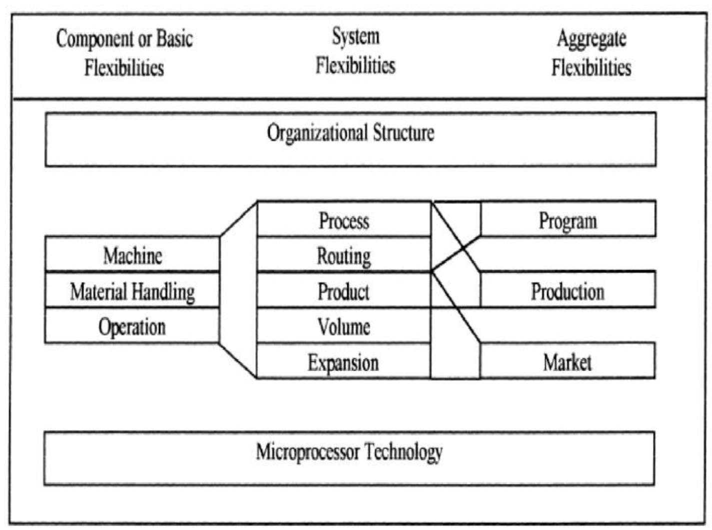
Table 5: Summary of effect of various flexibility types manufacturing system performance

S. No	Flexibility Type	Researcher	Major Findings / Conclusions
1	Routing Flexibility	Takano T. Mizukava H., &Mizoguchi K., 1991[23]	Just having 2 or 3 alternative machines, would greatly increase the flexibility and performance of the system. Contributions of having more than 3 alternative machines would be very small.
2	Volume Flexibility	MoutazKhouja, 1995[24]	More volume flexible a system, the larger the optimal production lot size and the smaller the optimal production rate.
3	Routing Flexibility	Albino,& A. C. Garavelli, 1998[25]	Routing flexibility can be effectively used to increase productivity
4	Flexibility and Decision Delays	Subhash Wadhwa, and RajatBhagwat, 1998[26]	Deterioration in make-span performance is observed with an increase in decision delays, and this deterioration is higher at higher levels of flexibility. Flexibility and decision delays will interact in such a way that, beyond certain level of decision delays, their cumulative effect will be to reduce the performance of the system.
5	Routing Flexibility	Felix T S Chan, 2001[27]	Increasing routing flexibility cannot be treated as a key role in the system improvement. In most situations, upto a certain level of routing flexibility, system performance will improve with the increase in the level of routing flexibility, beyond this optimal flexibility level, the system performance does not show any improvement, but it starts being worse.
6	Volume Flexibility	Jack , and Raturi, 2002 [28]	Volume flexibility has a positive impact on performance

7	Operation Flexibility, Dispatching Rules, and Combination of the above two factors	Felix T S Chan 2004 [29]	Alteration in the dispatching rules has a more significant effect on the performance of the FMS model than changing the levels of operation flexibility. The role of increasing the operation flexibility should not be taken as the key direction for performance improvement of the FMS. The Shortest Remaining Processing Time rule is found to be the best among the six dispatching rules in the current study. Although none of the level of operation flexibility can claim to be the best among the six levels
8	Product, Transformation, and Sequencing Flexibility	S. Wadhwa, K.S. Rao, & F.T.S. Chan, 2005[8]	The Comparative study indicates that among the three, product flexibility has the greatest influence followed by transformation flexibility and the sequencing flexibility in order.
9	Product Mix Flexibility	Charu Chandra, Mark Everson, J,anisGrabis, 2005[27]	Increasing product mix flexibility marginally affects the level of total demand at which production becomes profitable, under the specific scenarios considered. Meanwhile, increasing product mix flexibility improves profitability given a constant total demand, most significantly if the total demand is larger than the system's capacity.
10	Partial Manufacturing Flexibility	A Muriel,A Somasundaram, &Y.Zhang, 2006 [28]	Partial flexibility can lead to a significant increase in production variability Distributed tactical capacity allocation policies, which evenly allocate demand to the plants, lead to better performance of the flexible system.
11	Labor Flexibility	S. M. Horng, 2007[29]	With limited labor resources, mixed labor assignment directly and indirectly improves the performance within a cell. This study indicates that when more than 70 % of the skills are shared by all of the operators requiring higher training costs, system performance does not improve significantly.
12	Machine Flexibility, and Process Plan Flexibility	Adil Baykasoglu, & Lale Ozbakır, 2008[12]	Effect of machine flexibility on job shop performance is higher than the process plan flexibility. It is also figured out that after a certain level of machine flexibility, the speed of scheduling performance improvement decreases

			considerably.
13	Routing Flexibility, Sequencing Flexibility, and Part Sequencing Rules	O. A. Joseph & R. Sridharan, 2011[31,32]	No routing flexibility present in the system, sequencing flexibility leads to an improvement in all the performance measures The deterioration in system performance can be minimized substantially by incorporating either routing flexibility or sequencing flexibility or both. However, the benefits of either of these flexibilities diminish at higher flexibility levels
14	Routing Flexibility	A. K. Chauhan, 2013[30]	Beyond a suitable flexibility and pallet level, system performance deteriorates, as judged by the make-span measure of performance Continuous reduction in make-span time with increase in routing flexibility at a fixed level of delay time. When routing flexibility is further increased, the variability in make-span time due to delay time reduces.
15	Labor Flexibility	Sawhney R, 2013[35]	Impact of acquired labor flexibility on plant performance is not direct but experienced through the sophistication of labor flexibility implementation exercised by the plant. Findings also suggested that plants that emphasized process-focused training, provided greater job-rotation training, and designed positive reward structures, acquired higher labor flexibility and plant performance

Figure 1: Linkage among eleven flexibility dimensions



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