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Flexibility Measurement Criteria with Respect To Reconfigurable System Properties

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ABSTRACT
Flexible Manufacturing System (FMS) is used to cope up with the variety and fluctuating market demand. However FMS is very expensive system which increases the unit manufacturing cost. The paper suggests that whenever someone deals with such a condition the Reconfigure Manufacturing System (RMS) is suggested. The elements of the reconfigurable manufacturing system have been measure as partial and total reconfigureability. The reconfigure ability index such so measured to cope with the demand and variety and gives guidelines for measuring the flexibility. The factories s which possess the higher re reconfigureability index can became the preferred supplier for component.

Keywords- Flexibility, Flexible Manufacturing System (FMS), Reconfigurable Manufacturing System (RMS)

I. Introduction

The manufacturing sector is a constantly changing and upgrading sector that needs reforms for its sustainability. As the customer demands are getting complex and competition in market increasing, the manufacturing sector needs to be flexible in dealing with these changes. Flexibility refers to the ability of a manufacturing system to respond cost effectively and rapidly to changing production needs and requirements. This capability is becoming increasingly important to the design and operation of manufacturing systems, as these systems are called upon to operate in highly variable and unpredictable environments (Gupta et al., 1989, Sethi et al., 1992). In particular, manufacturing systems must be capable to adapt to shifting product demands, shorter product life cycles, higher product variety, and requirements for shorter delivery times and higher quality (Gerwin et al., 1989, 1993, Benjaafar et al., 1994, 1995b). In this context, investing in flexible technologies and adopting flexible production control practices is increasingly recognized as being critical to the success of any manufacturing organization (Gupta et al., Buzacott 1989, Benjaafar 1994). In the measurement of flexibility there lacks rigorous analytical models that are capable of generating clear relationship between degree of flexibility in system and level of performance of system. Most researches are towards the hardware requirement of flexibility with a little concern over process chain and management (Upton 1992). The paper thus tries to bring out criteria for making the process chain and management also part of flexible system. The paper links the reconfigurable system properties for the process chain and management to a performance-based approach for quantifying the value of flexibility. The approach studies the relationship between flexibility and system performance under a variety of design assumptions and operating conditions. The manufacturing system performance as measured by manufacturing lead time, Work-in-process inventory, and part waiting times in queue, is obtained and compared for varying levels of sequencing flexibility. The effect of flexibility on performance is studied at different levels of system loading, variability, and size, and for different types of production flow control policies. Each manufacturing system's process chain and management is then measured for reconfigurable characteristic of integrability, modularity, scalability and convertibility and the same sequence model is used for this measurement. Mechanisms that enable flexibility can be tested to specific physical and logical characteristic of a manufacturing system. In a study (Benjaafar 1995b) it was suggested that flexibility can either be product related or process related. Product flexibility is related to variety of manufacturing operation associated with product. Process flexibility is associated with adjustment of various operating conditions, delivery time, supplier order fulfilment and layout design etc. As the primary objective of paper is concerned with process related flexibility the characteristic of reconfigurable system is also measured.

II. Manufacturing Flexibility: *Flexibility taxonomies*

The taxonomy of flexibility types established by Browne et al. (1984) has formed the foundation of most subsequent research into measuring manufacturing flexibility. In an excellent review, Sethi and Sethi (1990) identify over 50 terms for various flexibility types. For completeness we restate the flexibility type definitions below.

2.1. Machine flexibility: refers to the various types of operations that the machine can perform without requiring prohibitive effort in switching from one operation to another (Sethi and Sethi, 1990).

2.2. Process flexibility: is the ability to change between the productions of different products with minimal delay.

2.3. Product flexibility: is the ability to change the mix of products in current production, also known as mix-change flexibility (Carter, 1986).

2.4. Routing flexibility: is the ability to vary the path a part may take through the manufacturing system.

2.5. Volume flexibility: is the ability to operate profitably at different production volumes.

2.6. Expansion flexibility: is the ability to expand the capacity of the system as needed, easily and modularly.

2.7. Operation flexibility*:* is the ability to interchange the sequence of manufacturing operations for a given part.

2.8. Production flexibility: is the universe of part types that the manufacturing system is able to make. This flexibility type requires the attainment of the previous seven flexibility types.

Measures for most of these flexibility types have been attempted. However, there has not been a consistent structured approach to the measure development and, therefore, the success of these measures has been sporadic. Gupta and Goyal (1989) presented a classification of flexibility measures ``based on the ways researchers have defined flexibility and the approaches used in measuring it''. The categories defined are: (1) measures based on economic consequences; (2) measures based on performance criteria; (3) the multi-dimensional approach; (4) the Petri-nets approach; (5) the information theoretic approach; and (6) the decision theoretic approach. The measures created and evaluated in this paper are based on performance criteria and economic consequences, although the multi-dimensional approach is also examined. Gupta and Goyal (1989) intend the multi-dimensional approach to encompass the variety of distinct dimensions. There are a variety of dimensions along which the measures can be developed and compared. A listing of these dimensions follows. The following taxonomy is a compilation of mutually exclusive ``dimensions of comparison'' from the literature. These dimensions are characteristic coordinates which help describe the nature of the flexibility types. The definitions of the dimensions and their respective authors are:

- System vs. machine: Buzacott (1982) regards machine level flexibility as a flexibility type which is contained or determined by the machine whereas system level flexibility is one which comes from the capabilities of the entire system.
- Action vs. state: Mandelbaum (1978) considers how flexibility accepts change. If the ability toper form well in the new state is already there whenthe change takes place, state flexibility is present. If this ability is acquired by taking appropriate action after the change takes place, action flexibility is present.
- Static vs. dynamic: Carlsson (1992) states ``Static flexibility refers to the ability to deal with foreseeable changes (i.e. risk), such as fluctuations in demand, shortfall in deliveries of inputs, or breakdowns in the production process'' and ``Dynamic flexibility refers to the ability to deal with uncertainty in the form of unpredictable events, such as new ideas, new products, new types of competitors, etc.''.
- Range vs. response: Slack (1987) suggested managers thoughts about flexibility were assisted by considering range and response dimensions. Range flexibility is typically regarded as the extent to which a system may adapt, whereas response flexibility captures the rate at which the system can adapt.
- Potential vs. actual: Browne et al. (1984) discuss the dimensions of potential and actual flexibility, particularly with respect to routing flexibility. Potential flexibility occurs when the flexibility is present but is utilized only when needed, such as a part being re-routed when a machine breakdown occurs. Actual flexibility refers to the flexibility which is utilized regardless of the environmental status.
- Short term vs. long term: Carter (1986) and others suggest the categories for which a flexibility type influences the system or the system's environment in particular time frames, and therefore the flexibility type is considered to be either a short, medium or long term flexibility.

III. Reconfigurable System: Future Industrial Scope:

It is a new class of system that is cost effective response to market changes. The system is able to react to changes quickly and efficiently and it achieves this through the characteristics that:

- The design of system and its machines for adjustable structure that enable system scalability in response to market demands and system adaptability to new products. Structure may be adjusted at system level and at machine level.
- The design of a manufacturing system around the part family with the customized flexibility required for producing all parts of this part family.

Reconfigurable systems must be designed at the outset to be reconfigurable and must be created using hardware and software modules that can be integrated quickly and reliably. Achieving this design goal requires a RMS that possesses key characteristics listed below (Y.Koren et al.):

- Modularity: In a reconfigurable system all major components are modular i.e. the components can be removed and machine can be broken down into several functional parts
- Integrability: Machine and control modules are designed with interfaces for component integration.
- Diagnosability: Detecting unacceptable part quality is critical in reducing ramp-up time in RMS. With system becoming more reconfigurable and modified more frequently, it is important to rapidly tune the new system so that it gives quality output.
- Scalability: It is the capacity of system that counterparts characteristic of convertibility. Scalability may require adding spindles to a machine to increase its productivity or even adding machines to expand the overall system capacity as a given market grows.

Reconfigurable manufacturing systems are designed and operate according to a set of basic principle (Y.Koren). The first three are core principles that define a reconfigurable system. The other are secondary principles that assist in designing a cost effective RMS.

1. The RMS contains adjustable production resources to respond to imminent market needs.
   - The RMS capacity is rapidly scalable in small, optimal increments.
   - The RMS functionality is rapidly adaptable to the production of new products.
2. The RMS is designed around a part family with just enough customized flexibility needed to produce all members of that family.
3. To enhance the responsiveness of manufacturing system RMS core characteristics should be embedded in whole system as well as its components
4. RMS contains an economical mix of flexible and reconfigurable equipment with customized flexibility.
5. Systems with large number of alternative routes to producing a part are more reconfigurable but they require higher investment cost in tooling and in material handling system.
6. The RMS possesses hardware and software capabilities to respond cost effectively to unpredictable events.

The more of these principles are applicable to a given manufacturing system the more reconfigurable the system is. Implementing these principles in the system design enables achieving the ultimate goal to create a “living factory” that is able to rapidly adjust its production capacity while maintaining high levels of quality from one part to the next.

IV. Flexibility and Reconfigurability Rating: The four point grade system

The measurement of flexibility and reconfigurability is done through various models, analytical and mathematical. The four point grade system is a sophisticated model where number 1 to 4 is used to allocate the standard of the process and management, 4 being the “Excellent” and 1 being “Poor”. The numbers are multiplied to the weights which are determined through expert opinion. The values are then compared to determine the quality of process. The model is primarily used in vendor evaluation (Stuart F. et al., 1992) and the same concept is being applied for measurement. In the next part of the paper is the tabular column with certain flexibility parameters and they are graded for each parameter. In addition to the commonly studied flexibility parameters, there will be the measurement of principle reconfigurability parameters too. As reconfigurable system the measuring standards are not well defined and hence it becomes difficult to build a mathematical model for it. In this paper suggested how to measure the reconfigurable characteristics by grading it and using weights. The problem here is a hypothetical one and the weights used are author defined.

Consider a manufacturing plant (Figure 1) where there exists a system with three machines performing operation in a series. During heavy demand there is probability of existence of queue. Now to this system a parallel Flexible Manufacturing System (FMS) can be attached. This FMS can act as a dedicated line.

The FMS is just to prevent existence of queue and for smooth running of the complete system. Adding a FMS is no doubt will be a beneficial but a substantial cost will increase. This type of reconfigurability is not advisable because of cost and comprehensiveness.

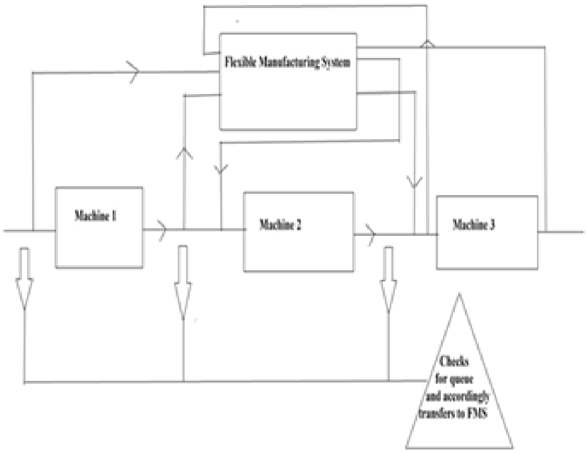

Fig: 1

Another alternative is suggest to look at the three machine and try to determine how effective, in case these machines has some element of reconfigurability, these three form a Reconfigurable Manufacturing System together even if, FMS is excluded from the scenario. The reconfigurable characteristic of the three are graded together. As the reconfigurability is novel concept and as such the only measurement possible is of Reconfigurability index and efforts, therefore we define a scale to rate the characteristics mentioned in table below. This should be based on expert opinion.

Reconfigurability Related	Excellent (4)	Good (3)	Fair (2)	Poor (1)
Modularity		3		
Integrability	4			
Convertibility			2	
Diagnosability	4			
Scalability	4			
Total=17	12	3	2	
1xTotal= 17				

Table: 1

4.1. Modularity:

The modularity measurement is taken on basis of value of reconfigurability index (RI) found through formula. More the value RI better is the modularity. This index shows the ability or flexibility of a generated configuration to be reconfigured. The important parameters that affect reconfigurability rate are possible reconfiguration numbers, number of the structural components (modules), auxiliary operations and the possible degree of the freedom (motions) of the tool. The below equation proposed by Carles Riba et al., shows the effect of these factors on machine tool reconfigurability:

$$R_{MT} = 0.368 . \ln(N_{Conf.}) . \ln\left(\frac{N_{Aop} \cdot N_{cm}}{\ln(N_{Stc})}\right)$$

Where:
R_{MT}: Reconfigurability of Machine Tool.
N_{conf}: Number of the possible configuration to make different operations like milling, turning…
N_{Aop}: Number of the auxiliary operations to develop the machine tool.
N_{cm}: Number of cutting tool motions.
N_{Stc}: Number of the structural components used in the machine tool
The value of this index would be between 0 and 1. The higher the value, the better reconfigurable is the machine. Based on the value obtained here is scale (author defined):

RMT Value	Grade
Up to 0.25	1
0.25-0.50	2
0.50-0.75	3
Above 0.75	4

Table 2: Scale for Modularity

4.2. Scalability

The change (increase) in production capacity due to change in machine configuration is measured on scale. The capacity increase can be done by adding one or multiple spindle or machine.

Increase in capacity	Grade
0-7%	1
7%-15%	2
15%-20%	3
>20%	4

Table 3: Scale for Scalability

4.3. Diagnosability:

The ease at which the parts defected can be found and replaced is measured on the scale.

Point of Inspection	Grade
At i/p and o/p	1
At i/p, o/p and one intermediate point	2
At i/p, o/p and two intermediate point	3
Detecting overall machine failures and cause for it	4

Table 4: Scale for Diagnosability

4.4. Integrability:

Here the grades are given on basis of the speed of the replacement of the modules because if set-up time or ramp-up time becomes long the productivity will be low and the reconfigurable machine tool will not be cost-effective. Taking e.g. of only the change in spindle.

Ramp-up time	**Grade**
Greater than 20min	1
15min-20min	2
10min-15min	3
Less than 10min	4

Table 4: Scale for Integrability

V. Measuring of Total and Partial Reconfigurability

In a manufacturing sector there are different types of production broadly divided into mass production and job production. Mass production is the production of large amounts of standardized products, including and especially on lines. Job production, sometimes called jobbing or one-off production, involves producing custom work, such as a one-off product for a specific customer or a small batch of work in quantities usually less than those of mass-market products. This paper discussed the concept of partial and total reconfigurability similar to how partial and total productivity is measured. The only difference being the factors that are different from the one in productivity.

The total reconfigurability is measure of "total output divided by total reconfigurable factors involved" for batch and mass production.

The total reconfigurability is measure of "total number of variants for the considered output divided by total reconfigurable factors involved" for job

$$\frac{\text{Number of Output for Batch and Mass Production}}{M+I+S+D}$$

production.

Total Reconfigurability (T.R.):

Where
M= modularity
I = integrability
S= scalability
D= diagnosability

Total Reconfigurability (T.R):

$$\frac{\text{Number of variants for job Production}}{M+I+S+D}$$

Number of variants here imply to type of variation that are part of output i.e. for how many characteristic the product can be ordered like size, colour, orientation etc.

Similarly the partial reconfigurability can be found out using one reconfigurable characteristic at a time as denominator and finding the reconfigurability in its respect.

Partial Modular Reconfigurability:

$$\frac{\text{Number of Output / Varients}}{M}$$

$$\frac{\text{Number of Output / Varients}}{I}$$

Partial Integrable Reconfigurability:
And so on.

The measure of principle characteristic of reconfigurability is done through multiplication of weightage (given as per expert opinion) with the grade given in accordance with four point grade system. As mentioned in previous part where hypothetical scenario was created and weightage was given to each characteristic of flexible and reconfigurable manufacturing system the same is conducted for different supplier and the factors of reconfigurability is considered in their order processing.

VI. Conclusion

Although further research is needed to better characterize the grades and weightage in accordance to flexibility and reconfigurability, this paper is step toward a useful and easily quantifiable measure of the value of flexibility and aligning it with RMS. The results relating flexibility and reconfigurability to system performance are in themselves very useful in understanding the nature of the effect of flexibility and reconfigurability. In practice, the results can serve to estimate the impact a given level of flexibility and reconfigurability may have on performance or to determine the required amount of duo required to attain a certain level of performance. This capability is useful for both the design and operation of manufacturing systems. Such a capability can also be effective in the economic justification of flexibility and reconfigurability and can be used strategically in identifying conditions and opportunities for which both can bring the greatest benefits.

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