# SEARCHING FOR DEFINITIONS AND BOUNDARIES IN FLEXIBLE MANUFACTURING SYSTEMS

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# SEARCHING FOR DEFINITIONS AND BOUNDARIES IN FLEXIBLE MANUFACTURING SYSTEMS

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ABSTRACT: An attempt is made in this paper to study the available literature in FMS and structure them in a synoptic framework. The purpose of this study is to capture the varied perspectives of the industries and researchers and to provide some conceptual directions for integrating into the planning, design and implementation aspects of such systems.

# INTRODUCTION

In the recent years, Flexible Manufacturing Systems(FMS) are being designed, experimented and implemented in many industrial undertakings particularly in the developed economies. These systems have evolved primarily to provide rapid responses to the diverse requirements of the pluralistic population of customers. Flexibility is embodied in the development of the production systems. Attempts are made to maintain the high efficiency of automated high volume mass production processes and at the same time persuing to utilise the characteristics of discretised low volume and large variety job shop production processes. Further, in planning and controlling the functional aspects, multiple and often conflicting attributes such as; customised, short delivery time, zero defect/superior quality, lowest possible costs etc., are incorporated.

Various pioneering researchers have made significant contributions towards the design, development and planning and control of such systems. Taking a very synoptic view of the existing state-of-the-art, we make an attempt in this paper to present some of the key researches with a focuss to answer the following specific questions:

1. What constitutes a FMS?
2. How is the acceptability of FMS?
3. What is the key concept of FMS?
4. How are flexibilities interrelated?

5. What is the available framework for evaluating flexibility and what are its drawbacks?

6. How flexibility should be linked in the management process and a suitable evaluation framework be developed to make various flexibilities congruent to satisfy the missions of an industrial-production system?

## 2. FMS - THE CONSTITUTION

In this section, we present some of the definitions existing in the literature and then describe specific systems which come under the purview of an FMS. The definitions of FMS are generic from two broad directions; academic and industries.

Buzacott and Shantikumar(1980) have defined the FMS as "... consists of machines where production operations are performed, linked by a material handling system and all under central computer control." Kusiak(1985) views FMS as a system consisting of three subsystems: fabrication, machining and assembly. These subsystems are integrated with automated storage, computer aided designs, material handling devices and a computer. Hill(1985) gives a different insight into FMS by incorporating inspection feature as "... consists of sets or cells of computerised numerically controlled machining stations with automated and integrated systems for tool changing, workpiece transfer, loading and inspection." These definitions are broadly conceptual and provide meanings and subtleties to understand and study FMS.

The view points of FMS put forth by industries are somewhat contextually different. Ingersoll Engineers(1982) suggests FMS as "... a process within its stated capability and to a predetermined schedule." This definition fails to capture the elements of FMS and its operating characteristics. The definition suggested by Draper Labs(1983) has however characterised the system elements and concurs with the academic's perspective: "... a computer controlled configuration of semi-independant work stations and a material handling system designed to efficiently manufacture more than one part number at low to medium volumes." In a recent article O'Grady (1989) have provided an exhaustive review of the various definitions of FMS. According to him, FMS is a logical arrangement (system) of transformation processes (manufacturing) that is adjusted to change (flexible).

The FMS consists of the following elements:

1. NC/CNC machining centres
2. Material handling systems to transport parts and tools between two successive stations or between any station and load/unload area. This system consists of guided and robot vehicles, shuttle cars, tow lines, roller conveyors etc.
3. A tool handling system to accomodate various tools and facilitate changing the tools.

4. A material storage system which makes use of pallet changers.

5. A computer system which coordinates the activities of all the above said systems.

Flexible Manufacturing System is a broad term and covers systems of different sizes and with different degrees of automation. The following is the specific systems having different capabilities but generally considered under the purview of an FMS:

1. Flexible Manufacturing Module(FMM) (Dupont and Gatelmand, 1981): FMM consists of a stand alone numerically controlled pallet changing device and a monitoring mechanism. The FMM can be incorporated as a module in a larger system.

2. Flexible Manufacturing Cell(FMC): FMC consists of a minimum of two numerically controlled machine tools and other elemens of a Flexible Manufacturing Module.

3. Flexible Manufacturing System(FMS): According to Warnecke(1983) FMS is defined as: "Several automated machine tools of the universal or special type and/or Flexible Manufacturing Cells and is necessary, further manual or automated work stations. These are interlinked by an automatic workpiece flow system in a way which enables the simultaneous machining of different workpieces which pass through the system along different routes."

4. Flexible Transfer Line(FTL): Warnecke (1983) has defined FTL as "several automated universal or special purpose machine tools and further automated work stations as necessary, interlinked by an automated workpiece flow system according to the line principles." A flexible transfer line is capable of simultaneously or sequentially machining different workpieces which run through the system along the same path. Flexible Transfer Lines are used when the number of workpieces of different kinds ranges between 2 and 8.

Potential Benefits of FMS:

The advantages of a flexible manufacturing system compared to the conventional systems are numerous as outlined below:

1. One of the important features of an FMS is that the set-up times to produce an item is negligible. It is this feature which facilitates these systems to produce items of a very small lot sizes (some times even a single unit) economically. As a result, it has become possible for the users of FMS to be more responsive to the changes in the market environment.

2. Since the WIP inventory is less, the production lead times are less and hence the finished goods inventory is also reduced.

3. Due to reduced inventories of various types, less floor space is required.

4. ATC report[1988] quotes, the flexible manufacturing systems can increase utilisation of high investment machinery to 80-90% compared to 10-15% found in traditional manufacturing systems.

5. Since the FMS uses automated material handling systems like AGVs, the material handling cost (including labor cost) have reduced substantially compared to conventional systems.

6. Implementation of modern manufacturing philosophies like JIT, MRP, GT can aid in increasing the capabilities of these systems. In particular, the manufacturing process within an FMS follows just-in-time production. In view of this, if the procurement, distribution of goods can follow using just-in-time philosophy, it will be a great aid to the FMS.

## 3. FMS - GLOBAL ACCEPTABILITY

According to the study of Bessant and Haywood(1985), an estimated number of 550 FMSs are existing around the world. This estimate was as low as 100 during the early 80's. According to ATC[1988] survey conducted in the year 1986 around 370 FMSs are operational throughout the world, much deviating from the Bessant and Haywood's estimate.

Table-1 presents a summary of FMS installations in various countries indicating the year of first installation, range of parts produced, type of material handling devices used, number of machining stations and finally the end products coming out of these systems. However, in some cases the information is not available to get a comparative scenario. It is evident that AGVs and robots are the most widely used means of material handling devices. From the data available on the number of machining stations, it may be concluded that on an average 10 machining stations are used in the systems installed. In most of the countries, this technology seems to have been widely used in the industries such as; machine tools manufacturing and automotive industries. Followed by these two sectors, aerospace industry also takes the lead, particularly in USA, UK and France. The use of FMS technology in manufacturing machine tools and automotive products can be attributed to the world-wide competition in these sectors with a need to respond to the customer requirements at the lowest production cost by way of slashing set-up times and diversifying the production capabilities.

Most often the manufacturers and academicians have perceived FMS as a machining system. Hence, a clear distinction needs to be made here between Flexible Manufacturing Systems and Flexible Machining Systems. FMS need not be confined to machining systems and can be applied to press shops, forges, injection moulding shops, inspection and testing(Hartley, 1980). FMS is a manufacturing phyilosophy rather than a new manufacturing process that will just give a marginal boost to manufacturing performance productivity. This technology is a mission for economic survival. The super-ordinate goal behind is to enhance the quality of life in general.

<u>FMS in Japan</u>:

In Japan, the major boost for FMSs came with the initiation of the project called Method for Unmanned Manufacture(MUM). The growth of FMS in Japan can be attributed to their innate ability to build CNC machines. The types of machines used in the FMSs include lathes, mills, drills, grinders and machining centres. About 70% of the FMS in Japan are classified as machining systems and the remaining 30% as FMS for assembly. About 35% of the machining systems are used for manufacturing diesel engines and machine tools. An estimated 30% of the systems for assembly are used in production of home appliances.

FMS in US:

The US has been the pioneer in using FMS. This pioneering position is credited due to the number of installations, capital investment, the quantum of research on the design, installation and operation principles of these systems compared to any other country in the world. The various types of machines used include lathes, mills, drills, borers, tappers and machining centres. Other facilities available on these systems are part-washing, automatic inspection units, tool monitoring and tool transporting devices.

FMS in Europe:

West Germany, UK, France and Italy are some of the European countries who are taking significant interests in using the FMS technology. The majority of FMS in West Germany are employed in industries of medium sizes. This is contrary to the situation in U.S. and Japan. In U.K., although there is an indication of the initiation of FMS projects in mid 60's, there is some gap in the development process until 1982 when the Science and Engineering Research Council(SERC) of Britain is established to promote

Flexible automation. In Scandinavian countries particularly in Sweden, the use of FMS is gradually increasing, because of their concerns for high productivity and competition in the global market. All Scandinavian countries are progressing fast to introduce FMS as a basic strategy to improve the quality of products and quality of working life in traditional industries.

## 4. FLEXIBILITY: THE KEY CONCEPT

The flexibility of a manufacturing system can be defined as the ability of the system to respond to the changes either in the environment or in the system it self. Burbidge(1984) has observed that a production system which, when it is required to change from making one product to making another of different design, loses a large part of its capital due to the obsolescence of special machines, tooling, parts and materials, which has to invest again heavily in new plant and tooling for the new product which requires many months to complete the change, is very inflexible. On the other hand, a production system which faces the same problem suffers only minor losses due to obsolescence, requires little or no investment in new plant and tooling and completes the whole change in a few days, is a very flexible system.

Gerwin(1987) has found that uncertainity is the root cause for the need of flexibility and summarised the various uncertainities and the corresponding flexibility. He also observed that manufacturing flexibility can be viewed at different levels

- the individual machine or work system,
- the manufacturing function such as forming, cutting etc.,
- the manufacturing process for a single product or group related ones,
- the factory,
- the company's entire factory system,

It is evidenced from the existing literature that focuss is more on the flexibility at individual machine level. Very little is researched on factory level to incorporate flexibility in its totality of operations.

Zelenovic(1982) has indicated that Group Technology approach is increasing flexibility in all segments of production system. He has identified three types of structure such as:

- space structure(material flow, information flow, energy flow)
- the structure of system components and
- the structure of organisation of production factors

as the components. He suggested that in order to obtain a satisfactory level of system flexibility, the flexibility must be thought of in these three structures.

Slack(1984) has viewed the flexibility as a manufacturing objective and has identified three dimensions of flexibility:

- the range of states a system can adopt,
- the cost of moving from one state to another and
- the time which is necessary to move from one state to another.

Linder(1984) has viewed the flexibility as related concepts which can be achieved through coordination of four manufacturing factors at the production organization level:

- work organisation,
- flow structure layout,
- control systems and
- equipment machinery.

He argues that these four factors cannot be thought in isolation to achieve the desired degree of flexibility.

Gupta and Buzacott(1989) in a recent paper have outlined different approach to the concept of flexibility which according to them determines the ability of a system to cope with the changes. They define sensitivity which relates to the degree of changes and stability, which relates to the magnitude of each disturbance. A system which is less sensitive for a change and having greater stability will have higher flexibility. One can draw a very clear-cut perspective thinking from this paper to understand the flexibility. For example, they provide four different directions:

- categorizing flexibility into various types (Brown(1985), Goldhar and Jelinek(1983), Hegland(1981) and Gerwin(1982))

- Flexibility measures based on the physical characteristics of the system(Zelenovic(1982), Gustavasson(1984), Chatterjee et.al.,(1984))

- Monitoring flexibility in terms of chosen performance criterion(Buzacott(1982), Mandelbaum(1978), Jaikumar(1984))
- Flexibility based on the number of choices available (Pye(1978), Kumar(1986), Yao(1985)).

However, Gupta and Buzacott(1989) have mentioned that there is no consensus to date on the precise definition of flexibility. We can put forth here that the lack of insight on flexibility and the inexperience of manufacturing firms in managing such systems are among the primary reasons for the disparity between the promised and actual performance. Slack(1984) has conducted a study to understand how the managers in U.K. view the flexibility. He comes out with his observations and concludes by saying that flexibility gets influenced by the authority-responsibility relationship of a production manager in the overall organisation. So, flexibility is not only a technical issue or a commercial concern, but it is above all a managerial system, which may have to involve all factors needed to effectively manage an organisation.

## 5. FLEXIBILITY: THE INTERRELATIONSHIPS

Numerous authors have attempted to identify and define various types of flexibilities. In this section, we present a comprehensive review of various flexibility types, and then attempt to redefine certain flexibility types and finally draw out the interrelationships between various types.

Machine Flexibility: is defined as the ease of making the change required to produce a given part types. Buzacott(1982) has defined machine flexibility as an efficiency ratio representing the expected production with disturbances to the expected production rate without them. This definition has focussed on the reliability and repair features of the machine and has failed to capture the other dimensions of machine flexibility(Barad and Sipper, 1988). Barad and Sipper (1988) have defined machine flexibility as the ability to change from one set-up to the other viz., activities related to tool preparation time, part positioning and releasing time, tool change over time. Warnecke and Steinhilper(1982) have provided a measure of this flexibility as equivalent to set-up cost when set-up is considered for evaluating a new production programme. Machine flexibility is of interest to batch and mass production systems(Slack, 1987).

Process Flexibility: This is similar to Buzacott's(1982) job flexibility which is defined as the size of the subset containing jobs that can be processed by the system and their respective probabilities of occurence. This definition does not clearly distinguish between process variety within machine level and process variety which can be achieved through making use of different machines. Barad and Sipper(1988) have clarified the concept behind this flexibility type and have decomposed this into two subtypes; namely process flexibility and transfer flexibility. While the former is termed as the process variety and the latter is designated as the system capability to move parts between machining centres. The new product flexibility defined by Slack(1984) is also similar to process flexibility defined by Barad and Sipper(1988).

In our opinion process flexibility refers to the ability to accomodate various processes and also refers to the capability of the system to change from one manufacturing process to the other viz.. milling to drilling, boring to turning etc. Thus process flexibility, a component of the machine flexibility refers to the range of proceses the system can accomodate and the ability to change from one process to the other as and when required. A manufacturing system with the characteristics described above will have the ability to produce a number of products at the same point of time, which is termed as mix flexibility as suggested by Gerwin(1987).

Based on the above discussions we would like to integrate machine flexibility and process flexibility and we redefine the machine flexibility as follows:

Machine flexibility may be defined as the ability to accomodate various tooling and process capabilities and to respond as and when these capabilities are required.

Material Handling Flexibility: Kusiak(1985) has defined this as the ability to handle different parts in a number of different routes. The need for this ability arises either due to breakdown of machines or due to the need to produce a number of different products at the same point in time.

Alptekin and Webber(1988) have identified two measures of flexibility which reflect to the system forecast sensitivity as given below:

Programming Flexibility: This refers to the ability to alter basic operating parameters via control instructions.

Communication Flexibility: This is the ability to transmit and receive information or instructions freely between system components.

Kusiak(1985) has identified the above two flexibilities as computer system flexibility, measured by the adaptability of the system to changing functions.

Volume Flexibility: Barad and Sipper(1988) have viewed this flexibility equivalent to machine set-up flexibility as they assumed that unprofitability stems from low volumes which do not economically justify in the investment of system set up. Azzone and Bertle(1989) have defined as "... the ability to operate with a low reduction of the operating margin during a decrease in market demand." This is equivalent to the definition of Barad and Sipper and doesn't consider the time dimension of flexibility. It is not only the ability to produce with a low reduction of operating margin during the periods of slump but also to produce at a faster rate during the periods of boom when high volumes are required.

We propose to define volume flexibility as the ability to change the level of aggregate output without affecting the production programme. This definition of volume flexibility considers time dimension, particularly when high volumes are required. This flexibility is of concern to process and mass producers (Slack, 1987).

Delivery flexibility: Slack(1984) has defined this flexibility as the ability of the system to shorten or lengthen its delivery time. Batch and jobbing industries are concerned with delivery flexibility (Slack, 1987).

Quality flexibility: Slack(1984) has defined this flexibility type as the ability of the system to change the quality requirements of various products that are manufactured on the system. Different products need different kinds of quality requirements at different points of time. This can be achieved by flexible tooling system and flexible machines.

Operation flexibility: Barad and Sipper(1988) have defined this as the ability to interchange the ordering of several operations on each part while complying with design restrictions. Operation flexibility is not an inherernt feature of FMS but may be regarded as the outcome of design flexibility.

Labour flexibility: This flexibility type has been identified by Slack(1987), but not formally defined. This refers to the ability of the workforce to attain new skills and changeover jobs as and when required.

Material flexibility: Gerwin(1987) has defined it as the ability to handle uncontrollable variations in the composition and dimensions of the parts being processed. It also encompasses the ability to handle more than one kind of substance either for the same component or for differernt components. The need for this flexibility may also be attributed to the changes in technology, uncertainity relating to the availability of material in terms of its size, shape and other properties.

Routing flexibility: Gerwin(1982) has defined as "dynamic assignment of parts to machines, coping with breakdowns." Slack(1984) has observed that routing flexibility depends upon the characteristics of the process technology.

Sequencing flexibility: Gerwin(1987) has defined it as the ability to rearrange the order in which different kinds of parts are fed into the manufacturing process. Sequencing and routing of parts are the means to cope up with the uncertainities like non-availability of materials or parts that should go as inputs respectively. Considering the Gerwin's(1987) concepts of rerouting flexibility which is the degree to which the operating sequence through which the parts flow can be chagned, implying that routing flexibility is the outcome of the sequencing flexibility. Hence, these two flexibilities are strongly interrelated.

We would like to integrate routing flexibility and sequencing flexibility and define sequencing flexibility as the ability to cope up with the non-availability of raw materials, parts, machine or material handling equipment by way of rearranging the order in which the different kinds of materials and parts are fed into the system.

Design flexibility: Gerwin(1987) has defined it as the ability to redesign the manufacturing process (including expanding it) and then develop measures of it based on range, time, cost and other facts. In our opinion, this flexibility is similar to the process component of the machine flexibility.

In our opinion, the design flexibility has two components:

a) With reference to the system indicating the ability to add more modules to increase the manufacturing activity on the system. This is equivalent to the expansion flexibility of Alptekin and Webber(1988).

b) With reference to the parts processed on the system indicating the ability of the system to process various alternative designs for a given part type. The modification flexibility of Gerwin(1987) is equivalent to this component of design flexibility.

Inter-relationships between different flexibility types:

Having identified different flexibility types we would like to explore the inter-relationships between these flexibility types.

Machine set-up vs Volume flexibility: Volume flexibility can be achieved through machines which have the ability to vary rates of production and the ability to changeover from one set-up to the other. Therefore, machine set-up flexibility determines volume flexibility.

Machine flexibility vs Material flexibility: If we consider tooling flexibility component of the machine flexibility indicating the ability of the tooling system to handle different shapes and sizes of the raw material, the material flexibility is dependant upon the tooling system flexibility(machine flexibility).

Machine flexibility vs Computer system flexibility (Programming and Communication flexibility): Flexible machines are of no use unless the advantages are thoroughly extracted. For this purpose an FMS needs flexibility in terms of its programming capabilites and communication system. Hence machine flexibility is dependant on the computer system flexibility which in turn has got two components viz., programming flexibility and communication flexibility.

Machine flexibility vs Material Handling flexibility: Flexible machines cannot be used effectively unless they are properly interlinked by flexible material handling system. Also flexible material hanlding system is of no use unless the machines are flexible. Therefore machine flexibility and material handling flexibility are dependant on each other.

Machine flexibility and its components: The three components of machine flexibility viz., machine set-up, tooling system, process variety are all dependent on each other. For instance, process flexibility and tooling system flexibility cannot be of any use unless they are aided by set-up flexibility. Hence, process flexibility and tooling system flexibility are dependent on machine set-up flexibility.

Thus. it is evident that there are only four key flexibilities of an FMS:

- machine flexibility,
- material handling flexibility,
- programming flexibility and
- communication flexibility are all dependant on each other.

Any attempt made to change the flexibility level of one type, there will be a significant impact on the others. However, empirical studies to validate such a statement are missing yet.

From the above discussion on flexibility types and their inter-relationships, it is easy to visualise that there are certain flexibility types which emerge due to a need in the system or in the system's environment which we term here as "Generic flexibilities", while, the other flexibility types are the means by which these needs can be satisfied, which we term as the "Coping flexibilities". Table-3 gives the components of these two types of flexibilities. In order to make these two broad types of flexibility operational in the system of management, we propose that managers should understand the concept of 'planning flexibility'.

While numerous authors have identified different types of flexibility, they have overlooked one important flexibility type, namely "planning flexibility". FMS being a complex manufacturing system, it needs somewhat different kind of production management concepts. Planning for FMS is very important to derive full benefits. Flexible machines, material handling system and computer system cannot be of any use unless flexible planning methods are incorporated to manage the system. Koontz and O'Donell(1972) have identified the planning flexibility and indicated that more this flexibility can be built into plans, the less the danger of losses incurred through unexpected events, but the cost of flexibility should be weighed against its advantages.

Figure-1 indicates a framework for understanding the concept of flexibility of an FMS. As indicated in Figure-1, the external environment has several subsystems such as supplier environment, customer environment, economic environment and technological environment. Any changes or disturbances in any one of these subsystems will have an impact on the remaining subsystems leading to pressures on the focal production system. These pressures are transmitted to the focal production system through generic flexibility types. The pressures created by "generic" flexibility types on the focal production system can be coped up by means of "coping" flexibility which in turn has got two components: hardware flexibility indicating the flexibility of machines, material handling systems and software flexibility indicating programming flexibility and communication flexibility. The objective of the focal production is to maintain internal balance and eventuate external equilibrium. The responsibility profile of the production manager of an FMS needs to be drawn through the understanding of the planning flexibility. Because, in managing a FMS, critical decisions must be made about the number and kinds of input-output parameters and relationships to be included, and about the means for meeting necessary conditions and simultaneity of those relationships. These decisions are very often judgmental and should be evolved through the planning process by linking demands and resources of the system as a whole.

## 6. FLEXIBILITY: THE PERSPECTIVES

The concepts of flexibility so far explained can be visualized in two important perspectives: functional aspects and hierarchical decision making aspects. These are of use in determining the flexibility needs of the system and attempting to decide on the flexibility levels of the system components.

As per the functional perspective, different functional subsystems and the associated flexibilities are identified. Table-4 shows the various flexibilities associated with each subsystem.

Hierarchical decision making perspective: Slack(1987) made an attempt to provide a flexibility hierarchy which would form the basis of a procedure for assessing the broad flexibility needs of the organization. He viewed this hierarchy at four levels viz., manufacturing resources level, manufacturing tasks level, production function level and finally the company level. In this paper, we provide an alternative hierarchical approach to the concept of flexibility following Anthony's (1965) framework. Anthony was the first to recognise the multiplicity of decisions in a production system. He proposed a framework for classifying the problems in three distinct categories: strategic level, tactical level and operational level. The flexibility decisions cannot be made without decomposing the production system into various functional subsystems, within the context of a hierarchical system that links higher level decisions with lower level decisions in an effective manner. Hax and Candea(1984) provide different tasks associated with each level of management hierarchy, which is taken as the basis for identifying the various components of flexibility at each decision level. Table-5 represents a list of different tasks performed by each level of management hierarchy and the associated flexibility. It may be noted that in the hierarchical representation of flexibility types indicated above, higher level decisions provide constraints for lower level decision making, in turn detailed decisions provide the necessary feedback to evaluate the quality of aggregate decision making.

However, we are of the opinion that each perspective is not stand-alone type when the management functions are to be performed from the view point of profitability and productivity. Therefore, we intend to submit here that a hybridised perspective which can integrate both hierarchical and functional aspects is necessary at this stage of evolution of FMS.

Our framework is shown in Figure-2. Planning for FMS, should be based upon a detailed knowledge of the plant's current manufacturing methods and problems. Having a good synoptic picture of the plant's problems and the firm's resources, the FMS designers/planners are ready to begin surveying available technologies for FMS. The perspective presented in Figure-2, may facilitate to carry out this survey.

## 7. MEASURES OF FLEXIBILITY

In this section, we briefly outline the various flexibility measures. There are many suggestions to measure flexibility. These suggestions can be broadly classified as 'for' and 'against' the concept of measurement of flexibility. While several resesarchers argued for the measurement of flexibility, Slack(1984) has stressed the need to have flexibility as a design objective rather than trying to measure it. Buzacott and Mandelbaum(1985) have suggested that FMS should be designed keeping in view the future needs and requirements, thereby eliminating the need to measure flexibility. The flexibility measures are mainly oriented towards productivity level, throughput efficiency ratio and routing options.

Zelenovic(1982) has mentioned that value of design adequacy as a measure of flexibility for all kinds of production systems, which he has defined as "the probability that the given structure of production will adopt itself to environmental conditions and to the process requirements within the limits of the given design parameters". Based on this concept, he has defined a term known as 'adaptation flexibility'. This is dependant on the ratio between capacity and utilization parameters of the production system and a time measure represents the time needed for system transformation which he termed as adaptation flexibility.

Barad and sipper(1988) have introduced the concept of 'operational flexibility' which comprises of machine set-up flexibility, system set-up flexibility and routing flexibility. They observed that time is a more distinctive performance measure than cost to measure operational flexibility. The method of Petri Net Modelling has been used to compare FMS on the basis of operational flexibility. Gupta and Buzacott(1989) observed that ranking of FMSs on the basis of their flexibility is a difficult task and suggested surrogate measures like value of flexibility. They defined value of flexibility as the difference between the expected profits achieved through an FMS and an inflexible system.

Brill and Mandelbaum(1989) have provided a quantitative framework to measure flexibility which is analogous to probability theory measures. In their opinion the flexibility measures depends on: the decision maker's view of the process, the reference task set, the weights of importance of tasks, the machine task efficiency ratings. Their flexibility measures are defined relative to task sets just as probability theory defines probability measures for event sets. Two types of flexibility measures are introduced: one for individual machines and the other for groups of machines or manufacturing systems.

Pye(1978) has sugested entropy as a measure of flexibility. This measure essentially considers the size of the set of choices available and is surrounding the concept of routing flexibility.

<u>A FRAMEWORK FOR MEASURING FLEXIBILITY</u>: Few attempts have been made to provide methodologies for measuring flexibility. Gupta and Buzacott's framework suggests to identify the flexibility objectives and determine the list of changes the proposed system should cope-up. For each of these changes they defined value of flexibility as the expected utility of having the ability to respond to the changes. Hutchinson and Sinha(1989) have suggested a decision-theoretic approach for assisting decison makers in choosing a manufacturing systems to meet a forecasted demand where the objectives include both cost and flexibility.

An outline of our framework for measuring flexibility is indicated in Figure-3. In our opinion, flexibility being a complex decision, the firm at the strategic level should initiate the decision making process and decide the strategic level flexibility. Although the flexibility of a manufacturing system is the result of a combination of factors like physical characteristics, management practices and operating policies(Gupta and Buzacott, 1989), the overall flexibility of an FMS depends to a large extent on the physical characteristics of the system. Flexible physical elements coupled with flexible planning methods will enhance the flexibility of the system. We suggest the following guidelines for measuring the flexibility:

1. The first step in making an attempt to measure or quantify flexibility should be to understand and list down what kinds of changes are possible in the environment that will have an impact on the operation of the system.

2. The anticipated changes identified for the future periods is based on some kind of forecasting and hence each of these changes will be associated with certain probability, as such, it is necessary to have an assessment of these probabilities. For each of the changes identified, develop expected utility functions as a result of accomodating these changes in the proposed system.

3. At this stage, using the expected utlitiy functions developed earlier, determine the range of changes the proposed system should accomodate using decision theoretic approaches.

4. The range of changes which the proposed system should accomodate should be translated in terms of the physical elements of the system which determines the strategic level flexibility in terms of design, quality and planning flexibilities.

5. Since, the strategic level flexibility decisions will form the basis for deciding the tactical level flexibility which inturn will dictate the operational level flexibility, develop appropriate measures to determine the flexibility of the system at tactical level interms of volume flexibility and delivery flexibility and operational level flexibility interms of sequencing and operation flexibility.

6. Finally, it is necessary to translate the flexibilities identified at different levels of management hierarchy in terms of the major functional subsystems viz., production hardware subsystem, software subsystem and management subsystem which will determine the flexibility of the manufacturing system under consideration.

The major advantage of our framework for measuring flexibility is that we aim at determining the flexibility of the entire system by identifying the possible changes which the proposed system should cope-up and determine the flexibilities at various levels of management hierarchy and the functional subsystems. This will help the managers at different levels of hierarchy to know the capabilities of the system and aids in their decision making process. However, we recognise the difficulties involved in translating the various flexibilities across different levels of management hierarchy and the functional subsystems.

## 8.CONCLUSIONS

The aim of this paper is to provide a complete picture of FMSs. In section 2 we have given the basic constitution of the FMS. In section 3 we have discussed the global acceptability of the FMS and found that the FMS technology has been widely used in machine tools and automotive industries and most often this technology is perceived as if it is confined to machining system. In section 4 we have provided a review of various concepts of flexibility offered by the researchers. In section 5 we have consolidated several types of flexibilities identified in literature and offered different insights into these definitions in some cases (machine flexibility, sequencing flexibility, volume flexibility and design flexibility). Further we have classified the various flexibilities into two types: "Generic flexibility", which emerges due to a need in the system or in the environment and "Coping flexibility", by means of which the system needs can be satisfied. We have introduced the concept of planning flexibility which is overlooked by the earlier researchers. Based on our concepts of flexibility we have provided a framework for understanding flexibility. In section 6 we have identified two broad perspectives of flexibility: functional perspective and hierarchical perspective and recommended for a hybridised perspective for the evolution of FMS. Finally, in section 7 we have reviewed the various approaches for measuring flexibility and suggested a framework for measuring flexibility which is aimed at helping managers at various levels of hierarchy to know the capabilities of the system and aid in their decision making process.

Attention to the field of research in FMS is recent, but efforts towards diffusion of such systems are increasing. Despite the efforts, there exists confusion in relation to definition, circumscription and application. It is indicative that there is no comprehensive conceptualisation about FMS. We recognise that although measures of flexibility are difficult to arrive at, but researchers are covering as many dimensions as possible pragmatically and attempts are being made to quantify verifiable goals and to recognise qualitative factors.

In summary, this paper is merely an attempt towards providing a synoptic conceptualisation about the subject. We have provided neither methods nor solutions towards FMS but have captured the differring perspectives and submitted some guidelines to view the field of research which is expanding.

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Table-1: COMPARISON OF FMS TECHNOLOGY IN VARIOUS COUNTRIES

| Country | Year of first installation | Range of parts produced | Type of Material Handling Devices | Number of machining stations | End Products |
|---|---|---|---|---|---|
| Japan | 1970 | 7 - 150 | conveyors AGV(wire guided,rail guided | 8 | Diesel engine parts. Transmission systems. machine tools |
| USA | 1965 | 3 - 150 | AGV(wire or rail guided) | 9-12 | Automotive. aerospace agriculture and machine tool industries |
| West Germany | 1971 | 50 - 250 | Not Available | 10 | Automotive industry |
| U.K. | 1967 | 5 - 120 | Manual, Automated Robot truck | Not Available | Mechanical, automotive machine tool, aerospace, defense industries. |
| East Germany | 1971 | 14 -200 | Not Available | Not Available | Not Available |
| France | Not Available | Not Available | AGVS | Not Available | Aerospace, automotive and machine tool industries |
| Sweden | Not Available | Not Available | Robots, Auto-Carriers | Not Available | Automotive and truck industry |
| Soviet Union | 1972 | Not Available | Close located Robots and AGVS | 10-20 | Not Available |

Table 2: COMPARISON OF FMS WITH CONVENTIONAL SYSTEMS

| Conventional System | FMS |
|---|---|
| 1. Job shops require longer set-up times to change-over batches. | 1. Set-up times in FMS are usually shorter |
| 2. WIP is more in case of job shops. | 2. Less WIP in FMS |
| 3. Workers in a job-shop are skilled and specialise in a particular operation | 3. Workers in an FMS do not specialise in any operation and are capable of handling variety of operations. |
| 4. Flow-shop employs product flow layout and utlises special purpose machines | 4. FMS employs flow layout as the system is not designed for a specific product. |
| 5. Production runs are long and processing times per unit are constant in flow shop. | 5. In FMS production runs are short and processing times per unit are vari--able. |
| 6. Project shop and job shop uses General Purpose Machines where as a flow shop uses Special Purpose Machines. | 6. FMS uses General Purpose Machines. |
| 7. Project shop is setup for completing a specific project. | 7. FMS is set-up for producing varieties of parts for varieties of products. |

Table-3: CLASSIFICATION OF FLEXIBILITY TYPES

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Generic Flexibilities

- Volume flexibility
- Delivery flexibility
- Quality flexibility
- Design flexibility
- Sequencing flexibility
- Material flexibility
- Operational flexibility

Coping flexibilities

- Machine flexibility
- Material Handling flexibility
- Programming flexibility
- Communication flexibility
- Labour flexibility

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Table-4: FLEXIBILITY CLASSIFICATION BASED ON FUNCTIONS

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A) PRODUCTION SYSTEM FLEXIBILITY

- Machine flexibility
  - a) set-up flexibility
  - b) Tooling system flexibility
  - c) process flexibility
- Labour flexibility

B) MATERIAL HANDLING SYSTEM FLEXIBILITY

C) COMPUTER SYSTEM FLEXIBILITY

- Programming flexibility
- Communication flexibility

D) Management System flexibility

- Volume flexibility
- Delivery flexibility
- Sequencing flexibility
- Material flexibility
- Operation flexibility
- Design flexibility
- Quality flexibility

---

Table-5: FLEXIBILITY CLASSIFICATION BASED ON HIERARCHY OF DECISIONS

| Hierarchical level | Main Tasks | Flexibility |
|---|---|---|
| Strategic level | Long term decisions regarding<br>- plant location & warehousing<br>- facilities planning<br>- capacity planning<br>- acquisition of new equipment<br>- design of transportation facilities<br>- design of communication equipment | design flexibility,<br>Quality flexibility<br>planning flexibility (including system structure) |
| Tactical level | Medium term decisions involving<br>- regular time and over time decisions<br>- allocation of aggregate capacity resources to product families<br>- accumulation of seasonal inventories<br>- definition of distribution channels<br>- selection of transporration & transhipment alternatives | volume flexibility<br>delivery flexibility |

..... contd.

| Hierarchical level | Main tasks | Flexibility |
| --- | --- | --- |
| operational level | Short term decisions involving | |
| | - assignment of customer orders to individual machines | sequencing flexibility |
| | - sequencing of these orders | |
| | - inventory accounting & inventory control activities | operation flexibility |
| | - dispatching, expediting and processing of orders | |
| | - vehicular scheduling | |

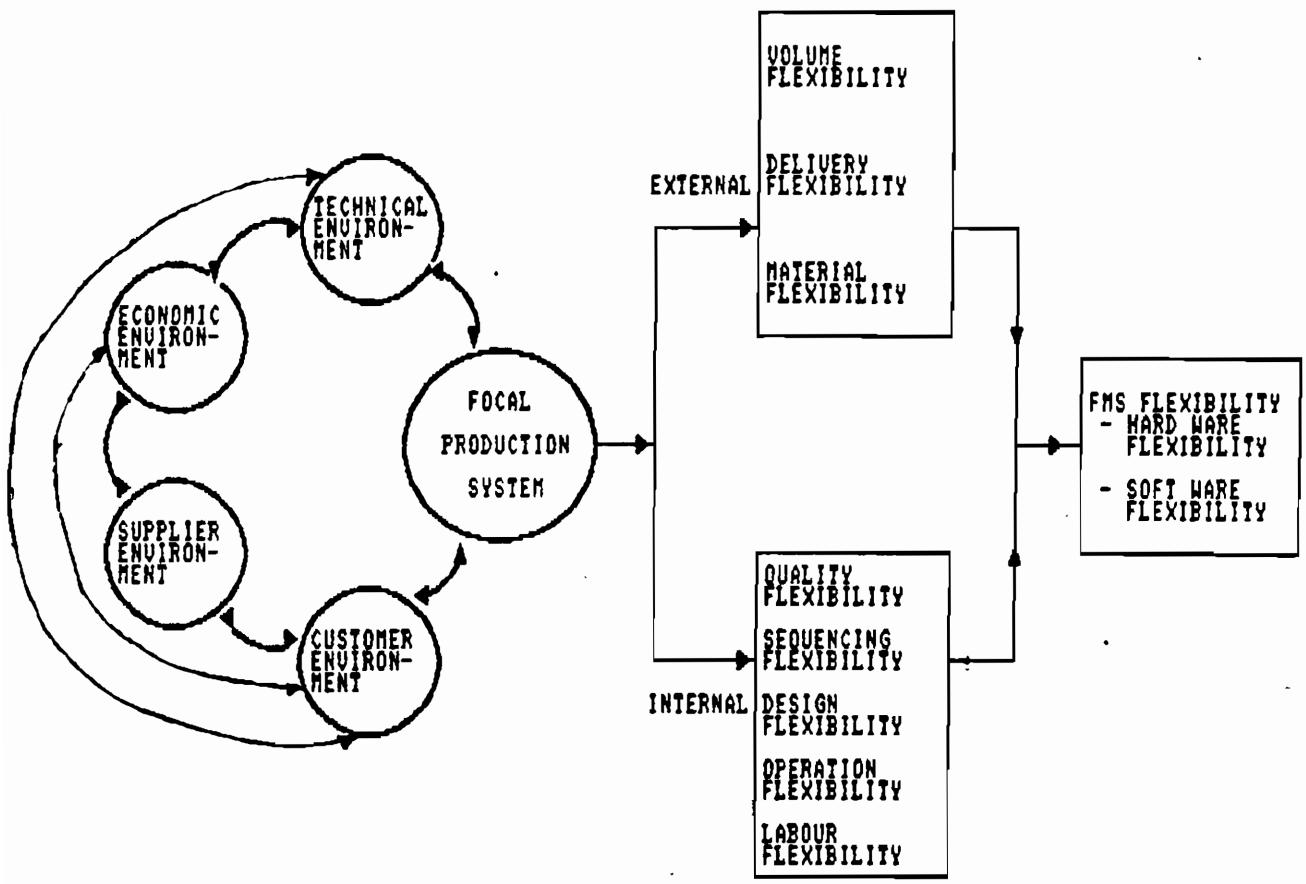


FIGURE1: FRAMEWORK FOR UNDERSTANDING FLEXIBILITY.

| | |
|---|---|
| LEVEL 6 | COMPANY-WIDE INTEGRATION FUNCTIONS |
| LEVEL 5 | FACTORY LEVEL OPTIMISATION FUNCTIONS |
| LEVEL 4 | MANUFACTURING LEVEL INTEGRATION FUNCTIONS |
| LEVEL 3 | PROCESS LEVEL OPTIMISATION FUNCTIONS |
| LEVEL 2 | SUPERVISORY SET POINTS PLANNING AND CONTROL FUNCTIONS |
| LEVEL 1 | REGULATORY AND SEQUENCING FUNCTIONS |

**Figure 2: HIERARCHICAL AND FUNCTIONAL PERSPECTIVES.**

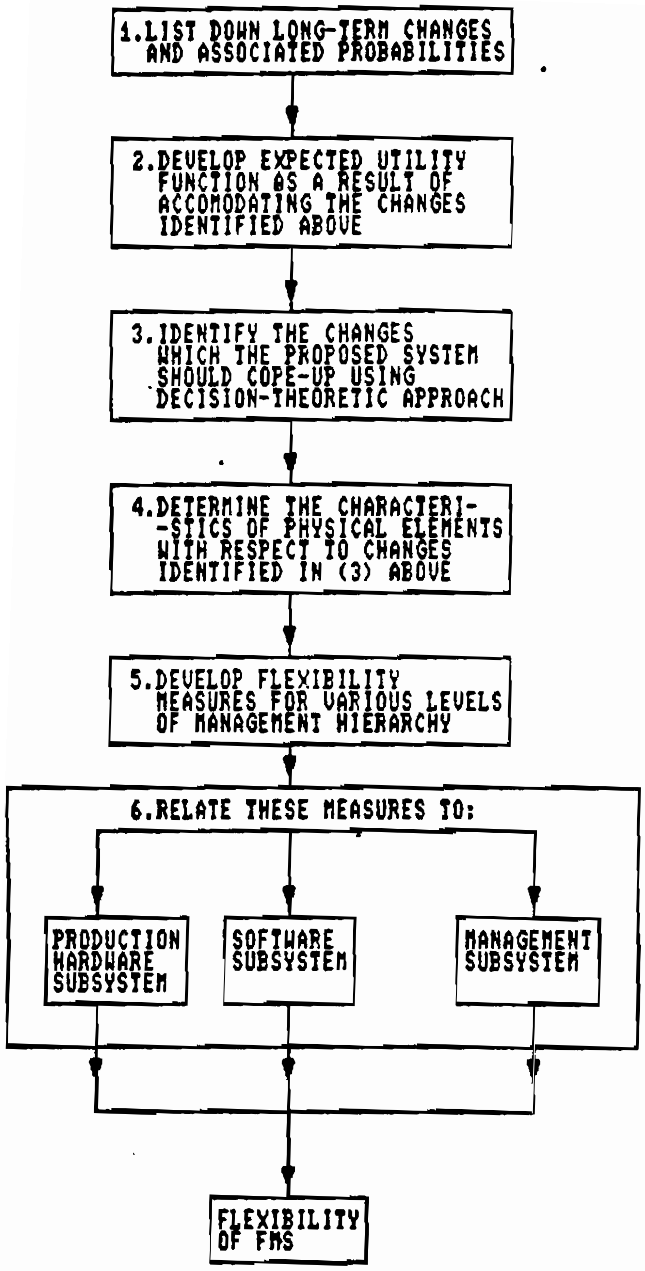


**Figure-3: A FRAMEWORK FOR MEASURING FLEXIBILITY.**