ISM and CFP Analysis of
Flexible Manufacturing System Implementation

A Major Project thesis

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by

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Under the guidance of

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Candidate's Declaration

I hereby certify that the work which is being presented in the dissertation entitled " ISM and CFP Analysis of Flexible Manufacturing System Implementation " , in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Production and Industrial Engineering, submitted in the Department of Mechanical Engineering, Delhi College of Engineering, Delhi is an authentic record of my own work carried out for a period of one year under the supervision of Dr. S. K. Garg, Professor of Mechanical Engineering Department, Delhi College of Engineering, Delhi.

I have not submitted the matter embodied in this dissertation for the award of any other degree.

Vikas Mali

This is to certify that the above statement made by the candidate is true to the best of my knowledge.

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Acknowledgment

Yes, a start leads to an end; initially I never thought that life would be as easy as now. That was in old days where everything was strange but thanks to the God and the institute community for their will and cooperation to feel the comfort I am feeling now. Here, I wish to express my heartily and sincere gratitude and indebtedness to Dr. S. K. Garg, Professor of Mechanical Engineering Department, Delhi College of Engineering, Delhi for his valuable guidance and wholehearted cooperation. He has a special place in my heart for many reasons but to be limited, he is the one who generated confidence in my inner being and helped my hidden energies to come out in full. I like to thank my seniors specially Research Scholar Mr. Pramod Kumar. M who helped me a lot during my project completion.

My heartily thanks to all my professors for their expertise and all rounded personality they have imparted me.

My credit also goes to all my pals for their humor, innocence, too much sincerity and cooperation, openness and the like which flourishes my stay here.

Finally, I have shortage of words to express my love and thanks to my beloved parents to whom I owe my knowledge.

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EXECUTIVE SUMMARY

The ability to respond quickly to changing market requirement is becoming more important, flexible manufacturing systems provide an opportunity to adjust these market changes the developments in technology, materials and customer preferences have resulted in products with shorter life span. New products are being launched more frequently Understanding the definition, classification and measurement of manufacturing flexibility is very important to researchers and practitioners in manufacturing management. The ambiguities and inconsistencies in the concept of manufacturing flexibility make the understanding of the subject difficult. Here we make use of a modeling tool known as ISM to find out the degree of importance of the ten pre implementation variables selected before the actual FMS implementation. .after that these ten variables are further grouped into three broad categories and a C-F-P analysis is done to find out the type of FMS needed in the resulting scenario.

ISM is a well known methodology for identifying and summarizing relationships among specific elements which define an issue or problem. It provides a means by which order can be improved on the complexity of such elements. Based on literature review and expert opinion ten FMS implementation variables have been identified namely cost of FMS, compatibility with existing system, technology change of the FMS, competitiveness in the market, uncertainty, customer preferences, productivity, product life cycle, human resources, Government policies. For analyzing these variables, a contextual relationship is chosen, such that one variable leads to another. Based on this contextual relationship a SSIM and a rechability matrix for the variables is prepared. After which a diagraph is obtained with the help of this rechability matrix and four different levels are obtained on which the ten variables can be placed. The variable at the top level are called the driven variables and the bottom level variables are called driver variables.

In Complexity- Flexibility- Performance framework (C-F-P framework), the various perspectives are interdependent and tightly interrelated. The concept of influence relationship- be it preference, pressure or power - is the pertinent

relationship between the three types of concepts. From the above framework it has been seen that complexities in supply chain leads to the need of flexibilities which in turns leads to the improvements in performance and level of competitiveness. In C-F-P analysis ten variables and 55 subfactors of FMS are taken which make the system complex. After taking these variables, they are described for the conditions of low complexity and high complexity at five levels. After having this format, a ABC company is mapped and its complexity score and dimensions of complexity is identified. Then based on this analysis a decision table is prepared. In this table the ten pre-implementation variables are grouped into three broad categories namely technology, market and production system. The three categories are examined and eight different scenarios are found to exist, these scenarios decide the type of FMS needed, based on the complexity of each category and the relationship within each variable.

CHAPTER-1

INTRODUCTION

The ongoing globalization of industry, both manufacturing and services, has been underpinned by declining computing, communications and transport costs, the liberalization of product and factor markets, and a range of institutional and microeconomic reforms which have facilitated market entry. It is characterized by a diversified pattern of cross-border activities of firms, with high growth in international trade, investment and collaboration between firms for the purposes of product development, production, purchase of inputs, and marketing. In parallel with economic expansion, however, most industrialized countries have witnessed greater unemployment and growing income disparities. The advancement of the globalised economy is intimately related to the development of new or improved goods and services which create additional demand, and firm-level innovations that increase productivity in the production of goods and services. Technological change both adds to the competitiveness of firms and increases competition amongst them. As a result, more firms from more countries operate in a greater number of markets, and competition is increasing nationally and internationally.

In this environment, businesses must improve their ability to deal with continuous change and build assets for the future. This includes becoming more responsive to customer needs, reorganizing and integrating development, production and sales, and locating activities where they can be most efficient. Greater investment in new kinds of assets is crucial for flexibility and long-term competitiveness. Probably the most important change in firm strategies to improve competitiveness is their emphasis on investment in intangible assets (R&D and technology, managerial, entrepreneurial and employee skills, business organisation, market development, software). Intangible assets provide firms with the capabilities and flexibility needed to survive and prosper.

At enterprise level, this shift is part of the larger move towards a more knowledge-based economy. This is characterized at firm level by increasing intangible investments, and by having a relatively large share of skill-intensive and technologyintensive economic activities. More broadly, the core mechanism of the new model which is emerging is increasing returns on knowledge across a broad spectrum. Meanwhile, capital and product markets are adapting more rapidly, owing in part to liberalization efforts in these areas, whereas labour markets and some elements of the economic infrastructure have been slower to adapt to the requirements of the emerging growth model.

Globalisation is a complex process which is not uniform in extent or characteristics across industries and countries. The strategies and patterns of global business expansion have important implications for the development of policy, and for their impacts. In the 21^{st} century, manufacturers are facing an increasingly uncertain external environment with a cumulative effect of changes in customer requirements, global competition, and technological advancement.

As a consequence, flexibility is now regarded by most manufacturing organizations as one of their most important competitive weapons, besides quality, cost and time.

Understanding the definition, classification and measurement of manufacturing flexibility is very important to researchers and practitioners in manufacturing management. The ambiguities and inconsistencies in the concept of manufacturing flexibility make the understanding of the subject difficult. Thus it has been suggested that the management of manufacturing flexibility could be understood, measured and managed better if the vagueness that surrounds it was removed, and researchers and practitioners had a framework which clarified the issues (Upton, 1994). This might include the basic structures for defining, characterizing and measuring flexibility.

One of the greater problems of the organizations is to be able to provide on time the offered products/services and with the effective fulfillments required by its clients. Traditionally organizations have solved it by increasing its productive capacity and/or using stored products to react to the demand variations. One of the most direct ways to solve this problem is through the level of its manufacturing system flexibility. To fix a required flexibility level, a measure of this concept is needed.

The business sector has the primary role in creating economic growth, wealth and employment. However, an increasingly integrated world typified by globalization, greater competition, and rapid technological change has altered the environment in which business operates, thus posing new challenges and opportunities for business and policy makers.

Firm-level competitiveness in many industries has shifted from being based simply on price factors, to being based much more on harnessing strategic intangible resources to achieve product innovation, more flexible high-quality production and new ways of marketing products. Competitiveness thus increasingly depends on the way that firms combine technology, managerial entrepreneurship, employee skills, business organization and software to service markets and interact with customers and suppliers. The ability of enterprises to adapt to continuous change and to build assets for the future is crucial. But firms, sectors, regions and countries vary in their use of and access to factors such as technology and skilled human resources which are critical for competitiveness.

The developments in technology, materials and customer preferences have resulted in products with shorter life span. New products are being launched more frequently. The high rate of environmental changes, increasing international competition, the big gaps between developed, developing and under developed countries, the increasing number of product variants, higher quality of technology innovations, the pressure of increasing production costs and the aim of designing attractive and interesting jobs on one side and the need of short throughput time, higher output values, increasing variety of products in order to ensure company's future on the other has made the manufacturing sector change strategies and decisions on a day to day basis .New products and designs require changes in production facilities. New technological advancement and management techniques have made manufacturing sector cope up with the changing environment. Manufacturing firms operates in an increasingly turbulent environment, shorter product life cycles, an increase in the number of new products introduced; segmented and fragmented markets, rapid technological changes, new events and fluctuating demand contribute to this turbulence. Manufacturing is an integral part of every economy. From the days of fixed assembly lines to present day techniques like flexible manufacturing systems, automation and information technology, the process and strategies of manufacturing are changing constantly. These changes are taking place globally and since industrial revolution manufacturing sector has under gone many radical changes due to either pressure from market or developments in industry. During the eighties and nineties, almost every business house was toying with the financial sector, I.T sector or both. The world economy is believed to have bypassed the traditional path of sectoral movement primary – to – secondary –to – tertiary. It jumped from the rustic agriculture sectoral growth to the sophisticated service sectoral growth without having passed through the tough and dirty manufacturing stage. The priorities and strategies manufacturing sector have been changing more radically since last decade.

As the ability to respond quickly to changing market requirement is becoming more important, flexible manufacturing systems provide an opportunity to adjust these market changes. The change from hard automation to flexible manufacturing systems, which can be readily rearranged to handle new market requirements, is what's needed today. In the discrete product manufacturing industries, the most automated form of production is the flexible manufacturing systems (FMS). FMS is designed to fill the gap between high production transfer lines and low production NC machines. Flexible manufacturing system related to the technology which focused on mid volume and mid variety manufacturing. In this turbulent environment conceptualization of some form of a real system is essential. Artificial intelligence, together with simulation modeling can help to replicate human expertise to understand and plan manufacturing system.

CHAPTER-2

CONCEPTS OF FLEXIBILITY

Today flexibility means to produce reasonably priced customized products of high quality that can be quickly delivered to customers. Table 1 indicates the different approaches to flexibility and their meanings.

Approach	Flexibility Meaning
Manufacturing	• The capability of producing different parts without major retooling. • A measure of how fast the company converts its process (es) from making an old line of products to produce a new product. • The ability to change a production schedule, to modify a part, or to handle multiple parts.
Operational	• The ability to efficiently produce highly customized and unique products.
Customer	• The ability to exploit various dimension of speed of delivery.
Strategic	• The ability of a company to offer a wide variety of products to its customers.
Capacity	• The ability to rapidly increase or decrease production levels or to shift capacity quickly.

Table 1: Different approaches to flexibility and their meanings

Types Of Manufacturing Flexibilities

For the sake of simplicity and ease of identification, the manufacturing flexibility is associated with the three regions are labeled, Automation Flexibility , Manufacturing Flexibility and Design Flexibility in the context of discrete products industries. The flexibility agents are- strategic choice, design, process, infrastructure, computer integration among design, process and infrastructure, computer integration among vendors and suppliers.

Automation Flexibility

It is used when there is high product volume and low variety. For Example: IMB Lexington, Kentucky: Electric system. They produce typewriters and printers with an annual production about 100, 0000 units. The goal of Automation flexibility is low cost, high volume production of very few models of stable design on a common line with ease of new product introduction. While low cost, high volume production has always been the result of automated lines, modern technologies such as robots provide the additional capability to introduce new models on the line with ease and more rapidly i.e., greater flexibility. Such lines have mixed model production capability and can handle lot sizes as small as one. Result of this flexibility is lead time for new product introduction reduced to 18 months.

Agents of Automation Flexibility

- Strategic choice: - low cost, high volume, new product introduction, and multiple models.
- Design: - a few stable frozen design.
- Process: - flexible automation, robotics, AS/RS, continuous flow.
- Infrastructure: - JIT, a few dependable vendors, flexible employees.
- Computer integration among design, process and infrastructure: - enhances production scheduling, reduces inventory and lead time.
- Computer integration among vendors and suppliers: -smooth production scheduling, reduces inventory and lead time.

Manufacturing Flexibility

Manufacturing flexibility is used where Mid-Volume and Mid-Variety is required. For Example: GE's series 8 locomotive plant, Erie, Pennsylvannia. Gidding and lewis FMS for machining a family of motor frame and gear boxes. Yearly capacity of 5000 motor frames of sizes up to 4' * 4' * 5' with over 100 machining surfaces. The system includes two vertical milling machines, three horizontal machining centers, three heavy horizontal machining center, three heavy horizontal boring mills and on medium horizontal mill. The machine include robot or automated tool changers with over 500 cutting tools. In manufacturing flexibility environments, although product design change capabilities exist, the goal is to minimize disruption due to design changes by concentrating on the production of relatively stable designs. This type of flexibility may be found most frequently in the manufacture of components or subassemblies requiring several machining operations. There is a moderate level of routing flexibility. By using manufacturing flexibility machining time can be reduced from 16 days to 16 hours per frame.

Agents of Manufacturing Flexibility

- Strategic choice: - high variety, mid volume, different configuration, different routing.
- Design: - variety of moderately stable designs.
- Process: - F.M.S/AGV, CAD, CAM, automated flow.
- Infrastructure: - G.T, Cells, MRP/ JIT, flexible multi-task employees.
- Computer integration among design, process and infrastructure: - enhance mix scheduling and routine flexibilities, reduces lead time.
- Computer integration among vendors and suppliers: - reduces inventory and lead time.

Design Flexibility

Design Flexibility is used where Low-Volume and High- Variety is required. For Example: Ingersoll Milling Machine Co., a very special machinery producer with a CIM system which includes CAD/CAM. A typical lot is one or two pieces; seldom builds a duplicate.

Agents of Design Flexibility

- Strategic choice: - custom design, very low volume, design change frequent.

- Design: - extremely variable custom design.
- Process: - F.M.S, NC/CNC, CAD/CAM, CIM, intermitted flow.
- Infrastructure: - G.T, flexible production planning and control, alternate schedule and routing.
- Computer integration among design, process and infrastructure: -enable concurrent engineering, reduces design time and changes, easier design changes.
- Computer integration among vendors and suppliers: - improves concurrent engineering, reduces lead time.

Every manufacturing facility experiences unique changes, and degrees of change, both in its internal and external environment. The best type of flexibility –in terms of benefits-is greatly dependent on the particular facility for which it is being sought. Clearly, not all the changes can be confronted with neither flexibility, nor can an exhaustive list of all possible types of flexibility is definitely compiled. Several types of flexibilities in FMS are shown in the table 2 below.

Type of flexibility	Definition
Machine flexibility	It refers to various types of operations that a machine can perform without requiring a prohibitive effort in switching from one operation to other.
Routing flexibility	It refers to ability of the manufacturing system to manufacture a product by alternate routes through the system.
Process flexibility	It refers to ability of the manufacturing system to produce the set of product types without major setups.
Product flexibility	It refers to the ease with which new products can be added or substituted for existing products.
Volume flexibility	It refers to ability of the manufacturing system to operate economically at different overall output levels.

Table 2: Different types of flexibilities encountered in FMSs

There are four flexibility contexts: -

- Type 1 -- Flexibility in automated lines.
- Type 2 – Flexibility in manufacturing.
- Type 3 – Flexibility in design and manufacturing.
- Type 4 – Process industry type.

The flexibility agents are-strategic choice, design, process, infrastructure, computer integration among design, process and infrastructure, computer integration among vendors and suppliers .The manufacturing topology is as follows: -

Type 1 –

- Strategic choice: - low cost, high volume, new product introduction, and multiple models.
- Design: - a few stable frozen design
- Process: - flexible automation, robotics, AS/RS, continuous flow
- Infrastructure: - JIT, a few dependable vendors, flexible employees.
- Computer integration among design, process and infrastructure: - enhances production scheduling, reduces inventory and lead time.
- Computer integration among vendors and suppliers: -smooth production scheduling, reduces inventory and lead time.

Type 2 –

- Strategic choice: - high variety, mid volume, different configuration, different routing
- Design: - variety of moderately stable designs.
- Process: -F.M.S/AGV, CAD, CAM, automated flow.
- Infrastructure: - G.T, Cells, MRP/JIT, flexible multitask employees.
- Computer integration among design, process and infrastructure: - enhance mix scheduling and routine flexibilities, reduces lead time. Computer integration among vendors and suppliers: - reduces inventory and lead time.

Type 3 –

- Strategic choice: -custom design, very low volume, design change frequent
- Design: -extremely variable custom design.
- Process: -F.M.S, NC/CNC, CAD/CAM, CIM, intermitted flow
- Infrastructure: - G.T, flexible production planning and control, alternate schedule and routing.
- Computer integration among design, process and infrastructure: -enable concurrent engineering, reduces design time and changes, easier design changes.
- Computer integration among vendors and suppliers: - improves concurrent engineering, reduces lead time.

Type 4 –

- Strategic choice: - low cost change over, range of process, process mobility
- Design: -not relevant.
- Process: - fixed at installation,
- Infrastructure: -flexible employees, computer control.
- Computer integration among design, process and infrastructure: - improves scheduling, decision making at plant floor.
- Computer integration among vendors and suppliers: - reduces inventory and lead time, consumer responsiveness, better planning and forecasting.

Defining Manufacturing Flexibility

There have been many definitions for the term manufacturing flexibility. The flexibility concept can be translated into the production context as 'the ability to take up different positions', or alternatively, 'the ability to adopt a range of states' (Slack, 1983). Zhang et al. (2003) regard manufacturing flexibility as "the ability of the organisation to manage production resource and uncertainty to meet various customer requests". The above definitions emphasize some important points. First, flexibility is used to accommodate uncertainty, usually in the form of changes emanating from both the internal and external environment, e.g. changes in product design or customer requirements. Second, flexibility refers to the capability of a manufacturing system to manage its resources in order to adapt successfully to these changes. Therefore, manufacturing flexibility could be defined as: the ability of manufacturing organizations to manage their resources in order to cope with environmental uncertainties, and to be able to produce variability in product outputs. There are also some manufacturing concepts that are similar to flexibility. However, even though they are not mutually exclusive concepts, they do differ in a number of important aspects. Spring and Dalrymple (2000) review the literature covering manufacturing strategy, flexibility and agile manufacturing concepts. Consequentially, they make the following distinction between each concept:

- *Flexibility* - the capacity to deploy or re-deploy production resources efficiently as required by changes in the environment.
- *Total flexibility* - the ability to deliver high quality product tailored to each customer at mass-production prices.
- *Agility* - the ability to alter any aspect of the manufacturing enterprise in response to changing market demands.
- *Flexibility/agility* - an ability to adapt rapidly and with constant coordination in an environment of constant and rapid change.

Measuring Manufacturing Flexibility

One area in manufacturing flexibility where researchers have experienced particular difficulties is in evaluating and measuring flexibility. The cause of the difficulties are said to be due to a number of factors (Slack, 1983) manufacturing flexibility is a measure of potential rather than actual performance; the concept lacks a logical and detailed classification and is multidimensional in nature. Difficulties encountered in measuring manufacturing flexibility are fundamentally based on the fact that the measurement must depend on factors such as the degree of uncertainty in the environment, management objectives, and machine capabilities (Gupta, 1993). From consideration of these unformulated factors it is clear why researchers have experienced some difficulty in defining the manufacturing flexibility concept and why measuring manufacturing flexibility as proved so problematic.

Research into the measurement of manufacturing flexibility can be classified according to the ways researchers have defined flexibility, and the approaches used in measuring it (Gupta and Goyal, 1989). These approaches are based on economic consequences, performance criteria, multi-dimensional approach, Petri-nets approach, decision theory approach, and information theory approach. It is quite possible that the difficulties of measuring flexibility are being aggravated by the diverse ways in which the subject is being approached. According to Gerwin (1993), the most common measurement approach in practice is to count the number of options at a given time. This approach actually represents the ability to take up different positions in the production context (Slack, 1983). Thus, one production system is more flexible than another if it is capable, for example, of producing a wide range of products. This also reflects the range in which the production resource can be managed to meet various customer requests. The production resource might involve, for example, workforce, machines, and technology.

Regarding the second attribute (mobility), cost and time are popular measurements for flexibility, as they are in other organizational performances contexts. A production system which moves smoothly, quickly and cheaply from one state to another should be considered more flexible than a system which achieves the same change, but at greater cost or time (Slack, 1983). Cost and time also can be regarded as the resistance elements of flexibility (Slack, 1987). They constrain the response of the system to move from one state to another, and manifest the difficulty of making a change. Since the third attribute (uniformity) represents the consistency of performance measurement, it can be assessed through efficiency, productivity, quality, and processing times (Koste and Malhotra, 1999). They suggest that a less flexible manufacturing system will exhibit peaks in performance outcomes, whereas a flexible manufacturing system is one in which such a performance measure is invariant with the position it occupies within the range (Upton, 1994).

The selection of the manufacturing flexibility dimensions and attributes to be used in this study involved reviewing the dimensions identified in the most recent research on manufacturing flexibility and a construct developed from what has been considered to be the most comprehensive synthesis of manufacturing flexibility. The flexibility dimensions and the rationale behind their selection are as shown in Table 1.

Four dimensions of flexibility: volume, variety, process, and material handling flexibility, appear to be particularly popular dimensions. According to D'Souza and Williams (2000), they are a economical set of primary dimensions for manufacturing flexibility. Indeed, one of the dimensions, i.e. volume flexibility, is considered to be a key contributor to an organization's competitive strategy (Jack and Raturi, 2002).

The flexibility dimensions suggested by Gerwin (1993) are: mix, modification, volume, changeover, rerouting, material flexibility, and flexibility responsiveness. These are shown in Table 3 Mix, modification, and volume flexibility are externally driven. The uncertainty associated with these dimensions is either from market and customer demand, in terms of product variety, product innovation and product quantity. Changeover, rerouting, and material are internally driven. The uncertainty associated with these dimensions is either from the production input or production environment, in terms of product specification, machine downtime and material characteristics. The comparison between Gerwin's original dimensions and the D'Souza and Williams' (2000) new dimensions is presented in Table 4. The rationale behind the changes proposed by D'Souza and Williams (2000) is explained below. According to D'Souza and Williams (2000), the mix and modification flexibility dimensions represent two perspectives on an underlying dimension that represents 'variety' of new and existing products that a manufacturing system can produce. In addition, changeover and rerouting flexibility reflect characteristics of the manufacturing 'process' itself, and are seen to represent a broader dimension of process flexibility. Regarding flexibility responsiveness, they recommend that this dimension be considered an element or sub-dimension of all manufacturing flexibility dimensions. Therefore, they suggest that while the flexibility responsiveness dimension is embedded in the other six dimensions, these six can be parsimoniously represented on four dimensions: volume, variety, process, and materials handling flexibility.

Type of uncertainty	Flexibility dimension
Market acceptance of kinds of products	Mix
Length of product life cycle	Modification
Aggregate product demand	Volume
Specific product characteristics	Changeover
Machine downtime	Rerouting
Characteristics of materials	Material
Change in the above uncertainties	Flexibility responsiveness

Source: Gerwin (1993)

Table 3 : Types of uncertainty and flexibility dimensions

D'Souza and Williams(2000)	Gerwin (1993)	Reasons for re-dimension
Volume	Volume	
Variety	Mix, Modification	Represent 'variety' of new and existing products that manufacturing system can produce
Process	Changeover, rerouting	Reflect characteristics of manufacturing 'process'
Material handling	Material	

Source: D'Souza and Williams(2000)

Table 4:- Comparison between Gerwin's (1993) and D'souza et al (2000) flexibility dimensions

At the level of the manufacturing function it is important for the study to focus on primary dimensions and not cloud the analysis with overlapping secondary dimensions (D'Souza and Williams, 2000). Thus the selection of the four manufacturing flexibility dimensions is mainly based on four justifications as given below:-

- They are a economical set of primary dimensions for manufacturing flexibility (D'Souza and Williams, 2000).
- Process and material handling flexibility represent an internally driven flexible manufacturing capability.
- Volume and variety flexibility represent an externally driven flexible manufacturing capability.
- They are the dimensions most frequently discussed in the extant literature concerned with flexibility research.

Two attributes have been emphasized as the basis of measuring manufacturing flexibility. The first is the number of range or options at a given time, and the second is the mobility or the ease with which the organization moves from one state to another. These attributes were chosen because they represented the most common measurement approach used in practice. The figure 1 below depicts the main classification of flexibilities. (Sethi and Sethi ,1990)

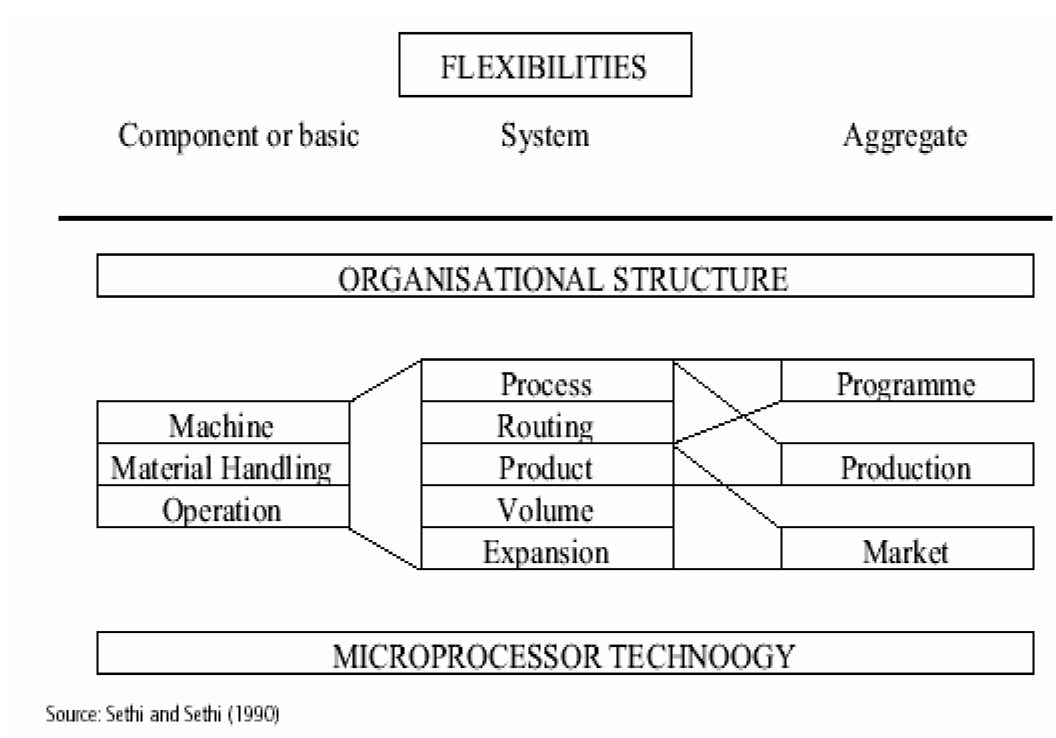

Figure 1: Main classification of flexibilities according to Sethi and Sethi ,(1990)

As flexibility is such a generic topic, with many different levels, it is difficult to identify a particular way to measure, or define metrics for it. To measure flexibility it is essential to be aware of the type of flexibility that is being considered and the context in which it is applied. With this in mind it is still difficult to isolate those critical criteria that influence flexibility. If these criteria can be identified, then they can be used as metrics. One way to consider flexibility measurement is to rate it in terms of performance measures, (Benjaafar and Ramakrishnan, 1995). These include production capacity, volume mix, production cycle times, operational costs, and investment. Investment is one of the most important criteria to consider, as, if a flexible system is too expensive compared to hard tooling, then it is unlikely to be considered a viable option.

Volume flexibility

This dimension of flexibility is defined as the ability of the manufacturing system to change the volume or output of a manufacturing process (Sethi and Sethi, 1990). This ability is related to the ability to increase and decrease production to satisfy upward and downward changes in demand required by customers (Gerwin, 1993). The range element of volume flexibility might be assessed by the range of the production volume in which the firm can run profitably (Sethi and Sethi, 1990)..

Variety flexibility

This is the ability of the manufacturing system to produce many different products simultaneously and to incorporate new designs as needed. Variety flexibility represents mix flexibility and modification flexibility in Gerwin's (1993) taxonomy. While mix flexibility is the ability of the system to produce many different products during the same planning period, modification flexibility is the ability of the system to incorporate design changes into a specific amount (Gerwin, 1993).Other researchers, such as Browne et al. (1984),Sethi and Sethi (1990), and Upton (1994), regard variety flexibility in other terms, i.e. product flexibility, is defined as the ability to change over to produce new products. This dimension of flexibility is related to the ability to offer varieties of products to customers in order to meet market requirements and to provide product innovation in encountering the length of product life cycles (Gerwin, 1993).. On the other hand, Gerwin (1987) suggests the use of the number of different part types that the system can produce without major set-ups. In terms of producing various types of products, Jaikumar (1984) recommends the use of the number of new parts introduced per year. Regarding the mobility element of variety flexibility, the time and cost required to introduce new products might measure this (Sethi and Sethi, 1990).

Process flexibility

This is the ability of the manufacturing system to adapt to changes in the production process. Examples of changes in the production process are machine breakdowns, changes in the production schedules, and changes in the sequence of steps through which the product must progress. This definition suggests that in order to adapt to these changes, there should be alternative routes to produce a part through the system. Process flexibility is comprised of changeover flexibility and rerouting flexibility in Gerwin's (1993) taxonomy. Changeover flexibility is the ability of the system to adapt to changes in the production process, while rerouting flexibility might be defined as the ability to change the sequence of steps in the production process through which the product must progress Gerwin (1987).This dimension of flexibility, according to Browne et al. (1984), Sethi and Sethi (1990), refers to the ability to produce a set of part types using several ways. Process flexibility is associated with the ability to produce items according to product specification required by customers, and to ensure product availability at the time it is required by customers, regardless of disruptions and changes in the production process.

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Material handling flexibility

Material handling flexibility is the ability of the material handling system to transport different materials between various processing centres over multiple paths (Sethi and Sethi, 1990). Sethi and Sethi (1990) suggest the ratio of the number of paths the material handling system can support to the total number of paths possible. Zhang et al. (2003) suggest the mobility element related to material handling flexibility could be measured by considering the cost and time required to change the material handling system between parts.

Flexibility in a manufacturing context is complicated by the complexity of manufacturing systems and operations so that flexibility can apply to different levels in a manufacturing organisation, .When considering flexibility it is essential to understand the type of flexibility in question, the level at which it operates, and the context to which it is applied. Without knowing these it becomes difficult to understand what is meant by flexibility. Flexibility exists not only at very generic levels, but also at more specific detailed levels, (Slack, 1991). An example of this is Ford Motor Company's 'Manufacturing Flexibility' structure, see figure 2.

<table>
<tr><th colspan="8">Manufacturing Flexibility</th></tr>
<tr><th colspan="8">Major Categories of manufacturing flexibility</th></tr>
<tr><th colspan="3">Volume/Mix Flexibility</th><th colspan="2">Product Changeover Flexibility</th><th colspan="3">Operational Flexibility</th></tr>
<tr><th colspan="8">Supporting Categories of Manufacturing Flexibility</th></tr>
<tr><td>Machine/Tooling Flexibility</td><td>Process/Operational Flexibility</td><td>Technological Flexibility</td><td>Location Flexibility</td><td>Material Flexibility</td><td>Product/Process Design Flexibility</td><td>Expansion Flexibility</td><td>Human Resources Flexibility</td></tr>
</table>

Figure 2: Ford Motor Company's 'Manufacturing Flexibility' structure

This structure uses the term 'Manufacturing Flexibility' as a banner under which every other form of flexibility exists. Ford believe that manufacturing flexibility is customer driven, and is defined as 'the availability of quality products that meet customer needs when they want them'. This structure will be used later to describe the meaning of flexibility in terms of the body construction phase of automotive production. Before a manufacturing organization can start to think about implementing any flexible strategy, it needs to be aware of the requirements for flexibility, and how these will influence the level of flexibility they require for product customization and global production.

Competitive Value Of Manufacturing Flexibility (MF)

In a changing environment, the primary challenge to manufacturing arises from the uncertainty associated with demand. The capability of manufacturing to respond appropriately to demand uncertainty will determine the stability and the growth of the business unit's profitability. The competitive value of MF lies in extend to which it can neutralize the effects of demand uncertainty. Manufacturing flexibility (MF) could help to maintain or stabilize the profitability of the business. It implies that the greater the demand uncertainty created by competitors, changing technology and so on, the greater the need for MF in preserving sales growth and profitability of the business. Manufacturing flexibility has been used strategically for offensive as well as defensive purposes as given in table 5.

IN OFFENSE	IN DEFENCE	IN OFFENCE AND DEFENCE
Responding to Opportunity	Desensitizing the System to Adverse Changes	Increasing Efficiency
(a) Ability to introduce large number of new models in to the market (Honda vs. Yamaha motorcycle). (b) Time required changing entire product line reduced.	(a) Less susceptibility to changes in demand, supply and tastes due to a broader range of product mix. (b) Enable the manufacturer to cope uncertainties caused by changes in the external environment- demand, mix, and material.	(a) Better utilization of capacity through wider range of product mix. (b) Reduction or elimination of setup time or change-over time. (c) Better use of capacity of the production of counter cyclical products.

Table 5:- Offensive and defensive factors in manufacturing flexibility

The Flexibility Hierarchy

From the figure 3, proposed by koste and Malhotra (1999), it is seen that machine flexibility is necessary building block for other flexibilities and is regarded as the requirement for the development of mix flexibility. The five flexibilities (expansion, mix, new product, volume and modification) do not support the development of other flexibilities. Thus, they are considered as higher level flexibilities. Lower level flexibilities mostly serve as the building blocks for higher level flexibilities

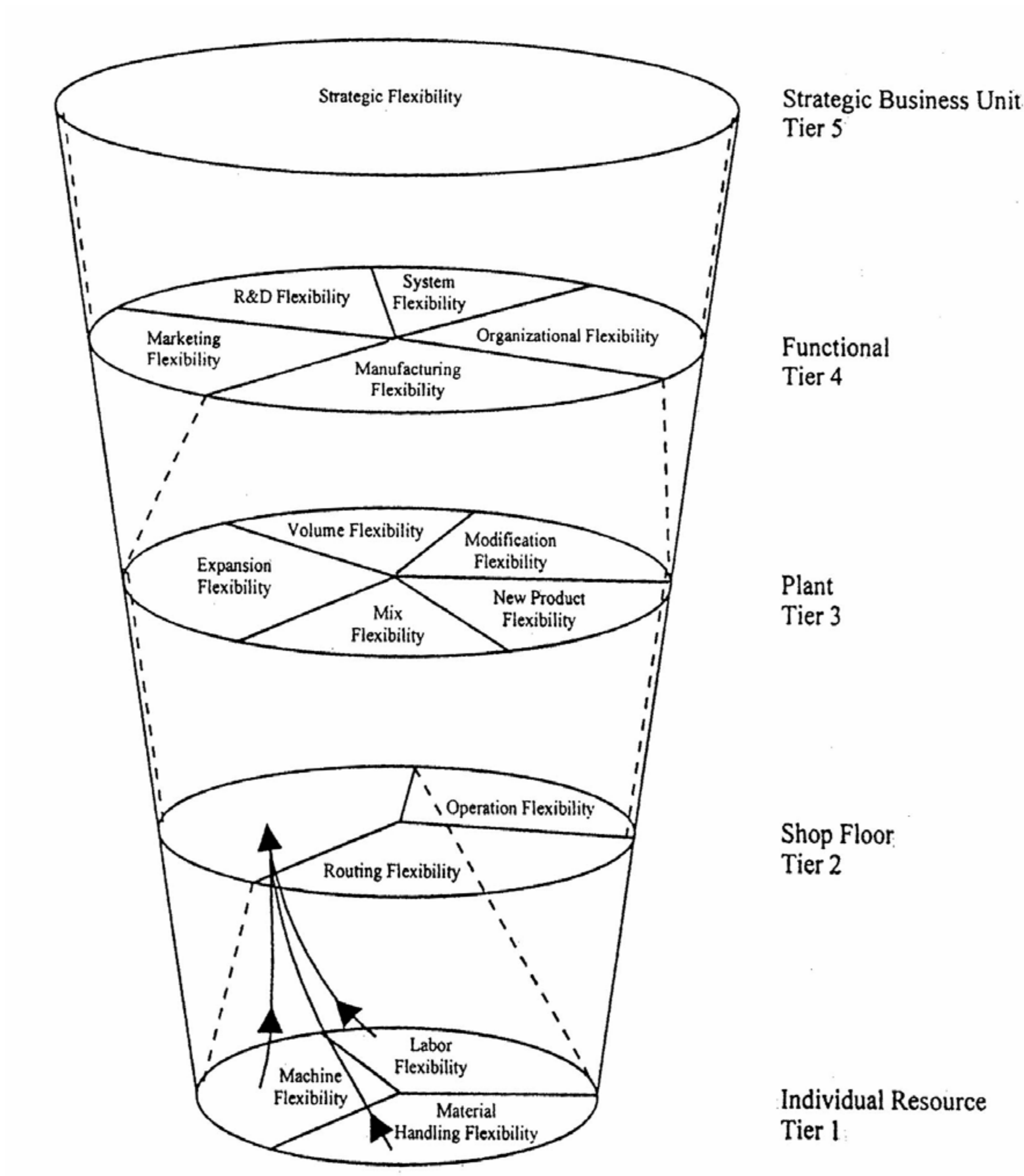

Figure 3: Levels in flexibility hierarchy

Manufacturing Flexibility Constructs

Many studies have been undertaken with the aim of extending our understanding of the nature of flexibility and its measurement. Beach et al. (2000) provide an extensive review of the literature in this area, examining many of the issues surrounding the concept of manufacturing flexibility, including the taxonomies used and the means of measuring flexibility. To date, there is no consensus regarding the classifications and definition of flexibility and its constituent elements. The lack of a homogeneous view of manufacturing flexibility, and the lack of consensus on the terms used to describe it, complicate our understanding of the different notions of manufacturing flexibility and their measurement (Swamidass, 1988). Furthermore, researchers have still to reach an agreement on the definitions used to describe some of the most basic terms

An highlight of this issue is the term used to describe the constituent elements of flexibility. These have been described variously as flexibility ‘types’, ‘dimensions’, and ‘kinds’.

In the early 1980s many new manufacturing facilities were labeled Flexible Manufacturing System (FMS) and as a consequence, some confusion emerged about what constituted a FMS. To overcome this, Browne et al. (1984) developed a taxonomy that defined and described eight dimensions of flexibilities. These are: machine, process, product, routing, volume, expansion, operation, and production flexibility. Slack (1983) describes the concept of manufacturing flexibility as an operation’s ability to take up different positions or to adopt a range of states, and the ease with which a system moves from one state to another, in terms of time and cost. Building on this reasoning, he proposed that manufacturing flexibility dimensions could be further divided into three lower order attributes: the range of states a system could adopt, the cost of making the change, and the time necessary for the change. Manufacturing flexibility, according to him, has five dimensions: product, product mix, quality level, volume, and delivery. Later, Slack (1987) sought managers’ views on manufacturing flexibility at the total manufacturing level. The empirical evidence showed that all the identified dimensions of flexibility were important, except for quality. The quality dimension was subsequently eliminated due to lack of support amongst the sample for the notion that companies might want to vary the quality of their products. One of the most widely accepted classification systems was developed by Sethi and Sethi (1990). They surveyed the literature on manufacturing flexibility over the previous 10 to 20 years and through reasoned argument identified eleven dimensions of manufacturing flexibility as well as the means of measuring and evaluating them. Interestingly, the eleven dimensions are developed from the eight original dimensions of Browne et al. (1984), the additional three dimensions that emerged from their synthesis of the literature were: material handling, programme, and market flexibility.

More recently, D'Souza and William (2000) have attempted to develop a generally acceptable taxonomy of the manufacturing flexibility construct. Their study is based on the taxonomy built by Sethi and Sethi (1990), Gupta and Somers (1992) and Gerwin (1993). A sample of manufacturing companies was used to identify the operational measures of manufacturing flexibility. The results provide support for the proposed taxonomy. Two generalized categories of manufacturing flexibility emerged as externally and internally driven. The externally driven manufacturing flexibility dimensions are volume and variety flexibility, while the internally driven manufacturing flexibility dimensions are process and material handling flexibility.

Having various dimensions of manufacturing flexibility, a manufacturing company must identify the dimension(s) it most needs (Gerwin, 1993). Furthermore, certain flexibility dimensions have been found to be more important than the others; specifically, machine, labour, mix, new product and modification (Koste and Malhotra, 2000).

Flexibility and Productivity

Production is defined as manufacturing of products with the help of personnel, material equipment (hard and software) and capital (Gustavsson, 1984). The consumption of resources is compared with earlier consumption in budget control and other steering instruments.

Products are subjected to changes:

(a) A change of technology (electronics take over from mechanics)

(b) Rationalization (one component does the work of several)

(c) Changes in fashion.

A company's ultimate success is depends on its ability to utilize resources and meet the need of the market. These internal factors steer demand and in turn the volume of business and the price of commodity. In addition to all this, there must be flexibility in respect of external factors. These may be:

(a) Fluctuation of the market

(b) Seasonal fluctuations

(c) Competition from other companies.

Flexibility And Production Management

There are many approaches to increase flexibility, Four central ways are:

- . Reductions of set-up time at installed equipment.
- . Multipurpose stations (FMS).
- . Parallel assembly lines.
- . Flexible work force.

The first three approaches are dependent on production equipment and the last on personnel. All approaches above require some kind of initial investment. Each approach is highlighted below to point at different important aspects, which affect flexibility and costs. Reduction of set-up time at equipment in place requires often some kind of additional investment in equipment. The result from the investment is an increase in process and volume flexibility due to shorter set-up time and that more capacity is made available. The effect on volume flexibility is marginal, but the effect on process flexibility is substantial. This is a consideration especially relevant to equipment based assembly systems, where set-up is a time consuming and costly activity. Multi-purpose stations are often built as flexible manufacturing system (FMS) where one machine performs a lot of operations with a minor or no set-up time at all. The multipurpose stations are characterized by high flexibility both in process and volume and taking care of most of the operations. The desired degree of flexibility can often be built in with different modules when the machine is bought and a higher degree of flexibility is associated with higher investment costs. Parallel stations increase flexibility because different products can be assembled in different stations. The flexibility of the whole system will depend on the capability and flexibility of the parallel machines. This approach can be carried out with more or less flexible machines, dedicated machines, human worker or a mix of these and is thereby of interest approach to both companies although this might be an expensive way to achieve flexibility.

Personnel with high skills are of great importance to companies using machines as well as they who do not. Well-trained and educated personnel also lead to process flexibility.

Flexibility can thus be acquired in different ways and each of these ways is associated with costs when acquiring them. Therefore, it is interesting to evaluate the benefits given by flexibility. Set-up time reduction investments can be applied to equipment in place and proactively for planned equipment. In both cases it is interesting to know if the value of the flexibility increase exceeds the cost of acquiring it and if the investment thereby should be carried out. It might in some cases be enough to do a smaller set-up time reduction than was thought from the beginning if this requires a smaller investment but might give substantial effects to the flexibility of the company. If the set-up time reduction investment is done for equipment in place it might be enough to evaluate this reduction investment alone, but if the investment concerns brand new equipment other aspects such as new capacity constraints has to be dealt with. In the latter case it could therefore be better to do an evaluation of the whole system.

Multi-purpose stations are often very expensive to acquire and it is thereby interesting to find out if the value of the benefits, given in form of flexibility by these stations, exceeds the cost of them. As in the case with the set-up time reduction, there might be a point where investment in more flexibility is not profitable any longer. Thereby, it can be interesting to find the point, if it exists, where investment in more flexibility is unprofitable and telling management that it is of no use to invest more.

Parallel stations gives flexibility as described above but requires substantial investments in capacity. The parallel stations can be set-up in different ways e.g. two dedicated lines producing two types of products or two flexible lines where both line are able to produce both products. The flexible lines are more expensive but give more flexibility when temporary demand peaks of one product can be produced in both lines if capacity is available. More parallel lines give even more flexibility but for a given uncertainty it might not be optimal to buy only flexible machines but mix dedicated with flexible machines, which might give a higher value. It might thereby be of great interest to evaluate different machine configurations and compare these to each other to find a tradeoff between acquired flexibility and the cost of acquiring it.

Flexible personnel give a way to handle fluctuations in demand. This flexibility is achieved at the companies by the possibility to hire and is of course worth something to the companies but the question is how much? Related to this way to achieve flexibility a couple of questions are interesting: i) what is the opportunity to hire a person for three months worth given demand today, uncertainty in demand, costs of hiring etc. This can, for example, be interesting if extra workers have to get some education before hiring or that the company has to pay for this opportunity in some other way. ii) How many people can be employed on short time contracts until the present value of the marginal worker is null or negative? iii) If a cost is associated with holding the pool of workers from where people are taken into production, how many workers should be connected to this pool? In summary, flexibility has a value and that an estimated value of flexibility might serve as an important input parameter in decision making resulting in better decision in favour to the company and its shareholder.

Flexibility and Option Pricing

Sethi & Sethi (1990) define volume flexibility as the ability to operate profitably at different output levels. Process flexibility according to Sethi & Sethi (1990) relates to the set of parts that can be produced without a major set-up. The latter is sometimes referred to as product-mix flexibility in the literature.

Tannous (1996) carries out capital budgeting for volume flexible equipment and compares a non-flexible to a flexible system in a case based on a real company. In his model demand is uncertain, dependent on price (downward-sloping demand curve) and a stochastic factor. In Tannous' model the effect of having inventory available is also considered. Andreou (1990) evaluates process flexibility in different configurations of dedicated and flexible equipment when demand of two products is uncertain. As in Tannous (1996) demand is uncertain but in this case differs, via a demand shift parameter depending on whether market is perfectly competitive or not.

The option pricing theory has also been used to evaluate projects with real options and flexibility on a more strategic level. McDonald & Siegel (1985) consider the valuation problem of the option to temporarily shut down production when output price is stochastic. McDonald & Siegel (1986) evaluate the option to wait to invest when the investment is irreversible.

Flexibility and Vertical Integration

For a vertically integrated firm, any advantages from vertical integration depend on the firm and the industry condition, and thus can change over time . The basic issue is whether successive activities within one firm or the use of exchanges between separate firms minimize agency and transaction costs (Richardson, 1996). As pointed out by agency theory, separate firms along a value chain have a greater incentive to innovate and to adapt to changing circumstances than fully integrated firms (Richardson, 1996), which correlates with a basic tradeoff between the improved information, but results in reduced performance incentives due to vertical integration (Riordan, 1995). For a firm that is confronted with an increasing competitive environment, flexible organizational forms “can respond to a wide variety of changes … in an appropriate and timely way” and be the foundation for building strategic flexibility (Hitt et al., 1998). However, an open issue is how to establish a flexible organizational form that is meeting market needs without having the trade-offs of vertical integration.

Strategic Flexibility Framework

The theories discussed above are the basic considerations for the development of the conceptual Strategic Flexibility Framework (SFF), given in figure which develops existing studies on flexibility (Gerwin, 1987). It builds on the concepts of resource based management and coordination flexibility, and illustrates how a firm’s strategic flexibility and competitive position correlate

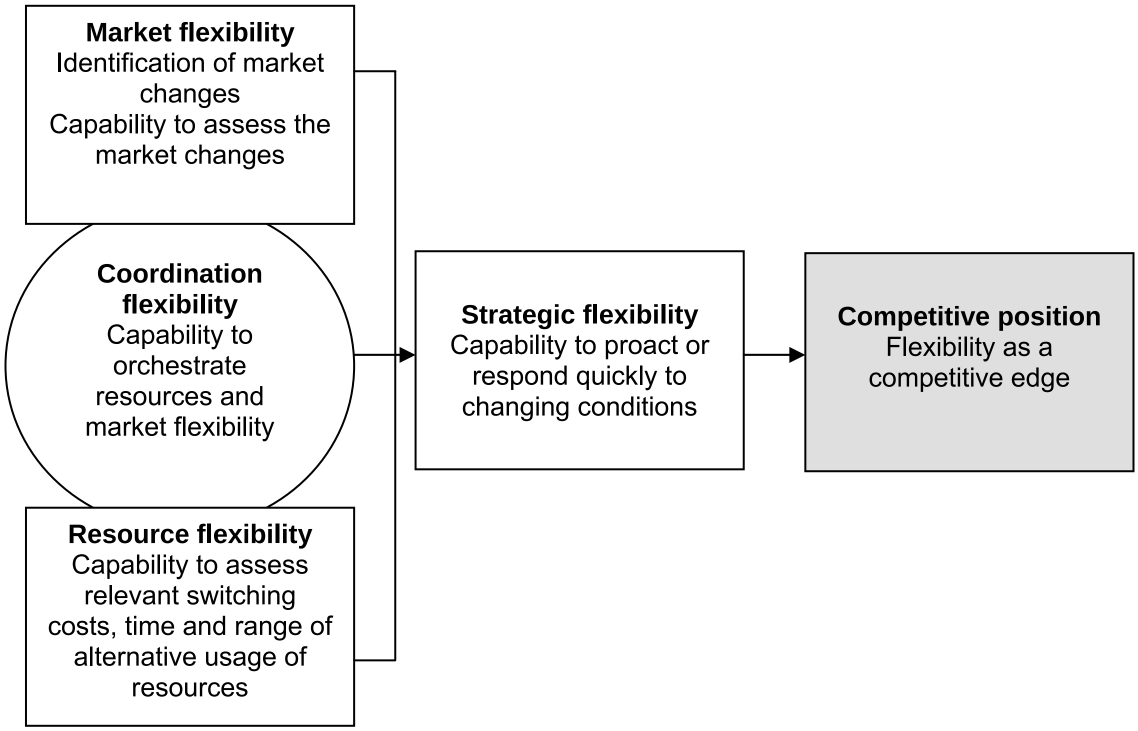

Figure 4: Strategic Flexibility Framework (SFF)

Market flexibility:

Dynamic environments call for consideration of relevant changes in strategic management and require responsive flexibility in order to be able to accommodate increased competition (De Meyer et al, 1989). This is especially true for product manufacturers (De Meyer et al., 1989), which are confronted with various types of external flexibility dimensions. Other studies further specify these types of flexibility (Slack, 1987), such as “readiness” (Bartezzaghi and Turco, 1989), new product flexibility (Suarez and Cusumano, 1996), expansion flexibility (Chen et al., 1992) or delivery speed flexibility (Chambers, 1992). However, these types of flexibility invariably refer to one specific market and do not consider potential intermediary markets along a manufacturer’s value chain. These markets can arise from the commingling of a firm with entities in its external environment and have

their foundation in a firm’s potential market power along its value chain . So market flexibility has been identified as a firm’s capability to identify market changes and assess market opportunities within the optimum constraints of its value chain.

Resource Flexibility

It is derived from a resource-based view of the firm (Wernerfelt, 1984) and closely correlates with a firm's "asset specificity" (Riordan and Williamson, 1985). Resource flexibility links firm resources with competitive advantage; or identifies firm resources as a primary determinant of firm value and firm performance. This leads to the introduction of concepts on resource flexibility (Gerwin, 1993, Slack, 1983), which specifies potential changes in the deployment and utilization of internal resources. Sanchez (1995) characterizes resource flexibility using three dimensions: the range of alternative use of resources, the cost and difficulty of switching resources, and the time for switching from one to another resource.

Coordination flexibility

This balances market and resource flexibility. Sanchez (1995) characterizes coordination flexibility as being able to "redefine a firm's product strategies, to reconfigure a firm's chain of resources and to redeploy the reconfigured chain of resources" effectively. This coordination flexibility is closely linked with the discussion of dynamic capabilities, which support the balancing a resource-based and a market-based view (Griffith and Harvey, 2001). Therefore, coordination flexibility is identified as a firm's capability to orchestrate resource and market flexibility.

Strategic flexibility

It is often used to explain how a market-based view or how coordination or resource flexibility can be utilized to strengthen a firm's competitive position in its marketplace (Sanchez, 1995). Within this context, a firm's *competitive position* determines a market position where competitive advantage can result in superior performance. Therefore, strategic flexibility becomes a major challenge for manufacturing firms (De Meyer et al., 1989). Consequently, a firm's competitive position is viewed as the superior goal, for which an increase in strategic flexibility is a pre-requisite requirement. The degree of flexibility needed to ensure a competitive position is commensurate with the volatility of the environment; and therefore needs continual assessment.

Requirments for Flexibility

Prior to considering a manufacturing strategy based on flexibility it is necessary to fulfill a number of requirements. Firstly, it is necessary to clarify manufacturing objectives by determining what is going to be produced, roughly in what volumes, and for how long. It must also be decided whether the same facilities are needed for the introduction of new models or products after a finite period of time. With these objectives in mind, it should clarify why flexibility is required. Does the manufacturing strategy need to be changed due to market pressures, or are new opportunities offered by tooling / facilities and systems technology? The answer to this will influence the extent of flexibility required, and whether flexibility is actually needed at all (Voss, 1992). From this a working plan can be formulated, and the performance measures required can be defined, leading to exactly what type of flexibility is required. This should consequently highlight the requirements for tooling, facility, technology, human resource, and product / process flexibility.

A number of inhibitors exist for the implementation of flexibility and these must be carefully considered before a manufacturer commits itself to a flexible strategy. The greatest of these is investment cost for tooling and facilities. Unless care is taken in optimizing manufacturing processes, and product designs, the investment for flexible systems can be significantly greater than for more conventional dedicated systems. Poor optimization can also have an effect on the operational cost of a flexible system. In some respect these two factors can be justified if the flexible system implemented exhibits greater production capacity flexibility than a similar dedicated line. Often this is not the case, and manufacturers find that their flexible systems cannot cope with the capacity, especially if there is an increase in market demand for the product. In this situation it is not unusual to see a manufacturer implement an additional manual system, at extra cost, to provide the capacity required. These manual systems tend to be low cost in terms of investment, but they are generally expensive in terms of running costs. Production cycle times must also be considered, as operations that have long cycle times will invariably create a bottleneck, slowing down the whole manufacturing system.

In reality, flexibility will only happen if there is good communication between the manufacturing and engineering phases of a product's development. Ideally concurrent engineering should take place, the integration of product and manufacturing design, (Nevins, 1989). Through the use of product and process design methods, an amicable flexibility concept should be achieved, by both engineering and manufacturing making compromises. Historically this has not been the case as manufacturing has generally been faced with the task of making a product that has not been optimized for manufacture. This is in no way the fault of engineering, but more a fault of the process of product development and manufacture, highlighting the 'wall' that has until very recently existed between design and manufacture. .

Achieving Flexibility

To achieve manufacturing flexibility requires input not only from manufacturing, but also from product design, product engineering, and purchasing. Manufacturing flexibility is in essence a collection of product and process design concepts, aimed at ensuring the competitive edge of a manufacturer. Ideally these concepts should be grouped into a flexibility strategy to ensure a framework exists for the ease of implementation

One of the key steps towards achieving flexibility is the appropriate use of manufacturing technology. Until now limited flexibility has been achieved by the use of facilities like robots, capable of a wide range of tasks and operations. These facilities are limited by the use of dedicated fixtures and tooling that can only cope with a limited number of product variants. Consequently the aim of many manufacturers is to try and re-design these fixtures and tools to be more flexible..

A significant means of moving towards manufacturing flexibility is to ensure as much product and process standardisation occurs as possible. In terms of automotive manufacturing non standardisation between models reduces the possibility of having more than one model being manufactured by the same system. Without common locations, common points for transport, common joints for welding, and common processes across a range of different models flexibility to any great degree is very limited.

Another technique that aids in achieving flexibility is dimensional management. Dimensional management is not so much a technique as a philosophy. It embodies the communication between engineering and manufacture to ensure the production of dimensionally accurate products (Craig, 1992). The philosophy relies on the use of a common quality strategy throughout the process of designing and manufacturing a product.

Flexibility Guidelines

To aid product designers and manufacturing engineers in optimising both products and processes for flexible manufacture in the automotive market of the 21st century, a series of flexibility guidelines is being developed by Loughborough University and Ford Motor Co. Although these guidelines are aimed at ensuring flexibility for assembly fixtures and tooling within the body construction phase of automotive manufacture, many of the guidelines relate specifically to engineering, and more generally to manufacturing implications. All of the guidelines represent best practice in terms of manufacturing, but not necessarily just automotive manufacturing. The guidelines fall under the headings of Manufacturing or Product Engineering, but some are common to both headings. Each of these headings has its own sub-headings under which the guidelines are grouped relevant to particular topics or job functions. This enables users of the guidelines to easily find information of value to them. Some of the manufacturing guidelines are very specific to elements of BIW assembly, while others are more general manufacturing flexibility guidelines. The Manufacturing sub-headings are:

- Tooling and Fixturing.
- Facilities and Utilities.
- Process Planning.
- Layout.

The Product Engineering guidelines are all very general in their nature, and are considered due to their influence on fixture and tooling design. The Product Engineering sub-headings are:

- Product.
- Process of product design.

Each of the guidelines has its own short description, often citing best practice examples, and justifications to emphasize applicability of the guidelines. These justifications generally have implications in terms of cost, cycle times, or production capacity. These guidelines are not to be considered as rules, but as aids to good product and process design. The guidelines on their own will not achieve a flexible environment, but allied with a good manufacturing strategy and the desire to become flexible for the right reasons, a manufacturer has a better chance of achieving the goal. These guidelines will be used as a basis for the flexibility evaluation of product design and manufacturing facilities within automotive plants, leading to the generation and implementation of concepts.

Benefits Of Flexibility

(a) It can reduce the amount of material handling, since it may be possible to perform more than one operation consecutively at one time.

(b) It provides the ability to alter the capacity of the production system.

(c) It can provide the back-up capacity for more than one operation.

Because of the environmental uncertainty and the variability of products and process, flexibility is very important for manufacturing. This subject is becoming more and more popular these years with vast and articulated literature. Flexibility is seen as a management task and the concern is the extensiveness of control capacity with respect to the environment.

An Alternative Approach To Analyzing Flexibility

Corrêa (1994) proposes an alternative approach, according to which manufacturing flexibility, at least at the operational level, should be seen in broader terms, as *'being able to respond effectively to unplanned change'*. The author considers that uncertainty and variability are only particular attributes of unplanned change and that in order to manage manufacturing systems effectively, it is important to understand the concept of unplanned change. Two large streams can be identified on managing unplanned change. One stream is found under the label 'flexibility' and aims to deal with the change and its effects *after the fact* or, in other words, after the unplanned change has occurred. The second stream, although not explicitly, aims at reducing the amount of the changes with which the system has to deal. Several management techniques are engaged in finding ways to control the dynamics and the magnitude of the changes which affect the manufacturing systems: forecasting techniques, maintenance systems, parts standardization and manufacture focusing are some examples. Their aim is to try to avoid the change *before the fact*, preventively. Although both streams aim at managing unplanned change, the current literature lacks an unifying framework which helps managers understand and analyze unplanned change, control and flexibility and their inter relation.

Corrêa's (1994) work is an attempt to provide such a framework, the main aspects of which are described below:

a) stimuli, or relevant unplanned changes have dimensions: size, frequency, novelty, certainty and rate. It is important to classify stimuli because different stimuli dimensions may call for different managerial actions.

b) there are two basic and complementary ways of managing stimuli in manufacturing systems: by controlling the stimuli and by being flexible. Control is defined here as the ability to interfere effectively with the causes of the changes or with the way the system senses the changes, in order to alter one or some of the dimensions of which effects the system will otherwise have to respond to.

Flexibility is defined as the ability to deal effectively with the effects, experienced by the system, of the unplanned changes. The unplanned change control methods thus work as a filter, restricting the amount of change effects the system has to deal with. The changes which 'pass through the control filter' have to be dealt with by the system, through its system flexibility characteristics.

CHAPTER-3

FLEXIBLE MANUFACTURING SYSTEMS

Cut throat competition and emergence of global markets have made business leaders to turn their attention to more critical issues like productivity, Flexible Manufacturing System ,Group technology and other strategies like just In Time, supply chain management etc. today one has to perform to the maximum in order to survive otherwise perish.

Even though FMS has gained wide acceptance world over, there is no precise definition of FMS. Most definitions are based on a particular composition or system. Brykett et al (1988) stated that *"FMS is a manufacturing system in which groups of numerically controlled machines (machine centres) and a material handling system work together under computer control"*

Despite the range of definitions, B.L Maccarthy et al (1992) have simply stated that: FMS contains three sub systems

1. A processing system
2. A material handling and storage system
3. A computer control system

The developments in technology, materials and customer preferences have resulted in products with shorter life span. New products are being launched more frequently. New products and designs require changes in production facilities. New technological advancement and management techniques have made manufacturing sector cope up with the changing environment .The change from hard automation to flexible manufacturing systems, which can be readily rearranged to handle new market requirements, is what's needed today. FMS consists of a group of flexible processing stations interconnected by means of automated Material Handling Systems and storage systems which are controlled by an integrated computer system. It is capable of processing a variety of different types of parts under NC programs at various work stations. FMS is a facility and not a machine.

In the discrete product manufacturing industries, the most automated form of production is the flexible manufacturing systems. Flexible manufacturing system is designed to fill the gap between high production transfer lines and low production NC machines. Transfer lines are very efficient when producing parts are in large volumes at high output rates. The limitation of this mode of production is that the parts must be identical. These highly mechanized lines are inflexible and can not tolerate variation in part design. If the design changes are extensive, the line may be rendered obsolete. On the other hand, stand-alone NC machines are ideally suited for variation in work-in-process (WIP) configuration.

In terms of manufacturing efficiency and productivity a gap exist between the high-production-rate transfer machines and the highly flexible NC machines. This gap includes parts produced in mid range volumes. These parts are of fairly complex geometry and the production equipment must be flexible enough to handle a variety of parts designs. Transfer lines are not suited to this application because they are inflexible; NC machines are not suited to this application because their production rates are too slow. The solution to this mid volume production problem is the computer integrated manufacturing system.

Types of Manufacturing Systems

The middle range can be further divided in to finer categories. Kearney and Trecker Corporation define three types of manufacturing systems to satisfy the variety of processing needs with in this middle range. They are:

(a) Mass production or Transfer lines System;

(b) Flexible Manufacturing Cell;

(c) Flexible Manufacturing System (FMS).

- Dedicated FMS.
- Random FMS.

Concept of Flexible Manufacturing System (FMS)

Although many definitions are available, key aspect of an FMS are generally agreed upon. First, flexible-manufacturing system (FMS) is computer-controlled system. It contains several workstations, each geared to different operations. Workstation machines are automated and programmable. Automated material handling equipment moves component to the appropriate workstation, then on to the programmed machines that select position and activate the specific tool for each job. Hundred of tool options are available. Once the machine has finished one batch the output signals the next quantity or component, and the machine automatically repositions and retools accordingly. Meanwhile, the just-finished batch is automatically transferred to the next work station in its routing.

FMS is used as a general term for a broad collection of production systems, which may take several different structural forms. A flexible manufacturing system (FMS) is a production system capable of producing a variety of part types, which consists of CNC or NC machine tools connected by an automated material handling system. The operation of the whole system is under computer control.

As long as it satisfies the definition, any production system, large or small, can be called an FMS. Within this group of systems, we believe that FMC is an important special type. In recent years, it is very common studied form in FMS research and many actual FMS installations claim to be FMC. Before giving a definition for FMC we first define a more basic unit of FMS, the single flexible machine (SFM), which is called a flexible machining cell (FMC) in Browne et.al (1984) and a flexible manufacturing module (FMM) in Kusiak (1985).

A single flexible machine (SFM) is a computer controlled production unit which consists of a single CNC or NC machine with tool changing capability, a material handling device and a part storage buffer.

The material-handling device is an SFM could be a robot or special purpose pallet-changing device. When an SFM is used as a component of a larger system the material-handling device may be removed if the material-handling device of the larger system can perform its function.

Despite all the interest in FMSs, there is no uniformly agreement on the definition of the terms in FMS. The main distinguishing feature of FMS from traditional manufacturing systems is “flexibility” which does not have a precise definition. One of the most referred to definition of FMS is by Ranky (1983), who defines an FMS as a system dealing with high level distributed data processing and automated material flow using computer-controlled machines, assembly cells, industrial robots, inspection machines and so on, together with computer integrated material handling and storage systems. In fact, the scope and variety of flexible manufacturing are commonly disputed and are the focus of many research efforts. However, the components and characteristics of an FMS, as described by different authors and researchers, are generally as follows.

- Potentially independent NC machine tools.
- An automated material-handling system.
- An overall method of controls those co-ordinates the functions of both the machine tools and material handling system so as to achieve flexibility.

It covers a wide middle territory within the mid-volume, mid-variety production range. A typical flexible manufacturing system (FMS) will be used to process several parts families with 4 to 100 part numbers being the usual case. Production rate per part would vary between 40 and 2000 per year. Table 6 shows the classification of a typical manufacturing system with respect to the level of flexibility, noumber of parts in the product family and the average lot size

Type of manufacturing system	Level of flexibility	Number of parts in product family	Average lot size
Transfer lines	Low	1-2	7,000 and up
Dedicated FMS	Medium	3-10	1,000-10,000
Sequential or random FMS	Medium	4-50	50-2,000
Manufacturing cell	Medium	30-500	5-500
Stand-alone NC machine	High	200 and up	1-50

Table 6:- Classification of manufacturing System

Components of FMS

Figure 5 shows a typical flexible manufacturing system layout and its components

(a) Machine Tools

These include CNC lathes, drill machines, milling machines etc. and any special purpose machines. They have automatic tool changer and measuring systems.

(b) Tool Systems

Machine tools are equipped with either turret or tool changer for supplying desired tools. For less machining parts a turret is used. For components with more cycle time automatic tool changers are used.

(c) Work Handling

In FMS installation, automatic changing of the work piece is essential. Such a system should be simple to reset and have freely programmable movements and short changeover time and have an adequate handling capacity. It is installed physically separated from the machine tools to eliminate vibration to machine tools.

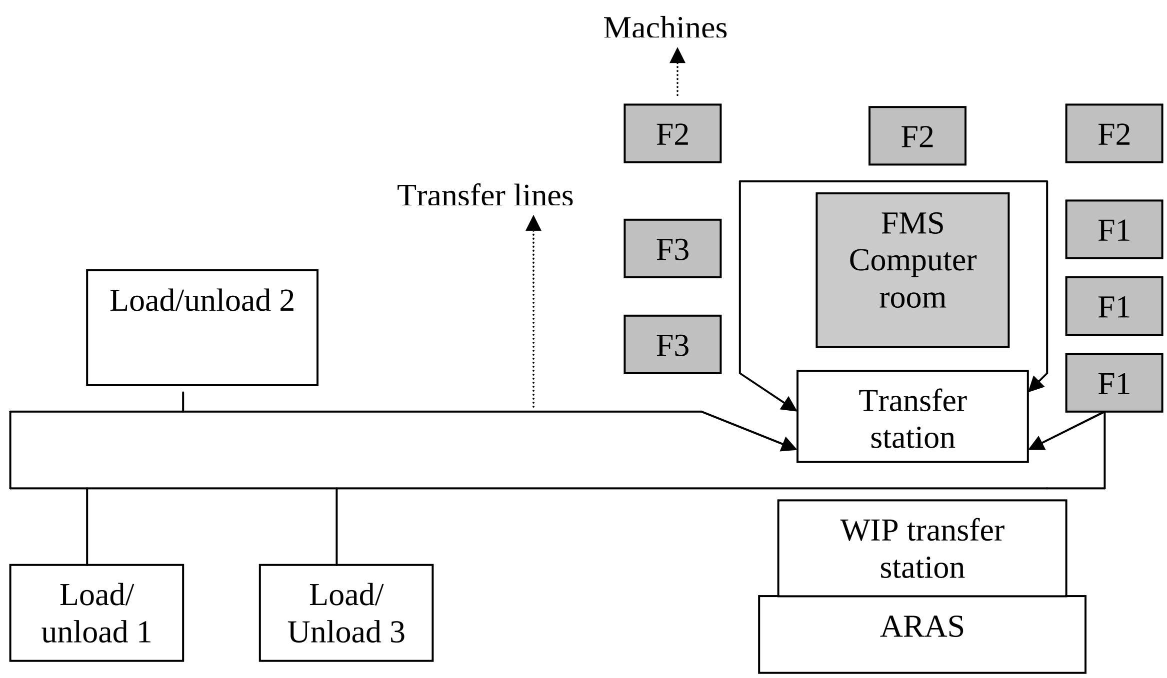

Figure 5: A typical FMS layout

(d) Material Handling System (MHS)

In order to achieve a high degree of flexibility of material flow, it is useful to use individual conveyors. They have the advantages that they can follow a predetermined route without interfering with other vehicles. In general the main objective of MHS is to help to achieve maximum workstation in utilization through effective work piece movement capacity and speeds are considered for design of MHS.

i) Primary Work Handling System

The primary work handling system is used to move parts between machine tools in the FMS. The requirements usually placed on the primary material handling system are:

- It must be compatible with computer control.
- It must provide random, independent movement of palletized work-parts between machine tools in the system.
- It must permit temporary storage or banking of work-parts.
- It should allow access to the machine tools for maintenance, tool changing and so on.
- It must interface with the secondary work handling system.

ii) Secondary Part Handling System

The secondary parts handling system must present parts to the individual machine tools in the FMS. The secondary system generally consists of one transport mechanism for each machine. The specifications placed on the secondary material handling system are:

- It must be compatible with computer control.
- It must permit temporary storage or banking of work-parts.
- It must interface with the primary handling system.
- It must provide for part orientation and location at each workstation for processing.
- It should allow access to the machine tool for maintenance, tool changing and so on.

(e) Monitoring System

It is incorporated with various means: Correct Clamping, Measurement Control, Tool Tip measurement, Programmable Wear Time of Tool, Cutting Force, and Collision Free Zones for Computerized Part Changer.

(f) Planning System

The planning system is done at three levels:

- Long term decision making;
- Medium term decision making;
- Short term decision-making.

So as to achieve maximum resource utilization by allocation of machine tools sequence of operations and tool management.

(g) Auxiliary Equipments

Besides machine tools, an FMS can also include cleaning on-line inspection, automated measurement and gauging equipments.

FMS selection criteria

- Total cost.
- Time available.
- Labor required.
- Work in process.
- Space available.
- Volume flexibility.
- Product mix flexibility.
- Process/routing flexibility.

Performance measures in FMS

The various types of measures that are commonly applied in FMS are

(1) PHYSICAL: This includes

- Number of part types handled by the system.
- Average change over time to switch between parts
- Average number of different routings available

(2) VALUE: These includes

- Shadow prices
- Incremental net optimal revenues

These are derived from appropriate mathematical programming models of the manufacturing system.

(3) RATIO MEASURES: These includes

- Ratio of part type to part families
- Ratio of part families to changeover time
- Part numbers scheduled per unit changeover time.

(4) PRODUCTIVITY: These includes

- Work productivity
- Output productivity
- Capital productivity

Tools to Solve FMS Related Problems:

There are basically 2 tools to solve the problems related to flexible manufacturing system:

(a) Analytical Tools: - Analytical tools are mathematical techniques such as queuing theory, integer programming, heuristic algorithm, and Markov Chains.

(b) Simulation Tools:- General-purpose simulation languages (e.g. SLAM II, SIMAN IV, etc.), Simulation packages designed for the general simulation of manufacturing systems (e.g. SIMPLE++, AutoMod II, ProModel, ARENA, SIMFACTORY II.5, etc.) and Simulation software specially created for a specific problem by using general programming languages such as C,FORTRAN, BASIC, LISP, etc.

Strategic issues in FMS

Before the implementation of FMS it is necessary to first study the various strategic issues in flexible manufacturing systems such as financial position of the company, market conditions, technological position etc. table 7 below shows various strategic issues in FMS.

Strategic issues	Related factors
Financial position	• Required finance. • Available finance. • Methods of finance.
Technology position	• Improvement. • Modernization. • Expansion.
Market position	• Market share. • New products/markets.
Product conception and resources	• Product quality. • Product research. • Product facilities. • Resource planning. • Inventory management. • Capacity utilization.
Human resource management	• Management development. • Training and education programmers. • Job placements. • Manpower planning. • Employee moral/motivation. • Employee participation in automation projects.
Government policies	• Cost of raw materials. • Import/export facilities. • Technical assistance. • Fiscal policy of governments.

Table 7:- Various strategic issues in FMS

Advantages of Flexible Manufacturing System (FMS)

- Integration of several machines or workplaces leads to smaller waiting time between machines and better utilization of each machine leading to greater productivity compare to stand-alone machines, many studies show the productivity to increase by a factor of 2 to 3.5.
- Integration of job planning and material planning leads to optimal material utilization dynamic scheduling of jobs in the light of process monitoring leads to reduction of downtimes and better utilization of machine meaning higher productivity and lower costs.
- Dynamic job scheduling also leads to greater flexibility in meeting production dead lines and therefore better markets images.
- Automatic supply of tools and work pieces from common storage to machine also leads to smaller inventory costs and human operation costs, further reducing the cost of productions.
- Production costs have been observed to decrease typically to 50% of the cost prior to the installation of FMSs.
- Very high product quality can be achieved due to integrated process monitoring, i.e. integrated tools, work pieces and error diagnosis monitoring virtually 100% inspection can be provided.
- Quick production in very small lot sizes with great variation of the same is possible.

Limitations of FMS

- Lack of top management commitment and support
- Inadequate training of personnel involved
- Improper evaluation
- Lack of long term committed relationship between vendor and user
- Lack of total commitment to the installation simplification of FMS
- Existence if misconceptions about FMS (such as FMS being good only for large companies and for large scale production)

Design and installation of F.M.S is not easy, as these systems are highly expensive and complex, a proper study of these systems is required. Now a day, with the advent of sophisticated computer and software technologies these studies have become easier from the past. The main and the most popular type of analysis of these systems are done using simulation techniques. Modeling of these complex systems are easier and effective than the mathematical or physical analysis that were previously done.

Since the F.M.S environment have a lot of variables that affect the performance of the system, proper identification and study of these variables are important for the successful modeling of the systems. There are numerous design related and operational related problems that have to be overcome before successful F.M.S installation.

Even though simulation is the most popular, cost effective and easier way to model F.M.S environments, it has one drawback. As the number of uncertainties increases, the system becomes more complex and the results obtained cannot be easily verified and validated. Actual F.M.S environments are stochastic, hence uncertainties cannot be overruled. So on e should limit the number of factors considered in a single system. This is one of the main principles of modeling and is termed as relevance.

One of the causes of the above drawbacks is the lack of clear understanding, by managers and designers, of flexibility options and their implications. Slack (1987) observed this in the studies.

CHAPTER - 4

LITERATURE REVIEW

On Flexibility Classification

Flexibility can be anywhere and everywhere. Swamidass.et.al (1987) lists some basic types of manufacturing flexibility in discreet product industry. They are:-Action flexibility, Adaptation flexibility, Application flexibility, Assembly system flexibility, Demand flexibility, Design flexibility, Dispatch flexibility, Job flexibility, Machine flexibility, Machining flexibility, Material flexibility, Mix flexibility, Modification flexibility, Process flexibility, Program flexibility, Product flexibility, Production flexibility, Routing flexibility, State flexibility, Volume flexibility.

A great deal of research has been done on flexibility classification. Basic categories of flexibility have been noted by Slack (1987). Relative vs. Absolute views of flexibility have been noted and discussed by Jaikumar (1984), Gerwin(1987). A classification of flexibility types based on uncertainty has been performed by Gerwin (1987), whereas classification based on the level of decomposition has been proposed by Gerwin (1987) and Taymaz (1988). Time dependant nature of flexibility has been studied by Gustavsson(1984), Gerwin (1987), Slack (1987), Wadhwa and Rao (2000).

On Environmental Uncertainties And Flexibility

Swamidass and Newell (1987) noted that increases in flexibility were generally linked to increased performance and also stated that one way to cope with increased environmental uncertainties is through increased manufacturing flexibility. Gerwin (1993) presented a model that states that environmental uncertainty leads to manufacturing strategy and hence the flexibility requirements of the system.

Zelenovic (1982) stated that the flexibility of a production system is the measure of its capacity to adapt to changing environmental conditions and process requirements. In the given sense one can differentiate:

- The measure of flexibility of a manufacturing system as the value of design adequacy, which is the probability that the given structure of a manufacturing system will adapt itself to environmental conditions and to the process requirements within the limits of the given design parameters.
- The measure of flexibility of a manufacturing system as the value of time needed for the system transformation from one to another job task.

Koste and Malhotra (2000) stated that, every manufacturing facility experiences unique changes, and degrees of change, both in its internal and external environment. The premise of flexible manufacturing is that a facility can be equipped and designed such that it is able to either avoid or adjust to the detrimental effects of these changes. The best type of flexibility –in terms of benefits-is greatly dependent on the particular facility for which it is being sought. A facility must first evaluate the changes it experiences and then appropriately pursue a type or types of flexibility. Clearly, not all the changes can be confronted with neither flexibility, nor can an exhaustive list of all possible types of flexibility can be compiled. They also observed that machine flexibility is necessary building block for other flexibilities and it is regarded as the requirement for the development of mix flexibility. Wadhwa and Rao (2004) have presented a unified framework to explain the manufacturing and supply chain flexibility. Many of these concepts have been derived from FMS flexibility experiences. Attempt to see flexibility in relatively generic way has also been made.

On Manufacturing Flexibility

A review of the manufacturing flexibility literature suggests that the environmental uncertainty and the variability of outputs are the most usually mentioned reasons for an organisation to seek manufacturing flexibility (Corrêa, 1994).

Uncertainty

Swamidass and Newell (1987) argue that 'an organization may find at least some help in coping with the high uncertainties imposed by the environment by increasing its manufacturing flexibility'. Gerwin (1986) suggests that, since there are several kinds of uncertainty, there should be several kinds of corresponding flexibilities to cope with them.

Variability

Together with uncertainty, variability has formed the rationale for the operation's interest in flexibility.

Flexibility,

According to Gerwin (1986) the need for flexibility is increasing because of the changing nature of competition, which, is increasingly based on the responsiveness of the companies to different customer requirements, shorter product life cycles and greater product proliferation. Some authors suggest that flexibility is not necessarily desirable in all circumstances, given that flexibility would never come cheap (Slack, 1989). Slack claims that 'organisations should not make their lives unnecessarily difficult by generating the need for flexibility internally, in order to cope with bad design, poor communication, lack of focus, excessive routing complexity and year-end spurs'. Instead, they should try to eliminate the causes of such imperfections. With regard to controlling uncertainty, Pagell et al (1999) proclaimed that flexibility is a multi dimensional construct. Researchers like Gerwin (1993), Swamidass and Newell (1987) have examined flexibility from the standpoint of the perceived importance of various types of flexibility, and under guise of developing an indicator for firm’s manufacturing strategy.

Researchers and manufacturers have focused on ways of improving the flexibility of a manufacturing system. Sethi and Sethi (1990) and Wadhwa and Rao (2000) have described various types of manufacturing flexibility and provided methods for its improvements. Das and Nagendra (1993) stated that for improving manufacturing flexibility, management should identify and decide on the type of flexibility and its scope corresponding to manufacturing environment, from perspective of benefits achievable by its applications. Brill and Mandelbaum (1990) specified measures of flexibility to correspond to machines performing or participating in tasks within a production environment. Also Brill and Mandelbaum (1990) developed measures of not only flexibility but also adaptivity for machines and groups of machines. Benjaafar (1994) presented various performance measures, such as production rate, flow time, machine utilization, and work in process inventory for evaluating machine sharing in manufacturing systems.

Buzacott (1982) defines two flexibility types, job flexibility and mix flexibility, based upon the premises that the system must be able to cope with two types of change: external and internal and the trade-off between productivity and flexibility, and between job flexibility and mix flexibility. Wadhwa and Rao (2000) have emphasized on manufacturing and design flexibility and suggested that often product flexibility can be more effectively derived as design flexibility. This reduces the need for more expensive manufacturing flexibility. Shewchuk and Moodie (2000), in their study regarding flexibility and manufacturing system design suggested the following recommendations to manufacturing system designers.

- Product flexibility can be increased by increasing part processing flexibility, the processing capabilities of the system and/or the processing capabilities of individual groups.
- Mix flexibility can be increased by employing larger quantity of less flexible machines when part-processing flexibility is low.
- Production flexibility can be increased by increasing the processing capabilities of the system.
- Volume flexibility can be increased simply by increasing the processing capabilities of the system.

On Volume Flexibility

Jack and Raturi (2002) suggested that firms deploy varying strategies for creating volume flexible responses. These include using overtime and temporary workers, cross-training worker, developing complementary product portfolios, creating and maintaining slack resources, creating a network of facilities, improving forecasting and planning systems with information technology, as well as leveraging the firm's ability to negotiate on volume with suppliers and customers. Many definitions of volume flexibility are present. Sethi and Sethi (1990) defined it as the ability to be operated profitably at different overall output levels. Jack and Raturi (2002) also stated it as the ability of an organization to change volume levels in response to changing socio-economic conditions profitably and with minimal disruptions. While Jorden and Graves (1995) stated that volume flexible firms are able to maintain a high level of delivery reliability by preventing out-of-stock conditions for products that are suddenly in high demand with relatively lower inventory than other firms. Vickery et al (1999), observed that firms may selectively choose from a variety of resources options like internal buffers or external outsourcing etc. However, at the core of this volume flexibility capability is the need for a firm to improve coordination at each echelon of its supply chain in the face of increasing demand.

Kaighobadi and Venkatesh (1993) stated that analytical and model building of FMSs is in themselves very significant areas which have to be cleared before a successful installation, integration and implementation of FMS is achieved. There are numerous simulation and analytical models dealing with various aspects of FMS. Among them are perturbation analysis, queuing theory, artificial intelligence and more recently Petri nets and computer simulations

On Machine Flexibility

Machine flexibility refers to various types of operations that a machine can perform without requiring a prohibitive effort in switching from one operation to other. A lot of research had been done in the area of machine flexibilities in manufacturing.

On Organizational Strategy

Many of the early works in organizational theory address how organizations should arrange their structures to respond to uncertainty in the external environment. Burnes and stalker (1961) proposed that as a firm's environment becomes more complex and/or unpredictable, there is a need for more organic structure. Thus, firms in relative certain and predictable environment would have a mechanistic structure with greater subdivision tasks and simpler jobs. In contrast, firms in uncertain and unpredictable environments would have organized structure, with less specialization and more complex jobs. Just as organic structures were deemed necessary for firms to adapt to uncertain external environment, flexibility is seen as a way for manufacturing organizations to adapt to uncertain external environments.

Goldhar (1984) stated that introducing an FMS into an organization has significant implications, such as replacing "economies of scale" with "economies of scope". Kaighobadi and Venkatesh (1993) observed that one of the most important factors contributing to the success of an FMS installation and implementation is the degree of commitment the potential user must make to be successful with its FMS. This degree of commitment is independent of the size of the firm. Contrary to common belief, installation of an FMS is not limited to large corporations with vast financial resources. An FMS can be installed incrementally and such a move can be made through employment of stand-alone machines or utilization of manufacturing cells. Whether FMS introduction is wholesale or incremental, understanding the characteristics of different manufacturing systems will help recognize the potential problems associated with the installation and implementation of these systems. .

On Service Flexibility

Despite the importance that flexibility as a strategic objective has in service operations, the literature still lacks a better understanding of the very nature of service flexibility. Silvestro (1993) proposes three dimensions of service flexibility: volume flexibility, delivery speed flexibility and specification flexibility. Silvestro's proposition is somewhat restrictive as an analytical tool, since her delivery flexibility is concerned only with speed of response and throughput time, not considering the location where the service is delivered. The existence of a number of branches of one bank or sites of one restaurant chain makes both businesses more flexible in terms of the *location.* Moreover, the flexibility dimensions adopted by Silvestro (1993) are only concerned with changes in the demand side of the service. However, unexpected changes can also affect the inputs or even the process itself, which would probably call for a certain level of ability/flexibility to respond/adapt to this kind of change. The approach adopted by Silvestro i.e. the adaptation of manufacturing flexibility concepts to service environments is valuable mainly because: (i) the production of goods and services can be seen as extremes of a continuum, (ii) the service and manufacturing sectors are continuously learning from one another, and (iii) the literature on manufacturing flexibility has already received contributions that allow for a good understanding of the nature of flexibility. However further work on the issue is still needed.

CHAPTER 5

ISM OF PRE-IMPLEMENTATION ISSUES OF FLEXIBLE MANUFACTURING SYSTEMS

INTERPRETIVE STRUCTURAL MODELING (ISM)

ISM is a well known methodology for identifying and summarizing relationships among specific elements which define an issue or problem. It provides a means by which order can be improved on the complexity of such elements (Mandal and Deshmukh 1994).

ISM is an interactive learning process. A set of different and directly related elements are structured into a comprehensive systematic model. The model so formed portrays the structure of a complex set of issue or problem, a system or a field of study. In a carefully designed pattern imply in graphics as well as words.

The method is interpretive as the judgment of the group decides whether and how the variables are related. It is structured as on the basis of relationship an overall structure is extracted from the complex set of variables. It is a modeling technique as the specific relationships and overall structure are represented in a digraph model. It is intended as a group learning process but it can also be used by individual.

ISM starts with an identification of elements which are relevant to the problem or issue and then extends with a group problem solving technique. Then a contextually relevant subordinate relation is chosen. Having decided the element set and the contextual relation, a structured sets interaction model (SSIM) is developed based on pair wise comparison of elements. SSIM is then converted into a rechability matrix and its transitivity is checked. Once transitivity embedding is complete a matrix model is obtained and then the partitioning of elements and extraction of structured model (ISM) is obtained.

STEPS IN ISM

1. Variables are listed down which can be objectives, actions, individuals etc and a contextual relationship is established among variables with respect to which pairs of variables would be examined.
2. A SSIM is developed for variables which indicates pair wise relationships among variables of the system
3. A rechability matrix is developed from SSIM and checked for transitivity
4. The rechability matrix is partitioned into different levels
5. This matrix is developed in its conical form with most zero variables in the upper diagonal half of the matrix and most unitary variable in the lower half.
6. Based on the above matrix, a digraph is drawn with transitive links removed and then connected into ISM by replacing variable nodes with statements.
7. Ism model is checked for conceptual inconsistencies.

STRUCTURED SETS INTERACTION MODEL (SSIM)

Keeping in mind the conceptual relationship for each variable, the existence of a relation between any two sub variables (I and j) and the direction of the relation is questioned. Four symbols are used for the type of relation that exists between two sub variables under consideration.

- V- for relation from I to j but not in both directions.
- A - for relation from j to j but not in both directions
- X- for relation s in both directions
- O- If relation between the variables does not exit.

For analyzing the variables, a contextual relationship is chosen, such that one variable leads to another based on this a SSIM is developed. To obtain consensus, the SSIM was discussed in a group of experts.

RECHABILITY MATRIX

The SSIM format is transformed into a rechability matrix format by transforming the information in each entry of the SSIM into 0's and 1's in the rechability matrix.

The situations are as follows

1. If the (i, j) entry in the SSIM is V, then the (i, j) entry in the rechability matrix becomes 1 and that of (j, i) entry becomes 0.
2. If the (i ,j) entry in the SSIM is A , then the (i, ,j) entry in the rechability matrix becomes 0 and that of (j, i) entry becomes 1.
3. If the (i, j) entry in the SSIM is X, both entries in the rechability matrix becomes 1.
4. If the (i, j) entry in the SSIM is O, both entries in the rechability matrix becomes 0.

FLOW DIAGRAM FOR PREPARING ISM

The figure 6 below shows the flow diagram for the preparation of ISM model for the pre- implementation issues in Flexible manufacturing systems.

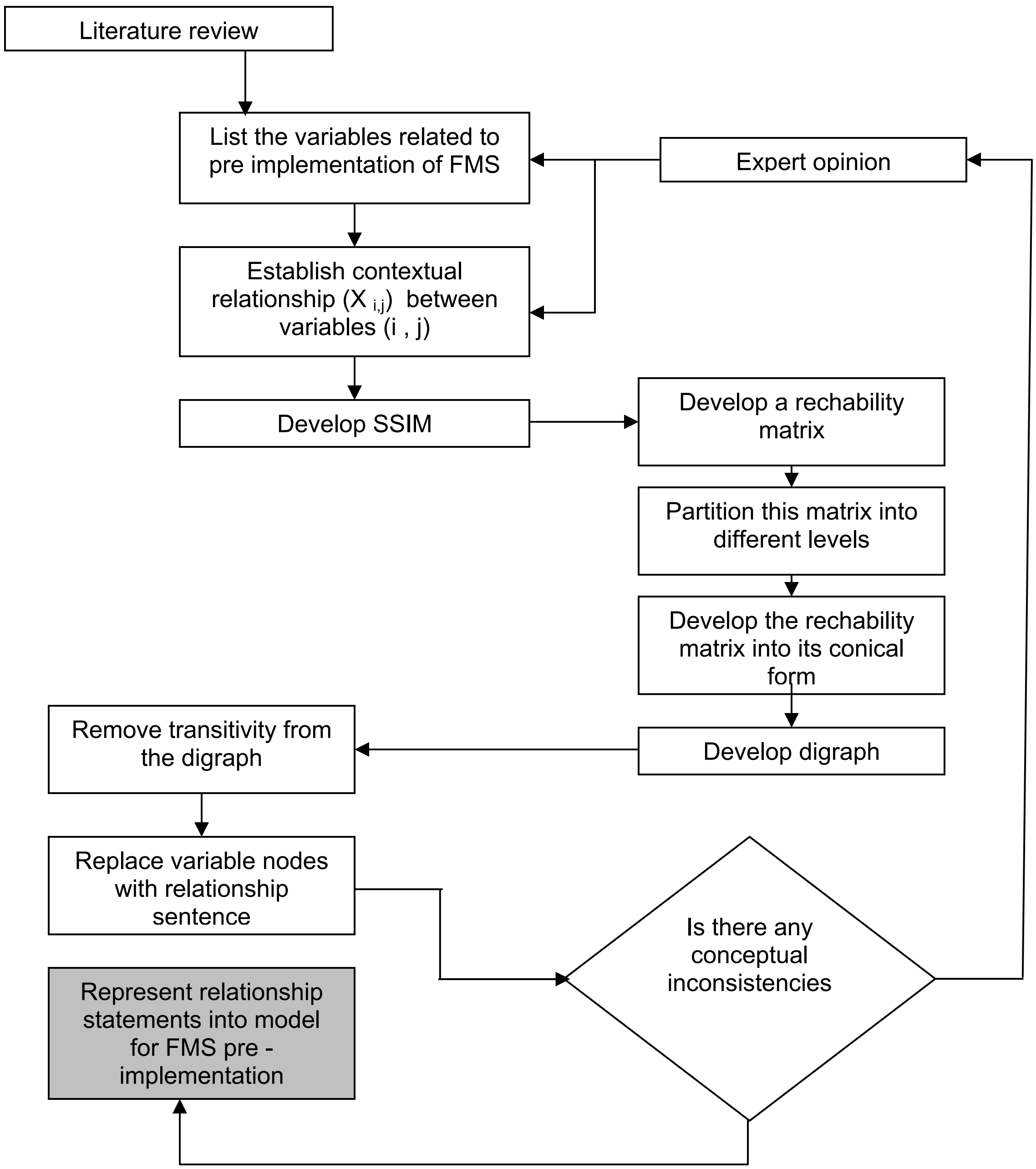

Figure 6: The flow diagram for the preparation of ISM model

ISM CONSTRUCTS

1. Starting point – a list of more or less related concepts. These may be a result of Brain storming or informal representation scanning.
2. Result – the starting concepts are grouped, categorized or arranged in hierarchies or arbitrary graphs according to some set of relations. Thus existing knowledge is refined and made formal.
3. Techniques – historically a manual technique but computerized assistance exists. The procedure varies depending on the number of concepts and the types of structure to be build. Main ingredients are a well structured and a rapid sequence of moderate discussions. ISM can be used to classify concepts when building an hierarchy or to structure conceptual relations, such as temporal or importance graph.
4. Interface modality – largely modal, the group members responds to prompts that require them to vote.
5. Interruptability – interruptible to perform brain storming and some other technique particularly when the group feels that the input concepts are inadequate to compose the structure being built.
6. Feedback potential – typically low, it is possible to observe the structure being built but this can distract the elicited knowledge. It is generally best to let the participants respond t the prompts by thinking about what they are being asked rather than attempting to look it up.
7. Group efficiency – most useful in a group but can be performed individually.

LITERATURE REVIEW ON ISM

Mandal and Deshmukh (1994) have stated that ISM is a well known methodology for identifying and summarizing relationship among specific elements which define an issue or problem and it provides a means by which order can be impaired on the complexity of such elements.

Saxena et al (1990) identifies the key variables using direct as well as indirect inter relationships amongst the variables and presents the results of the application of ISM methodology to the case of “energy conservation in Indian cement industry”.

Saxena et al (1992) also used ISM to develop direct relationship matrices.

Sharma et al (1995) also used ISM to develop a hierarchy of actions required to achieve future objectives of waste management in India. Mandal and Deshmukh (1994) have analyzed some important vendor selection criteria using ISM which shows the inter relationship of criteria and their levels. These criteria have also been categorized depending on their driver power and dependence.

FMS IMPLEMENTATION VARIABLES

Based on literature review and expert opinion the following FMS implementation variables have been identified:-

1. Cost of FMS
2. Compatibility with existing system
3. Technology change of the FMS
4. Competitiveness in the market
5. Uncertainty
6. Customer preferences
7. Productivity
8. Product life cycle
9. Human resources
10. Government policies

Cost of FMS installation

The value of the financial aspects of FMS is a main item in the decision making process of FMS implementation. FMS is a concept rather than a machine. It is a collection of many aspects of manufacturing in a very effective and logical way, with complete control and flexibility. This makes the system very expensive and that's why vary many organizations are very much reluctant to go for FMS. The cost of implementation of FMS also depends on the level of flexibility required.

Since the evolution of FMS can be attributed to the complexities and uncertainties in the business process and manufacturing, and since the expanses of acquiring or implementing FMS in an organization is very high. Managers find it very hard to take a timely decision towards FMS implementation. Although the traditional concept of economics of scale is being replaced by the notion of economics of scope, it has been observed that the current practice of justification of investment in FMS is difficult as there exists only very weak methods for analyzing the economic value of flexibility in manufacturing.

Both the internal and external attribution of implementation cost one time investment and overhead investment should be thoroughly analyzed before going for FMS implementation.

Productivity, compatibility, Government regulations, human resources, technology can have direct relations with this cost factor. Availability of materials, machines etc. can be attribute to government regulations, taxations, sanctions will also have a profound impact on the installation and working of a FMS.

Compatibility with existing systems:-

The full utilization of FMS is obtained only when the implemented system is compactable with the existing system. If the implementation is done on a pre-existing system and if no other compatibility issue arises in the future, if the implementation of FMS is from scratch.

It is seen that management problems associated with new manufacturing systems arises from their dependence on integration, not just within the manufacturing process, but across the enterprise as a whole and even extending beyond the enterprise to include suppliers and customers.

Aggarwal (1995) stated that even the best of individual subsystems will fail to deliver goods. Collectively if they are not fully and functionally integrated and in practice achieving integration is quite hard and often extremely difficult task.

At the physical facility or plant level, the system integration relates to interfacing various organs like CNC machining centers, conveyors, robots AGV, ASRS and other elements of FMS. Computer plays a major role in the control aspect electronics is the critical and most vital facilitator of the process (shaw et al 1997).

Other critical elements of integration include the interface between design engineering and plant control, between marketing design and quality control, between management practices and CAD. (Malhotra et al 2001)

Another level of integration is that between manufacturing and organizational strategies, manufacturing and human resources management and between human knowledge and mechanical system.

Technology change of the FMS

Change in technology should be thoroughly visioned and analyzed before any pre-implementation decision is taken. Now-a-day changes in technologies are taking place at a rapid rate and an organization has to realize and cope up with these changes in order to become competitive.

Starting with a conceptual framework, Aggarwal (1995) distinguished between hard C, CAD/CAM, NC/CNC, robots etc.); soft (JIT, TQM, concurrent engineering etc.) and hybrid (materials requirement planning, manufacturing resource planning etc.)

Implementation and operation of computerized manufacturing systems is a very well understood and one reason could be that FMS is very much a technological version.

Thus technology changes have a profound impact in the cost of implementation of FMS and also on the productivity of the organization. New and improved machine and techniques when applied at the right time and in the right way have always contributed to the enhancement of productivity thus improving the competitiveness of the organization.

Competitiveness

The goal of every organization is to be competitive in the market and hence profitable. Many a times the decision pertaining to the implementation of FMS is taken in haste as to remains the front runner in the market and to sustain/increase its market share. Competitiveness is also a major factor in determining the level of flexibility required. The change in customer preference which may lead to the introduction of a new product or the modification of an existing product determines the competitive position of the organization. The various factors like cost of implementation, technological changes, uncertain environment, length of product life cycle, customer preference, etc. will affect this variable.

Uncertainty present in the market

The evolution of the concept of FMS took place with the advent of uncertainty. In today's manufacturing environment uncertainty is present everywhere and to be competitive and profitable the organization has to address the issues of uncertainty very systematically and minutely.

An organization must first evaluate the changes it experience and then appropriately pursue a type or types of flexibility needed and then go for the implementation decision of FMS uncertainty can be both internal and external and classification of flexibility based on uncertainty has be done Gerwin (1987), Swamidass and Newell (1987) noted that increase in flexibility were generally linked to increased performance and also stated that one way to cope with increased uncertainty is through FMS.

This pre-implementation variable has a profound effect on the other variables like cost, technology change, productivity and product life cycle, which in turn decides the competitive nature of the organization.

Customer preferences:-

In today's business environment customer is the main factor who makes or breaks an organization. The organizations have to cater to the small needs of the customer to remain competitive in its field. A competitive organization will quickly respond to th customers needs. For this it should be both flexible in both its operational and managerial levels. FMS is a management tool to respond to the smallest variations in customer preferences.

It is seen that customer preference has a direct relation with the length of product life cycle and competitiveness. Changes in customer preference can lead to changes in product life cycle, uncertainty, technology change, cost of FMS, productivity, and finally to the competitive position of the organization.

Productivity:-

An organizations ultimate success depends on its ability to utilize resources and meet the needs of the market. There internal factors steer demand and in turn volume of commodity and cost. In addition to this there must be flexibility with respect to external factors like fluctuations, technological changes, uncertainty; human resources have a profound effect on this productivity variable. Changes in the length of product life cycle have an indirect effect on the productivity. Effective installation and working of FMS will lead to effective productivity and thus to the maximum profitability of the organization

Length of product life cycle:-

This factor decides the length or duration, the product takes from its birth to decline phase. Every product has its own specific life cycle and it is important for an organization to understand the various facets of this variable. in the case of organization producing a variety of product , it is even more necessary to analyze the various time limit of each product and manufacture accordingly so that the competitive aspect of the firm is still maintained

Customer preference and length of product life cycle have a two way relation in the analysis of pre installation variables. The direct relationship, this variable can have is with uncertainty, technology change, but when we take the whole scenario, the length of product life cycle have indirect relation with cost, productivity and finally to competitiveness.

Government policies:-

There are many factors by which government policies effect the cost of FMS. Like sometimes the raw material is to be imported from outside countries. The import duty or taxation is very high; it will increase the cost of FMS. Also if the company decides to expand the existing manufacturing system and if they have to buy the nearby land of government, the land prices decided by the government will also effect the cost of FMS. Also sometimes there are some special materials or some hazardous materials which are to be imported for which government permission is necessary.

Human Resources:-

The availability of human resources also affects the cost of FMS. As sometimes to increase the productivity we are required to increase our manpower or also because of lack of skilled labor we have to call the manpower from outside countries also. So their higher salaries or their extra remunerations like air fare, lodging, boarding etc. will increase the cost of FMS. Also sometimes to improve the skills of manpower the management is required to send them outside the countries for training for training. This will also increase the cost of FMS.

For analyzing these variables, a contextual relationship is chosen, such that one variable leads to another. Based on this contextual relationship a SSIM is developed. This is shown in figure 7.

Structural self – interaction matrix

	10.	9.	8.	7.	6.	5.	4.	3.	2.
1.	A	A	O	O	O	O	V	A	A
2.	O	O	O	O	O	O	O	O	
3.	O	O	A	V	O	A	O		
4.	O	O	V	O	X	A			
5.	O	O	A	V	V				
6.	O	O	X	O					
7.	O	A	O						
8.	O	O							
9.	O								

Figure 7:- Structural self – interaction matrix

Following the rules given above, rechability matrix for the variables is prepared as in table 8

Elements	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**10.**
1.	1	0	0	1	0	0^+	0	0^+	0	0
2.	1	1	0	0^+	0	0	0	0	0	0
3.	1	0	1	0^+	0	0	1	0	0	0
4.	0	0	0^+	1	1	1	0	1	0	0
5.	0^+	0	1	0^+	1	1	1	0^+	0	0
6.	0	0	0^+	1	0^+	1	0	1	0	0
7.	0	0	0	0	0	0	1	0	0	0
8.	0^+	0	1	0^+	1	1	0^+	1	0	0
9.	1	0	0	0^+	0	0	1	0	1	0
10.	1	0	0	0+	0	0	0	0	0	1

Table 8:- Rechability matrix for the variables

1^+ entries are included to incorporate transitivity to fill the gap if any in the opinion collected during development of structural self instructional matrix.

The diagraph obtained from the above table is represented below as figure 8

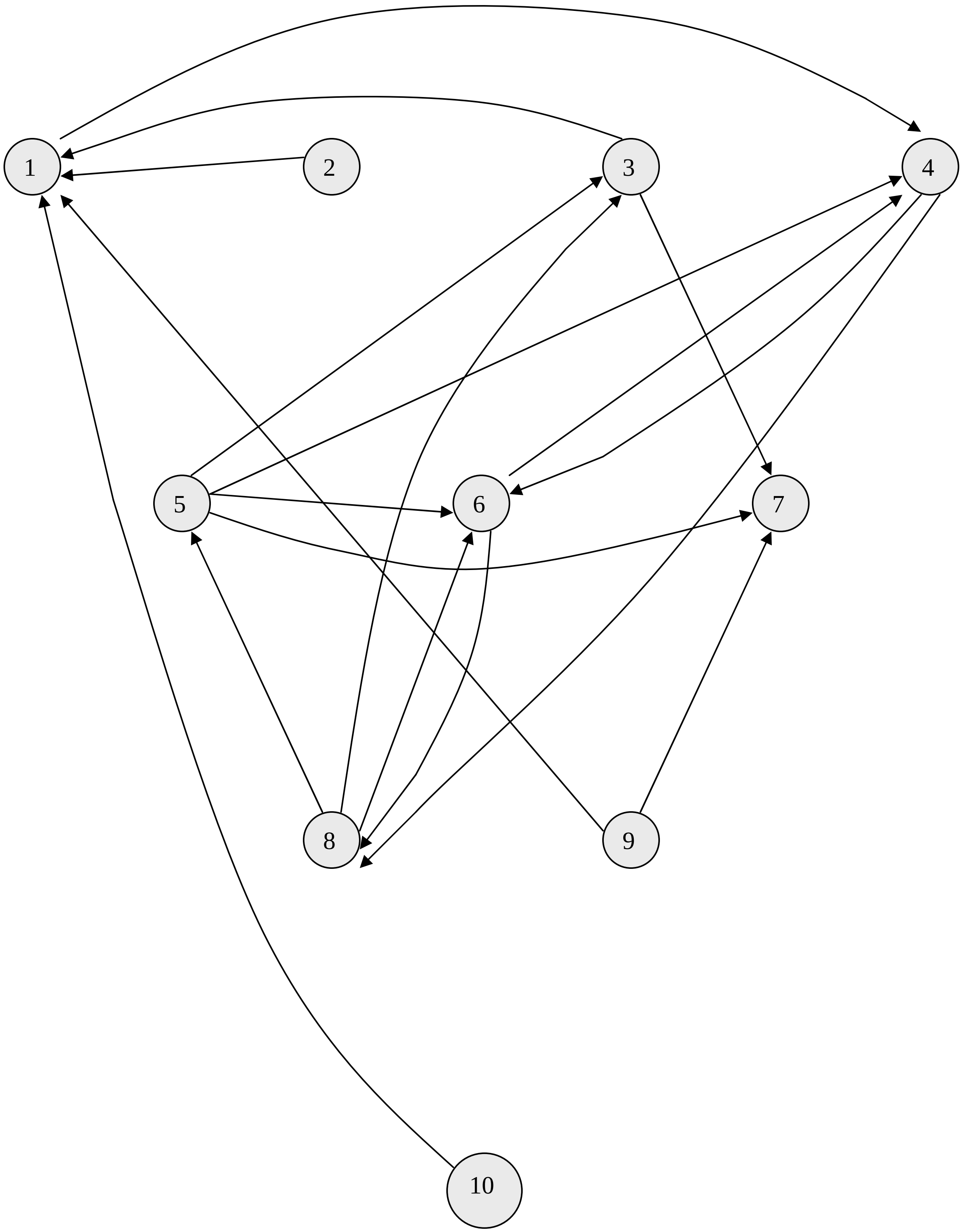

Figure 8:- Diagraph of pre-implementation issues

Table 9 shows the levels of FMS variables obtained from the rechability set, Antecedent set and their intersection

Elements	Rechability set	Antecedent set	Intersection	Level
1.	1, 4, 6, 8	1, 2, 3, 5, 8, 9, 10	1, 8	3
2.	1, 2, 4	2	2	4
3.	1, 3, 4, 7	3, 4, 5, 6, 8	3, 4	3
4.	3, 4, 5, 6, 8	1, 2, 3, 4, 5, 6, 8, 9, 10	3, 4, 5, 6, 8	1
5.	3, 4, 5, 6, 7, 8	1, 4, 5, 6, 8	4, 5, 6, 8	2
6.	3, 4, 5, 6, 8	1, 4, 5, 6, 8	4, 5, 6, 8	2
7.	7	3, 5, 7, 8, 9	7	4
8.	1, 3, 4, 5, 6, 7, 8	1, 4, 5, 6, 8	1, 4, 5, 6, 8	1
9.	1, 4, 7, 9	9	9	4
10.	1, 4, 10	10	10	4

Table 9: levels of FMS variables

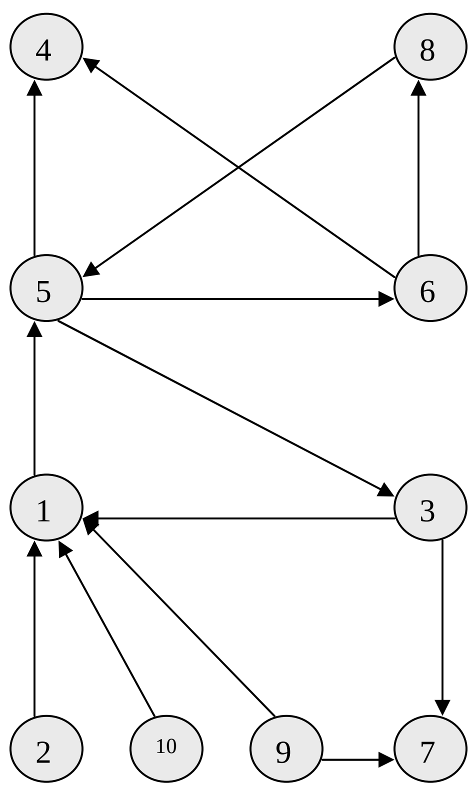

Figure 9:- ISM Model of pre-implementation issues

With the help of the rechability matrix four different levels of these variables and their relationships with each other is obtained. The variable at the top level are called the driven variables and the bottom level variables are called driver variables. For improving the overall performance of the flexible manufacturing systems, it's necessary to view the system as a whole. Before the actual implementation of FMS, the mapping of the processes and environment helps in selecting the right type of FMS..

The variables product life cycle and competitiveness is driven by uncertainty and customer preferences which are further driven by cost of FMS and technology change of the FMS. The drivers of all these variables are government policies, productivity, human resources and compatibility with existing system

CHAPTER-6

C-F-P ANALYSIS IN THE DESIGN OF FLEXIBLE MANUFACTURING SYSTEMS

In the recent past flexible manufacturing systems has caught the attention of the researchers and practitioners. Building flexibility in the manufacturing systems to cope up the uncertainties and variabilities has been the approach followed. Many a time, the flexibility dimensions proposed are not matching with the requirement. This approach has resulted in improving the performance of the supply chain but in many cases such intervances have increased the cost of operations. It is important to design the manufacturing system contingent upon the environment in which it has to operate.

From the literature the various dimensions of flexibility related to supply, production and distribution sides are identified. A model is proposed to select the right dimension of flexibilities based on complexity index of the flexible manufacturing systems. The proposed model will enhance the responsiveness of the manufacturing systems at minimum cost and efforts leading to greater competition.

Turbulent environment has brought about drastic changes in how we define and manage today's industry. The importance of the concept of flexibilities in manufacturing system and the economical design and integration of flexible manufacturing systems are the crucial areas in this competitive and unpredictable environment. Intense worldwide industrial competition has endangered the volatile dynamics of business environment change. These two factor i.e. competition and dynamism have brought a number of changes in the nature and structure of global industry. Some observable changes are shorter product life cycles, shorter product change-over cycles, higher rate of new product development, shorter production runs, quality, and productivity - quality integration, in terms of zero-defect production, Total Quality Control (TQC), or company wide Total Quality Management (TQM), equipment and process technology as a strategic resource, flexible manufacturing systems (FMS), increasing importance of project management, new approaches to and styles of marketing, training of employees in multiple work skills, team participation, and responsibility , increasing role and use of information technology in management including Internet, intranet and extranet, increasing use of automated decision aids like Decision Support Systems (DSS), Expert Systems (ES), Executive Information Systems (EIS), and simulation experiments, computer aided design (CAD) and manufacturing (CAM), redesign of business processes and work flows. These changes combined together improve the flexibility and performance of the Flexible manufacturing systems.

In such a turbulent and volatile environment, both increasing uncertainty and complexity characterize the nature and intensity of global industrial competition. These two factors are further complicated by the sub factors and their interactions as shown in figure 10.

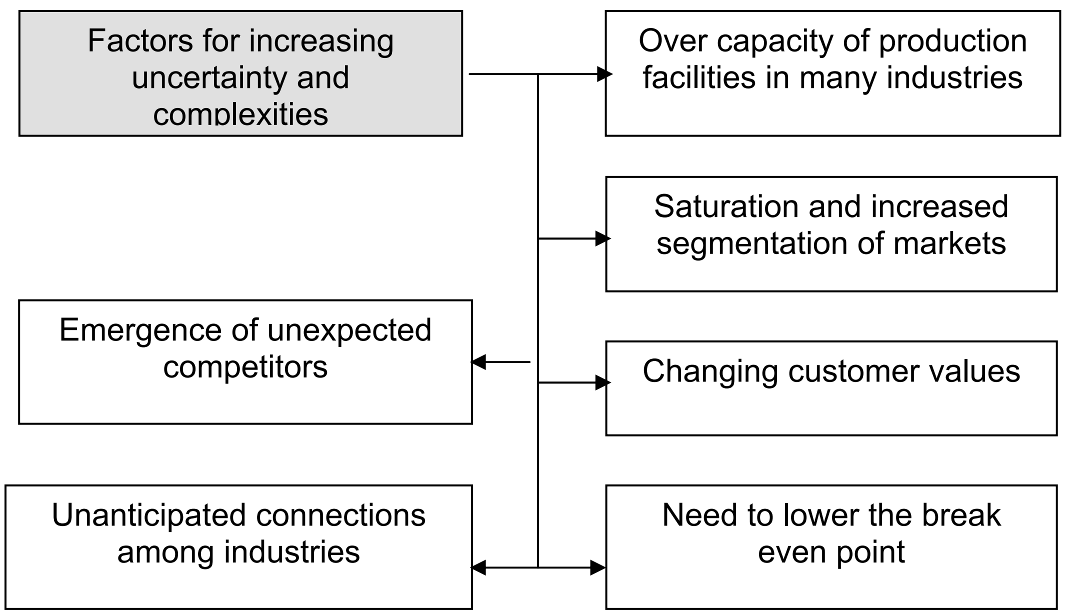

Figure 10: Factors for Increasing Uncertainty and Complexities

C-F-P FRAME WORK

In Complexity- Flexibility- Performance framework (C-F-P framework), the various perspectives are interdependent and tightly interrelated. The concept of influence relationship- be it preference, pressure or power - is the pertinent relationship between the three types of concepts. This is as shown in the figure 11.

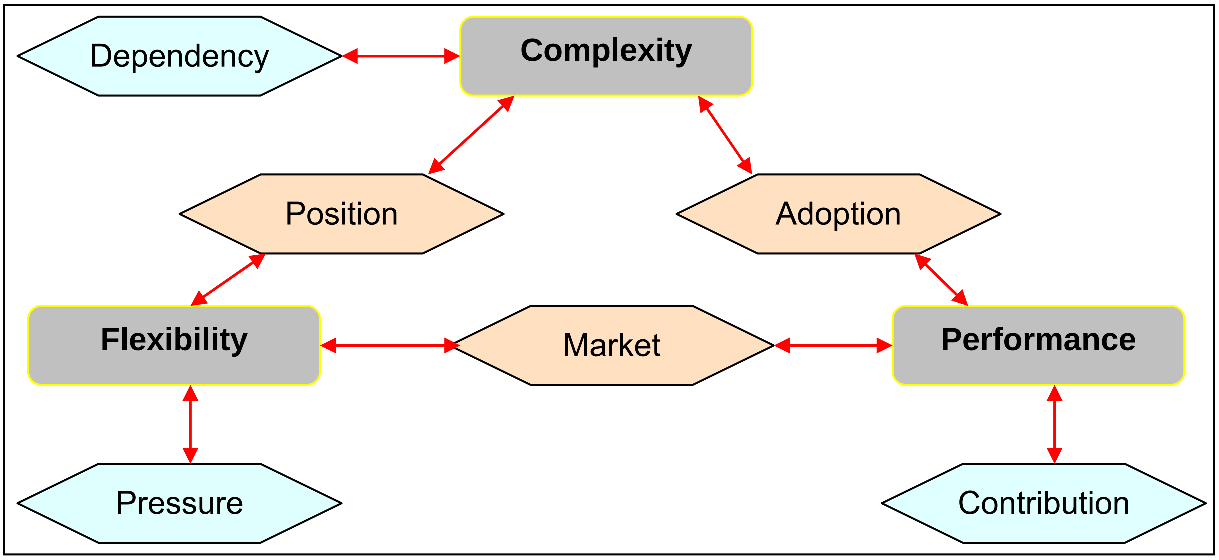

Figure 11: Complexity –Flexibility – Performance Framework

While the influence concept is generic, relationships between a particular pairs of elements have an adapted meaning.

Flexibility and Performance are linked by a ***"market"*** relationship. By adopting certain value scheme as an expression of their needs, end users influence the type of products that are offered by the different flexibility systems and determine their relative power (market pull). Conversely, flexibility can often shape and even create user (Performance) needs by offering innovative value propositions (technology push).

Flexibility and Complexity are linked by a ***"position"*** relationship. On the one hand, Flexibility can influence the outcome of certain issues by strategically positioning themselves on them and exerting their power. On the other hand, the awareness of certain issues constrains the strategic positioning that flexibility can take and influences their power.

Performance and Complexity are linked by an ***"adoption"*** relationship in the sense that the awareness of complexity issues can affect end user needs and, therefore, their decision to adopt a particular value offer or technology. Conversely, the adoption of certain solutions may affect, positively or negatively, the future outcome of certain complexity issues.

Flexibility is influenced by ***"pressure"*** relationship which may stem from an uneven power balance in a business negotiation, competitive threats or other kinds of intentional and social relationships.

Complexities are influenced by ***"dependency"*** relationship i.e. The realization of a particular outcome of an issue can have an impact on the likelihood of realization of the outcomes of other issues.

Finally, Performance is influenced by ***"contribution"*** relationships i.e. The adoption of a particular use or technology can influence another one. The contribution can be positive, such as with complementary uses, but also negative, such as with substitute uses, as well as disruptive.

DESIGN OF FLEXIBLE MANUFACTURING SYSTEMS

From the above framework it has been seen that complexities in supply chain leads to the need of flexibilities which in turns leads to the improvements in performance and level of competitiveness. Flexible manufacturing systems in any organization can totally change the concept of traditional business unit and if designed and implemented properly will result in cost effectiveness and greater flexibilities in manufacturing, improved quality, lower unit cost and reduced lead time. These issues span a large spectrum of a firm's activities from strategic through tactical to operational level. Other than these important issues the various key areas that should be taken care off are in the field of distribution network configuration, inventory control, distribution strategies, integration and partnering, product design, IT, DSS and customer values.

The C-F-P analysis for the design of flexible manufacturing system is as shown in Figure 12.

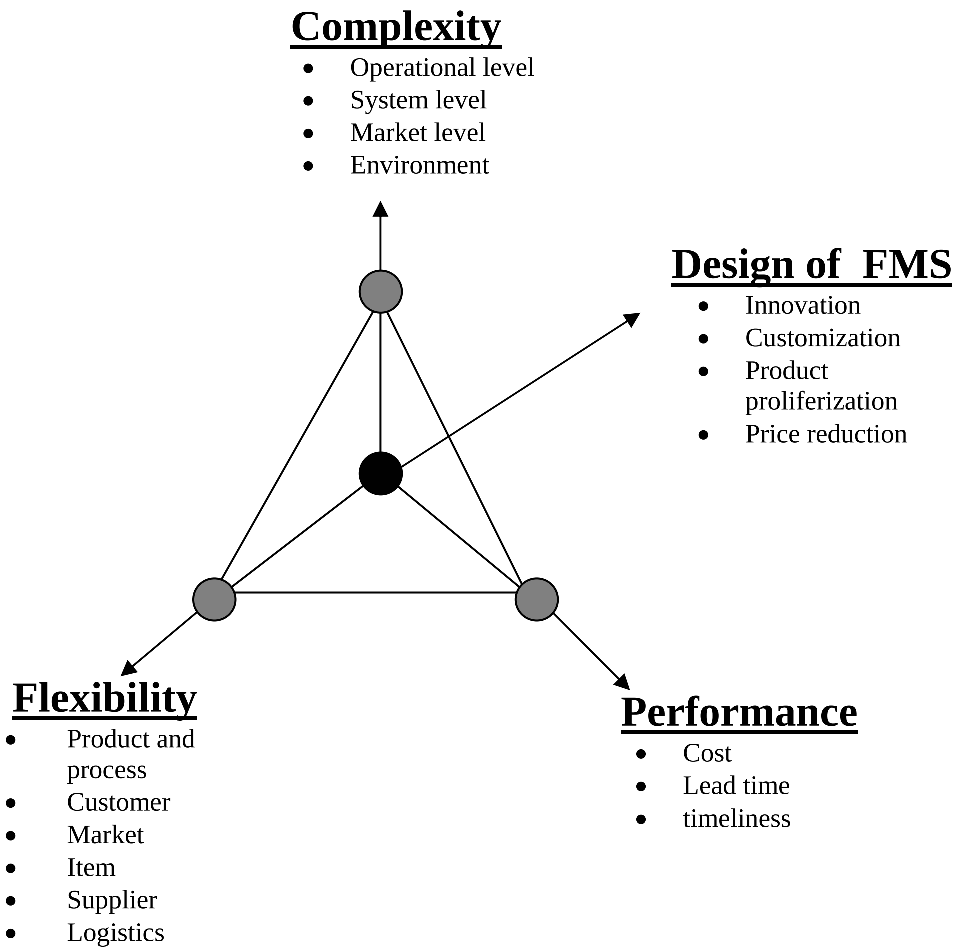

Figure 12: The C-F-P analysis of the design of flexible manufacturing system

MAPPING OF ATTRIBUTES FOR THE FMS IMPLEMENTATION OF ABC Ltd.

For C-F-P analysis the first step is identification of the variables which make the system complex. These variables can be from the following categories:-

- Product related
- Process related
- Customer related
- Market related
- Supplier related
- Logistics related

After identifying these variables, they are described for the conditions of low complexity and high complexity at five levels. A score of 0 is given for negligible complexity and 1.0 if variable is highly complex. After having this format, a company can be mapped and its complexity score and dimensions of complexity can be identified. Based on this diagnosis, a plan for incorporating suitable dimensions of flexibility can be prepared. The plan can be simulated to see its impact on the key performance areas of the organization. Table 10 gives the mapping of attributes for the FMS implementation of ABC Ltd. Table 11 gives the scoring of variables which indicates the contribution of each variable in the pre implementation decision making process

S. No	**Attributes**	**Characteristics**				
		1.0	0.75	0.50	0.25	0
	Cost of FMS					
1.	Available capital	V. large	Large	Sufficient	Less	V. less
2.	Inflation and Capital Market	V. large	Large	Sufficient	Less	V. less
3.	Pressures to continually drive down FMS cost	V. large	Large	Sufficient	Less	V. less
4.	Financial System Capability	V. large	Large	Sufficient	Less	V. less
5.	Availability of reserve capital	V. large	Large	Sufficient	Less	V. less
	Compatibility with existing system					
6.	Substitutability in process	V. large	Large	Sufficient	Less	V. less
7.	Levels in BOM structure	Flat	Few	Moderate	Many	Too Many
8.	Substitutability in software	V. High	High	Medium	Low	V. Low
9.	Substitutability in hardware	V. High	High	Medium	Low	V. Low
10.	Compatibility with suppliers	V. Good	Good	Average	Poor	V. Poor
11.	Compatibility with end customers	V. Good	Good	Average	Poor	V. Poor
12.	Length in compatibility makeover	V. Short	Short	Moderate	Long	V. Long
	Technology change of the FMS					
13.	Process technology	V. Good	Good	Average	Poor	V. Poor
14.	Materials technology	V. Good	Good	Average	Poor	V. Poor
15.	Development of Materials	V. Good	Good	Average	Poor	V. Poor
16.	New Technological Strategies	V. Good	Good	Average	Poor	V. Poor
17.	Developing new manufacturing capabilities	V. Good	Good	Average	Poor	V. Poor
18.	Quality technology	V. Good	Good	Average	Poor	V. Poor
19.	Design Modularity	V. Good	Good	Average	Poor	V. Poor

	Competitiveness in the market					
20.	Capability of other companies dealing with same product	V. Good	Good	Average	Poor	V. Poor
21.	Market share	V. low	Low	Moderate	High	V. high
22.	Ease in forecasting	V. Difficult	Difficult	Average	Easy	V. Easy
23.	Marketing strategies	V. Poor	Poor	Average	Good	V. Good
24.	Company objectives	V. Rigid	Rigid	Average	Flexible	H. Flexible
25.	Ease of decision making	V. Difficult	Difficult	Average	Easy	V. Easy
	Uncertainty present in the market					
26.	Uncertainties Due To Measurement Procedure	V. high	High	Moderate	Low	V. low
27.	Uncertainties Due To Production Variation	V. high	High	Moderate	Low	V. low
28.	Uncertainties at distribution centres	V. high	High	Moderate	Low	V. low
29.	Demand uncertainty	V. high	High	Moderate	Low	V. low
30.	Supply uncertainty	V. high	High	Moderate	Low	V. low
31.	Lead Time Uncertainty	V. high	High	Moderate	Low	V. low
	Customer preferences					
32.	Market	V. Poor	Poor	Average	Good	V. Good
33.	Manufacturing and marketing requirements	V. low	Low	Moderate	High	V. high
34.	Customer Satisfaction	V. low	Low	Moderate	High	V. high
35.	Product Variety	Few	Low	Medium	High	V. High
36.	New product introduction	V. Difficult	Difficult	Average	Easy	V. Easy
	Productivity					
37.	Number of Units produced	Few	Low	Medium	High	V. High
38.	No. of Components	Few	Low	Medium	High	V. High
39.	Manufacturing Lead Time	V. low	Low	Moderate	High	V. high
	Product life cycle					
40.	Time taken Product to mature	V. large	Large	Sufficient	Less	V. less
41.	Difficulties to change the Life cycle period	V. Difficult	Difficult	Average	Easy	V. Easy
	Human resources					
42.	Safety and Health	V. Good	Good	Average	Poor	V. Poor
43.	Education & Training	V. Good	Good	Average	Poor	V. Poor

44.	Workforce Suggestions	V. Good	Good	Average	Poor	V. Poor
45.	Teamwork, Morale, Pride	V. Good	Good	Average	Poor	V. Poor
46.	Injuries, Absenteeism	V. low	Low	Moderate	High	V. high
47.	Desired Skills	V. Good	Good	Average	Poor	V. Poor
48.	Labour Market	V. Good	Good	Average	Poor	V. Poor
49.	Quality and Experience of Employees	V. Good	Good	Average	Poor	V. Poor
50.	Multiskilled Workers	V. High	High	Medium	Low	Few
51.	Empowerment, teamwork, skills	V. Good	Good	Average	Poor	V. Poor
	Government policies					
52.	Cost of raw materials	V. high	High	Moderate	Low	V. low
53.	Import/export facilities	V. Poor	Poor	Average	Good	V. Good
54.	Technical assistance	V. Poor	Poor	Average	Good	V. Good
55.	Fiscal policy of governments	V. Poor	Poor	Average	Good	V. Good

Table 10: Mapping Of Attributes for the FMS Implementation of ABC Ltd

Attribute No	Attribute	Value	Score	Discussion
	Cost of FMS			
1.	Available capital	1.0	0.85	Highly contributing variable
2.	Inflation and Capital Market	1.0		
3.	Pressures to continually drive down FMS cost	0.5		
4.	Financial System Capability	1.0		
5.	Availability of reserve capital	0.75		
	Compatibility with existing system			
6.	Substitutability in process	0.75	0.5	Neutral variable
7.	Levels in BOM structure	0.75		
8.	Substitutability in software	0.5		
9.	Substitutability in hardware	0.75		
10.	Compatibility with suppliers	0.25		
11.	Compatibility with end customers	0.25		
12.	Length in compatibility makeover	0.25		

Technology change of the FMS				
13.	Process technology	0.5	0.71	Contributing variable
14.	Materials technology	0.75		
15.	Development of Materials	0.75		
16.	New Technological Strategies	0.5		
17.	Developing new manufacturing capabilities	0.75		
18.	Quality technology	1.0		
19.	Design Modularity	0.75		
Competitiveness in the market				
20.	Capability of other companies dealing with same product	1.0	0.75	Contributing variable
21.	Market share	0.5		
22.	Ease in forecasting	0.75		
23.	Marketing strategies	0.75		
24.	Company objectives	0.75		
25.	Ease of decision making	0.75		
Uncertainty present in the market				
26.	Uncertainties Due To Measurement Procedure	0.75	0.62	Contributing variable
27.	Uncertainties Due To Production Variation	0.75		
28.	Uncertainties at distribution centers	0.5		
29.	Demand uncertainty	0.5		
30.	Supply uncertainty	0.5		
31.	Lead Time Uncertainty	0.75		
Customer preferences				
32.	Market	0.75	0.6	Contributing variable
33.	Manufacturing and marketing requirements	0.75		
34.	Customer Satisfaction	0.5		
35.	Product Variety	0.25		
36.	New product introduction	0.75		
Productivity				
37.	Number of Units produced	0.25	0.33	Nominal variable
38.	No. of Components	0.5		
39.	Manufacturing Lead Time	0.25		

Product life cycle				
40.	Time taken Product to mature	1.0	0.87	Highly contributing variable
41.	Difficulties to change the Life cycle period	0.75		
Human resources				
42.	Safety and Health	0.5	0.35	Nominal variable
43.	Education & Training	0.25		
44.	Workforce Suggestions	0		
45.	Teamwork, Morale, Pride	0.5		
46.	Injuries, Absenteeism	0.25		
47.	Desired Skills	0.5		
48.	Labour Market	0.75		
49.	Quality and Experience of Employees	0.25		
50.	Multiskilled Workers	0.25		
51.	Empowerment, teamwork, skills	0.25		
Government policies				
52.	Cost of raw materials	0.75	0.75	Contributing variable
53.	Import/export facilities	0.75		
54.	Technical assistance	0.75		
55.	Fiscal policy of governments	0.75		

Table 11:- Scoring of variables

Discussion

The variables analyzed during the pre implementation stages are:

1. Cost of FMS (0.85)
2. Compatibility with existing system (0.5)
3. Technology change of the FMS (0.71)
4. Competitiveness in the market (0.75)
5. Uncertainty (0.62)
6. Customer preferences (0.6)
7. Productivity (0.33)

8. Product life cycle (0.87)
9. Human resources (0.35)
10. Government policies (0.75)

It is seen that the variable greater than the C-F-P index play a greater role in the pre implementation decision making process and that less than the C-F-P index play a small role.

In the given scenario we find that the variables cost of FMS (0.85) and Product life cycle(0.87) have a greatest contribution to the pre implementation decision. Then comes the variables Technology change of the FMS (0.71), Competitiveness in the market (0.75), Uncertainty (0.62), Customer preferences (0.6) and Government policies (0.75). The variable Compatibility with existing system (0.5) is seen to be a neutral variable. The variables Productivity (0.33) and Human resources (0.35) are seen to play a nominal role in the implementation decision.

Taking the variables as a whole, we find that the obtained index of 0.65 is greater than the taken C-F-P index. So the pre implementation decision regarding the organization as a whole is slightly complex.

Then based on this analysis and figure 13, a decision table is prepared as given in table 12.

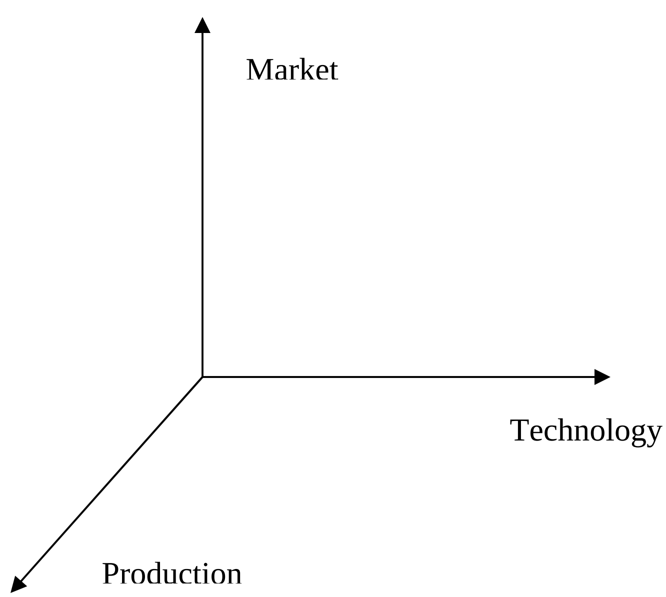

Figure 13:- Three broad areas of pre-implementation decision process

Scenario	Need of FMS due to			Comment
	Technology condition	Market condition	Production condition	
1.	Low	Low	Low	No need for FMS
2.	Low	Low	High	Limited automation
3.	Low	High	Low	Need base FMS as FMS technology is not available or expensive
4.	Low	High	High	Strategies for manufacturing to improve competition (like JIT, SCM, Kanban, Kaizan, simulation etc…)
5.	High	Low	High	Full automation and exploitation of easy availability of flexibility
6.	High	Low	Low	Need base FMS as the market and is very low
7.	High	High	Low	Need base FMS as the production is low and market is high
8.	High	High	High	Full FMS as the conditions are very conducive, the technology, market and production all are high

Table 12:- Eight scenarios of C-F-P analysis

I

In this table the ten pre-implementation variables are grouped into three broad categories namely technology, market and production system, with the exception of the last variable i.e. government policy which have a separate existence in itself. The variables coming under technology are cost of FMS, compatibility with existing system and technology change of the FMS; the variables coming under market are competitiveness in the market, uncertainty and customer preferences; and the variables coming under production system are productivity, product life cycle and human resources.

The three categories are examined and eight different scenarios are found to exist, these scenarios decide the type of FMS needed, based on the complexity of each category and the relationship within each variable.

The first scenario is when market is low, technology is low and production is also low. In this case there is no need for any FMS. The second scenario is when technology is low, market is also low but production is high, it is required to limit the automation processes to improve the competitiveness. The third scenario is when technology is low, market is high and production is low, in this case the implementation of FMS is need based. The forth scenario is when technology is low and market and production is high, here since the technology is low we have to go for the various indigenous strategies and technology management process to remain competitive. The fifth scenario is when technology is high, market is low and production is high, in this case it is seen that the management usually go for full automation in their manufacturing system. In the sixth and seventh scenario i.e. when technology is high, market is low and production is low; and technology is high, market is high and production is low, in both these cases the implementation of FMS is need based. In the final scenario i.e. when technology, market and production all are high then the management is required to go for full FMS to survive in the market.

The variable Government policies have an indirect and superficial affinity to all the three categories. If the value of this variable increases then the decision making process regarding the FMS pre-implementation will be complex and difficult and if the value is low then the decision making process will be simple and easy.

CHAPTER-7

CONCLUSIONS

Flexible manufacturing systems are a dynamic, stochastic and complex system that might involve hundreds of participants. For a successful design of a Flexible manufacturing systems all the three flows namely material flow, information flow and cash flow along with the variables should be taken care. For improving the overall performance of the flexible manufacturing systems, it's necessary to view the system as a whole. Before the actual implementation of FMS, the mapping of the processes and environment helps in selecting the right type of FMS. Ten factors and 55 subfactors are considered that effect the choice of FMS. An interpretive structural modeling approach is used to develop the structural relationship between the variables. The model shows the arrangement of these variables at four different levels and their relationships with each other. The variables product life cycle and competitiveness is driven by uncertainty and customer preferences which are further driven by cost of FMS and technology change of the FMS. The drivers of all these variables are government policies, productivity, human resources and compatibility with existing system. The optimum performance of any particular variable depends to a larger extend on the performance of the other variables.

.After ISM, CFP analysis is carried out. Complexity- Flexibility- performance analysis can be one of the approaches to design a flexible manufacturing system that takes care of complex variables of the environment and provide improvements in the desired measures of performance. Coordination between participants of a flexible manufacturing system is also very important. Each participant in a flexible manufacturing system has its own set of activities to perform. The study shows that the variables like cost of FMS (0.85) and product life cycle (0.87) had greatest contribution to the pre implementation decision followed by technology change of the FMS (0.71), competitiveness in the market (0.75), uncertainty (0.62), customer preferences (0.6) and government policies (0.75). The variable Compatibility with existing system (0.5) is seen to be a neutral variable. The variables Productivity (0.33) and Human resources (0.35) are seen to play a nominal role in the implementation decision. Taking the variables as a whole, the study shows that the obtained index of 0.65 is greater than the taken C-F-P index. So the pre implementation decision regarding the organization as a whole is slightly complex.

Other than that there is a set of activities that are common to the participants. Extend to which the commonality and the differences can be addressed together decided the success of flexible manufacturing systems.

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