PERFORMANCE MEASURES USING PETRI NET AND ISM ANALYSIS IN FLEXIBLE MANUFACTURING SYSTEM

A MAJOR PROJECT THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF DEGREE OF

MASTER OF ENGINEERING
IN
PRODUCTION AND INDUSTRIAL ENGINEERING

SUBMITTED BY:

HIMANSHU

ROLL NO. (2K13/PIE/08)

UNDER THE GUIDANCE OF

DR. A K MADAN

(ASSOCIATE PROFESSOR)

DEPARTMENT OF MECHANICAL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
(FORMERLY DELHI COLLEGE OF ENGINEERING)
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CANDIDATE'S DECLARATION

I hereby declare that the work being presented in the major thesis entitled "**PERFORMANCE MEASURES USING PETRI NET AND ISM ANALYSIS IN FLEXIBLE MANUFACTURING SYSTEM**" in the partial fulfillment for the award of degree of MASTER OF ENGINEERING with specialization in "PRODUCTION AND INDUSTRIAL ENGINEERING" submitted to DELHI TECHNOLOGICAL UNIVERSITY(FORMELY DCE), NEW DEHI is an authentic record of my own work carried out under the guidance of DR. A K MADAN, Department of Mechanical and Production Engineering, Delhi technological university (dce), Delhi.

I have not submitted the matter in this dissertation for the award of any other Degree or Diploma or any other purpose what so ever.

HIMANSHU
Roll No.2K13/PIE/08

CERTIFICATE

This is to certify that dissertation entitled "**PERFORMANCE MEASURES USING PETRI NET AND ISM ANALYSIS IN FLEXIBLE MANUFACTURING SYSTEM**" being submitted by Mr. HIMANSHU in the partial fulfillment for the award of degree of "MASTER OF ENGINEERING**"** with specialization in "PRODUCTION AND INDUSTRIAL ENGINEERING**"** submitted to Delhi technological University (FORMERLY DCE), NEW Delhi, is an authentic project work carried out by him under our guidance and supervision.

The matter in this dissertation has not been submitted to any other university or institute for the award of any degree.

DR. A K MADAN
(ASSOCIATE PROFESSOR)
Department of Mechanical and Production Engineering
Delhi Technological University(FORMERLY DCE)
NEW DELHI

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HIMANSHU
Roll No.2K13/PIE/08

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CHAPTER-1

1.1 INTRODUCTION

A Perti net is a dynamic, formal model of data stream. The properties, considerations, and strategy of Petri nets are being made in a mission for consistent, major, and amazing methods for portraying and isolating the surge of data and control in frameworks, especially structures that may exhibit odd and concurrent activities. The critical use of Petri nets has been the exhibiting of structures events to happen all the while yet there are impediments on the concurrence, need, or repeat of these occasions.

The perspective taken in this prologue to discrete occasion framework (DES) is that they comprise of communicating hubs. Every hub can be a framework in itself and may be considered as a part of the DES. These parts can work simultaneously, i.e., a segment can be performing one of its capacities while another segment is doing one of its particular capacities. For instance, a client at an Automated Teller Machine (ATM) can be making a store when another client at another ATM of the same system can be making a withdrawal. Consider now the circumstance when the two customers get to the same record - a mate and wife with a mutual administration, or two laborers in the records payable range of the same association. Issues of synchronization of the two operations rise. Note that there is not changed, predestined solicitation to the two events. The store may be made before the withdrawal or the withdrawal before the store. The particular request may prompt diverse results; banks have created point by point regulations in regards to the timing and sequencing of stores and withdrawals. How then would we be able to depict these sorts of issues in an exact, unambiguous way?

The need to address such issues of simultaneousness in frameworks drove Carl Adam Petri to present in his Ph.D. proposal (1962) an uncommon class of summed up diagrams or nets now called Petri Nets. They are a demonstrating and examination apparatus that is appropriate for the investigation of Discrete Event Systems. The utilization of Petri Nets prompts a numerical depiction of the framework structure that can then be researched systematically. In this presentation, the fundamental definitions and properties of Petri Nets are exhibited. While there is a broad writing on the subject, both on the hypothesis additionally, on applications, there is no real essential perusing material available that shows Petri Net speculation and contains in a dependable manner the various late theoretical and computational results. Here, just the fundamental thoughts and properties are examined. References related to specific subjects are given all through the note. Early on material about Petri Nets may be found in Peterson (1981), Reisig (1985), and Cassandras (1993). Extra material can be found in Jensen (1991), Beccelli et al. (1992); Zhou and DiCesare (1993).

"Petri Nets" have their commencement to the early work of "C.A. Perti" in his "correspondence with robotization" where the characterized the reason for a speculation of correspondence between a synchronous sections of a PC system concerning accommodating relationship between events.

During the time PNS have shaped into skilled instruments for exhibiting synchronous concurrent structures in graphical and numerical terms. The model is thusly used to examination & generation for getting information about bottlenecks, gridlocks, and whatever different issues, avoiding test continues running on the honest to goodness structures. Starting late petri nets have been associated for illustrating "Versatile gathering Frameworks."

1.2 PETRI-NET MODELLING CONCEPT AND UTILITY:

Here the accentuation is on a dynamic procedure for building "PETRI-NET MODEL "of FMSs, subjective examination with uncommon emphasis on quantitative execution and evaluation. Illustrative instances of collecting cells with different robots and a fundamental FMS involving few machines, gathering parts, are shown to draw out the important issues that can be had a tendency to using Petri-net models.

In the substance of FMS Petri-net models can be used as a piece of a blended pack of employments. As an issue of first significance a Petri-net model gives a graphical representation of the FMS being illustrated. The model could be used as a diversion model for delineating mindful event propagation of FMSs.

Likewise sound or subjective examination of the FMS can be finished to help imperative framework and control decision to be made. Under the characterization the focal properties that can be investigated join boundedness (breaking point of advantages). Liveness (nonappearance of gridlocks), propriety (recoverability from disillusionments) and sensibility (unfortunate inadequacy of starvation).

Thirdly by accomplice "stochastic times" to the Petri-net moves, the execution of a FMS can be quantitatively evaluated.

Execution evaluation of FMS incorporates building up an execution models and enlisting from its distinctive execution measures, for instance,-

Machine uses,

Throughput rates of parts,

Mean bolster inhabitances,

And average holding up times.

Execution studies give knowledge into blueprint and operational issues. For example - They can be used for building up the achievability of a particular setup, for picking the perfect number of mechanical assemblies, beds, and supports, for perceiving bottleneck resources; and for choosing perfect working methodologies.

1.3 OBJECTIVE AND SCOPE OF THE THESIS:

The use of PETRI-NET based models in the modelling, analysis and performance evaluation of FMSs is currently an active research area.

In the region of demonstrating, Extensions of Petri-nets, for example, coloured PNS also, predicate - moves nets are currently being utilized. Modern PC helped instruments for intelligent investigation are being presented at different Universities.

In the zone of execution & assessment, three themes that ought to get quick future consideration are: - More practical execution models, for example, DSPHs (Petrinets with deterministic and stochastic timed moves);

Incorporated plans joining GSPNs (Generalized stochastic Petri nets) with lining systems; and

All around detailed hypothesis for the accumulation of GSPNS

Other than these, beginning from an assembling module to a mind boggling assembling cell, FMS execution & assessment could be effortlessly conceivable just through the petri net modeling.

CHAPTER – 2

2.1 FUNDAMENTALS

Since Petri Nets (PN) is an exceptional sort of chart, the presentation will begin with some essential thoughts from diagram hypothesis. A diagram comprises of two sorts of components, hubs or vertices and edges, and the way in which these components are interconnected.

Definition : A chart G = (V, E, ø) comprises of a nonempty set V called the arrangement of hubs of the diagram, a set E called the arrangement of edges of the chart, and a mapping ø from the arrangement of edges E to an arrangement of sets of components of V.

In case the pair of center points joined by an edge is asked for, then the edge is composed and a jolt is situated on the edge showing the bearing. If each one of the edges of the graph are shown in Figure 1. Note that the to begin with, involving only two separated center points, can be seen as both as a composed and an undirected diagram.

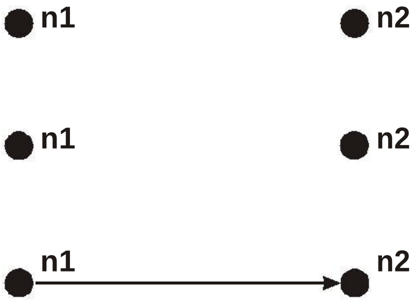


Figure 1: Examples of graphs

Two nodes that are connected by an edge in a graph are called *adjacent* nodes. Nodes need not be represented by dots only; they can be represented by circles, bars, boxes, or any other convenient symbol for the particular application.

When a graph contains parallel edges, i.e., edges that connect the same pair of nodes and, if directed, have the same direction, then it is called a *multigraph*.Examples of multigraphs are shown in Figure 2.

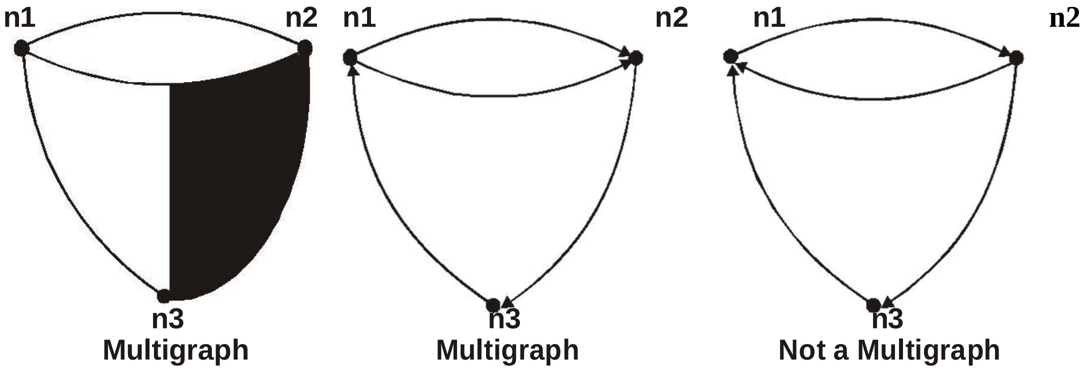
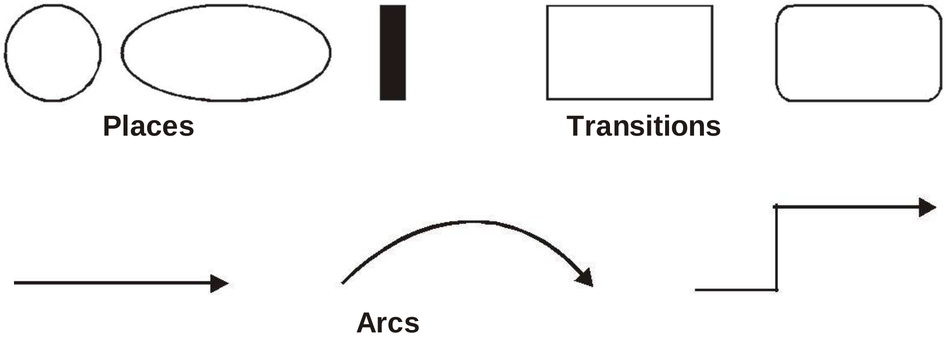


Figure 2: Examples of multigraphs

While Petri Nets are multigrahps, in this note we will consider ordinary Petri Net only. In many applications, parallel edges are very useful and the multigraph properties of Petri Nets can be used to advantage. However, they introduce notational and other complexities that are best addressed when extensions to Ordinary Petri Nets are considered (e.g., colored Petri Nets).

A second characteristic of Petri Nets as graphs is that they are *bipartite* graphs. This means that they have two types of nodes. Different symbols are used to distinguish the two types of nodes. By convention, the first type of node is called a place and is denoted by a circle or ellipse. The second type is called a transition and is denoted by a solid bar, or a rectangle. The edges of a Petri Net are called arcs and are always directed. The symbols are shown in Figure 3.



Figures 3 Places, Transitions, and Arcs

CHAPTER - 3

3.1 What is a Petri Net?

Petri Net is a 5 tuple

PN = (P, T, F, W, M_0)

WHERE

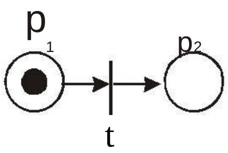
P = {p_1, p_2, pm} is a finite set of places T = {t_1, t_2, TN} is a finite set of transitions F φ (P x T) χ (T x P) is a set of arcs
W: F — {1, 2, 3,} is a weighting function

M_0: P — {0, 1, 2,} is the initial marking // defines number of tokens per

Place

P ∩ T = φ and Pχ T ≠ φ

Example



This Petri net has:

2 places: p_1, p_2
1 transition: t_1

P1 has one token: M (p_1) = 1 p_2 has 0 tokens: M (p_2) = 0

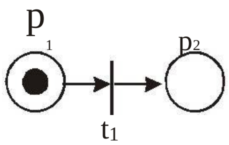
Firing a Transition

When a transition t fires

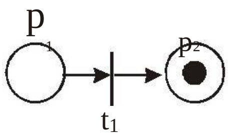
Each p_i that has an edge from p_i to t removes a token from p_i
Each p_j that has an edge from t to p_j adds a token to p_j

Example

Petri net before t_1 fires:



Petri net after t_1 fires:



A transition must be enabled before it fires

• There is a token in each p_i that has an edge to the transition

An enabled transition may or may not fire.

3.2 Types of Petrinet

Original Petri Nets

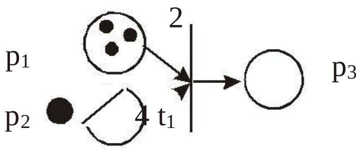
Only 1 token can be uprooted/included from a spot when a move fires (i.e., the weight is dependably

Weighted Petri Nets

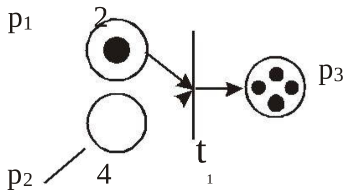
- Generalized the first Petri net to permit numerous tokens to be included/evacuated when a move fires.
- The edges are named with the weight (i.e., number of tokens)
- If there is no name, then the default worth

Example 1

Petri Net before transition t_1 fires



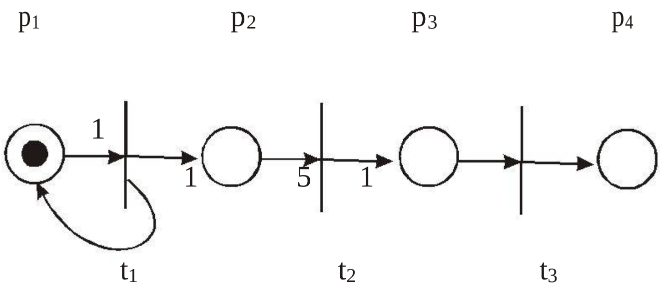
Petri Net after transition t_1 fires



Example 2

Model a system on an assembly line that counts 5 cans and then sends a signal to the operator.

Petri Net before transition t_1 fires



p_1 - can prepared on assembly line
p_2 - p_2 is accumulator (counting
Cans) p_3 - signal is on
p_4 - signal is off
t_1 - sensor recognizes can going
By t_2 - turn signal on
t_3 - turn signal off

Petri Net after transition t_1 fires

Once?

2?

3 times?

4 times?

5 times?

6 times? (Is there only one possible marking here?)

...

9 times?

10 times?

11 times?

Other Types of Petri Nets

Petri nets have been extended over the years in many directions including time, data, and hierarchy.

Time Extended Petri nets

— First grew in the mid-1970s

— For genuine frameworks it is regularly critical to depict the worldly conduct of the framework, i.e. we have to model spans and postponements.

— There are 3 fundamental approaches to bring time into the Petri net. Time can be connected with:

– Token
– Transitions

The first introduction of time in Petri nets is in the Timed Petri net model

— In this model, time duration is associated with each transition.

— The firing rules in this model are that the transition must fire as soon as it is enabled, and firing a transition takes a fixed, finite amount of time.

— The notion of instantaneous firing of transitions is not preserved in the Timed Petri net model.

— When a transition becomes enabled, the tokens are immediately removed from its input places.

— After the time delay, tokens are deposited in the output places.

— The result is that the state of the system is not always clearly represented during the process.

Colored Petri Nets

Developed in the late 1970s

— Token often represents objects (e.g. resources, goods, humans) in the modeled system.

— To represent attributes of these objects, the Petri net model is extended with color or typed tokens.

– Each token has a value often referred to as 'color'.

— Transitions use the values of the consumed tokens to determine the values of the produced tokens.
– A transition describes the relation between the values of the
'Input token'
— It is also possible to specify 'preconditions' which take the colors of tokens to be consumed into account.

CHAPTER-4

4.1 A REVIEW OF PETRI-NETS:

A Petri-net, models the static properties of a discrete event system, concentrating on two basic conceptions:-

“Events and Conditions”.

In a system at a given time certain conditions hold (i.e. a job is waiting to be processed and a machine is available). The fact that these conditions hold, may cause the occurrence of certain events (starting of job processing) which may change the state of the system, causing some of the previous conditions to cease holding (the job is no longer waiting and the machine is not available any more) and causing other conditions to begin to hold (the job is being processed).

The vast majority of the hypothetical deal with Petri-net structures, which consists of four fundamental components:-

- Set of places (P)
- Set of Transitions (T)
- Input function (1) and
- Output function (0).

Petrinets graphically spoke to by circles, called 'spots', bars of rectangles called 'Moves', and coordinated circular segments, Connecting places and move. Here spots speak to condition or the condition of any procedure or any stage simultaneously, whereas moves model exercises speaking to or sign change or pre essentials for the resulting process, condition or state. Easygoing relationship is demonstrated by joining the spot with the move or viceversa by coordinated curves with arrow points. A spot is a data to a move if a coordinated bend associate the spot with that move. Likewise a spot can be a yield to a "move".

Various inputs or yields to a move are meant by numerous curves or weights appended to a solitary circular segment.

4.2 MODELLING METHODOLOGY OF PETRI NETS:

(A) ORDINARY PETRINETS

In a common kind of petri net demonstrating, diagram asses circles to speak to places (states) and bars to speak to moves (Events). Information yield connections are spoken to by coordinated bends in the middle of spots and moves.

Dark spots inside a circle or spot called tokens. To-kens dwell at a spot when it is dynamic. Tokens move through the "net" contingent upon the present stamping of the net.

The stamping of a Petri net is packed in a vector dimension n, where "n" is the quantity of spots and every estimation of the vector relates to the quantity of tokens in the comparing spots, when there is a token in each of the information spots of a move, that move is empowered to flame.

In the event that the weights on each of the circular segments in the middle of spots and moves are equivalent to one, than the move fires by expelling a token from each of its data places and by setting a token in each of its yield places.

Fig. 4 (a) demonstrates a Petri net illustration of evaluating a robot. The token, places and moves relate to the different components found in assembling frameworks. Places as a rule speak to "assets" (machine, parts & information and so forth). A token in a spot demonstrates that the asset is accessible, else it is occupied. A spot can likewise be utilized to suggest that a coherent condition holds. Moves are by and large used to speak to the start or end of an occasion.

B. TIMED PETRI-NET:

Petri nets can show a wide mixed bag of discrete occasion dynamical frameworks. In any case, the normal petri nets don't demonstrate the progression of time.

Time is a discriminating considers the vast majority of the framework for assessing execution and approval control rationale.

Time is a vital component in capacities, for example, creation booking and control in FMS.

The rate of operation of timed Petri net (T. PN) is like a conventional Petri-net. When a move is empowered, the tokens are expelled from the info puts and are held for time (ti) (where is a vector of preparing time works that appoints discerning number top every move of the net) after which the tokens are sent to all the yield places.

Moves in timed petri-net can be seen as an arrangement of occasions, in that various arrangements of tokens can be at distinctive dates of the time delay.

Fig. 10 (b) demonstrates a period Petri-net sample utilizing a robot. Move T1 has an Related deferral time. At the point when the transport and robot are both accessible (i.e. token is available in every spot) the preparing time for move T1 starts.

The time delay "D" speaks to the material taking care of time for the

Transport to move a section to the robot.

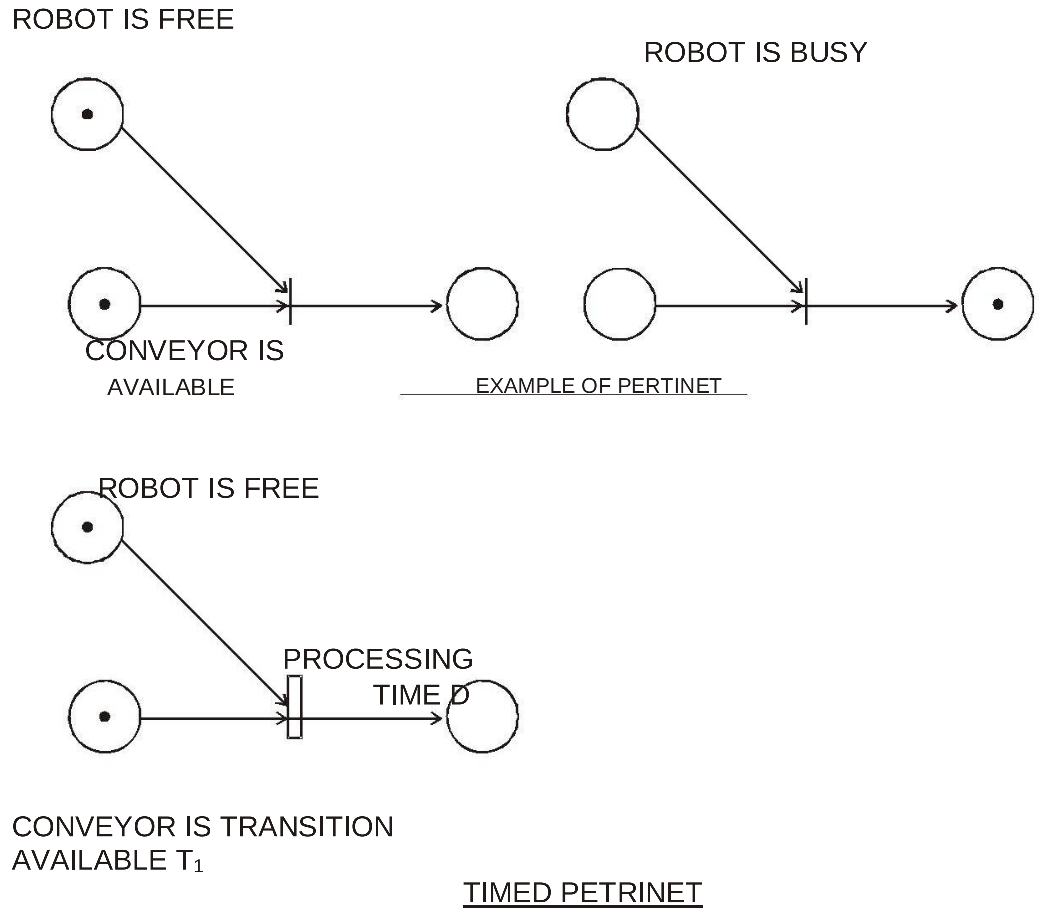


FIGURE. 4 EXAMPLE OF PN

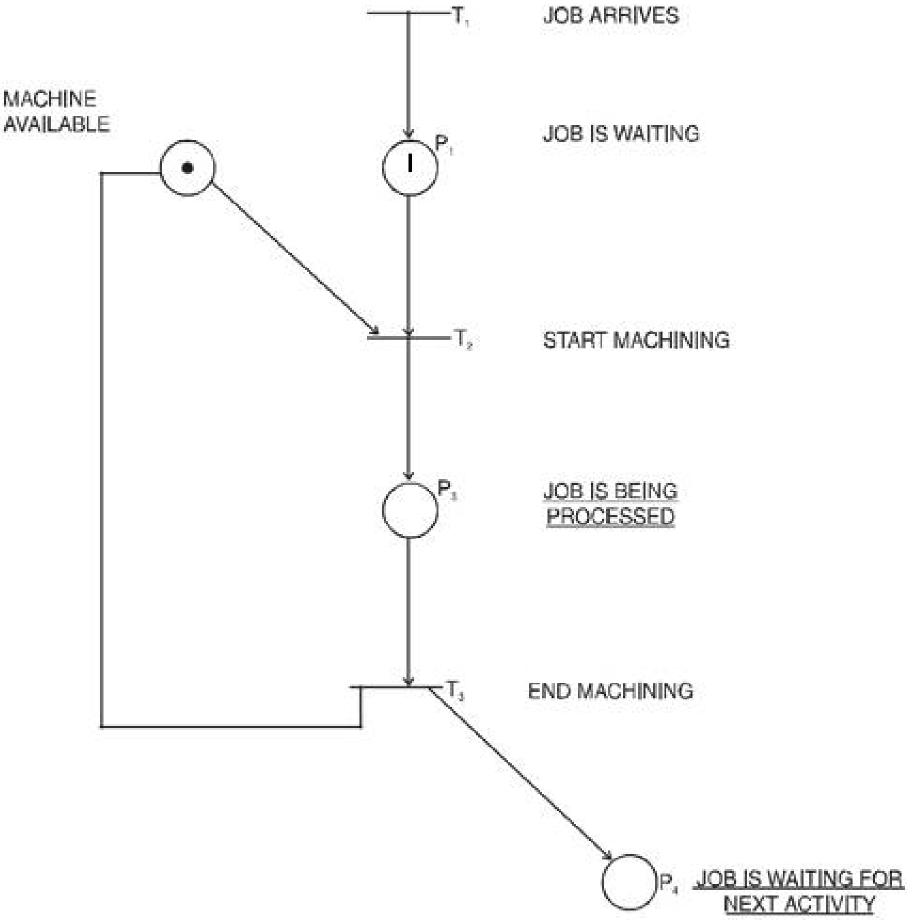


FIGURE 5.PETRI NET STRUCTURE CONCEPT

5.3 EXECUTION OF PETRINET MODEL AND CONCEPT OF MARKINGS:

The net fundamentally a static model, gets to be powerful on presentation of 'TOKENS', which are spoken to by little dabs inside the spots.

Presently a petrinet model is execute by characterizing a "stamping" and after that terminating 'moves'. A marking is a distribution of Tokens to the places of a petri-net. The number and position of tokens divert amid execution. Fig. 5 is a sample of an occupation handling on one machine portrayed by a petrinet .

Here we can see that the machine is available (a token in P_2) and that there are no jobs waiting to be processed.

As shown in fig. II a petri net execution models, the system's behavior through a sequence of transitions which represent discrete events. The firing of a transition is considered to an instantaneous event taking zero time, also called a 'primitive' event. If the event is not primitive i.e. may take time greater than zero, it can be decomposed into two transitions with a place between them representing the condition, the non-primitive e event is occurring as shown in the fig. 5 by transitions T_2, T_3 and place P_3.

5.4 DEFINITIONS AND TERMINOLOGIES:

DEFINITION 1.

A Petri net is a 4 tuple

(P, T, IN, OUT) here P = P1, P2, P3 ....Pm is set of places.

T = t1, t2, t3 ....tn is a set of transitions $P \cup T \neq \varphi$, $P \cap T = \varphi$

Also,

Where IN: $(P \times T) \rightarrow N$ is a data work that characterizes circular segments from spots to move and where OUT: $(P \times T) \rightarrow N$ is a yield work that characterizes guided curves from m

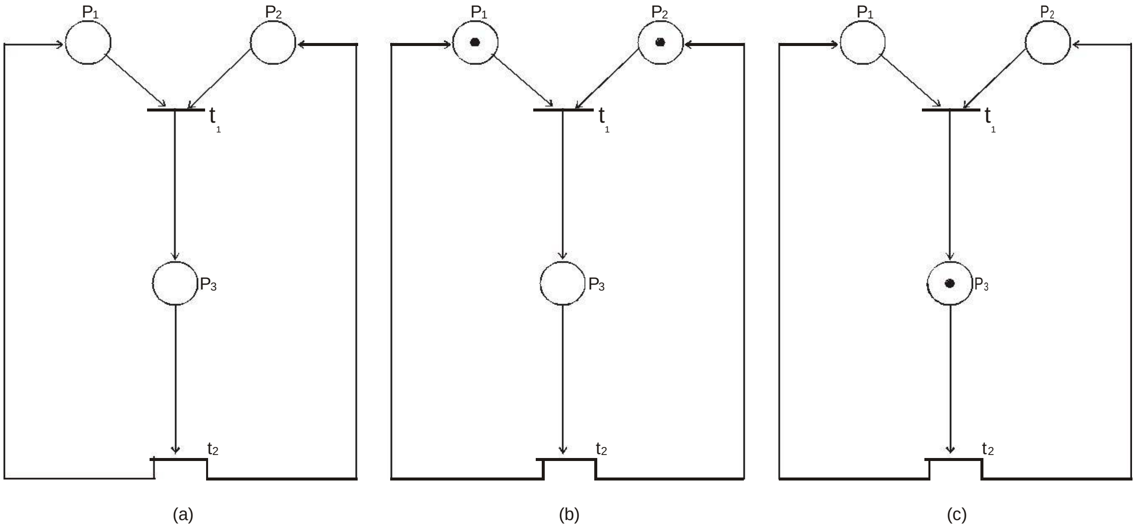


FIG. 6 PETRINET MODEL

Pictorially, places are represented by circles and transitions by bars.

In the event that IN (Pi tj) = K where k ≥ 1 is a whole number, a guided circular segment from spot Pi to move tj is drawn with mark K.

On the off chance that IN (Pi tj) = 0, no bend is attracted from Pi to tj. Thus if OUT (Pi, tj) = K a coordinated circular segment is incorporated from move tj to place Pi with mark K if K > 1 and without name if K = 1.

Yet, in the event that K = 0 no arc is included from tj to Pi

EXAMPLE - 1

Let us consider a machine that processes one job at once. When the preparing is done, another employment is made accessible, and the machine begins handling once more. Fig. 12 gives a petri net model (PNM) of the given system.

The spots and move have the accompanying elucidation: - P1: Machine ready to process (machine is free)

P2: Job waiting for processing

P3: Job undergoing machining (machine busy). t1: Machining starts.

t2: Machining finishes.

In the above illustration spots speak to different conditions in the framework and moves speak to the beginning or completing of exercises. Case in point - place P1
Models the condition - machine is free. We have assumed that the machine in the event that it fizzles will be repaired and will continue its operation at work.

For the purpose of straightforwardness, disappointments and repair have not been displayed in this

PNM.

Here, $P = P^1, P^2, P^3$; $T = t^1, t^2$ and

$IN(P^1, t^1) = IN(P^2, t^1) = IN(P^3, t^2) = 1$
$IN(P^1, t^2) = IN(P^2, t^2) = IN(P^3, t^1) = 1$
Similarly, OUT (P1, t2) = OUT (P2, t2) = OUT (P3, t2) = 1
OUT (P1, t1) = OUT (P2, t1) = OUT (P3, t2) = 0

DEFINITION - 2

Let 2P be power set of P. We then define functions IP: $T \rightarrow 2P$

Also, OP: $T \rightarrow 2P$ as follows :-

$IP\ (tj) = \{Pi \in P : IN\ (Pi, tj) \neq 0\}\ V\ tj \in T$

Operation $(ti) = \{Pi \in P : OUT\ (Pi, tj) \neq 0\}\ V\ tj \in T$

Where IP (tj) is the set of input places of tj and OP (tj) is the set of output places of tj. Illustration - 2

For the (PN) of fig. III (a)

IP (ti) = OP (t2) = {P1, P2}

what's more, OP (ti) = IP (t2) = {P3}

DEFINITION - 3

A transition tj of PN is said to be enabled in a marking M, if - $M\ (Pi) \geq IN\ (Pi, tj)\ V\ Pi \in IP\ (tj)$

An enabled transition t_j can fire at any instant of time when a transition t_j enabled in marking M fires, a hew marking M' is reached according to the equation:-

$M'\ (P) = M(P_i) + OUT\ (P_i, t_j) - IN\ (P_i, t_j)\ \forall\ P_i \in P$

we say marking M' is reachable from M and write $M\ t_j \rightarrow M'$

<u>EXAMPLE – 3</u>

In fig. 12 (b) transition t_1 is empowered in marking M_0 when t_1 fires, the marking M_1 is reached. Transition t_2 is enabled in M_1, and when t_2 fires, the new marking are M_0. It can be seen that reachability of marking is a transitive relation of the set of all markings. In addition by convention, we regard that a marking is reachable from itself in zero steps (i.e. by firing no transition).

DEFINITION - 4

The set of all marking reachable from an initial marking Mo of a PN is called the reachability set of the Mo and is expressed by R (Mo).

EXAMPLE - 4

It can be seen from fig. 12 (a) & (b) that

$R(M_o) = R(M_1) = \{M_o, M_1\}$.

DEFINITION - 5

Let G1 = (P1, T1, IN1, OUT1) and G2 = (P2, T2, IN2, OUT2)

Be two petrinets, such that there exist no pair. $(P1\ t) \in (P1 \cap P2) \times (T1 \cup T2)$ fulfilling either $IN1(P, t) \neq 0$ & $IN2(P, t) \neq 0$

On the other hand $OUT1(P, t) \neq 0$ and $OUT2(P, t) \neq 0$ we characterize the union of G1 & G2 as the

Petrinet G = (P, T, IN, OUT) where -

$P = P1 \cup P2$; $T = T1 \cup T2$

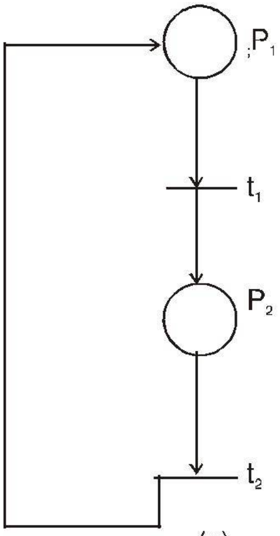
$IN = IN1 \cup IN2$ & $OUT = OUT1 \cup OUT2$

The Union of any limited number of petrinets is additionally characterized moreover.

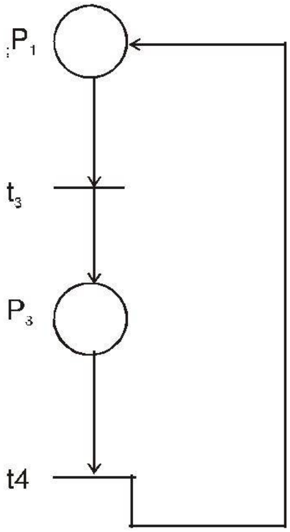
Illustration - 5

The PN of fig. 7(c) is the union of the patients (7) (a) & (b).

Utilizing the idea of union petri-net, a PNM can be built in a bottom up design from the littler PNM's 7 (a) & (b) i.e. the Petri-net models of individual operation or subsystem of a FMS can be consolidated in.



(a)



(b)

CHAPTER - 5

5.1 INTRODUCTION OF FMS

As of late, there has been extensive enthusiasm for strategies for configuration, demonstrating, arranging, and planning and execution assessment of adaptable assembling framework (FMS). A FMS is an automated generation framework that can deal with a vast and continually changing mixture of part sorts. FMS are portrayed by a huge arrangement of distinctive substances, for example, workstations, NC machines, and/or robots, and mechanized material taking care of frameworks. At the point when such a framework is watched, these substances show both deterministic and stochastic practices and it is hard to break down it hypothetically. In this way, a FMS test system is regularly used to break down the conduct of FMS on different perspectives, for example, framework outline, execution assessment, and generation arranging, and so forth. In any assembling framework, items are made by directing material through the workstations to execute endorsed sequence(s) of operations and these recommended arrangements may require a few adaptabilities to meet out the dynamic way of the framework. FMS are uniquely intended to consolidate these adaptabilities into the framework to meet out the dynamic and stochastic nature of the framework and its workplace. The adaptability of these systems depends on a programmable transportation system joining the workstations and a complex control framework that screens the advancement of the occupations in the assembling framework and directions different activates of the workstations and transport framework.

Every occupation has a best operation arrangement that decides the request in which assets must be assigned to the employment, yet the proficient usage of assets on constant premise in FMS obliges an ongoing resource allotment strategy to appoint assets to occupations as they progress through the framework. Also, the simultaneous stream of various occupations in a FMS, which all go after a limited arrangement of assets, can prompt the issues of assets discord and roundabout hold up. The center of this work is on the advancement of a framework controller for the programmed arrangement of an asset dispute issue in FMS on an ongoing premise. The proposed FMS controller has been created by utilizing Petri net hypothesis for framework demonstrating for the arrangement of the problems.

5.2 CONCEPTS OF FLEXIBILITY

Today adaptability intends to create sensibly evaluated altered results of excellent that can be immediately conveyed to clients. Table 1 shows the distinctive ways to deal with adaptability and their implications.

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 flexibility and their meanings

5.3 TYPES OF MANUFACTURING FLEXIBILITIES

For the purpose of straightforwardness and simplicity of recognizable proof, the assembling adaptability is connected with the three districts are named, Automation Flexibility , Manufacturing Flexibility and Design Flexibility in the setting of discrete items commercial ventures. The adaptability specialist's are-key decision, configuration, process, framework, PC mix among outline, procedure and base, PC combination among sellers and suppliers.

Automation Flexibility

It is utilized when there is high item volume and low mixed bag. For Example: IMB Lexington, Kentucky: Electric framework. They create typewriters and printers with a yearly generation around 100, 0000 units. The objective of Automation adaptability is minimal effort, high production creation of not very many variants of stable plan on a typical line without breaking a sweat of new item presentation. While minimal effort, high volume creation has dependably been the consequence of mechanized lines, cutting edge advances, for example, robots give the extra ability to present new models on hold without hardly lifting a finger and all the more quickly i.e., more noteworthy adaptability. Such lines have blended model generation capacity and can deal with parcel sizes as little as one. Aftereffect of this adaptability is lead time for new item acquaintance decreased with year and a half.

Specialists of Automation Flexibility

- Strategic decision: - ease, high volume, new item presentation, and numerous models.
- Design: - a couple stable solidified configuration.
- Process: - adaptable mechanization, apply autonomy, AS/RS, consistent stream.
- Infrastructure: - JIT, a couple of trustworthy merchants, adaptable workers.
- Computer mix among outline, procedure and framework: - upgrades creation planning, decreases stock and lead time.
- Computer joining among merchants and suppliers: - smooth creation

Planning diminishes stock and lead time.

Manufacturing Flexibility

Manufacturing adaptability is utilized where Mid-Volume and Mid-Variety is needed. For Case: GE's series 8 locomotive plant, Erie, Pennsylvania. Gidding and lewis FMS for machining a family of motor frames and rigging boxes. Yearly limit of 5000 engine casings of sizes up to 4' * 4' * 5' with more than 100 machining surfaces. The system includes 2 vertical milling machines, 3 even machining focuses, three heavy horizontal machining center, three substantial flat exhausting plants and on medium level factory. The machine incorporate robot or robotized device changers with more than 500 cutting instruments. In assembling adaptability situations, in spite of the fact that item outline change capacities exist, the objective is to minimize interruption because of configuration focusing on the creation of generally stable plans. This sort of adaptability may be discovered most every now and again in the production of segments or subassemblies obliging a few machining operations. There is a sufficient level of steering adaptability. By utilizing assembling adaptability machining time can be decreased from 16 days to 16 hours for every casing.

Specialists of Manufacturing Flexibility

- Strategic decision: - high mixture, mid volume, diverse design, distinctive directing.
- Design: - mixture of tolerably stable plans.
- Process: - F.M.S/AGV, CAD, CAM, mechanized stream.
- Infrastructure: - G.T, Cells, MRP/JIT, adaptable multi-assignment workers.
- Computer mix among configuration, procedure and base: - upgrade blend booking and routine adaptabilities, decreases lead time.
- Computer coordination among sellers and suppliers: - decreases stock an

Design Flexibility

Design Flexibility is utilized where Low-Volume and High-Variety is needed. For

Illustration: Ingersoll Milling Machine Co., an extremely extraordinary apparatus maker with a CIM system which incorporates CAD/CAM. A normal part is maybe a couple pieces; at times constructs a copy.

Specialists of Design Flexibility

- Strategic decision: - hand craft, low volume, and configuration change regular
- Design: - to a great degree variable hand craft.

- Process: - F.M.S, NC/CNC, CAD/CAM, CIM, intermitted stream.

- Infrastructure: - G.T, adaptable generation arranging and control, exchange calendar and steering.

- Computer combination among outline, procedure and base: - empower simultaneous building, decreases configuration time and changes, less demanding outline changes.

- Computer coordination among sellers and suppliers: - enhances simultaneous building, decreases lead time.

Each assembling office encounters one of a kind changes, and degrees of change, both in its internal and external environment. The best sort of adaptability –in terms of advantages is extraordinarily subject to the specific office for which it is being looked for.

Unmistakably, not every one of the progressions can be gone up against with neither adaptability, nor can a thorough rundown of every single conceivable sort of adaptability is certainly assembled. A few sorts of adaptabilities in FMS are demonstrated in the table 2

Type of flexibility	Definition
Machine flexibility	It indicates to different types of operations that a machine can perform without requiring a much effort in changing From one operation to other.
Routing flexibility	It refers to skill of the manufacturing system to manufacture a product by other routes via the System.
	It alludes to capacity of the assembling framework to deliver

Process flexibility	the arrangement of item sorts without significant setups.
Product flexibility	It alludes to the simplicity with which new items can be included or substituted for existing items.
Volume flexibility	It alludes to capacity of the assembling framework to work financially at distinctive general yield levels.

Table 2: Different types of flexibilities encountered in FMSs

There are four adaptability connections: -

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

The adaptability specialists are-key decision, configuration, process, base, PC incorporation among outline, procedure and framework, PC reconciliation among merchants and suppliers. The assembling topology is as per the following: -

Type 1 –

- Strategic decision: - ease high volume, new item presentation, and different models.
- Design: - a couple stable solidified configuration
- Process: - adaptable mechanization, mechanical autonomy, AS/RS, nonstop stream
- Infrastructure: - JIT, a couple of trustworthy merchants, adaptable representatives.
- Computer mix among outline, procedure and base: - upgrades creation booking, diminishes stock and lead time.
- Computer joining among sellers and suppliers: - smooth generation booking, scheduling, reduces inventory and lead time.

Type 2 –

- Strategic decision: - high mixed bag, mid volume, diverse arrangement, distinctive directing

- Design: - mixed bag of reasonably stable plans.

- Process: - F.M.S/AGV, CAD, CAM, robotized stream.

- Infrastructure: - G.T, Cells, MRP/JIT, adaptable multitask representatives.

- Computer reconciliation among outline, procedure and framework: - upgrade blend planning and routine adaptabilities, lessens lead time. PC mix among sellers and suppliers: - decreases stock

Type 3 –

- Strategic decision: - hand craft, low volume, outline change incessant

- Design: - to a great degree variable specially craft.

- Process: - F.M.S, NC/CNC, CAD/CAM, CIM, intermitted stream

- Infrastructure: - G.T, adaptable generation arranging and control, interchange timetable and directing.

- Computer combination among outline, procedure and base: - empower simultaneous building, lessens configuration time and changes, less demanding configuration changes.

- Computer joining among sellers and suppliers: - enhances simultaneous designing, decreases lead time.

Type 4 –

- Strategic decision: - minimal effort change over, scope of procedure, procedure versatility

- Design: - not applicable.

- Process: - altered at establishment,

- Infrastructure: - adaptable workers, PC control.

- Computer mix among configuration, procedure and base: - enhances booking, choice making at plant floor.

- Computer coordination among sellers and suppliers: - decreases stock and lead time, customer responsiveness,

5.3 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 on the other hand, 'the capacity to embrace a scope of states' (Slack, 1983). Zhang et al. (2003) view fabricating adaptability as "the capacity of the association to oversee generation asset and vulnerability to meet different client demands". The above definitions underline some critical focuses. To start with, adaptability is utilized to suit vulnerability, more often than not as changes radiating from both the internal and external environment, e.g. changes in product design or customer requirements. Second, flexibility alludes to the ability of an assembling framework to deal with its assets keeping in mind the end goal to adjust effectively to these progressions. In this way, fabricating adaptability could be characterized as: the capacity of assembling associations to deal with their assets keeping in mind the end goal to adapt to ecological vulnerabilities, and to have the capacity to deliver variability in item yields. There are additionally some assembling ideas that are like adaptability. In any case, despite the fact that they are not fundamentally unrelated ideas, they do vary in various imperative angles. Spring and Dalrymple (2000) audit the writing covering assembling technique, adaptability and coordinated assembling ideas. Significantly, they make the accompanying refinement between every idea:

- Flexibility-the ability to send or re-convey creation assets effectively as needed by changes in the earth.

- Total adaptability the capacity to convey top notch item custom-made to every client at large scale manufacturing costs.

- Agility-the capacity to modify any part of the assembling undertaking in light of changing business requests.

- Flexibility/deftness a capacity to adjust quickly and with steady coordination in a domain of consistent and fast

5.4 MEASURING MANUFACTURING FLEXIBILITY

One territory in assembling adaptability where specialists have encountered specific challenges is in assessing and measuring adaptability. The reason for the challenges are said to be because of various elements (Slack, 1983) assembling adaptability is a measure of potential as opposed to genuine execution; the idea does not have a consistent and nitty gritty grouping and is multidimensional in nature. Challenges experienced in measuring assembling adaptability are in a general sense in view of the way that the estimation must rely on upon elements, for example, the level of instability in the earth, administration targets, and machine capacities (Gupta, 1993). From the 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 estimation of assembling adaptability can be characterized by ways scientists have characterized adaptability, and the methodologies utilized as a part of measuring it (Gupta and Goal, 1989). These approaches are in view of financial outcomes, execution criteria, multi-dimensional approach, Petri-nets approach, design theory approach, and data hypothesis approach. It is quite possible that the difficulties of measuring flexibility are being aggravated by the diverse ways in which the subject is being drawn closer. As indicated by Gerwin (1993), the most well-known estimation approach practically speaking is to tally the quantity of choices at a given time.

This methodology really speaks to the capacity to take up distinctive positions in the generation setting (Slack, 1983). Hence, one generation framework is more adaptable than another in the event that it is competent, for instance, of creating an extensive variety of items. This additionally mirrors the reach in which the creation asset can be figured out how to meet different client demands. The generation asset may include, for instance, workforce, machines, and innovation.

As to second property (portability), cost and time are popular measurements for flexibility, as they are in other organizational performances context. A production system which moves smoothly, quickly and efficiently starting with one state then onto the next ought to be viewed as more adaptable 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 show the trouble of rolling out an improvement. Since the third property (consistency) speaks to the consistency of execution estimation, it can be assessed through efficiency, productivity, quality, and processing times (Kostas and Amphora, 1999). They suggest that a less flexible manufacturing system will exhibits peaks in execution results, though an adaptable assembling framework is one in which such a performance measure is invariant with the position it occupies within the range (Upton, 1994).

The determination of the assembling adaptability measurements and ascribes to be utilized as a part of this study included assessing the measurements distinguished in the latest research on assembling adaptability and a build created from what has been thought to be the most far reaching combination of assembling adaptability. The adaptability measurements and the rationale behind their selection are as shown in Table 1.

Four dimensions of flexibility: volume, variety, process, and material handling flexibility, give off an impression of being especially well known measurements. As per D'Souza and Williams (2000), they are an economical set of primary dimension for assembling adaptability. For sure, one of the dimensions, i.e. volume flexibility, is considered to be a key contributor to an organization competitive strategy (Jack and Raturi, 2002).

The adaptability measurements proposed by Gerwin (1993) are: mix, modification, volume, changeover, rerouting, material flexibility, and flexibility responsiveness. These are indicated in Table 3 Mix, alteration, and volume adaptability is remotely determined. The instability connected with these measurements is either from business sector and client request, as far as item assortment, item advancement and item amount. these dimensions is either from the production input or production environment, as far as item determination, machine downtime and material characteristics. The comparison between Gerwin's original dimension and the D'Souza and Williams' (2000) new dimensions is displayed in Table 4. The rationale behind the changes proposed by D'Souza and Williams (2000) is explained below. As per D'Souza & Williams (2000), the blend and alteration adaptability measurements speak to two viewpoints on a hidden measurement that speaks to "mixed bag" of new and existing items that an assembling framework can deliver. What's more, changeover and rerouting flexibility reflect aspects of the manufacturing "process" itself, and are seen to represent to a broader dimension of procedure adaptability. With respect to responsiveness, they prescribe that this measurement be viewed as a component or sub-measurement of all assembling adaptability measurements. Hence, they propose that while the flexibility responsiveness dimension is embedded in the other six dimensions, these six can be moderately represented on four measurements: volume, variety, process, and material handling adaptability.

Type of uncertainty	**Flexibility dimension**
Market acceptance of kinds of Products	**Mix**
Length of item life cycle	**Modification**
Overall product demand	**Volume**
Required product characteristics	**Changeover**
Machine downtime	**Rerouting**
Aspects of materials	**Material**
Change in the above uncertainties	**Flexibility responsiveness**

Source: Gerwin

Table 3: Types of uncertainty and flexibility dimension

D'Souza and Williams(2000)	Gerwin (1993)	**Reasons for re-dimension**
Volume	Volume	
Variety	blend,	**Represent 'variety' of new and existing**

	Modification	**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 practical set of essential dimensions for assembling adaptability (D'Souza and Williams, 2000).
- Process & material handling flexibility represent an internally determined adaptable assembling capacity.
- Volume and mixed bag adaptability speak to a remotely determined adaptable producing capacity.
- They are ethdimens particles most as often as possible examined in the surviving writing concerned with adaptability 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 depicted the most common dimensions methodology used in practice. (Sethi and Sethi ,1990)

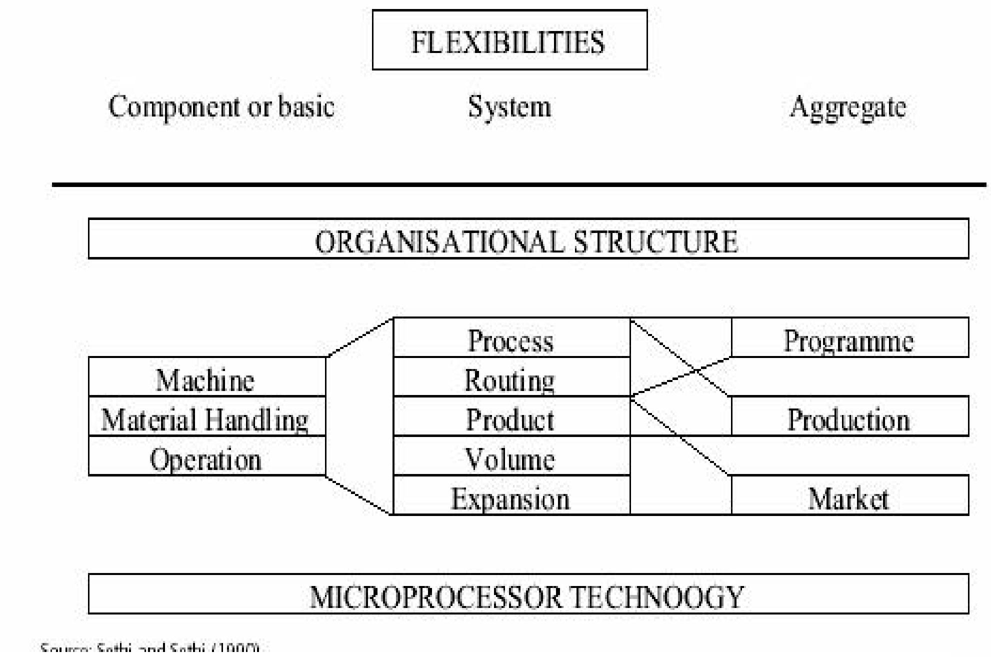


Figure 8: Main classification of flexibilities according to Sethi and Sethi ,(1990)

As adaptability is such a non specific point, with a wide range of levels, it is hard to recognize a specific approach to gauge, or characterize measurements for it. To quantify adaptability it is vital to be mindful of the sort of adaptability that is being considered and the setting in which it is connected. Because of this it is still hard to seclude those discriminating criteria that impact adaptability. On the off chance that these criteria can be distinguished, then they can be utilized as measurements.

VOLUME FLEXIBILITY

These attributes were chosen because they represented the most common measurement approach used in practice. The figure 16 below depicts the main classification of flexibilities. (Sethi and Sethi ,1990) 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).

5.6 THE FLEXIBILITY HIERARCHY

From the figure 9, proposed by koste and Malhotra (1999), it is seen that machine flexibility is important building block for different flexibilities and is regarded as the important for the development of mix flexibility. The five flexibilities do not support the development of other flexibilities. Thus, they are considered as higher level flexibilities. Lower level flexibilities most of the periods act as the building blocks for higher level flexibilities

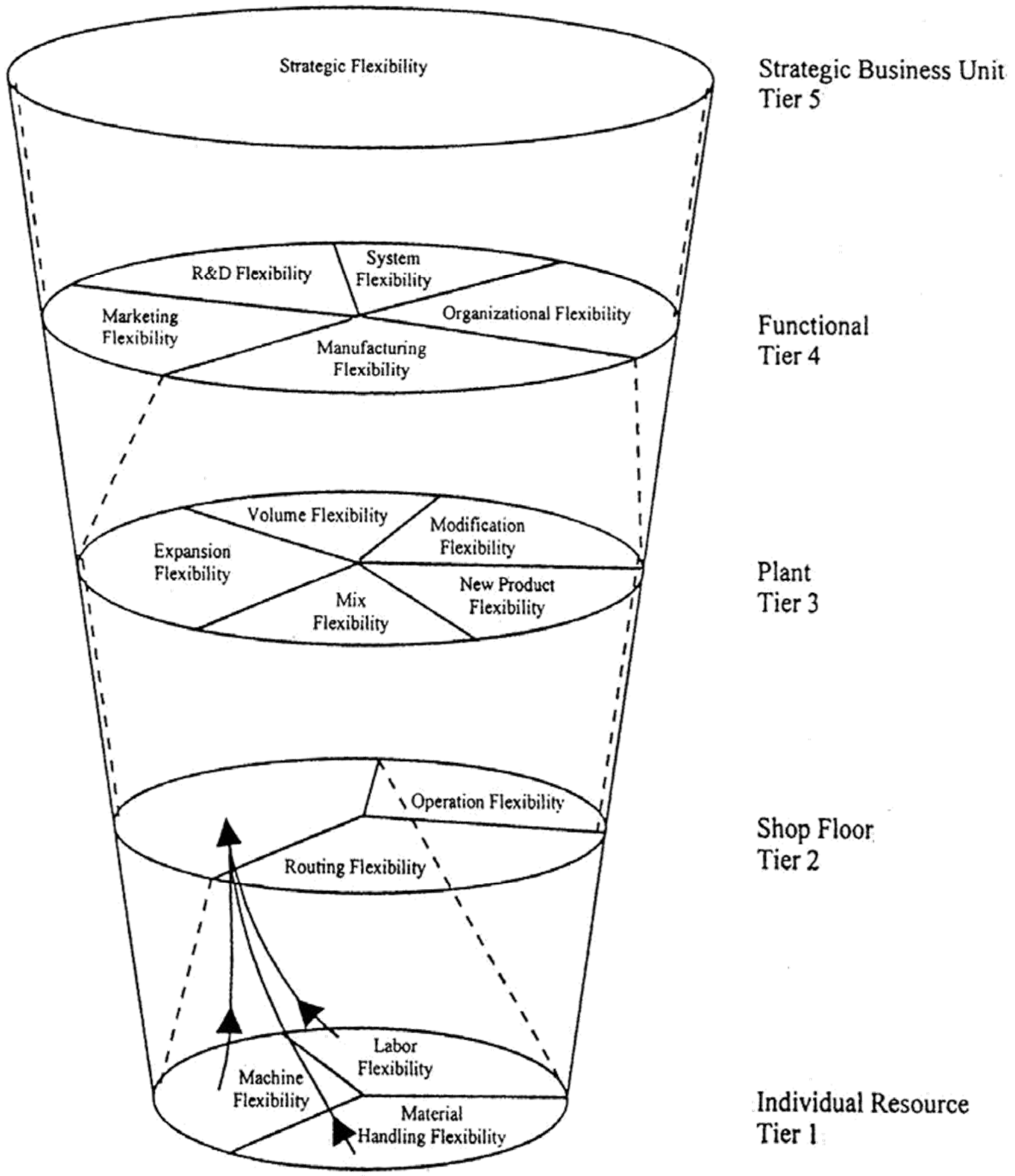


Figure 9: Levels in flexibility hierarchy

5.7 MANUFACTURING FLEXIBILITY CONSTRUCTS

Many studies have been undertaken with the aim of expanding our understanding of the way of flexibility and its measurement.Beach et al. (2000) give a broad survey of the writing here, analyzing huge numbers of the issues encompassing the idea of assembling adaptability, including the scientific categorizations utilized and the method for measuring adaptability. To date, there is no accord with respect to the characterizations and meaning of adaptability and its constituent components. The absence of a homogeneous perspective of fabricating adaptability, and the absence of accord 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 basic terms.

A highlight of this issue is the term used to portray the constituent components of adaptability. These have been depicted differently as adaptability 'sorts', 'measurements', and 'sorts'.

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 different measurements of assembling adaptability, an assembling organization must distinguish the dimension(s) it most needs (Gerwin, 1993). Moreover, certain adaptability measurements have been discovered to be more imperative than the others; particularly, machine, work, blend new item and adjustment (Koste and Malhotra, 2000).

5.8 PRODUCTIVITY AND FLEXIBILITY

Generation is characterized as assembling of items with the assistance of work force, material gear (hard and programming) and capital (Gustavsson, 1984). The utilization of assets is contrasted and before utilization in spending plan control and other controlling instruments.

Items are subjected to changes:

(a) A change of innovation (gadgets assume control from mechanics)

(b) Rationalization (one segment takes every necessary step of a few)

(c) Changes in design.

An organization's definitive achievement is relies on upon its capacity to use assets and address the issue of the business sector. These inner components cow request and thus the volume of business and the cost of merchandise. Notwithstanding this, there must be adaptability in admiration of outer components. These may be:

(a) Fluctuation of the business

(b) Seasonal variances

(c) Competition from different organizations.

5.9 FLEXIBILITY AND PRODUCTION MANAGEMENT

There are numerous ways to deal with expansion adaptability, four focal ways are:

- Reductions of set-up time at installed equipment’s.
- 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 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.

5.10 BENEFITS OF FLEXIBILITY

(a) It can diminish the measure of material taking care of, since it might be conceivable to perform more than one operation continuously at one time.

(b) It gives the capacity to modify the limit of the generation framework.

(c) It can give the go down limit for more than one operation.

As a result of the natural vulnerability and the variability of items and procedure, adaptability is imperative for assembling. This subject is turning out to be more famous these years with immeasurable and explained writing. Adaptability is seen as an administration errand and the worry is the breadth of control limit as for the earth.

5.11 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) infer that *“FMS is a manufacturing system in which groups of numerically controlled machines (machine centers) 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 control system

The improvements in innovation, materials and client inclinations have brought about items with shorter life compass. New items are being dispatched all the more as often as possible. New items and outlines oblige changes underway offices. New innovative headway and administration procedures have made assembling division adapt up to the evolving environment .The change from hard automation to adaptable assembling frameworks, which can be readily rearranged to handle new market requirements, is what's needed today. FMS comprises of a gathering of adaptable preparing stations interconnected by method for computerized Material Handling Systems and capacity frameworks which are controlled by a coordinated PC framework. It is fit for handling a mixture of distinctive sorts of parts under NC programs at different work stations. FMS is an office and not a machine.

In the discrete item fabricating commercial ventures, the most mechanized type of generation is the adaptable assembling frameworks. Adaptable assembling framework is intended to fill the gap between high production transfer lines and low production NC machines. Exchange lines are exceptionally effective when creating parts are in substantial volumes at high yield rates. The constraint of this method of creation is that the parts must be indistinguishable. These profoundly motorized lines are firm and cannot endure variety to some extent outline. In the event that the configuration changes are broad, the line may be rendered old. Then again, remain solitary NC machines are in a perfect world suited for variety in work-in-procedure (WIP) arrangement.

Regarding assembling proficiency and profitability a crevice exist between the high-generation rate exchange machines and the exceptionally adaptable NC machines. This hole incorporates parts delivered in mid extent volumes. These parts are of genuinely complex geometry and the creation gear must be sufficiently adaptable to handle an assortment of parts outlines. Exchange lines are not suited to this application on the grounds that they are resolute; NC machines are not suited to this application on the grounds that their generation rates are too moderate. The answer for this mid volume generation issue is the PC coordinated assembling framework.

5.12 TYPES OF MANUFACTURING SYSTEMS

The middle range can be further divided in to finer categories. Kearney and Trecker Corporation defines 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 MC;

(c) Flexible Manufacturing System (FMS).

- Dedicated FMS.
- Random FMS.

5.13 CONCEPT OF FLEXIBLE MANUFACTURING SYSTEM (FMS)

Albeit numerous definitions are accessible, key part of a FMS are by and large settled upon. In the first place, adaptable assembling framework (FMS) is PC controlled framework. It contains a few workstations, each equipped to diverse operations. Workstation machines are computerized and programmable. Mechanized material taking care of hardware moves part to the suitable workstation, then on to the customized machines that select position and initiate the particular apparatus for every occupation.

Hundreds of hardware choices are accessible. When the machine has completed one bunch the yield flags the following amount or part, and the machine naturally repositions and retools in like manner. In the interim, the simply completed clump is consequently exchanged to the following work station in its directing. FMS is utilized as a general term for a wide accumulation of generation frameworks, which may take a few diverse auxiliary structures. An adaptable assembling framework (FMS) is a generation framework equipped for delivering a mixture of part sorts, which comprises of CNC or NC machine instruments joined by a computerized material taking care of framework. The operation of the entire framework is under PC control.

The length of it fulfills the definition, any creation framework, substantial or little, can be called a FMS, within the group of systems; we believe that FMC is a critical uncommon sort. As of late, it is extremely basic contemplated shape in FMS research and numerous real FMS establishments' case 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 known as a flexible machining cell (FMC) in Browne et.al (1984) and a flexible manufacturing module (FMM) in Kusiak (1985).

The material-taking care of gadget is a SFM could be a robot or extraordinary reason bed evolving gadget. At the point when a SFM is utilized as a segment of a bigger framework the material-taking care of gadget may be uprooted if the material-taking care of gadget of the bigger framework can perform its capacity.

Regardless of all the enthusiasm for FMSs, there is no consistently concession to the meaning of the terms in FMS. The principle recognizing element of FMS from customary assembling frameworks is "adaptability" which does not have an exact definition. A standout amongst the most alluded to meaning of FMS is by Rank (1983), who characterizes a FMS as a framework managing abnormal state disseminated information preparing and mechanized material stream utilizing PC controlled machines, get together cells, mechanical robots, investigation machines et cetera, together with PC coordinated material taking care of and stockpiling frameworks. Truth be told, the extension and mixture of adaptable assembling are regularly debated and are the center of numerous exploration endeavors. On the other hand, the segments and attributes of a FMS, as depicted by diverse creators and specialists, are by and large as takes after.

- 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 5 shows the classification of a typical manufacturing system with respect to the level of flexibility, number 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 5:- Classification of manufacturing System

5.14 COMPONENTS OF FMS

Figure 10 demonstrates a regular adaptable assembling framework format and its parts

(a) Machine Tools

These incorporate CNC machines, drill machines, processing machines and so forth and any unique reason machines. They have programmed apparatus changer and measuring frameworks.

(b) Tool Systems

Machine devices are furnished with either turret or apparatus changer for supplying wanted devices. For less machining parts a turret is utilized. For parts with more process duration programmed device changers are utilized.

(c) Work Handling

In FMS establishment, programmed changing of the work piece is vital. Such a framework ought to be easy to reset and have openly programmable developments and short changeover time and have a sufficient taking care of limit. It is introduced physically isolated from the machine apparatuses to dispense with vibration to machine instruments

.

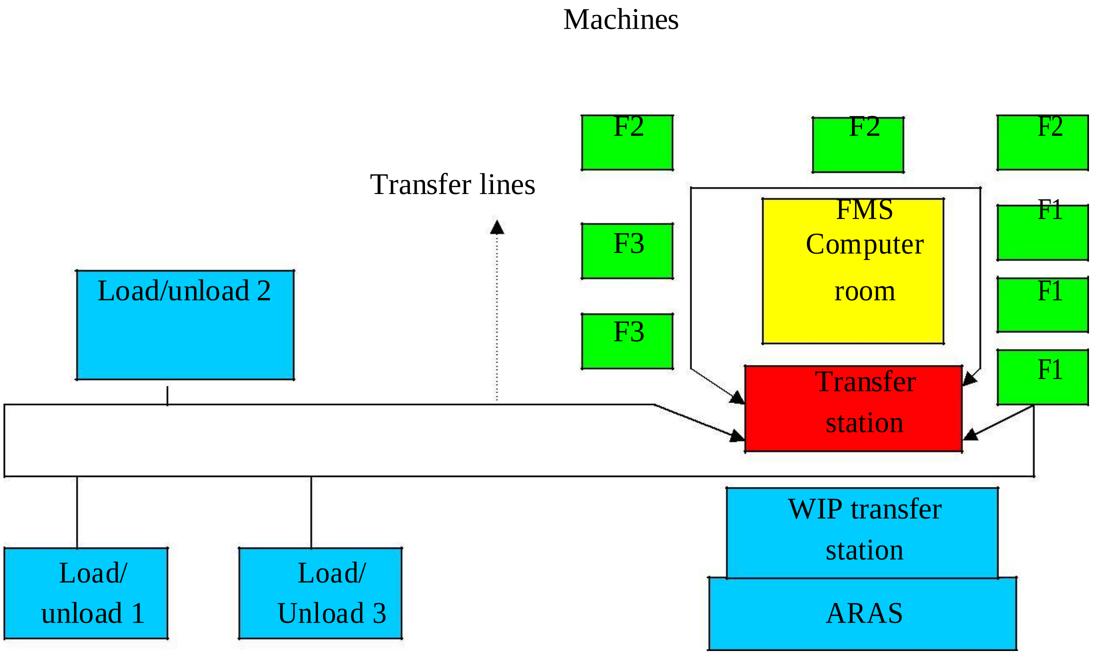


Figure 10: A typical FMS layout

(d) Material Handling System (MHS)

Keeping in mind the end goal to accomplish a high level of adaptability of material stream, it is helpful to utilize singular transports. They have the focal points that they can take after a foreordained course without meddling with different vehicles. All in all the fundamental goal of MHS is to help to accomplish most extreme workstation in usage through powerful work piece development limit and paces are considered for configuration of

MHS.

i) Primary Work Handling System

The essential work taking care of framework is utilized to move parts between machine apparatuses in the FMS. The prerequisites generally put on the essential material taking care of framework are:

- It must be good with PC control.
- It must give arbitrary, autonomous development of palletized work-parts between machine apparatuses in the framework.

- It must allow makeshift stockpiling or keeping money of work-parts.
- It ought to permit access to the machine instruments for upkeep, apparatus changing et
- It must interface with the auxiliary work taking care of framework.

ii) Secondary Part Handling System

The auxiliary parts taking care of framework must present parts to the individual machine instruments in the FMS. The auxiliary framework for the most part comprises of one vehicle component for every machine. The details put on the optional material taking care of framework are:

- It must be perfect with PC control.
- It must allow brief stockpiling or saving money of work-parts.
- It must interface with the essential taking care of framework.
- It must accommodate part introduction and area at every workstation for preparing.
- It ought to permit access to the machine device for support, instrument changing etc.

(e) Monitoring System

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

(f) Planning System

The arranging framework is done at three levels:

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

In order to accomplish most extreme asset usage by distribution of machine apparatuses arrangement of operations and instrument administration.

(g) Auxiliary Equipment’s

Other than machine devices, a FMS can likewise incorporate cleaning on-line investigation, computerized estimation an

5.15 FMS SELECTION CRITERIA

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

5.16 PERFORMANCE MEASURES IN FMS

The different sorts of measures that are regularly connected in FMS are

(1) PHYSICAL: This incorporates

•Number of part sorts took care of by the framework.

•Average change after some time to switch between parts

•Average number of distinctive routings accessible

(2) VALUE: These incorporates

•Shadow costs

•Incremental net ideal incomes

These are gotten from proper scientific programming models of the assembling framework.

(3) RATIO MEASURES: These incorporates

•Ratio of part sort to part families

•Ratio of part families to change over time

•Part numbers booked per unit changeover time.

(4) PRODUCTIVITY: These incorporates
•Work profitability
•Output profitability

5.17 PROBLEMS IN FMS

Some of the problems in FMS related to the design, planning scheduling, and controls are very troublesome in nature.
These problems can be encountered both at the technical as well as the organization level.

DESIGN PROBLEMS

These incorporate, for instance deciding the suitable number of machine modules of every sort the limit of the 'MHSs', size of the cradles, size and quality identified with the installations and beds.

PLANNING PROBLEMS

Arranging issues incorporate the focus of the ideal parcel of machine instruments, plant format, portion of the beds and apparatuses to part sorts and task of operations and related cutting devices among the restricted limit device magazines.

SCHEDULLING PROBLEMS

These issues are exceptionally confounded of all. They incorporate deciding the ideal input sequence of parts and an ideal grouping at every machine apparatus given the present part range.

These problems alter with the order of the flexibility.

CONTROL PROBLEMS

Control issues are those, concerned with the observing of the framework, to the due dates and the greatest usage of assets.

Every one of these issues are handled with various critical thinking philosophies, procedures and "reproduction models", Queuing Network", artificial knowledge" based methodologies and PC intuitive reenactments".

5.18 TOOLS TO SOLVE FMS RELATED PROBLEMS:

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

(a) **Analytical Tools**: - These are the techniques like queuing theory, integer programming, heuristic algorithm, and Markov

(b) **Simulation Tools**:- Universally useful reproduction (e.g. Pummel II, SIMAN IV, and so on.), Simulation programming intended for the general reproduction of assembling frameworks (e.g. SIMPLE++, Auto Mod II, ProModel, ARENA, SIMFACTORY II.5, and so forth.) and Simulation programming exceptionally made for a particular issue by utilizing general programming dialects, for example, C,FORTRAN, BASIC, LISP, and so forth

5.19 STRATEGIC ISSUES IN FMS

Prior to the usage of FMS it is important to first study the different key issues in adaptable assembling frameworks, for example, budgetary position of the organization, economic situations, mechanical position and so forth table 7 beneath shows different key issues in FMS.

Strategic issues	**Related factors**
Financial position	• Required finance. • Available finance. • Methods of finance.
Technology position	• Improvement. • Modernization. • Expansion.
Market position	• Share. • New products/markets.
Product conception and resources	• Product quality. • Product research. • Product facilities. • Stock planning. • Stock management. • Total utilization.
Human resource management	• Management development. • Training & education programmes. • Job offers. • Manpower. • Employee moral/motivation. • Employee participation in automation projects.
Government policies	• Cost of raw materials. • Import/export amenities • Technical support. • Debt policy of governments.

Table 6:- Various strategic issues in FMS

5.20 ADVANTAGES OF FLEXIBLE MANUFACTURING SYSTEM (FMS)

- Integration of a few machines or working environments prompts littler holding up time in the middle of machines and better use of every machine prompting more noteworthy efficiency contrast with stand-alone machines, numerous studies demonstrate the profitability to increment by an element of 2 to 3.5.

- Integration of employment arranging and material arranging prompts ideal material usage element booking of occupations in the light of procedure checking prompts decrease of downtimes and better use of machine significance higher profitability and lower expenses.

- Dynamic employment planning likewise prompts more prominent adaptability in meeting generation deadlines and along these lines better markets pictures.

- Automatic supply of instruments and work pieces from normal stockpiling to machine additionally prompts littler stock expenses and human operation expenses, further diminishing the expense of preparations.

- Production expenses have been seen to diminish ordinarily to half of the expense before the establishment of FMSs.

- Very high item quality can be accomplished because of incorporated procedure observing, i.e. coordinated instruments, work pieces and mistake finding observing for all intents and purposes 100% review can be given.

- Quick production in very small lot sizes with great variation of the same is possible.

5.21 LIMITATIONS OF FMS

- Lack of top administration responsibility and back
- Improper guidance of personnel involved
- irregular measure
- Lack of long term committed relationship between vendor and user
- Lack of aggregate duty to the establishment rearrangements of FMS
- Existence if misinterpretations about FMS, (for example, FMS being great just for extensive organizations and for expansive scale generate

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 got to be simpler from the past. The principle and the most prevalent sort of examination of these frameworks are done utilizing reenactment systems. Demonstrating of these mind boggling frameworks is less demanding and successful than the scientific or physical investigation that was beforehand done.

Since the F.M.S environment have a ton of variables that influence the execution of the framework, legitimate recognizable proof and investigation of these variables are essential for the fruitful demonstrating of the frameworks. There are various outline related and operational related issues that must be overcome before effective F.M.S establishment.

Despite the fact that recreation is the most prominent, financially savvy and less demanding approach to show

F.M.S situations, it has one downside. As the quantity of instabilities builds, the framework turns out to be more minds boggling and the outcomes got can't be effortlessly confirmed and accepted. Genuine F.M.S situations are stochastic, consequently instabilities can't be overruled. So one ought to confine the quantity of elements considered in a solitary framework. This is one of the primary standards of displaying and is termed as significance.

One of the reasons for the above downsides is the absence of clear seeing, by directors and creators, of adaptability alternatives and their suggestions. Slack (1987) watched this in the studies.

CHAPTER - 6
MODELLING MANUFACTURING FLEXIBILITY WITH PETRI NET

6.1 FLEXIBILITY OF A MANUFACTURING SYSTEMS:

Adaptable assembling frameworks are a class of computerized assembling frameworks. Their name infers that the component which portrays them among the various elements in their adaptability

A FMS involves Processing modules or machines connected by MHS all under Central Computer Control (BUZACOTT & SHANTI KUMAR 1980).

Different sorts of adaptability were characterized in this connection and a few endeavors were made to evaluate and measure adaptability (BUZACOTT' 1982, "ZELENOVIE" 1982, "SLACK" 1983, "BROWNE" et al 1984).

As indicated by "BUZACOTT", any endeavor to assess the adaptability of an assembling framework must start by thinking seriously about the way of the change that the framework needs to adapt to. Outer changes as item sorts, blends, amounts are managed by mechanical advance, market and firm approach.

6.2 TIME - PERFORMANCE ANALYSIS FOR FLEXIBILITY:

(i) Flexibility is an obscure idea, containing different equipment outline and operation choice, taking various time skylines (short, medium, and long).

In this manner demonstrating and measuring aggregate adaptability of a framework through a generative (or prescriptive) model (SURI 1985) resembles an incomprehensible assignment.

(ii) A most important element of framework's adaptability to change amid operation, we propose to call this operational adaptability embodying the accompanying components, machine setup adaptability, framework setup adaptability and directing adaptability.

(iii) For measuring operational adaptability time is a more unmistakable parameter than expense, in the time - expense exchange off connections. Adaptability can be assessed as the time required for framework solace capacity.

(iv) It is consequently conceivable to evaluate operational adaptability of a given framework and moreover, to look at changed frameworks on an adaptability premise.

(v) Having evaluated in a general manner that "operational adaptability" of a framework can be communicated as far as time.

6.3 MODELLING FLEXIBILITY WITH PETRI-NET:

Neither of the methodologies endeavors to utilize Petri nets for demonstrating changes or unsettling influences in FMS. Here we handle the likelihood through the exemplary elucidation for spots and move.

"SIFAKIS" method of considering time depicted above inferring:-

1. Places speak to assets or conditions (machines or part and so forth.) A token in a spot demonstrates accessibility of the machine or status of the part. Time is communicated by tokens being deferred in spots speaking to events of non-primitive occasions as preparing, exchanging and so forth.

2. Transitions speak to quick occasions.

This displaying methodology has been decided for two reasons:

(a) It jam the excellent petri net thought of moves as quick occasions and so on and

(b) It does not cloud the condition of the framework spoke to by the stamping amid the time the procedure is in execution, which is particularly important to demonstrating understandings.

Our displaying reason for existing is to build up a general comprehension of the path in which the execution of a FMS is influenced by unsettling influences and how operational adaptability can lessen these impacts.

The fundamental thought of utilizing Petri nets to this end is their ability to obviously evidence of incomplete execution strings, speaking to conceivable arrangements of occasions.

There will be diverse such arrangements for frameworks handling a given adaptability highlight when contrasted with those which don't have it.

Time goes between progressive moves strings speaking to execution strings. For sure there is no inborn measure of time in the petri net the length of there is no data in regards to the time slipped by between two progressive moves inside of a given fractional grouping or execution string. Supplying the above data of succession length of time & therefore examinations between terms & of diverse groupings, which for our situation will be influenced by the framework's adaptability level.

Some extra suspicions are needed by these displaying ideas:-

(i) The part landing occasion is spoken to by a move which is actuated

(ii) In a comparative way the entry of a disappointment (to a machine or whatever other Equipment) will be exhibited by a move impelled by an adequate stochastic methodology identifying with frustrations.

(iii) A non-incite activity as (get ready or trading) obliging openness of an advantage may be impeded by a breakdown move which gets the opportunity to be engaged before the activities ordinary end.

The issue in fig. 11 spotlights on showing interruption of a development (taking after the passage of a failure).

As showed by the fabulous model we have taken, while taking care of (or whatever other non-zero time activity) is carried on, there is a token in the spot addressing the conditions (P3 as in fig VII). Here we can say that it will stay there till the end of the get ready period or delay time (whose time allotment we have thought to be t3 time units). By then its fulfillment move T3 will be enabled; given no benefit dissatisfaction happens in the midst of the above time interval. If this happens (ending of T4) the activity will be upset in view of the ending of a substitute moves (T5) which will end up being immediately engaged as a result of the failure's entrance (checking of spot P5).

FIG.11 **INTERPRETATIONS OF PLACES AND TRANSITIONS PLACES**

p_1: Job waits

p_2: Machine free

p_3: Job process

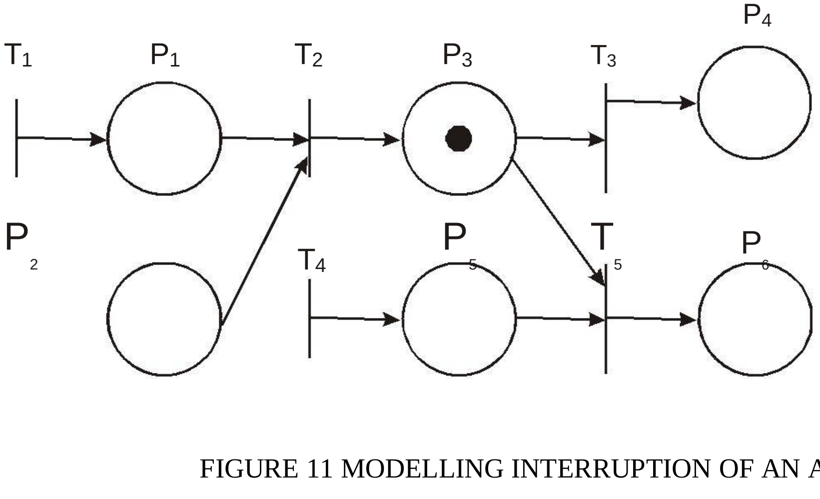


FIGURE 11 MODELLING INTERRUPTION OF AN ACTIVITY

P_4: Job is waiting for next Activity
P_5: Machine break down
P_6: Job is waiting to resume machining

TRANSITIONS:

t_1: Job Arrives
t_2: MACHINING BEGINS
t_3: MACHINING END: t_3: Processing duration
t_4: MACHINE OBSTRUCTION ARRIVES
t_5: MACHINING ENDS.

6.4 DEAD-LOCKS IN AUTOMATED MANUFACTURING SYSTEMS:

A gridlock is a profoundly undesirable circumstance in a FMS, in which each of an arrangement of two or more employments continues sitting tight inconclusively for alternate occupations in the set to discharge assets.

The event of a halt can cripple the whole framework and renders computerized operation outlandish. Also a halt happening in a subsystem of the given framework can spread to different parts of the framework. At long last totally slowing down all exercises in the whole framework.

Halts typically emerge as the last condition of a mind boggling arrangement of operations on employments streaming simultaneously through the framework and are along these lines for the most part hard to foresee.

In a despicably outlined FMS, the main solution for gridlock may be yearly clearing of supports or machines and restart of the framework from an introductory condition that is known not halt free operations under typical generation conditions.

Both the lost generation and the work cost in resetting the framework thusly can be kept away from by legitimate configuration and cautious operation (3).

Here we can take a case of stop in an assembling framework. As indicated in the fig. IX there is stacking/emptying station were crude materials are accessible. An AGV is utilized here to convey a crude part from the stacking and emptying station, where it is emptied. The AGV can just convey one section at once. The NC machine additionally forms one section at once. Other than this, the AGV takes a certain measure of time to convey a section from L/U to machine or from machine to L/U. Be that as it may, in the event that it doesn't conveying a section, it can travel immediately between the L/U and AGV.

In the event that the machine and the AGV can just oblige one section at once and there is no other cradle space the two assets here are then included in a "stop", following every continues sitting tight for the other inconclusively.

Regardless of the fact that some support space is accommodated crude parts and completed parts in the framework, a halt can in any case happen in light of the fact that the AGV can fill the whole cushion with crude parts amid the preparing of part A1 by the machine.

These studies from the presence & unlucky deficiency of halts utilizing the invariants of the PN model. In PN-based procedures the expressions "Counteractive action" & evasion halts in mechanized assembling frameworks have been utilized.

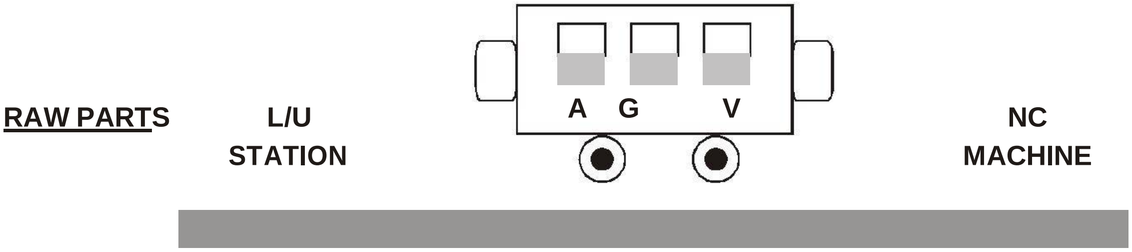


Figure 12 DEAD LOCKS IN AUTOMATED SYSTEM

6.5 SOLUTIONS OF FEW PROBLEMS REGARDING FMS:

The solutions of the problems, can be illustrated with an example using a manufacturing cell with multiple robots and simple FMS consisting of three machines, manufacturing three different parts - using “PETRI-NET MODELS”

Considering a simple manufacturing cell consisting of three machines, M_1, M2, and M3 & Rb_3. The three machines process three different part types i.e. parts type A, B and C respectively.

The processing of each part type proceed in two phases - in phase one only one robot is required. Here machine M_1 which processes part type ‘A’ uses robot Rb_1 in phase I, and then uses Rb_2 & Rb_3 in phase 2nd.

It is assumed that M_1 will start phase 1 when robot Rb_1 is available and after finishing phase 1 will wait for Rb_2 without leaving Rb_1. Similar is the case with Rb_2 & Rb_3 as shown in figs. 13 (a, b & c).

Petri net model shown in fig. (a, b & c) shows the operation performed by machines M_1, M_2 & M_3 respectively.

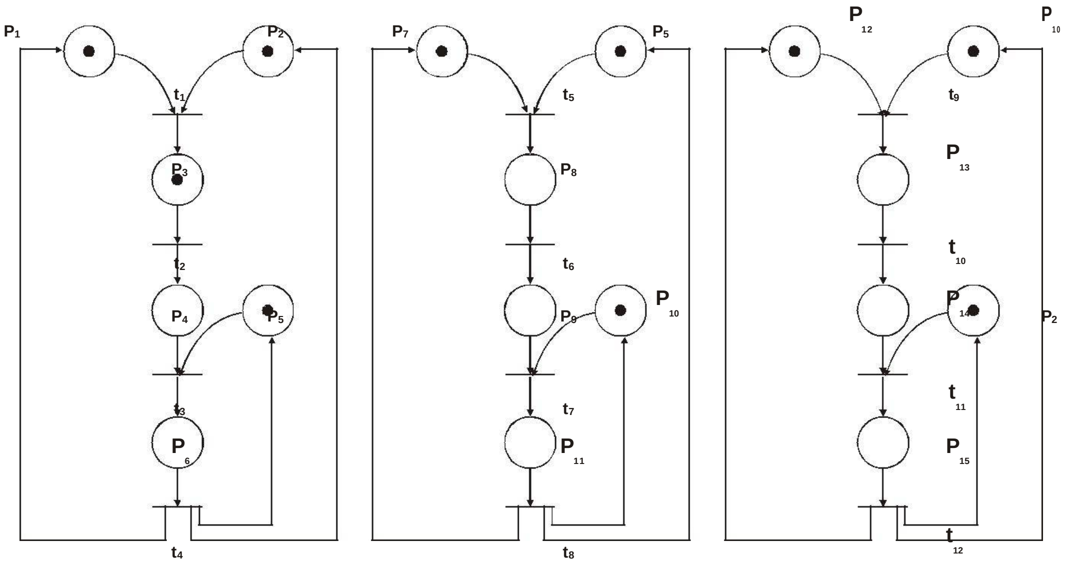
The interpretation of the places and transition of these models are given in below. Further we can obtain a petri net model (PNM) for the overall cell operations by the union of

PNMS of fig. (a), (b) & (c).

The overall model is shown in the fig. (d). Referring to the definitions of petrinet in Chapter 5 definition 5.

The methods of union of petri nets can be conveniently applied to any general

FMS configuration based on the structure of the part types and the structure of the routings.



(A) (B) (C)

Figure: 13

Petri Net models — Processing three part types using three m/c

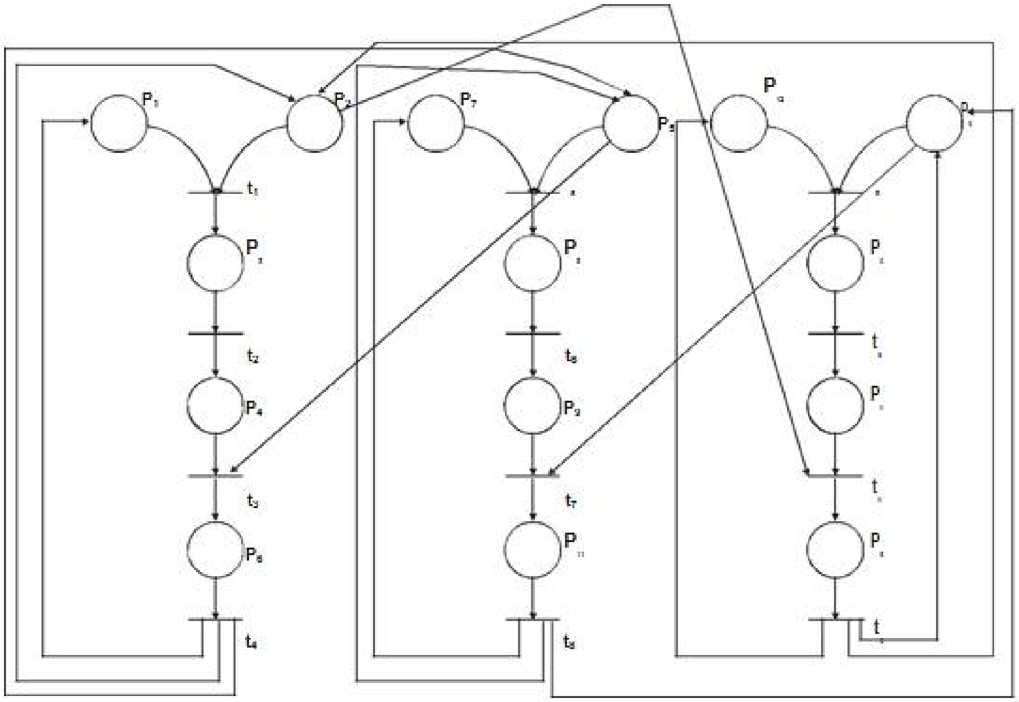


Figure: 13(d)

Compact models using union of colored Petrinets

Using coloured petri nets (CPNS) and the concept of the union of CPNS, compact models can be obtained for complex generalized FMS configurations. A CPN provides an abstracted model by folding sub models.

For example the PNMS of fig 13 a, b & c, which are all structurally identical can be folded, into a single model of identical type by associating colors to places and transitions and appropriately defining functional dependencies among these colors

INTERPRETATIONS OF PLACES AND TRANSITIONS:-

PLACES:

p_1: Machine M_1 is ready

p_2: Robot Rb_1 is available

p_3: Machine M_1 utilizing the robot Rb_1

p_4: Machine M_1 waiting for robot Rb_2

p_5: Robot Rb_2 is available

p_6: Machine M_1 using both robots Rb_1 & Rb_2.

p_7: Machine M_2 is available

p_8: Machine M_2 using robot Rb_2

p_9: Machine M_2 is waiting for robot Rb_3

p_{10}: Rb_3 is available

p_{11}: Machine M_2 utilizing both Rb_2 & Rb_3

p_{12}: Machine M_3 is available

p_{13}: Machine M_3 utilizing Rb_3

p_{14}: Machine M_3 is waiting for Rb_1

p_{15}: Machine M_3 is utilizing both Rb_1 & Rb_3

TRANSITIONS:

t_1 - machine M_1 starts utilizing Robot Rb_1
t_2 - use of Rb_1 by machine M_1

t_3 - machine M_1 starts using Rb_2

t_4 - utilization of Rb_1 & Rb_2 by machine M_2 t_5 - machine M_2 starts using Rb_2

t_6 - utilization of Rb_2 by machine M_2 t_7 - machine M_2 starts using robot Rb_3

t_8 - use of robots Rb_2 & Rb_3 by machine M_2 t_9 - machine M_3 starts using robot Rb_3

t_{10} - utilization of robot Rb_3 by machine M_3 t_{11} - machine M_3 starts using robot Rb_1

t_{12} - use of Rb_1 & Rb_3 by machine M_3

CHAPTER - 7

MODELLING OF MANUFACTURING CELLS

FOR FIG. 14 (b)

Interpretation of “Places and Transitions”

PLACES:

P_1: Machine M_1 is available

P_2: Robot R_1 is ready

P_3: Machine M_1 using robot R_1

TRANSITIONS:

T_1: Machine M_1 starts using robot R_1

T_2: Use of robot R_1 by machine M_1

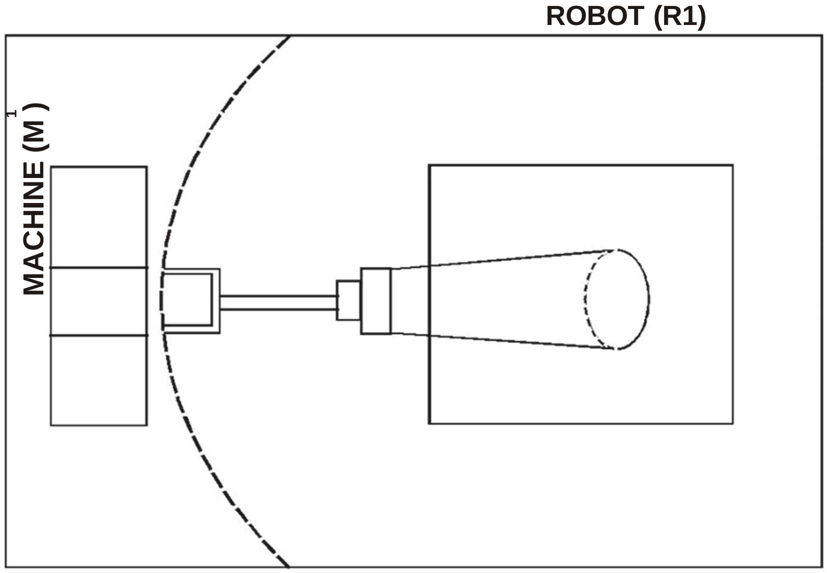


FIGURE 14A ONE MACHINE AND ONE ROBOT

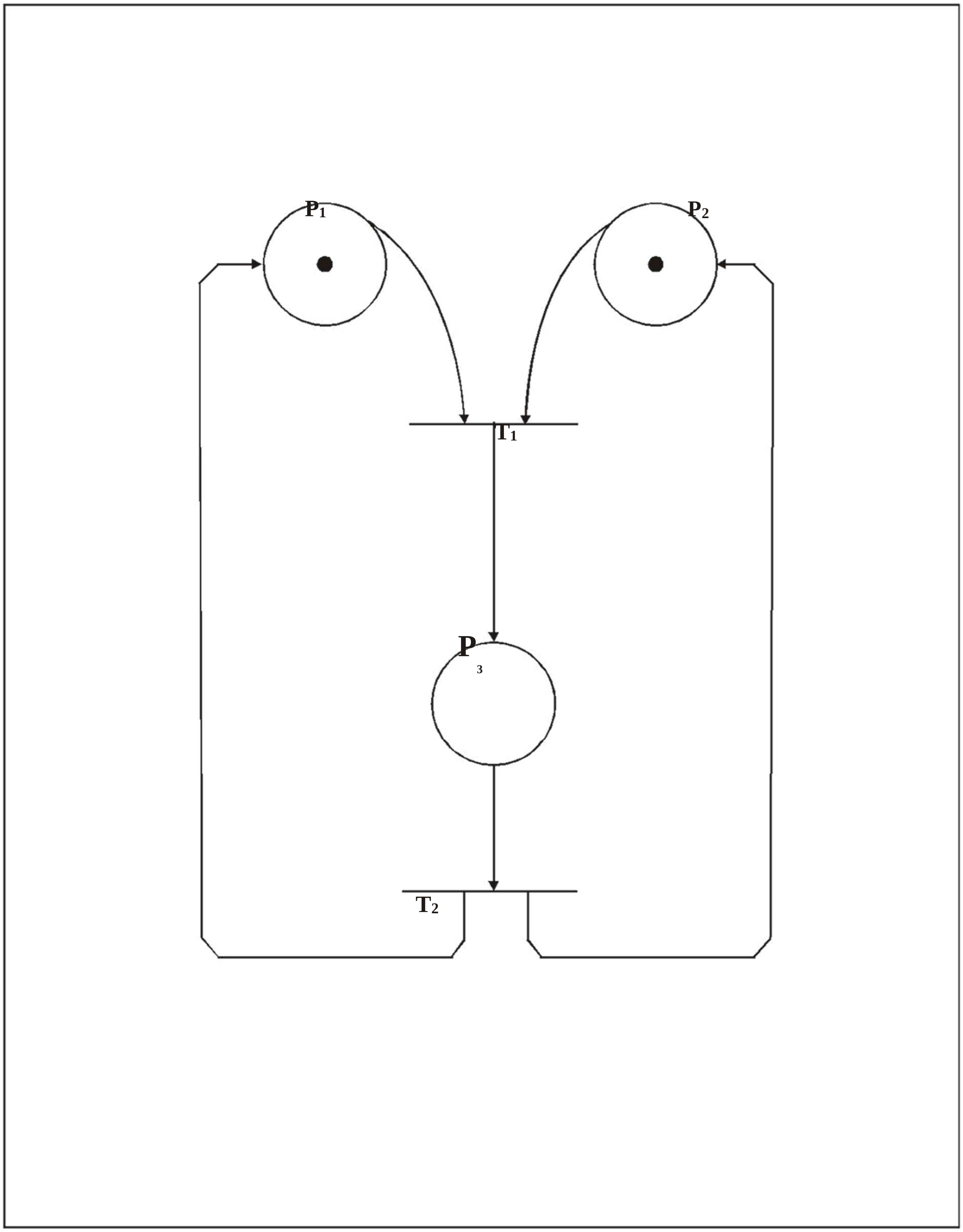


Fig. 14 (b) A PNM (PERTINENT MODEL) OF A SIMPLE MFG. MODULE COMPRISING ON M/C AND ONE ROBOT.

FOR FIG. 15 (b)

Interpretation of “places and Transitions”

PLACES:

P_1: Machine M_1 is available

P_2: Robot R is ready

P_3: Machine M_1 using robot R

P_4: Robot R waiting for machine M_2

P_5: Machine M_2 is available

P_6: Machine M_2 is busy with the robot R

TRANSITIONS

T_1: M_1 starts using ‘R’

T_2: Use of ‘R’ by machine M_1

T_3: Machine M_2 starts using robot ‘R’

T_4: Use of ‘R’ by machine M_2

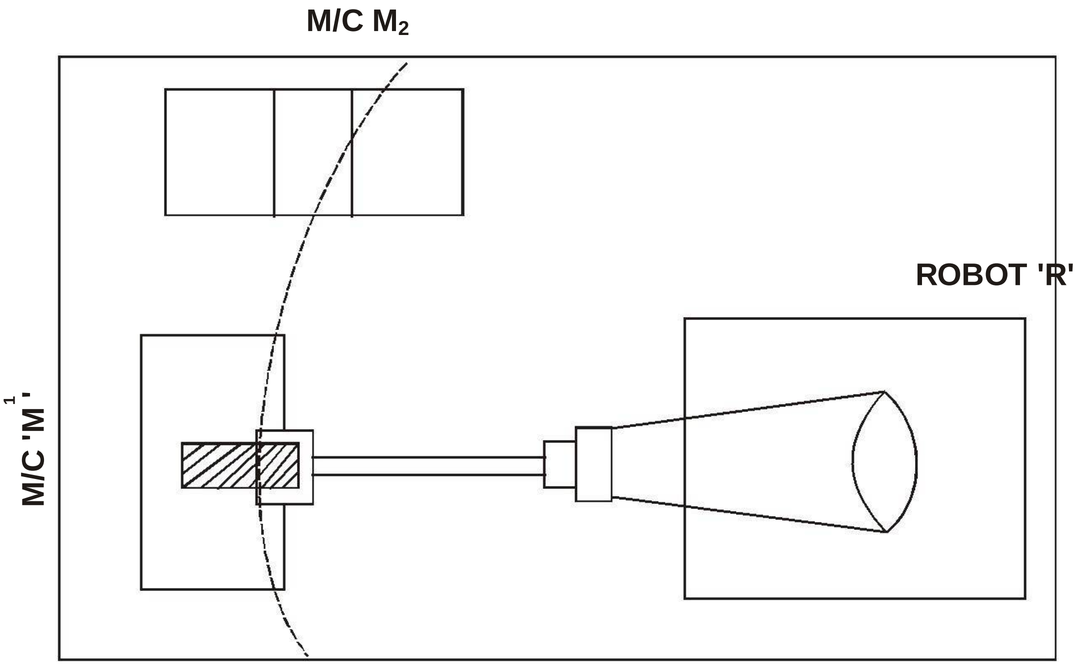


Fig. 15 (a)
LAYOUT OF A MFG. CELL WITH ONE
ROBOT AND TWO MACHINES.

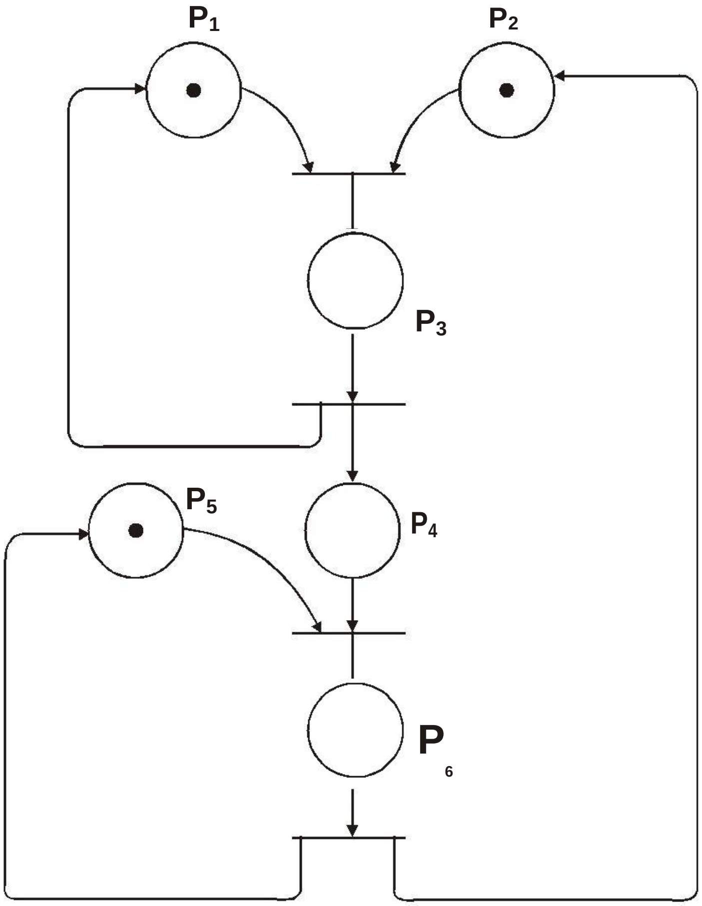


Fig. 15 (b) Petrinet Model of a Mfg. Cell

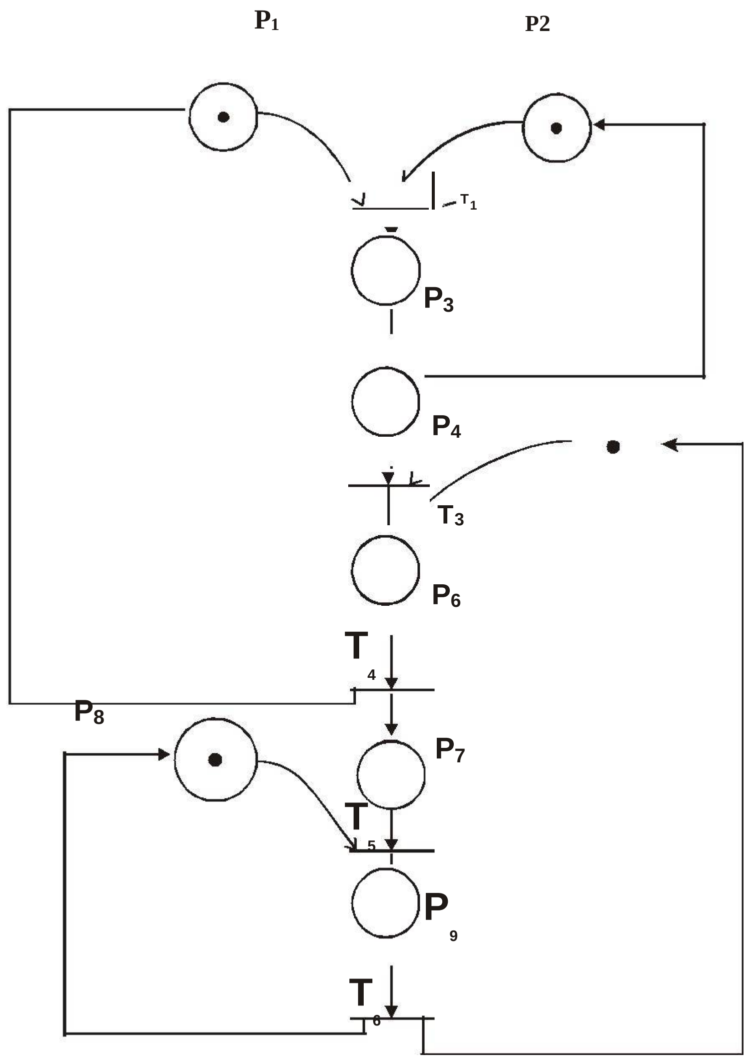


Fig.: 16 (b)
PNM OF A MFG. CELL

FOR FIG. 16 (b)

Interpretation of “places and Transitions”

PLACES:

P_1: Machine M_1 is available

P_2: Robot R_1 is ready

P_3: Machine M_1 using R_1

P_4: Machine M_1 is waiting for robot R_2

P_5: Machine R_2 is available

P_6: Machine M_1 is using R_2

P_7: Robot R_2 is waiting for machine M_2

P_8: Machine M_2 is available

P_9: M_2 is busy with R_2

TRANSITIONS

T_1: M_1 starts using ‘R’

T_2: Use or R_1 by machine M_1

T_3: M_1 starts using R_2 robot

T_4: R_2 is used by M_1

T_5: M_2 starts using R_2

T_6: R_2 is used by machine $M_{2.}$

CHAPTER-8

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

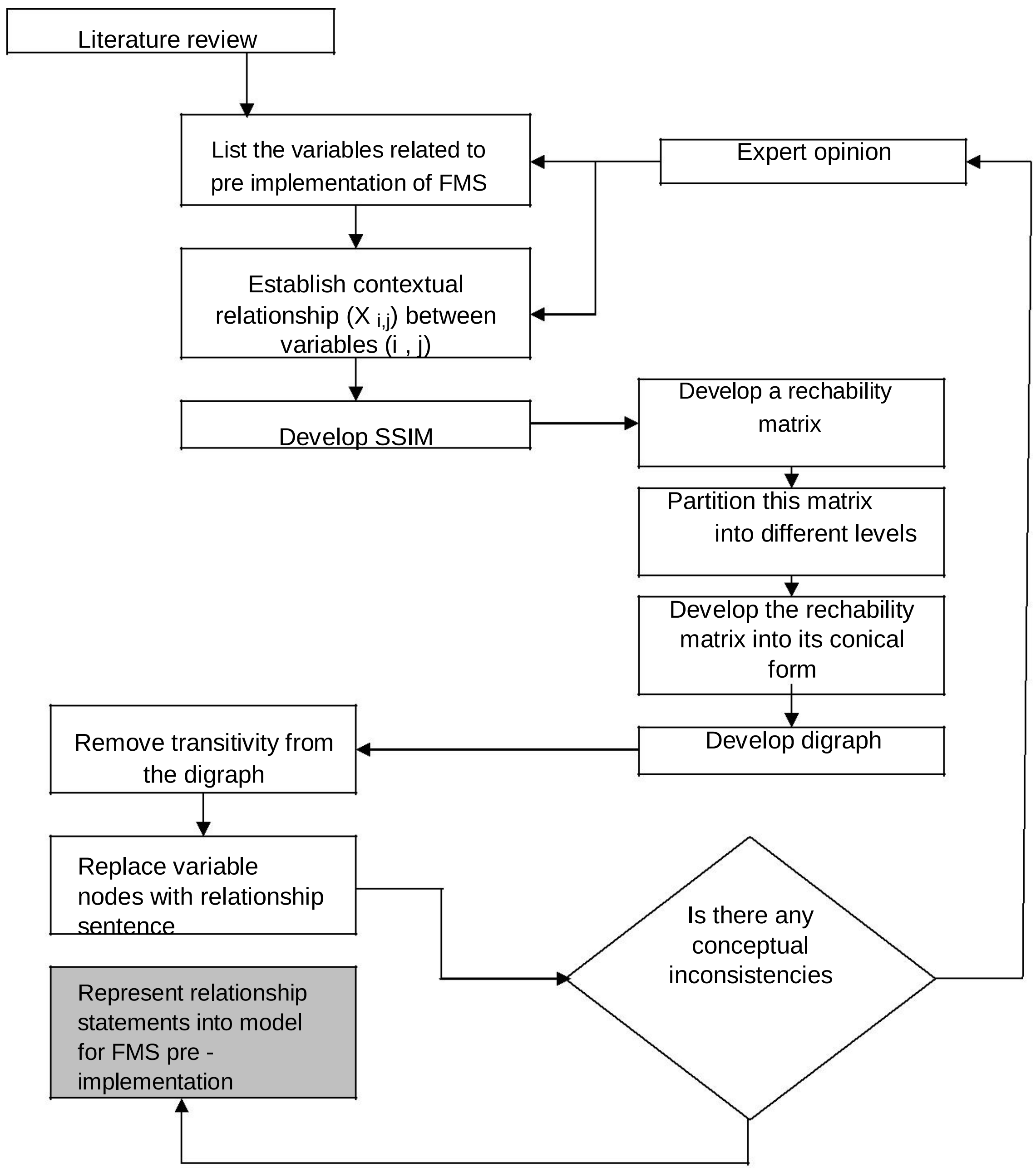
The SSIM format is transformed into a rechability matrix format by transforming the information in each entry of the SSIM into 0's and 1's in the rechability matrix.

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 below shows the flow diagram for the preparation of ISM model for the pre implementation issues in Flexible manufacturing systems



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

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 28.

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							

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

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

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

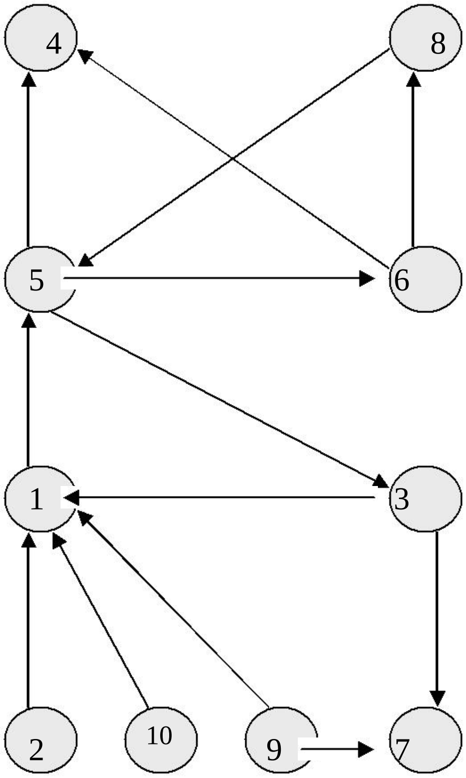


Figure 17:- ISM Model of pre-implementation issues

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

C F P

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

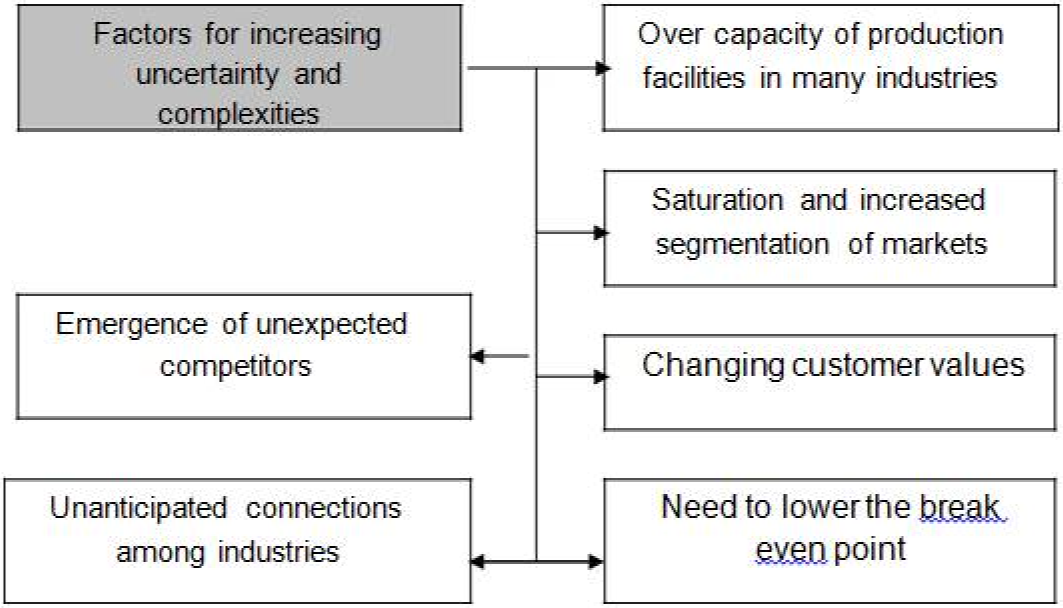


FIGURE. FACTOR FOR INCREASING UNCERTAINITY AND COMPLEXITIES

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.

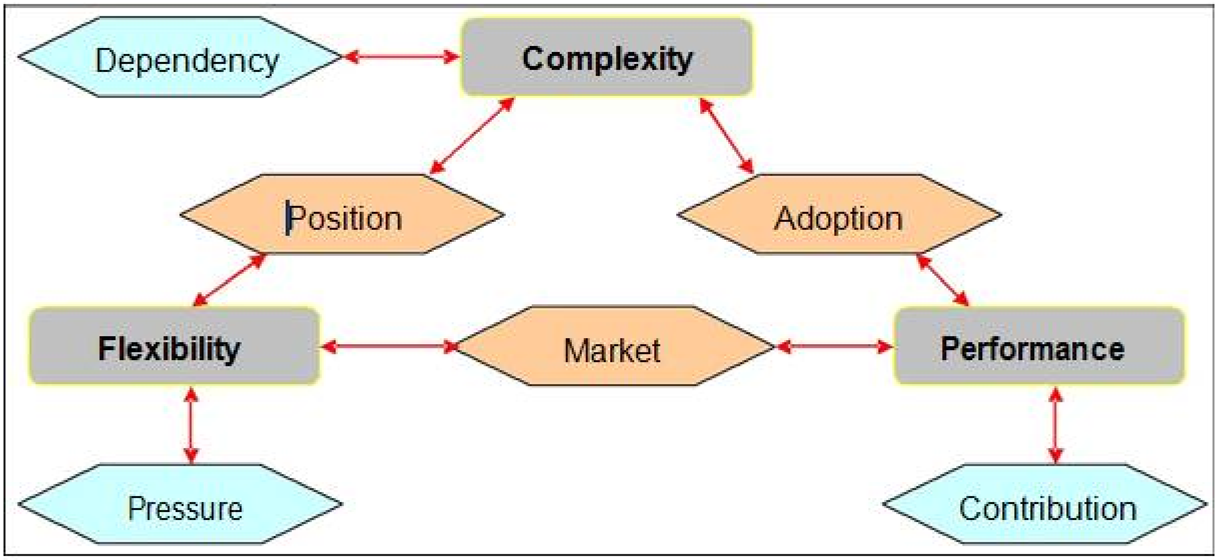


FIGURE.18 C F P

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.

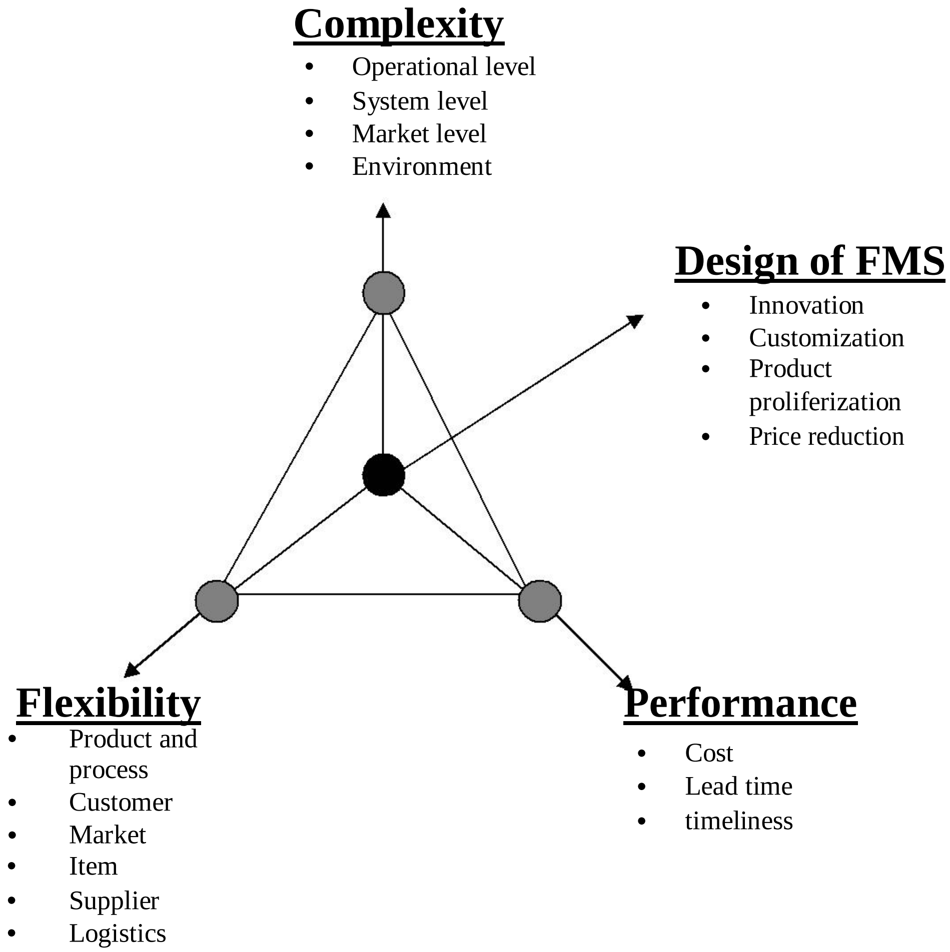
Flexibility is influenced by ***“pressure”*** relationship which may stem from an uneven power balance in a business negotiation, competitive threats or other kinds of intentional and social relationships.

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.



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. Givern Table gives the mapping of attributes for the FMS implementation of ABC Ltd. Table 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	V. Short	Short	Moderate	Long	V. Long

	makeover					
	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

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		
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 presentin 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		
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		

53.	Import/export facilities	0.75	0.75	Contributing variable
54.	Technical assistance	0.75		
55.	Fiscal policy of governments	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.

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 7:- Eight scenarios of C-F-P analysis

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 theFMS; 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.

CONCLUSION

The Petri net has been defined as a model for systems exhibiting concurrent asynchronous activities. The major factors that might affect its acceptance are concerns regarding the modeling power and decision power of the model. Although

Petri nets are not the only models of asynchronous concurrent systems, they are equivalent to or include most other models. In addition they have a certain clearness and cleanness which permits a simple and natural representation of many systems.

Thus they have gained increasing acceptance in the last decade, and their use is growing.

A major modeling system must provide more that simply a convenient representation system however. It must also provide analysis procedures that can be used to determine properties of the modeled system through the model. Some such analysis procedures for Petri nets do exist, allowing the analysis of system for boundedness, conservation, coverability, and reachability of a marking.

In Petri-net modelling of Flexible Manufacturing Systems, starting from a module to a complex system, it is found that the graphical representation of the system reveals many useful information, such as :-

- It represents discrete events and conditions or states, processing stage or any stage in the processes.
- Entry/Exit of a part.
- Starting/Finishing of a part transfer by a robot
- Starting/Finishing of Processing by a machine.
- Robot failure and machine breakdown.
- Coucurrency in activities.
- No. of resources, such as machine tools, pallets, buffers, Robots, conveyors etc. is contention of the resources.
- Provide insight into how a system behaves and how the system’s component interacts.
- Gives quantitative as well as qualitative performance. Such as :-
  - (i) Production rate of parts
  - (ii) Queueing times
  - (iii) Rerouting in case of machine failures, or breakage of tools.
  - (iv) Machines, Robots, and AGV unitlization.
  - (v) Wait time of parts on machines or conveyors.

For the real working of the system or to ascertain whether the system will work or not, the system is first modelled (PNM) and then simulated in a computer system, which will be a test run of the system without being run on the actual system.

Hence the PETRI NET modelling of the system simplifies many problems which were faced before automization of the systems

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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