Petri Net Modelling of Flexible Manufacturing System

A Major Project thesis

submitted in partial fulfillment

for the requirement of the degree of

Master of Engineering

in

Production Engineering

by

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CANDIDATE’S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled “Petri Net modelling on flexible manufacturing system”, in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Production Engineering, University of Delhi, Delhi is an authentic record of my own work carried under the supervision of Sh. Rajiv Chaudhary, Lecturer of Mechanical Engineering Department, Delhi College of Engineering, Delhi.

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

Sanjeev Kumar

<u>CERTIFICATE</u>

This is to certify that the major project work thesis entitled **“Petri Net Modelling of Flexible Manufacturing System”** being submitted by SANJEEV KUMAR, in partial fulfillment for the award of the degree of Master of Engineering (M.E.) in Production Engineering of UNIVERSITY OF DELHI , is a record of bonafide work carried out by him.

He has worked under my guidance and supervision and has fulfilled the requirements for the submission of the major project thesis. Further, it is also certified that this work has not been submitted for any degree or diploma in any college to the best of my knowledge and belief.

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ACKNOWLEDGMENT

Yes, a start leads to an end; initially I never thought that life would be as easy as now. That was in old days where everything was strange but thanks to the God and the institute community for their will and cooperation to feel the comfort I am feeling now.

It is a privilege to thank **Prof. P.B. SHARMA**, PRINCIPAL, Delhi College of Engineering, **Prof. S. MAJI**, HOD, Department of Mechanical Engineering, Delhi College of Engineering, **Prof. C.K. DUTTA**, HOD Department of Production Engineering, University of Delhi and **Prof. S.K. GARG**, Department of Mechanical Engineering for being the source of constant motivation and encouragement to me throughout the course of this project work.

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

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

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

Sanjeev Kumar

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CHAPTER-1

1.1 INTRODUCTION

A Perti net is an abstract, formal model of information flow. The properties, concepts, and techniques of Petri nets are being developed in a search for natural, simple, and powerful methods for describing and analyzing the flow of information and control in systems, particularly systems that may exhibit asynchronous and concurrent activities. The major use of Petri nets has been the modeling of systems events to occur concurrently but there are constraints on the concurrence, precedence, or frequency of these occurrences.

The point of view taken in this introduction to discrete event system (DES) is that they consist of interacting nodes. Each node can be a system in itself and may be thought of as a component of the DES. These components can operate concurrently, i.e., a component can be performing one of its functions at the same time that another component is carrying out one of its respective functions. For example, a customer at an Automated Teller Machine (ATM) can be making a deposit when another customer at another ATM of the same network can be making a withdrawal. These two activities are not independent from the system's perspective : they change the state of the system by changing the level of deposits (assets) of the bank. Consider now the case when the two customers access the same account - a husband and wife with a joint account, or two employees in the accounts payable section of the same company. Problems of synchronization of the two operations arise. Note that there is not fixed, predetermined order to the two events. The deposit may be made before the withdrawal or the withdrawal before the deposit. The specific order may lead to different results; banks have developed detailed regulations regarding the timing and sequencing of deposits and withdrawals. How then can we describe these kinds of problems in a precise, unambiguous manner?

The need to address such problems of concurrence in systems led Carl Adam Petri to introduce in his Ph.D. thesis (1962) a special class of generalized graphs or nets now called Petri Nets. They are a modeling and analysis tool that is well suited for the study of Discrete Event Systems. The use of Petri Nets leads to a mathematical description of the system structure that can then be investigated analytically. In this introduction, the basic definitions and properties of Petri Nets are presented. While there is an extensive literature on the subject, both on the theory and on applications, there is no major introductory textbook available that presents Petri Net theory and contains in a consistent manner the many recent theoretical and computational results. Here, only the basic notions and properties are discussed. References related to specific topics are given throughout the note. Introductory material about Petri Nets may be found in Peterson (1981), Reisig (1985), and Cassandras (1993). Additional material can be found in Jensen (1991), Beccelli et al. (1992); Zhou and DiCesare (1993).

"Petri Nets " have their origin to the early work of "C.A. Perti" in his "communication with automation" where the formulated the basis for a theory of communication between a synchronous components of a computer system concerning casual relationship between events.

Over the years PNS have developed into a powerful tools for modelling a synchronous concurrent systems in graphical as well as mathematical terms. The model is thus used to analysis & simulation for obtaining information about bottlenecks, deadlocks, and any other problems, avoiding test runs on the actual systems. Recently petrinets have been applied for modelling "Flexible manufacturing Systems."

1.2 <u>PETRI-NET MODELLING CONCEPT AND UTILITY:</u>

Here the focus is on a hierarchical method for constructing "PETRI-NET MODEL"of FMSs, qualitative analysis with special emphasis on quantitative performance and evaluation. Illustrative examples of manufacturing cells with multiple robots and a simple FMS consisting of few machines, manufacturing parts, are presented to bring out the significant issues that can be addressed using Petri-net models.

In the content of FMS Petri-net models can be used in a variety of applications.

First of all a Petri-net model gives a graphical representation of the FMS being modelled. The model could be used as a simulation model for designing discreet-event simulation of FMSs.

Secondly logical or qualitative analysis of the FMS can be carried out to assist important design and control decision to be made. Under the category the principal properties that can be investigated include boundedness (finiteness of resources).

Liveness (absence of deadlocks), properness (recoverability from failures) and fairness (absence of starvation).

Thirdly by associating “stochastic times” to the Petri-net transitions, the performance of an FMS can be quantitatively evaluated.

Performance evaluation of FMS involves constructing a performance models and computing from it various performance measures such as :-

- Machine utilizations,
- Throughput rates of parts,
- Mean buffer occupancies,

and
- average waiting times.

Performance studies provide in sight into design as well as operational issues. For example - They can be used for establishing the feasibility of a particular configuration, for choosing the optimal number of fixtures, pallets, and buffers, for identifying bottleneck resources; and for determining optimal operating policies.

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 area of modelling, Extensions of Petri-nets, such as coloured Petri-nets and predicate - transitions nets are now being used. Sophisticated computer aided tools for logical analysis are being introduced at various Universities.
- In the area of performance & evaluation, three topics that should receive immediate future attention are:-
- More realistic performance models such as DSPHs (Petrinets with deterministic and stochastic timed transitions);
- Integrated schemes combining GSPNs (Generalised stochastic Petri nets) with queuing networks; and
- well formulated theory for the aggregation of GSPNS.

Finally in the area of control, direct implementation of control logic from petri-nets models will be an extremely useful development.

Besides these, starting from a manufacturing module to a complex manufacturing cell, FMS performance & evaluation could be easily possible only through the petri net modelling.

CHAPTER - 2

2.1 FUNDAMENTALS

Since Petri Nets (PN) are a special type of graph, the presentation will start with some basic notions from graph theory. A graph consists of two type of elements, nodes or vertices and edges, and the manner in which these elements are interconnected.

Definition : A graph G = (V, E, ø) consists of a nonempty set V called the set of nodes of the graph, a set E called the set of edges of the graph, and a mapping ø from the set of edges E to a set of pairs of elements of V.

If the pair of nodes connected by an edge is ordered, then the edge is directed and an arrow is placed on the edge indicating the direction. If all the edges of the graph are shown in Figure 1. Note that the first one, consisting of only two unconnected nodes, can be considered both as a directed and an undirected graph.

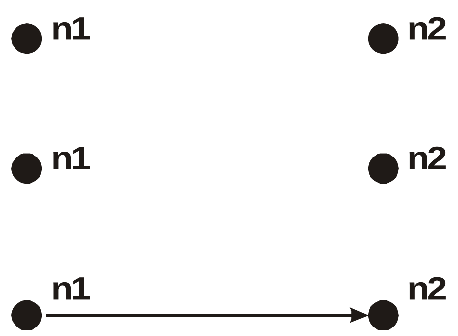


Figure 1 : Examples of graphs

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.

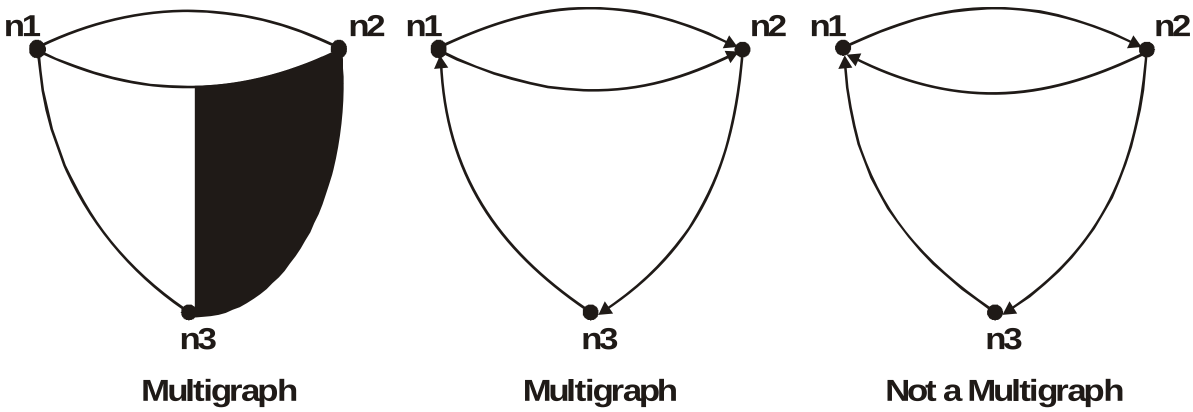
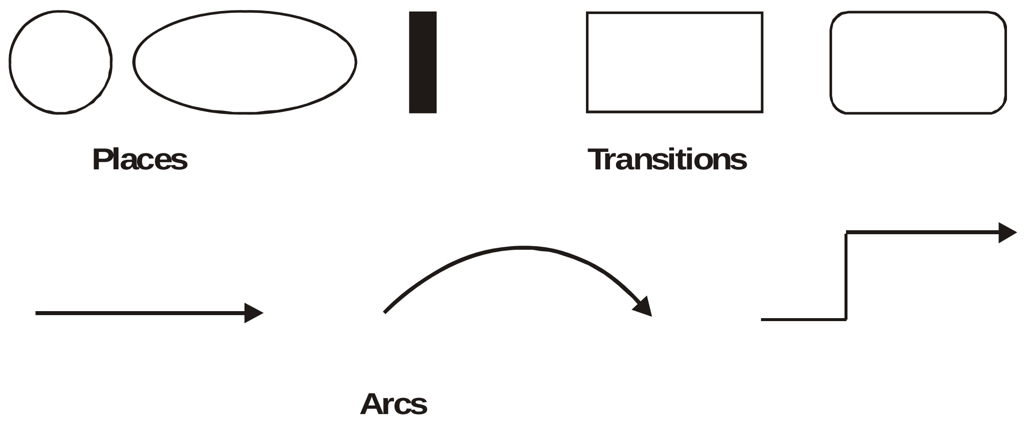


Figure 2 : Examples of multigraphs

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

A bipartite graph has a special property; and edge can connect only two nodes that belong the different types. Therefore, there can be an are from a place to a transition, from a transition to a place, but bot from a place to a place or a transition to a transition.

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

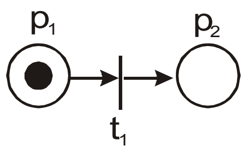
$F \phi (P \times T) \chi (T \times P)$ is a set of arcs

$W : F — \{1, 2, 3, ...\}$ is a weighting function

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

$P \cap T = \phi$ and $P \chi T \neq \phi$

Example



This Petri net has:

2 places: p_1, p_2

1 transition: t_1

p_1 has one token: $M(p_1) = 1$

p_2 has 0 tokens: $M(p_2) = 0$

Firing a Transition

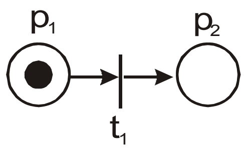
When a transition t fires

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

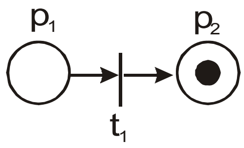
Each p_j that has an edge from t to p_j adds a token to p_j

Example

Petri net before t_1 fires:



Petri net after t_1 fires:



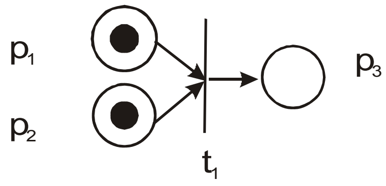
A transition must be enabled before it fires

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

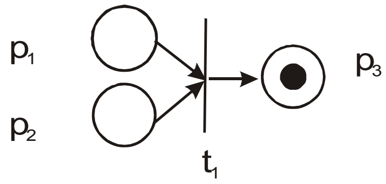
An enabled transition may or may not fire.

EXAMPLE

Petri Net before t_1 fires:



Petri Net after t_1 fires:



3.2 Types of Pertinet

Original Petri Nets

• Only 1 token can be removed/added from a place when a transition fires (i.e., the weight is always 1)

Weighted Petri Nets

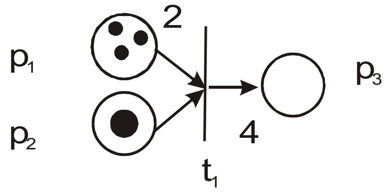
• Generalized the original Petri net to allow multiple tokens to be added/removed when a transition fires.

• The edges are labeled with the weight (i.e., number of tokens)

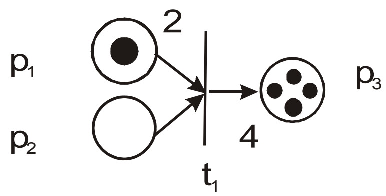
• If there is no label, then the default value is 1

Example 1

Petri Net before transition t_1 fires



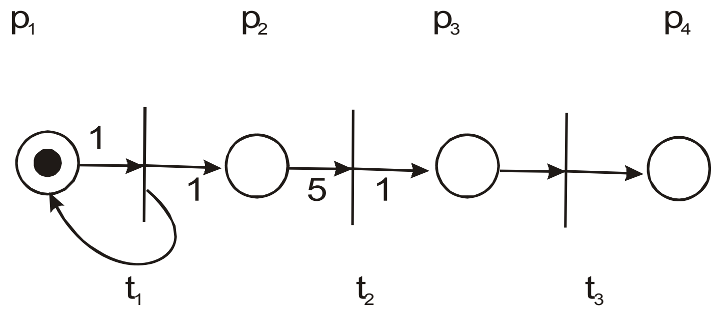
Petri Net after transition t_1 fires



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?

Twice?

Three times?

Four times?

Five times?

Six times? (is there only one possible marking here?)

...

Nine times?

Ten times?

Eleven times?

Other Types of Petri Nets

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

Time Extended Petri nets

- First developed in the mid 1970s
- For real systems it is often important to describe the temporal behavior of the system, i.e. we need to model durations and delays.
- There are 3 basic ways to introduce time into the Petri net. Time can be associated with:
  - token
  - places

– transitions

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

— In this model, a 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.

// Note : There are many other extensions to Petri Nets that consider time.

Colored Petri Nets

— Developed in the late 1970s

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

— To represent attributes of these objects, the Petri net model is extended with *colour 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.

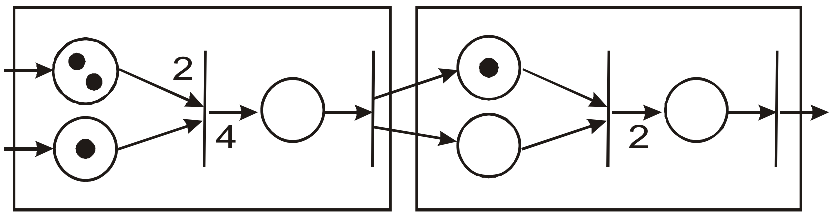
  – A transition describes the relation between the values of the ‘input token’

— It is also possible to specify ‘preconditions’ which take the colours of tokens to be consumed into account.

Hierarchical Petri Nets.

— Developed in the Late 1970 by Valette.

- Specifications for real systems have a tendency to become large and complex.
- An abstraction mechanism, hierarchical structuring, is used to make constructing, reviewing, and modifying the model easier.
- The hierarchy construct is called a subnet.
- A subnet is an aggregate of a number of places, transitions, and subsystems
- Such a construct can be used to structure large processes.
- At one level we want to give a simple description of the process (without having to consider all the details). At another level we want to specify a more detailed behavior.
- Each subnet is represented with a rectangular box that encapsulates part of the Petri Net model.



CHAPTER - 4

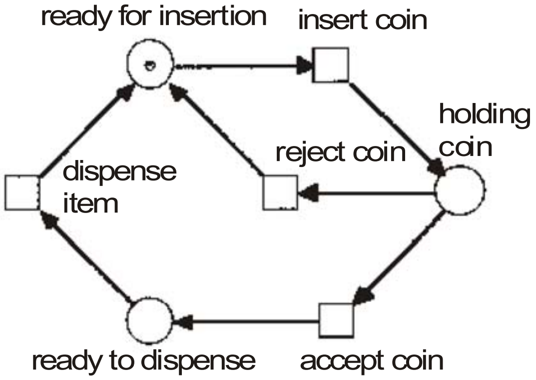
4.1 A PLACE / TRANSITION NETS

An example :

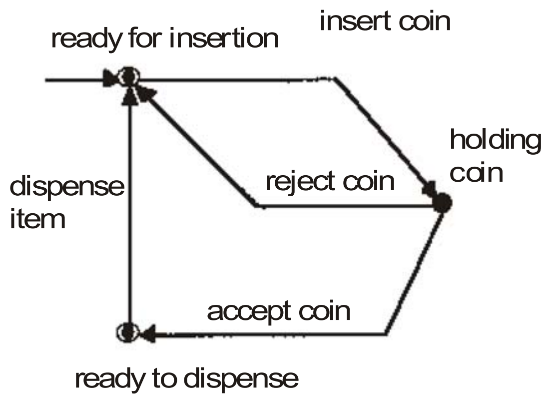
Different features of place/transition-net

Place/transition-nets vs en-sytems.

An Example : a vending machine
Control structure of a vending machine

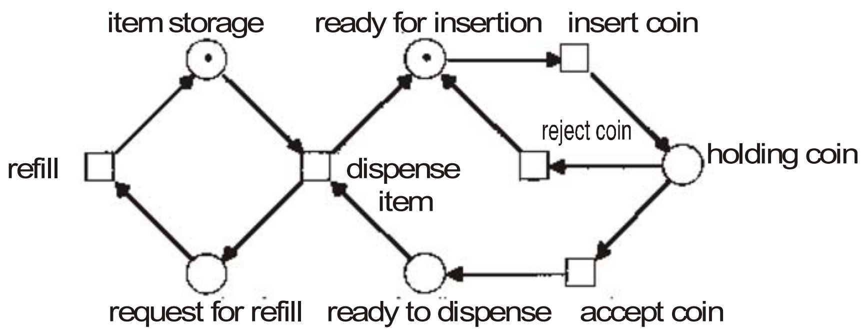


an en-system



its behaviour

Adding concurrency : a vending machine with capacity 1 ....



.... and its behaviour

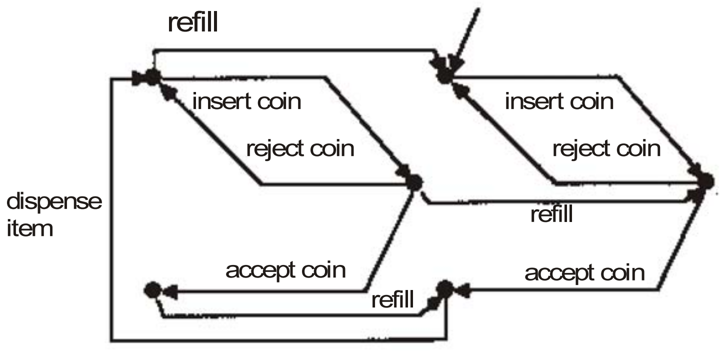
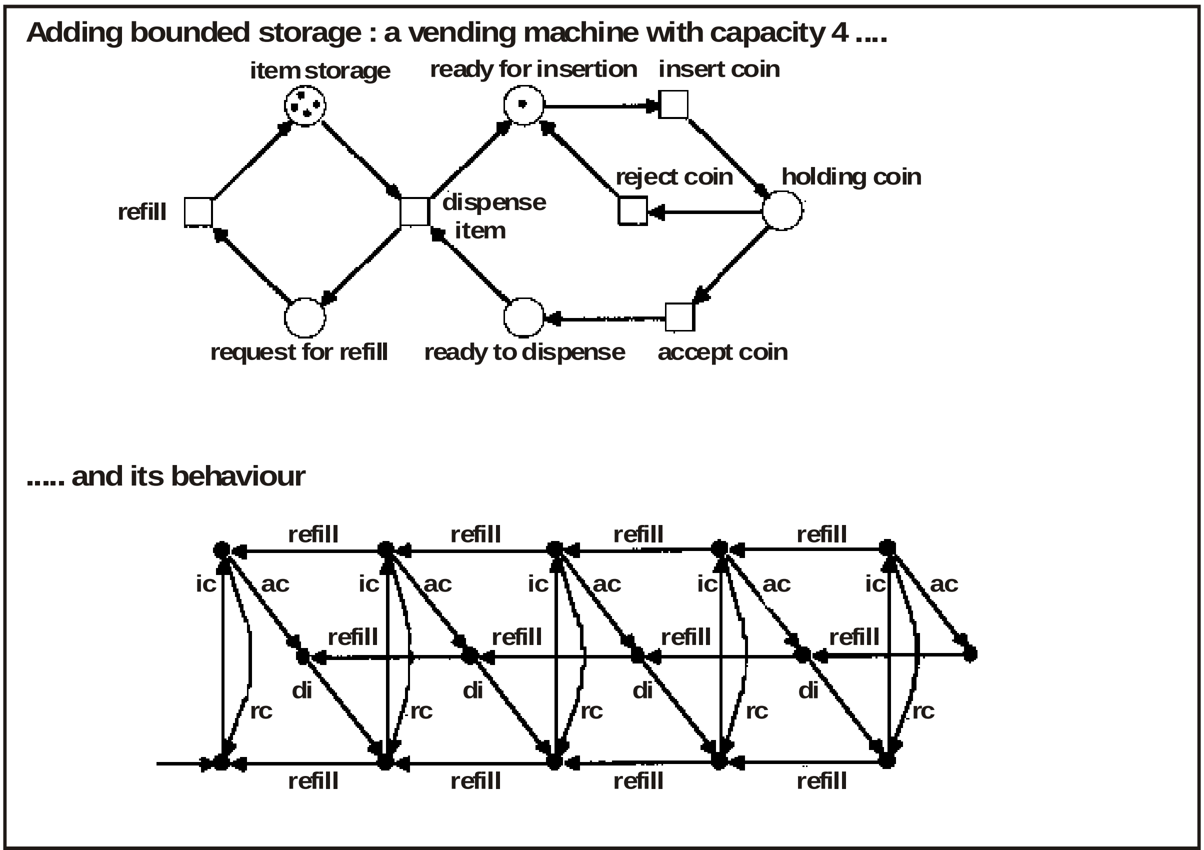


FIGURE : 5



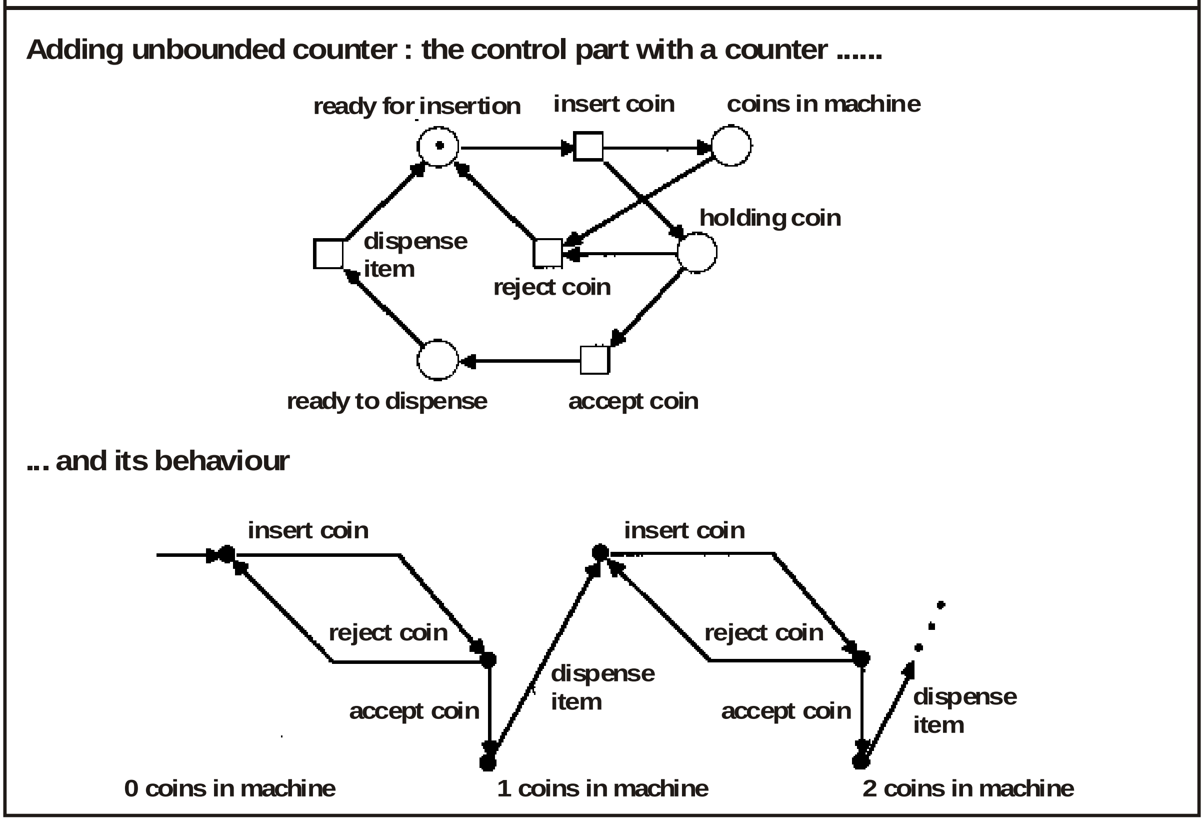


Figure : 6 & Figure : 7

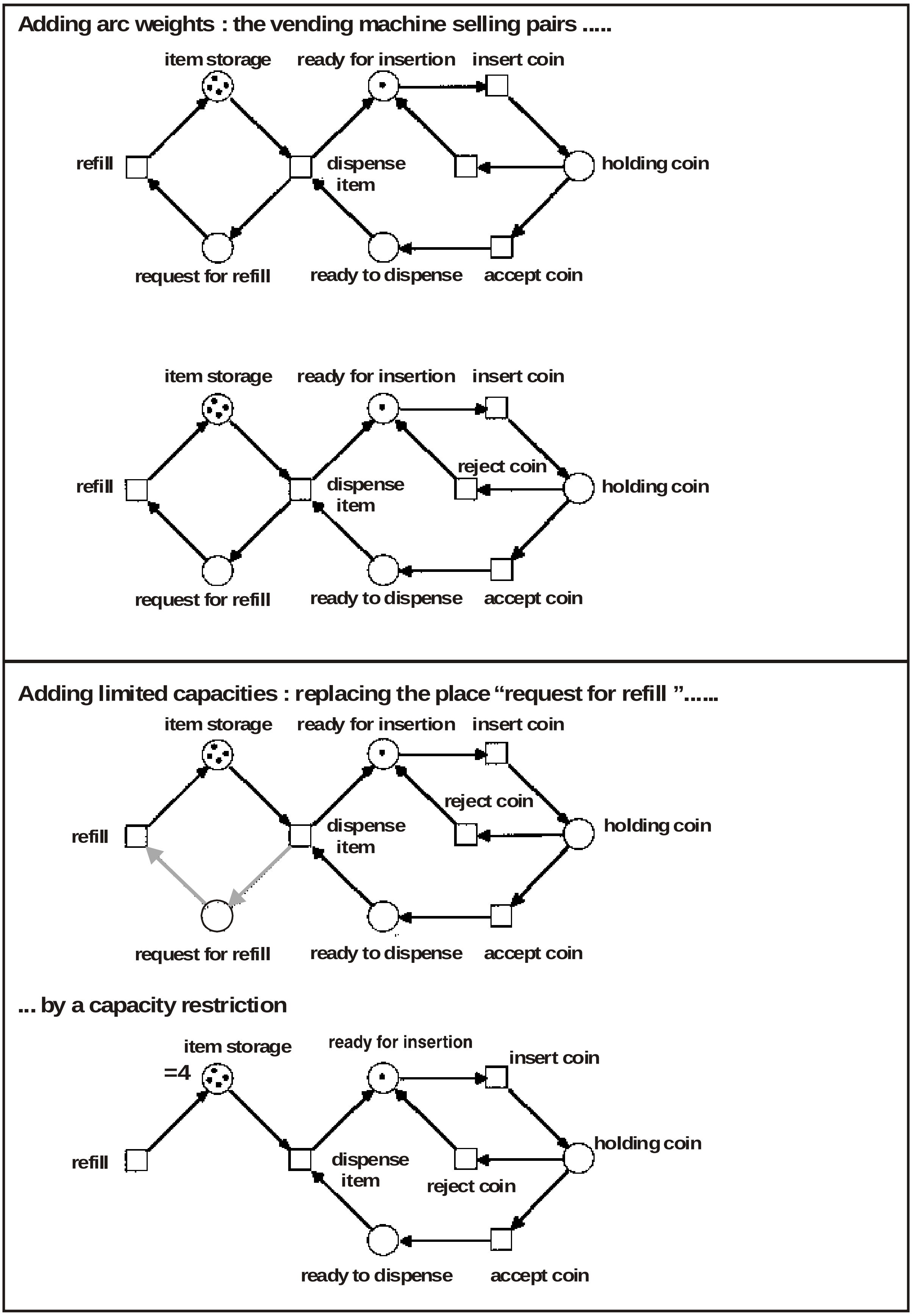

Adding arc weights : the vending machine selling pairs .....
item storage
ready for insertion
insert coin
refill
dispense item
holding coin
request for refill
ready to dispense
accept coin
item storage
ready for insertion
insert coin
reject coin
refill
dispense item
holding coin
request for refill
ready to dispense
accept coin
Adding limited capacities : replacing the place “request for refill ”......
item storage
ready for insertion
insert coin
reject coin
refill
dispense item
holding coin
request for refill
ready to dispense
accept coin
... by a capacity restriction
item storage
=4
ready for insertion
insert coin
refill
dispense item
holding coin
reject coin
ready to dispense
accept coin

Figure : 9

CHAPTER-5

PETRI-NETS

5.1 A REVIEW OF PETRI-NETS :

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

"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).

Most of the theoretical work on Petri-net structures, which consists of four basic elements :-

. A set of places (P)

. A set of Transitions (T)

. An Input function (1) and

. An output function (0).

Petrinets graphically represented by circles, called 'places', bars of rectangles called 'Transitions', and directed arcs, Connecting places and transition. Here places represent condition or the state of any process or any stage in the process, where as transitions model activities representing or indication change or pre requisites for the subsequent process, condition or state. Casual relationship are modelled by connecting the place with the transition or viceversa by directed arcs with arrow heads. A place is an input to a transition if a directed arc connects the place with that transition. Similarly a place can be an output to a "transition".

Multiple inputs or outputs to a transition are denoted by multiple arcs or weights attached to a single arc.

5.2 MODELLING METHODOLOGY OF PETRI NETS :

(A) ORDINARY PETRINETS

In an ordinary type of patrinet modelling, graph asses circles to represent places (states) and bars to represent transitions (Events). Input-output relationships are represented by directed arcs between places and transitions.

Black dots inside a circle or place called tokens. To-kens reside at a place when it is active. Tokens flow through the 'net' depending on the present marking of he net.

The marking of a Petri net is contained in a vector dimension n, where 'n' is the number of places and each value of the vector corresponds to the number of tokens in the corresponding places, when there is a token in each of the input places of a transition, that transition is enabled to fire.

If the weights on each of the arcs between places and transitions are equal to one, than the transition fires by removing a token from each of its input places and by placing a token in each of its output places.

Fig. 10 (a) shows a Petri net example of assessing a robot. The token, places and transitions correspond to the various elements found in manufacturing systems. Places usually represent "resources" (machine, parts & data etc). A token in a place indicates that the resource is available, otherwise it is unavailable. A place can also be used to imply that a logical condition holds. Transitions are generally used to represent the initiation or termination of an event.

B. TIMED PETRI-NET :

Petri nets can model a wide variety of discrete event dynamical systems. But the ordinary petri nets do not indicate the passage of time.

Time is a critical factor in most of the system for evaluating performance and validation control logic.

Time is an essential element in functions such as production scheduling and control in FMS.

The rate of operation of timed Petri net (T. PN) is similar to an ordinary Petri-net. Once a transition is enabled, the tokens are removed from the input places and are held for time (ti) (where is a vector of processing time functions that assigns a rational number top each transition of the net) after which the tokens are sent to all the output places.

Transitions in timed petri-net can be viewed as a set of events, in that multiple sets of tokens can be at different dates of the time delay.

Fig. 10 (b) shows a time Petri-net example using a robot. Transition T_1 has an associated delay time. When the conveyor and robot are both available (i.e. token is present in each place) the processing time for transition T_1 begins.

The time delay 'D' represents the material handling time for the conveyor to move a part to the robot.

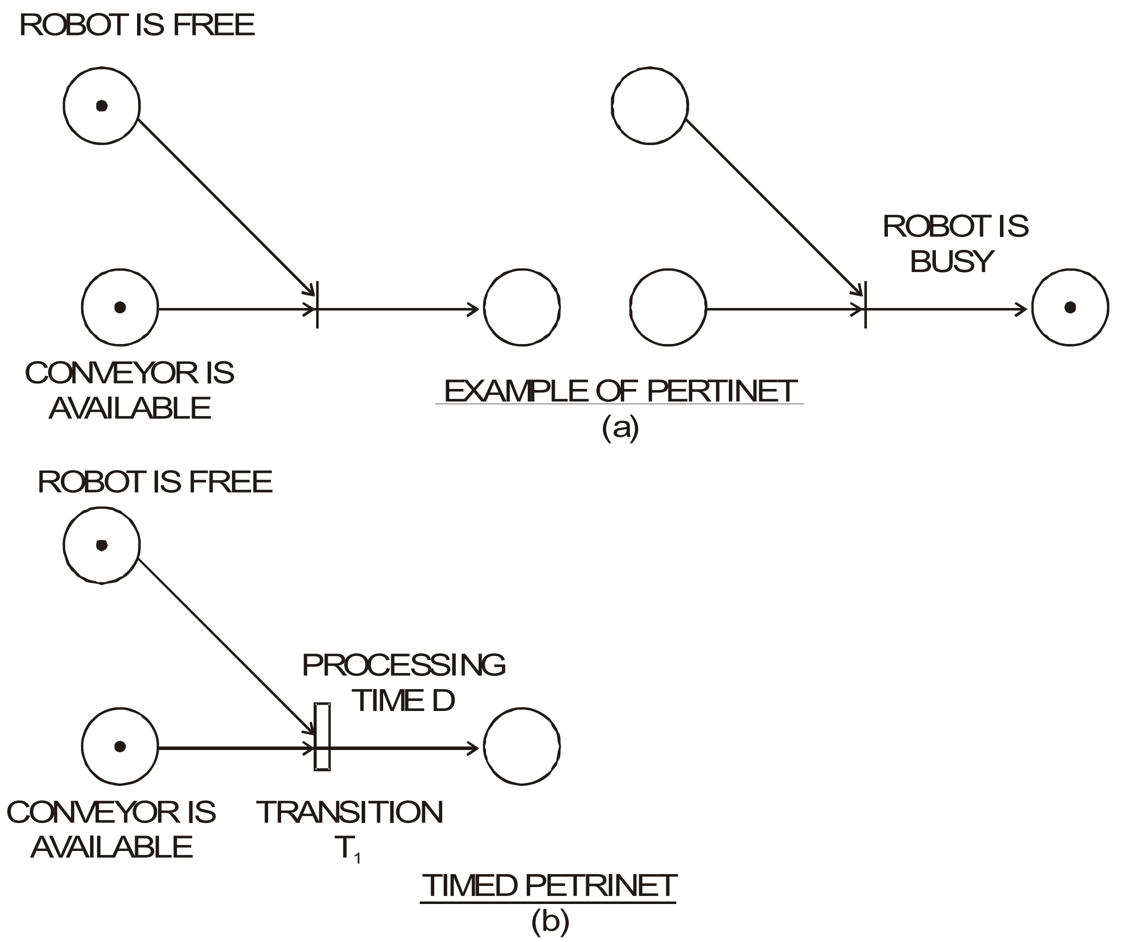


Fig. 10.

EXAMPLES OF ORDINARAY AND TIMED - PETRINET

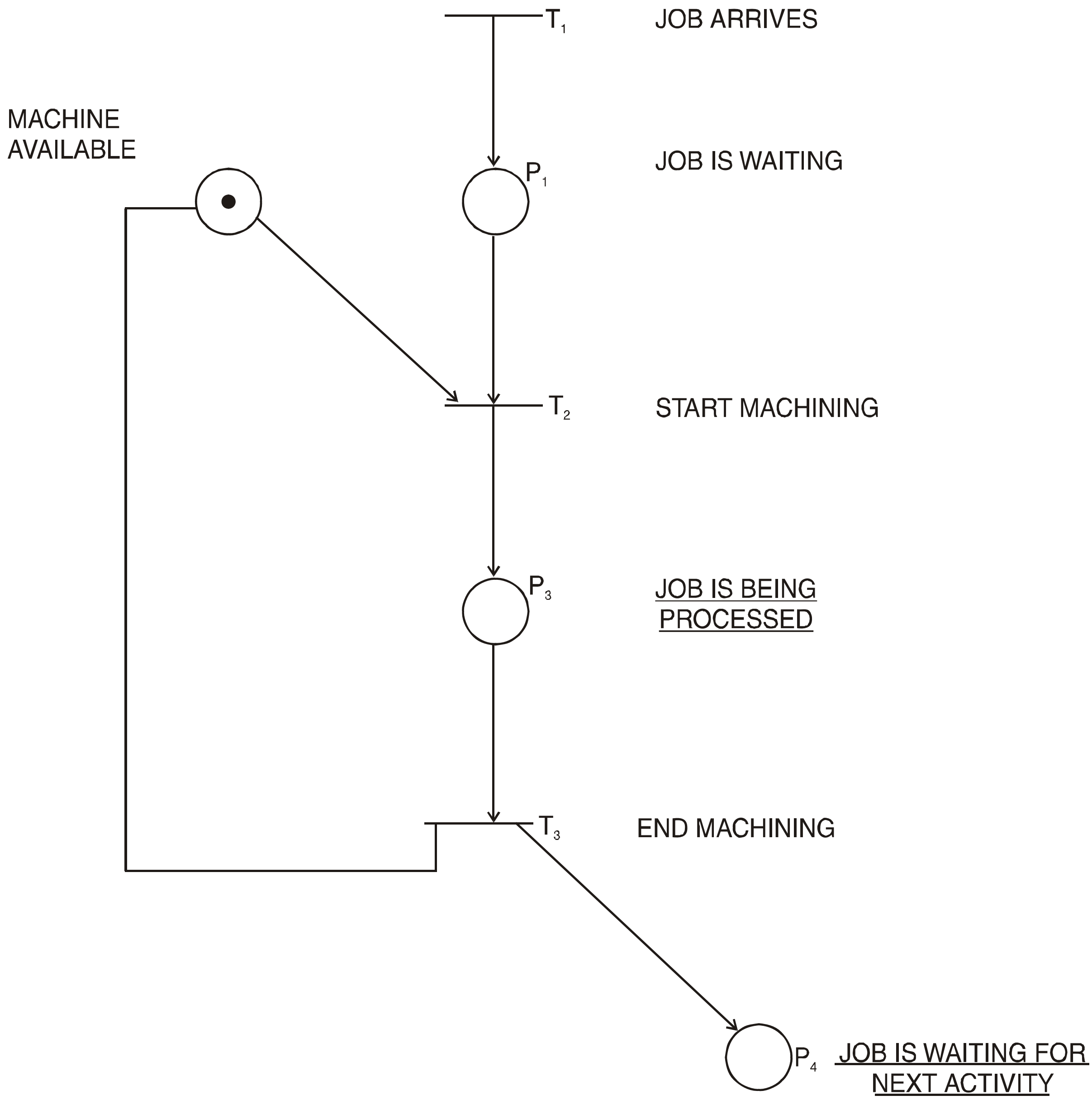


FIG. 11

PETRI NET STRUCTURE CONCEPT

5.3 EXECUTION OF PETRINET MODEL AND CONCEPT OF MARKINGS :

The net basically a static model, becomes dynamic on introduction of 'TOKENS', which are represented by small dots inside the places.

Now a petrinet model is execute by defining a 'marking' and then firing 'transitions'. A marking is a distribution of Tokens to the places of a petri-net. The number and position of tokens change during execution. Fig. 11 is an example of a job processing on one machine described 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.

The marking of a Petri net is changed by the firing of transition. A transition is 'enabled' if there is at least one token in each of its input places.

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 promotive i.e. may take time greater than zero, it can be decomposed into two transition with a place between them representing the condition, the non-primitive e event is occurring as shown in the fig. 11 by transitions T_2, T_3 and place P_3.

5.4 DEFINITIONS AND TERMINOLOGIES :

DEFINITION 1.

A Petri net is a four tuple (P, T, IN, OUT)

where $P = P_1, P_2, P_3 \ldots\ldots\ldots P_m$ is a set of places.

$T = t_1, t_2, t_3 \ldots\ldots\ldots t_n$ is a set of transitions

$P \cup T \neq \phi$, $P \cap T = \phi$

and where IN: $(P \times T) \rightarrow N$ is an input function that defines arcs from places to transition and where OUT : $(P \times T) \rightarrow N$ is an output function that defines directed arcs from transition to places.

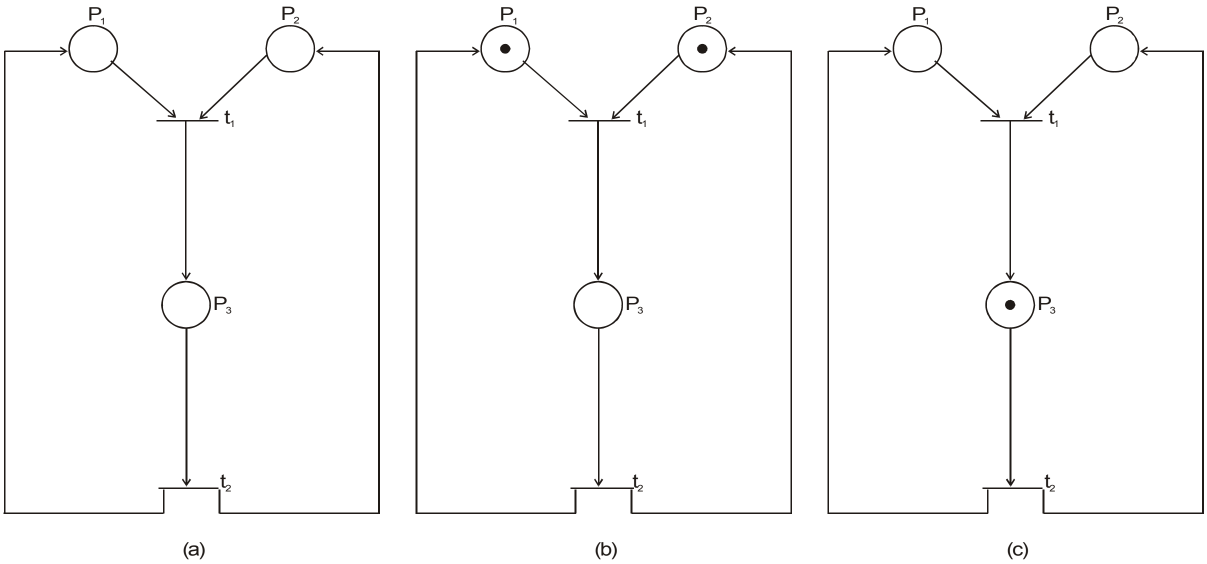


FIG. 12

PETRINET MODEL

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

If IN (P_i t_j) = K where k ≥ 1 is an integer, a directed arc from place P_i to transition t_j is drawn with label K.

If IN (P_i t_j) = 0, no arc is drawn from P_i to t_j. Similarly if OUT (P_i, t_j) = K a directed arc is included from transition t_j to place P_i with label K if K > 1 and without label if K = 1.

But if K = 0 no arc is included from t_j to P_i

EXAMPLE - 1

Let us consider a machine that processes one job at a time. As soon as the processing is finished, another job is made available, and the machine starts processing again. Fig. 12 gives a petri net model (PNM) of the above system.

The places and transition have the following interpretation :-

P_1 : Machine ready to process (machine is free)

P_2 : Job waiting for processing

P_3 : Job undergoing machining (machine busy).

t_1 : Machining commences.

t_2 : Machining finishes.

In the above example places represent various conditions in the system and transitions represent the starting or finishing of activities. For example - place P_1 models the condition - machine is free. We have assumed that the machine, if it fails will be repaired and will resume its operation on the job.

For the sake of simplicity, failures and repair have not been modeled 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 (P_1, t_2) = OUT (P_2, t_2) = OUT (P_3, t_2) = 1

OUT (P_1, t_1) = OUT (P_2, t_1) = OUT (P_3, t_2) = 0

DEFINITION - 2

Let 2^P be the power set of P. We then define functions IP : T $\rightarrow 2^P$ and OP : T $\rightarrow 2^P$ as follows :-

$$IP (t_j) = \{Pi \in P : IN (P_i, t_j) \neq 0 \} \forall \ t_j \in T$$

$$OP (t_i) = \{Pi \in P : OUT (P_i, t_j) \neq 0 \} \forall t_j \in T$$

Where IP (t_j) is the set of input places of t_j and OP (t_j) is the set of output places of t_j.

EXAMPLE - 2

For the Petri-net (PN) of fig. III (a)

IP (t_i) = OP (t_2) = $\{P_1, P_2\}$

and OP (t_i) = IP (t_2) = $\{P_3\}$

DEFINITION - 3

A transition t_j of a PN is said to be enabled in a marking M, if -

$$M (P_i) \geq IN (P_i, t_j) \forall P_i \in IP (t_j)$$

An enabled transition t_j can fire at any instant of time when a transition t_j enabled in a 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 reachables from M and write M $t_j \rightarrow$ M'

EXAMPLE - 3

In fig. 12 (b) transition t_1 is enabled 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 is 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 denoted 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 $G_1 = (P_1, T_1, IN_1, OUT_1)$ and $G_2 = (P_2, T_2, IN_2, OUT_2)$

be two petrinets, such that there exist no pair.

$(P_1\ t) \in (P_1 \cap P_2) \times (T_1 \cup T_2)$ satisfying

either $IN_1(P, t) \neq 0$ & $IN_2(P, t) \neq 0$

or $OUT_1(P, t) \neq 0$ and $OUT_2(P, t) \neq 0$

we define the union of G_1 & G_2 as the

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

$P = P_1 \cup P_2$; $T = T_1 \cup T_2$

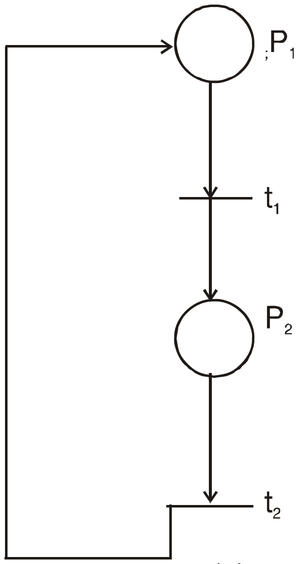
$IN = IN_1 \cup IN_2$ & $OUT = OUT_1 \cup OUT_2$

The Union of any finite number of petrinets is also defined likewise.

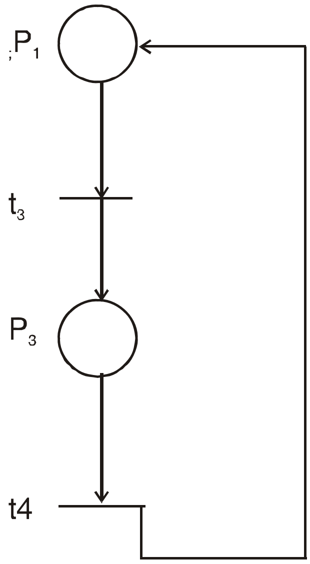
EXAMPLE - 5

The PN of fig. 13 (c) is the union of the petrinets (13) (a) & (b).

Using the concept of union petri-net, a PNM can be constructed in a botton up fashion from the smaller PNM's 13 (a) & (b) i.e. the Petri-net models of individual operation or subsystem of an FMS can be combined in a hierarchical way to obtain the overall PNM of the FMS. as shown in fig. 13 (c).



(a)



(b)

CHAPTER - 6

6.1 INTRODUCTION OF FMS

In recent years, there has been considerable interest in methods for design, modelling, planning, scheduling and performance evaluation of flexible manufacturing system (FMS). An FMS is a computerized production system that can handle a large and constantly changing variety of part types. FMS are characterized by a large set of different entities such as workstations, NC machins, and / or robots, and automated material handling systems. When such a system is observed, these entities exhibit both deterministic and stochastic behaviours and it is difficult to analyse it theoretically. Thus, an FMS simulator is often used to analyse the behaviour of FMS on various aspects such as system design, performance evaluation, and production planning, etc. In any manufacturing system, products are manufactured by routing material through the workstations to execut prescribed sequence(s) of operations and these prescribed sequences may need some flexibilities to meet out the dynamic nature of the system. FMS are specially designed to incorporate these flexibilities into the system to meet out the dynamic and stochastic nature of the system and its working environment. The flexibility of these sytems relies on a programmable transportation network connecting the workstations and a sophisticated control system that monitors the progress of the jobs in the manufacturing system and coordinates various activites of the workstations and transport system.

Each job has a best operation sequence that determines the order in which resources must be assinged to the job, but the efficient utilization of resources on real-time basis in FMS requires a real-time resorce allocation policy to assign resources to jobs as they advance through the system. Moreover, the concurrent flow of multiple jobs in an FMS, which all compete for a finite set of resources, can lead to the problems of resources contention and circular wait. The focus of this work is on the development of a system controller for the automatic solution of a resource contention problem in FMS on a real-time basis. The proposed FMS controller has been developed by using Petri net theory for system modeling for the solution of the probelms.

6.2 CONCEPTS OF FLEXIBILITY

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

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

Table 1: Different approaches to flexibility and their meanings

6.3 Types Of Manufacturing Flexibilities

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

Automation Flexibility

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

Agents of Automation Flexibility

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

Manufacturing Flexibility

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

Agents of Manufacturing Flexibility

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

Design Flexibility

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

Agents of Design Flexibility

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

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

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

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

Table 2: Different types of flexibilities encountered in FMSs

There are four flexibility contexts: -

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

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

Type 1 –

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

Type 2 –

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

Type 3 –

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

Type 4 –

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

6.4 Defining Manufacturing Flexibility

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

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

6.5 Measuring Manufacturing Flexibility

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

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

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

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

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

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

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

Source: Gerwin (1993)

Table 3 : Types of uncertainty and flexibility dimensions

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

Source: D'Souza and Williams(2000)

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

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

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

Two attributes have been emphasized as the basis of measuring manufacturing flexibility. The first is the number of range or options at a given time, and the second is the mobility or the ease with which the organization moves from one state to another.

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

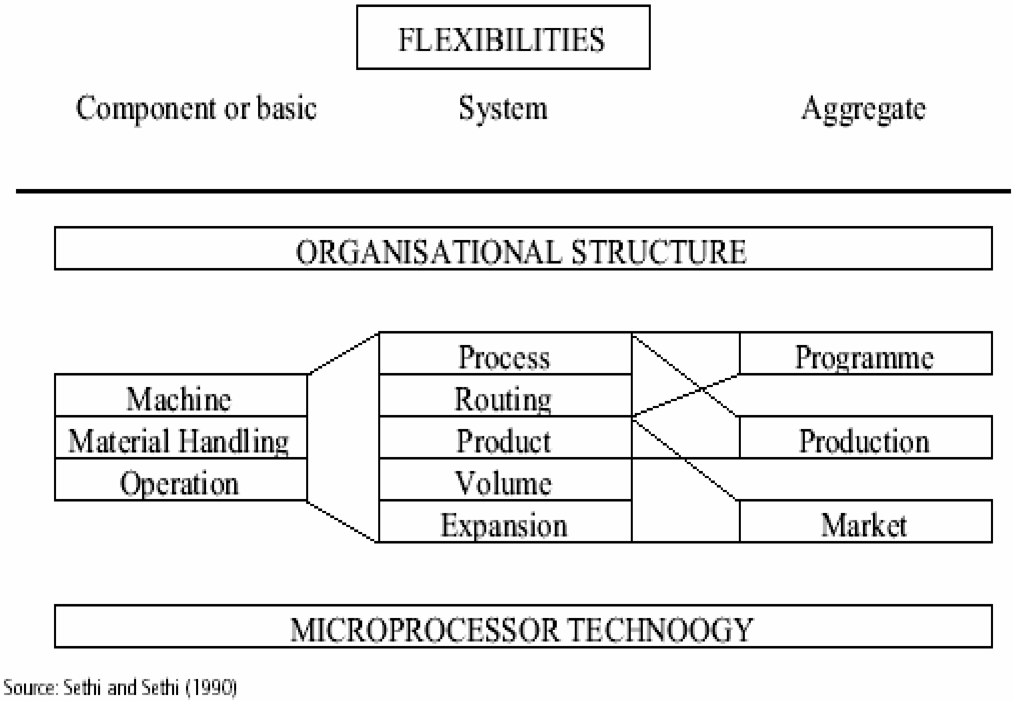


Figure 16: Main classification of flexibilities according to Sethi and Sethi ,(1990)

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

Volume flexibility

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

Variety flexibility

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

Process flexibility

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

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6.6 The Flexibility Hierarchy

From the figure 17, proposed by koste and Malhotra (1999), it is seen that machine flexibility is necessary building block for other flexibilities and is regarded as the requirement for the development of mix flexibility. The five flexibilities (expansion, mix, new product, volume and modification) do not support the development of other flexibilities. Thus, they are considered as higher level flexibilities. Lower level flexibilities mostly serve as the building blocks for higher level flexibilities

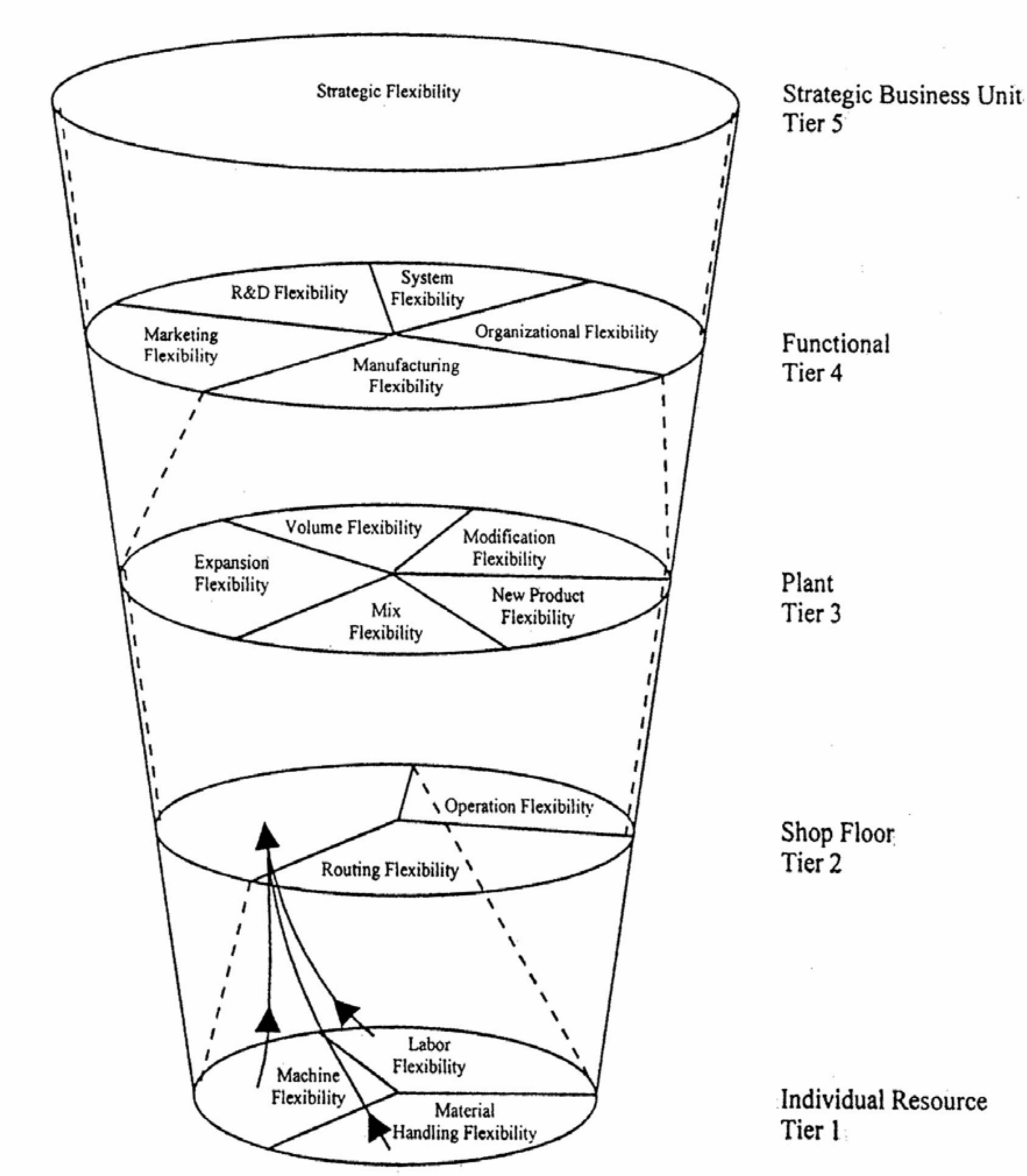


Figure 17: Levels in flexibility hierarchy

6.7 Manufacturing Flexibility Constructs

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

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

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

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

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

6.8 Productivity And Flexibility

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

Products are subjected to changes:

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

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

(c) Changes in fashion.

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

(a) Fluctuation of the market

(b) Seasonal fluctuations

(c) Competition from other companies.

6.9 Flexibility And Production Management

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

- Reductions of set-up time at installed equipment.

- Multipurpose stations (FMS).
- Parallel assembly lines.
- Flexible work force.

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

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

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

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

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

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

6.10 Benefits Of Flexibility

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

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

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

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

6.11 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) stated that *"FMS is a manufacturing system in which groups of numerically controlled machines (machine centres) and a material handling system work together under computer control"*

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

1. A processing system
2. A material handling and storage system

3. A computer control system

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

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

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

6.12 **Types of Manufacturing Systems**

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

(a) Mass production or Transfer lines System;

(b) Flexible Manufacturing Cell;

(c) Flexible Manufacturing System (FMS).

- Dedicated FMS.
- Random FMS.

6.13 **Concept of Flexible Manufacturing System (FMS)**

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

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

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

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

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

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

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

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

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

Table 5:- Classification of manufacturing System

6.14 **Components of FMS**

Figure 18 shows a typical flexible manufacturing system layout and its components

(a) Machine Tools

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

(b) Tool Systems

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

(c) Work Handling

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

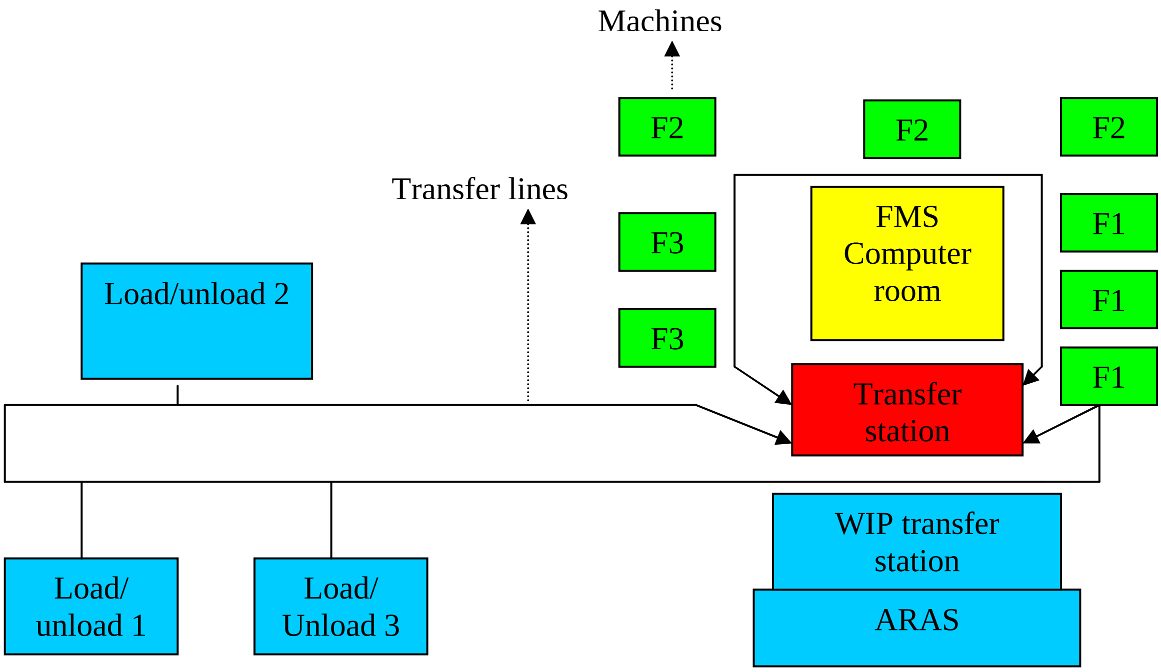


Figure 18: A typical FMS layout

(d) Material Handling System (MHS)

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

i) Primary Work Handling System

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

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

- It must interface with the secondary work handling system.

ii) Secondary Part Handling System

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

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

(e) Monitoring System

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

(f) Planning System

The planning system is done at three levels:

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

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

(g) Auxiliary Equipments

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

6.15 **FMS selection criteria**

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

6.16 **Performance measures in FMS**

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

(1) PHYSICAL: This includes

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

(2) VALUE: These includes

- Shadow prices
- Incremental net optimal revenues

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

(3) RATIO MEASURES: These includes

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

(4) PRODUCTIVITY: These includes

- Work productivity
- Output productivity
- Capital productivity

6.17 Problems In FMS

Some of the problems in FMS related to the design, planning schedulling, and controls are very trouble some in nature.

These problems can be encountered both at the technical as well as the organisation level.

Design Problems

These include, for example determining the appropriate number of machine modules of each type the capacity of the 'MHSs', size of the buffers, size and quality related to the fixtures and pallets.

Planning Problems

Planning problems include the determine of the optimal partition of machine tools, plant layout, allocation of the pallets and fixtures to part types and assignment of operations and associated cutting tools among the limited capacity tool magzines.

Schedulling Problems

These problems are very complicated of all. They include determining the optimal inputsequence of parts and an optimal sequence at each machine tool given the current part spectrum.

These problems alter with the order of the flexibility.

Control Problems

Control problems are those, concerned with the monitoring of the system, to the due dates and the maximum utilization of resources.

All these problems are tackled with a number of problem solving methodologies, techniques and "simulation models", Queueing Network", Artificial intelligence" based approaches and computer interactive simulations".

6.18 Tools to Solve FMS Related Problems:

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

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

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

6.19 <u>Strategic issues in FMS</u>

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

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

Table 6:- Various strategic issues in FMS

6.20 **Advantages of Flexible Manufacturing System (FMS)**

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

6.21 **Limitations of FMS**

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

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

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

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

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

CHAPTER - 7

MODELLING MANUFACTURING FLEXIBILITY WITH PETRI NET

7.1. FLEXIBILITY OF A MANUFACTURING SYSTEMS:

Flexible manufacturing systems are a class of automated manufacturing systems. Their name implies that the feature which characterises them among all the other features in their flexibility.

An FMS comprises Processing modules or machines linked by a material handling system (MHS) all under Central Computer Control (BUZACOTT & SHANTI KUMAR 1980).

The flexibility of such a system is therefore dependent upon its components capabilities, their inter connections & upon the operation and control.

Various types of flexibility were defined in this context and several attempts were made to quantify and measure flexibility (BUZACOTT' 1982, 'ZELENOVIE' 1982, 'SLACK' 1983, 'BROWNE' et al 1984).

According to "BUZACOTT", any attempt to evaluate the flexibility of a manufacturing system must begin by taking into consideration the nature of the change that the system has to cope with. External changes as product types, mixes, quantities are dictated by technological progress, market and firm policy.

7.2 TIME - A PERFORMANCE MEASURE FOR FLEXIBILITY:

We can draw several conclusions from the review:-

(i) Flexibility is a complex concept, involving various hardware design and operation decision, taking different time horizons (short, medium, and long). Thus modelling and measuring total flexibility of a system through a generative (or prescriptive) model (SURI 1985) looks like an impossible task.

(ii) A most relevant feature of system's flexibility to change during operation, we suggest to call this operational flexibility comprising the following elements, machine setup flexibility, system setup flexibility and routing flexibility.

(iii) For measuring operational flexibility time is a more distinctive parameter than cost, in the time - cost trade off relationships.

Flexibility can be evaluated as the time needed for system adaptation (for various change or disturbance levels).

(iv) It is thus possible to quantify operational flexibility of a given system and further more, to compare different systems on a flexibility basis.

(v) Having assessed in a general way that "operational flexibility" of a system can be expressed in terms of time.

7.3 MODELLING FLEXIBILITY WITH PETRI-NET:

Neither of the approaches, attempt to use Petri nets for modelling changes or disturbances in FMS. Here we tackle the possibility through the classic interpretation for places and transition.

"SIFAKIS" mode of considering time described above implying:-

1. Places represent resources or conditions (machines or part etc) A token in a place indicates availability of the machine or status of the part. Time is expressed by tokens being delayed in places representing occurrences of non-primitive events as processing, transferring etc.

2. Transitions represent instantaneous events.

   This modelling approach has been chosen for two reasons:

   (a) it preserves the classic petri net notion of transitions as instantaneous events etc. and

   (b) it does not obscure the state of the system represented by the marking during the time the process is in execution, which is especially relevant to modelling interpretations.

Our modelling purpose is to develop a general understanding of the way in which the performance of an FMS is affected by disturbances and how operational flexibility can attenuate these effects.

The main idea of using Petri nets to this end is their capability to clearly indication of partial execution strings, representing possible sequences of events. There will be different such sequences for systems processing a given flexibility feature as compared to those which do not possess it.

Time passes between successive transitions strings representing execution strings. Indeed there is no inherent measure of time in the petri net as long as there is no information regarding the time elapsed between two successive transitions within a given partial sequence or execution string. Supplying the above information of a sequence duration & consequently comparisons between durations & of different sequences, which in our case will be affected by the system's flexibility level.

Some additional assumptions are required by this modelling concepts:-

(i) The part arrival event is represented by a transition which is activated by a stochastic or any other process, expressing the rules governing the loading of parts to the system (see Transition T_1 in fig. 19)

(ii) In a similar way the arrival of a failure (to a machine or any other equipment) will be modelled by a transition activated by an adequate stochastic process representing failures.

(iii) A non-instantaneous activity as (processing or transferring) requiring availability of a resource may be interrupted by a breakdown transition which becomes enabled before the activities normal termination.

The problem in fig. 19 focuses on modelling interruption of an activity (following the arrival of a failure).

According to the classic model we have taken, while processing (or any other non-zero time activity) is carried on, there is a token in the place representing the conditions (P_3 as in fig VII). Here we can say that it will stay there till the end of the processing period or delay time (whose duration we have assumed to be t_3 time units). Then its ending transition T_3 will be enabled, provided no resource failure occurs during the above time interval. If this happens (firing of T_4) the activity will be interrupted due to the firing of a different transitions (T_5) which will become immediately enabled as a consequence of the failure's arrival (marking of place P_5).

FIG.19 **INTERPRETATIONS OF PLACES AND TRANSITIONS PLACES**

P_1: Job is waiting

P_2: Machine Available

P_3: Job is being processed

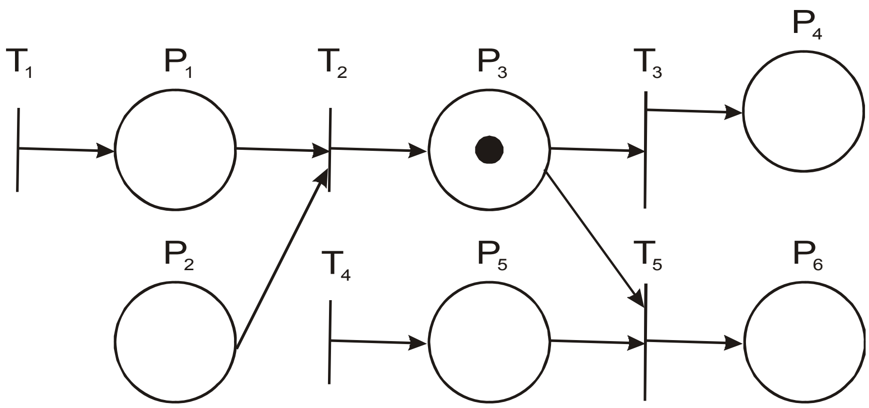


FIG. 19
MODELLING INTERRUPTION OF
AN ACTIVITY THROUGH
PETRI NET

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: START MACHINING

T_3: END MACHINING : t_3 : Processing duration

T_4: MACHINE FAILURE

ARRIVES

T_5: STOP MACHINING.

7.4 PETRINET MODULAR STRUCTURE USING - BREAKDOWN INTERRUPTIONS:

A weak point of Petri nets is the practical difficulty of representing system of increasing size (MARSAN) et al 1983). The petri net becomes rather complex, though conceptually there is no increasing difficulty.

A modular description of the petrinet is recommended. Here "machining module" and material handling module" as shown in the fig. 20. The material handling module is similar to the previously described structure. The Petri net modelling of an integrated system is shown in the fig. 20.

As mentioned in the previous section various sequences of transitions are possible here. For normal operation we describe here only the partial sequence, i.e. with no breakdown arrival T_1, T_2, T_3, where transition T_3 fires 't_3' time units after T_2 as opposed to two types of partial sequences with breakdown interruptions:

(a) T_1 - T_2 - T_5 - T_6 - T_9 - T_3 represent a system without routing flexibility. Where as following the arrival of a breakdown (expressed by the firing of T_4) transition T_5 is enabled and fires (instead of T_3) (causing the part being currently processed and those arriving in the meantime, to wait for the repair to be finished (firing of T_6) in order that their processing be continued.

In this flexible system, the condition adjusting for re-routing represented by place P_7 will have a long duration, T_7 (Assumed longer than the repair) in order for transition T_7 to be enabled (start of re-routing control). Under these conditions when repair is finished, P_9 will become marked and will immediately enable the firing of T_9 consequently employing P_7 and thus cancelling the condition "adjusting for rerouting".

(b) T_1, T_2, T_5, T_7, T_8 represents a system with routing flexibility, where adjusting for rerouting (t_8) will be relatively short duration, enabling firing of T_7 i.e. the start of a control procedure for rerouting the parts to an alternative operation sequence. The parts arriving during the repair will be directly rerouted. (T_1 - T_8). When repair is done, P_9 will become marked and transition - T_{10} will be enabled, Putting an end to the rerouting control period.

As shown in Fig. 20.

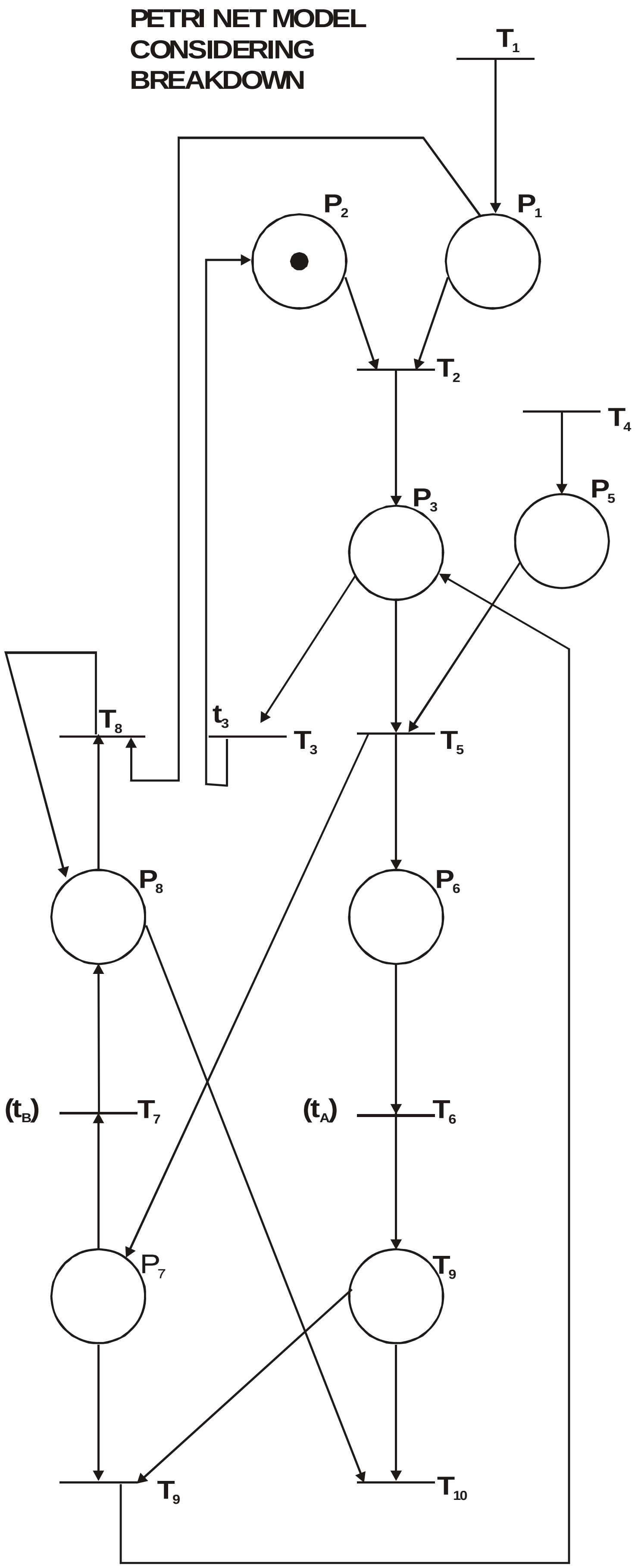

PETRI NET MODEL
CONSIDERING
BREAKDOWN
T1
P2
P1
T2
T4
P3
P5
T8
t3
T3
T5
P8
P6
(tB)
T7
(tA)
T6
P7
T9
T9
T10

Figure : 20

PLACES

P_1: Job is waiting

P_2: Machine available

P_3: Job is being processed

P_5: Machine breakdown

P_6: Machine in repair

P_7: Adjusting for rerouting

P_8: Control rerouting

P_9: Machine in working conditions

TRANSITIONS

T_1: Job arrives

T_2: Start machining

T_3: End of machining

(t_3): Processing duration

T_4: Machine failure arrives

T_5: Stop machining

T_6: End of repair

t_A: Repair duration

t_B: Duration of adjusting for Rerouting

T_7: Start control rerouting

T_8: Reroute

T_9: Cancel adjusting for Re-routing

T_{10}: End control Rerouting

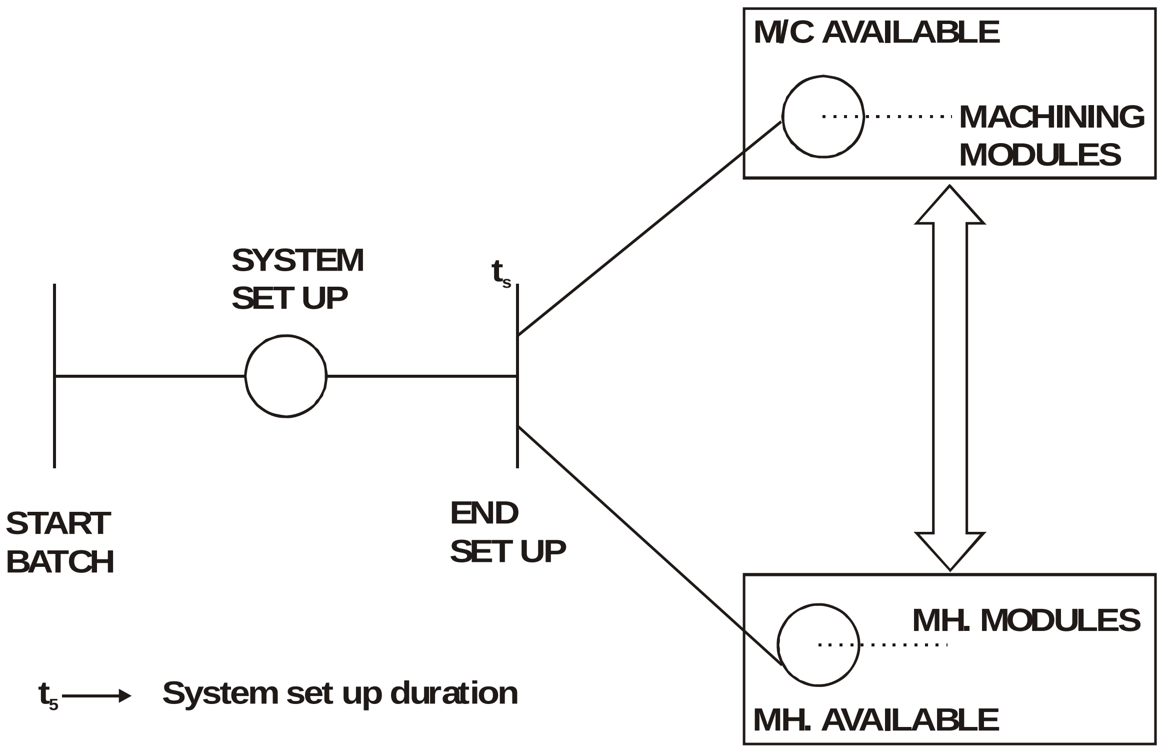

M/C AVAILABLE
MACHINING MODULES
SYSTEM SET UP
t_s
START BATCH
END SET UP
MH. MODULES
MH. AVAILABLE
t_5 → System set up duration

FIGURE 20 (b)

An overall view of the manufacturing mode can be obtained through integration of basic modules into a systyem as shown in fig. 20 (b)(2).

Although the model can be expanded to give operational flexibility.

We can see here that the petri net of system, which includes the set up is not a proper petri net which by its definition requires the initial marking to be reachable from all reachable markings.

According to the current Petri net design of the system (ie operational flexibility for a batch production), the initial marking can not be reached again thus differentiating the set up and the rest of the petri net and emphasizing our interpretation of volume (or batch) flexibility as system set up flexibility.

7.5 DEAD-LOCKS IN AUTOMATED MANUFACTURING SYSTEMS:

A deadlock is a highly undesirable situation in an FMS, in which each of a set of two or more jobs keeps waiting indefinetely for the other jobs in the set to release resources.

The occurrence of a deadlock can disable the entire system and renders automated operation impossible. In addition a deadlock occuring in a subsystem of the given system, can propagate to other parts of the system. Finally completely stalling all activities in the entire system.

Deadlocks usually arise as the final state of a complex sequence of operations on jobs flowing concurrently through the system and are thus generally difficult to predict.

In an improperly designed FMS, the only remedy for deadlock may be annual clearing of buffers or machines and restart of the system from an initial condition that is known to produce deadlock free operations under normal production conditions. Both the lost production and the labour cost in resetting the system in this way can be avoided by proper design and careful operation (3).

Here we can take an example of deadlock in a manufacturing system. As shown in the fig. IX there is loading/unloading station were raw materials are available. An AGV is used here to carry a raw part from the loading and unloading station, where it is unloaded. The AGV can only carry one part at a time. The NC machine also processes one part at a time. Besides this, the AGV takes a certain amount of time to carry a part from L/U to machine or from machine to L/U. But if it does not carrying a part, it can travel very quickly between the L/U and AGV.

In the initial state in which the AGV and the machine are free, and raw parts are available. The AGV carries a raw part, say part A_1 and loads it on the NC machine, which start processing part A_1. The AGV returns to the L/U station carries another raw part, say part A_2 to the machine. But AGV waits for the machine, which is still processing part A_1. Thus the AGV gets blocked waiting for the machine, The machine finishes the operation on part A_1 and starts waiting for the AGV to carry the finished part A_1 to the L/U station. At this time the machine gets blocked waiting for the AGV.

If the machine and the AGV can only accommodate one part at a time and there is no other buffer space the two resources here are then involved in a "deadlock", since each keeps waiting for the other indifinitely.

Even if some buffer space is provided for raw parts and finished parts in the system, a deadlock can still occur because the AGV can fill the entire buffer with raw parts during the processing of part A_1 by the machine.

These studies from the existance & absence of deadlocks using the invariants of the PN model. In PN-based techniques the terms "Prevention" & avoidance deadlocks in automated manufacturing systems have been used.

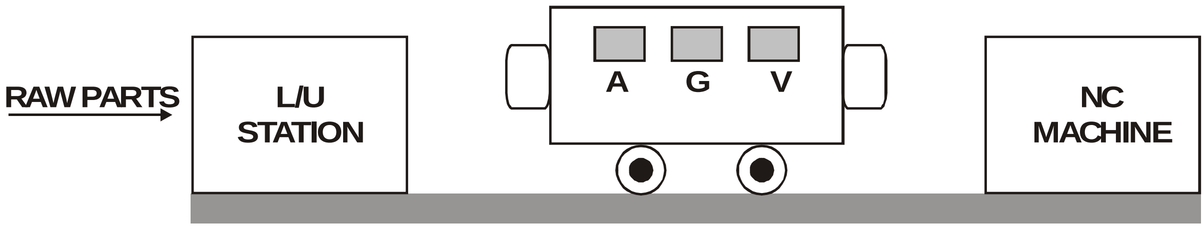


FIG. 21 : DEAD - LOCKS IN AUTOMATED MFG. SYSTEM

But it is known that deadlock prevention policies that are usually implemented in the design stage lead to inefficient resource utilization. Deadlock avoidance policies that can be used during the operation of a system lead to better resource utilization and throughput.

7.6 **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,M_2, & M_3 & Rb_3. The three machines process three different part types i.e. parts type A, B & 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. 22 (a, b & c).

Petri net model shown in fig. 22 (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. 22 (a), (b) & (c).

The overall model is shown in the fig. 22 (d). Referring to the definitions of petrinet in Chapter 5 definition 5.

The methods of union of petri nets can be conviniently applied to any general FMS configuration based on the part types and the structure of the routings.

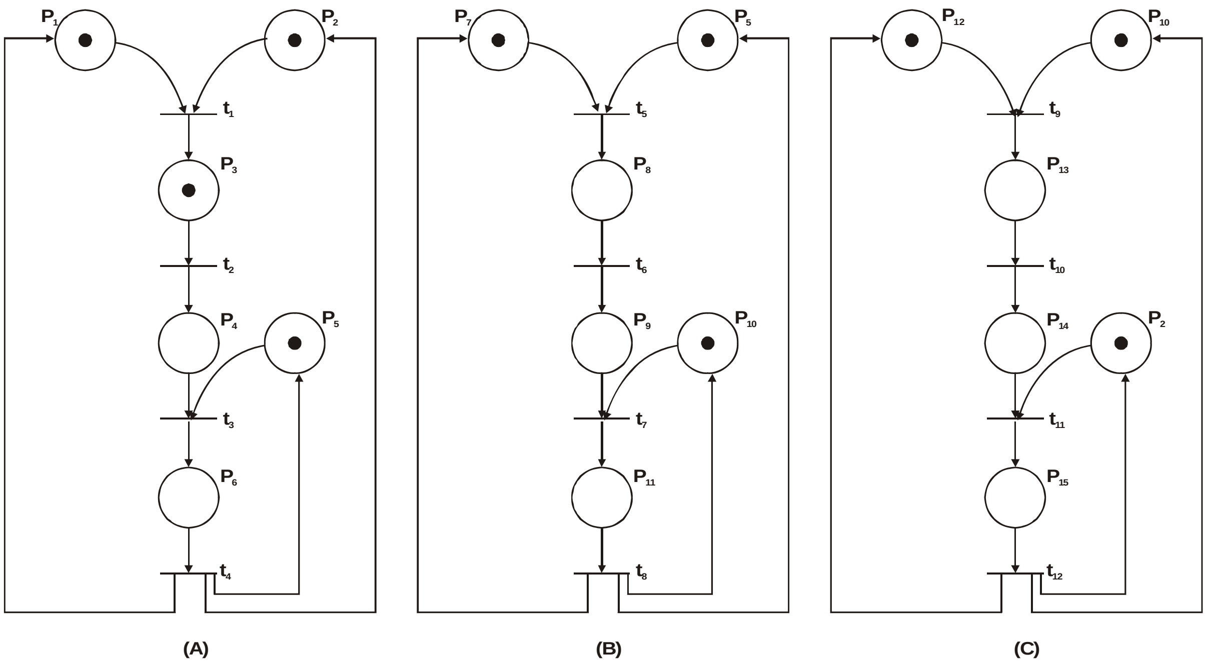


Figure : 22
Petri Net models — Processing three part types using three m/c

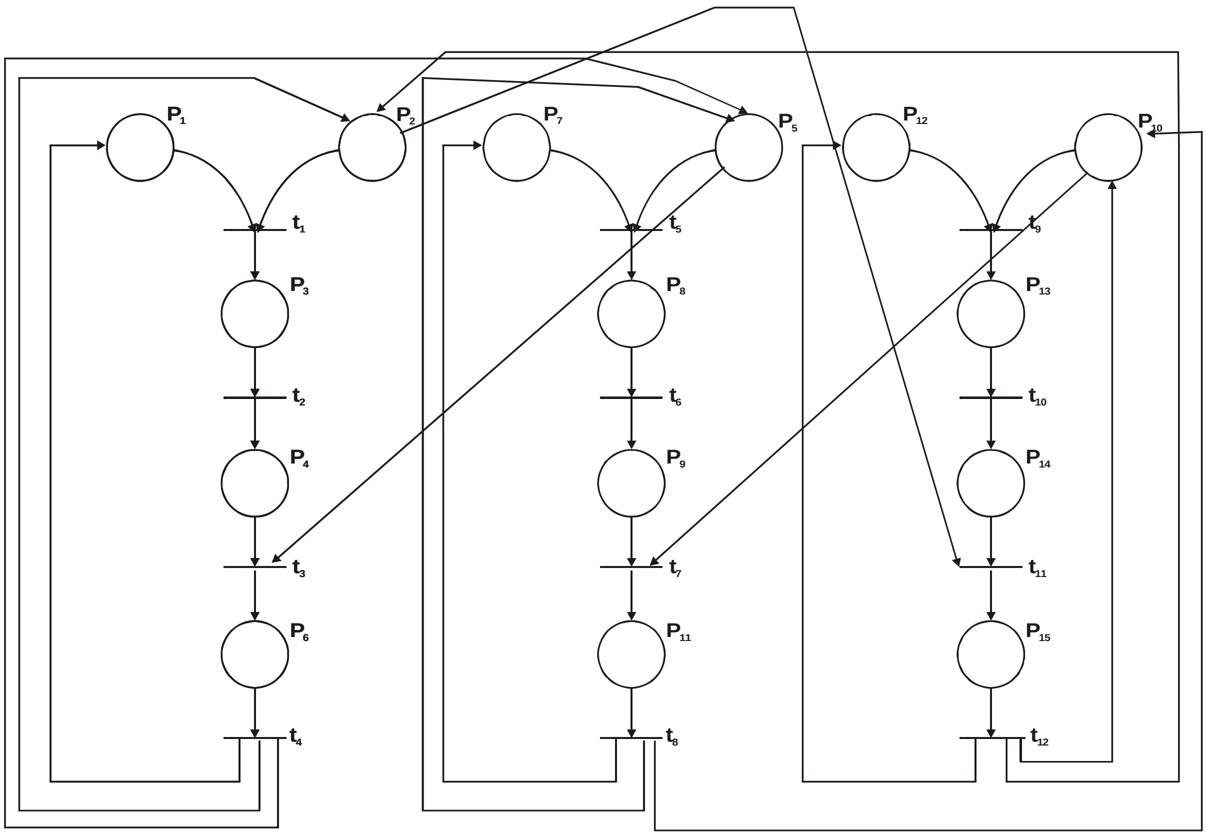


Figure : 22 (d)
Compact models using union of colored Petrinets

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

For example the PNMS of fig 22 a, b & c, which are all structurally identical can be folded, into a single model of identical type by associating colours to places and transitions and appropriately defining functional dependencies among these colours.

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 usingboth 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 machin M_3

CHAPTER - 8

MODELLING OF MANUFACTURING CELLS

FOR FIG. 23 (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

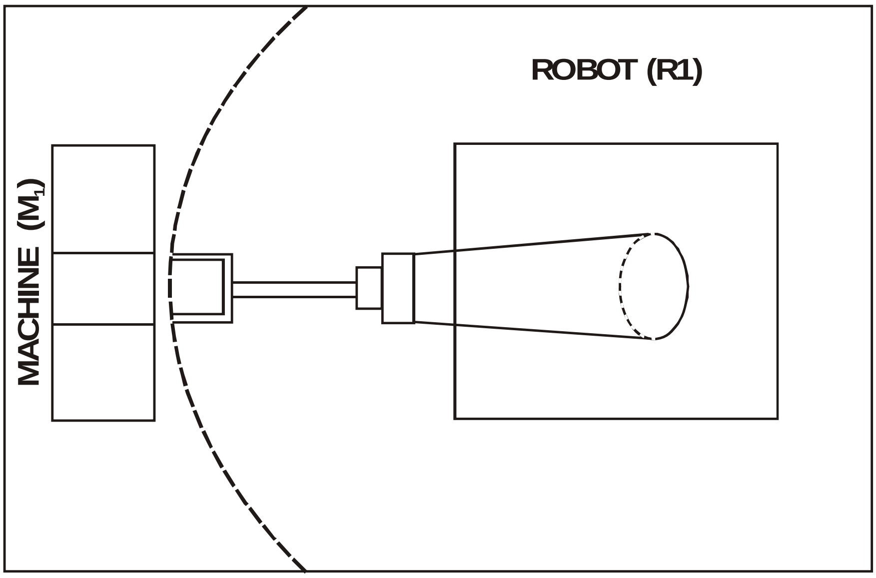


Fig. 23 (a) MFG. MODULE WITH ONE M/C AND ONE ROBOT

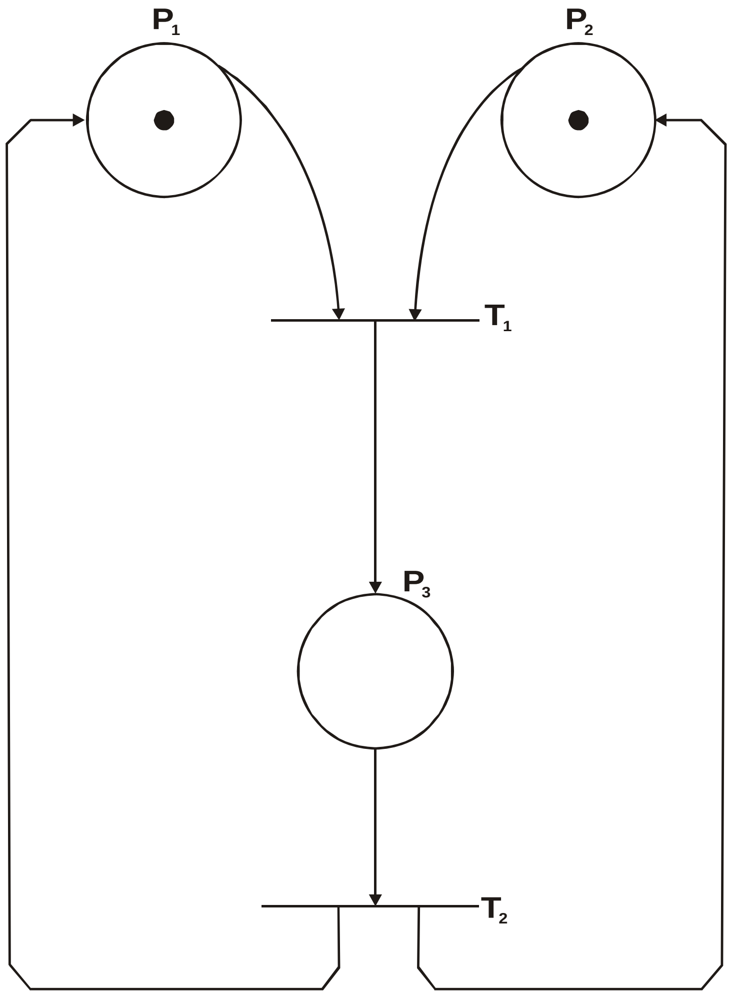


Fig. 23 (b) A PNM (PERTINENT MODEL) OF A SIMPLE MFG. MODULE COMPRISING ONE M/C AND ONE ROBOT.

FOR FIG. 24 (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 wating 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

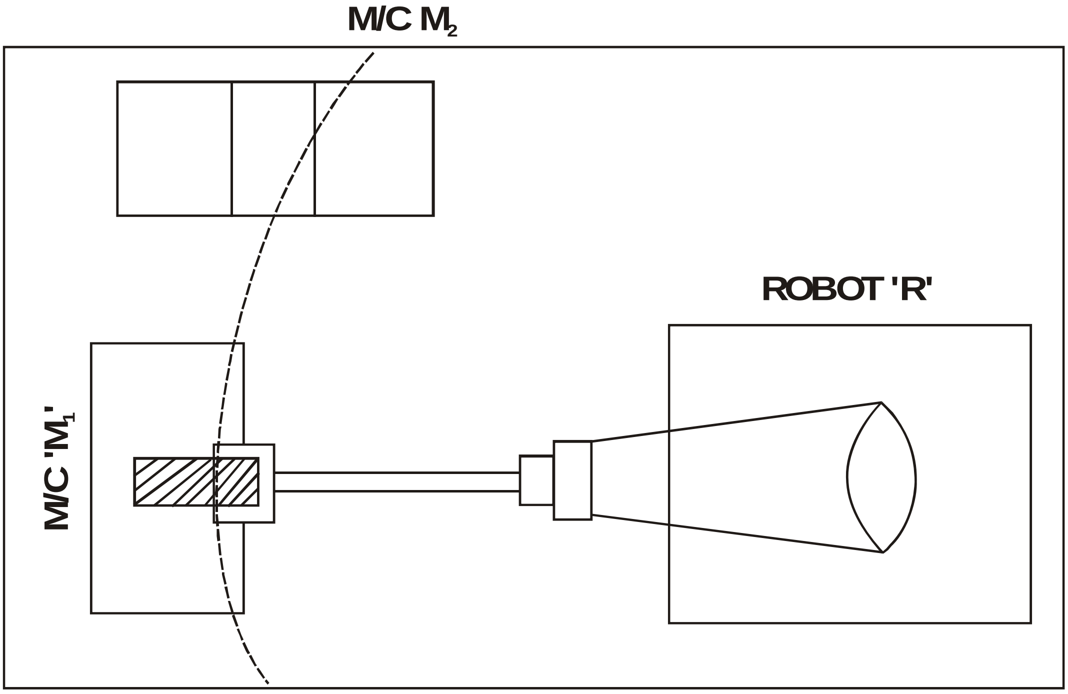


Fig. 24 (a)
LAYOUT OF A MFG. CELL WITH ONE ROBOT AND TWO MACHINES.

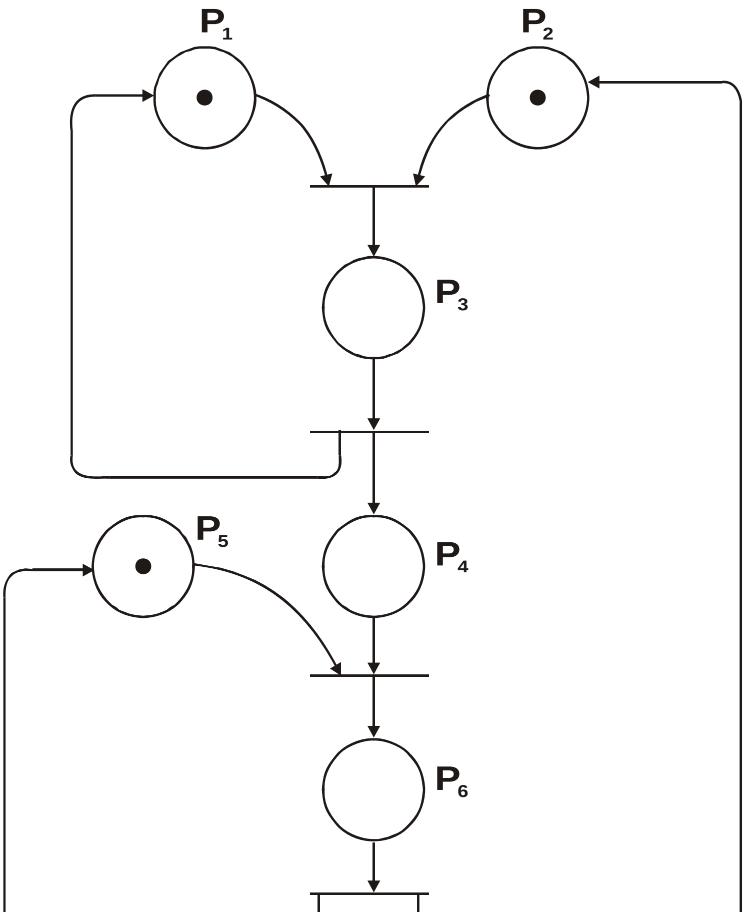


Fig. 24 (b) Petrinet Modle of A Mfg. Cell

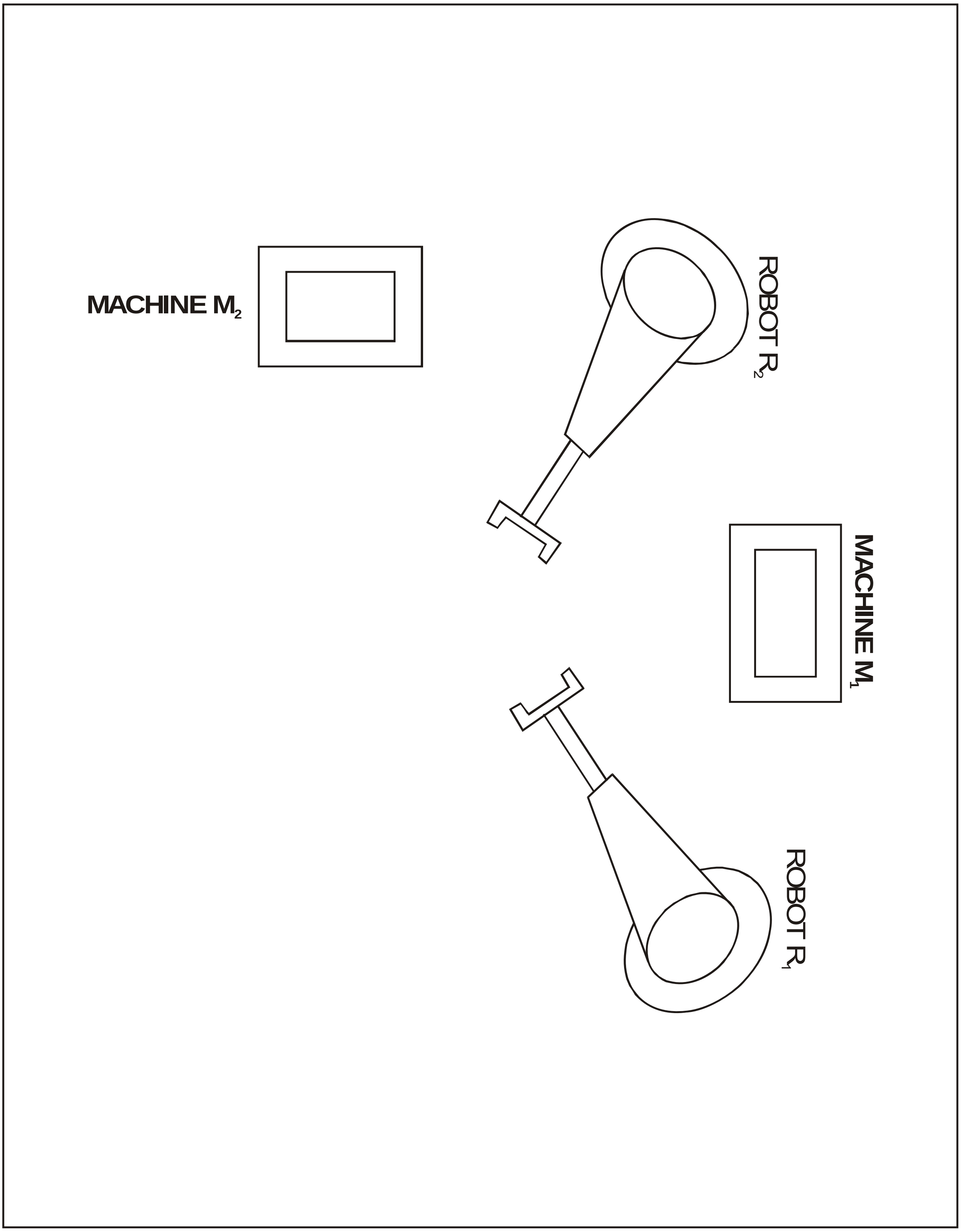


Fig.: 25 (a)
Layout of an FMS cell using two m/c & two robot

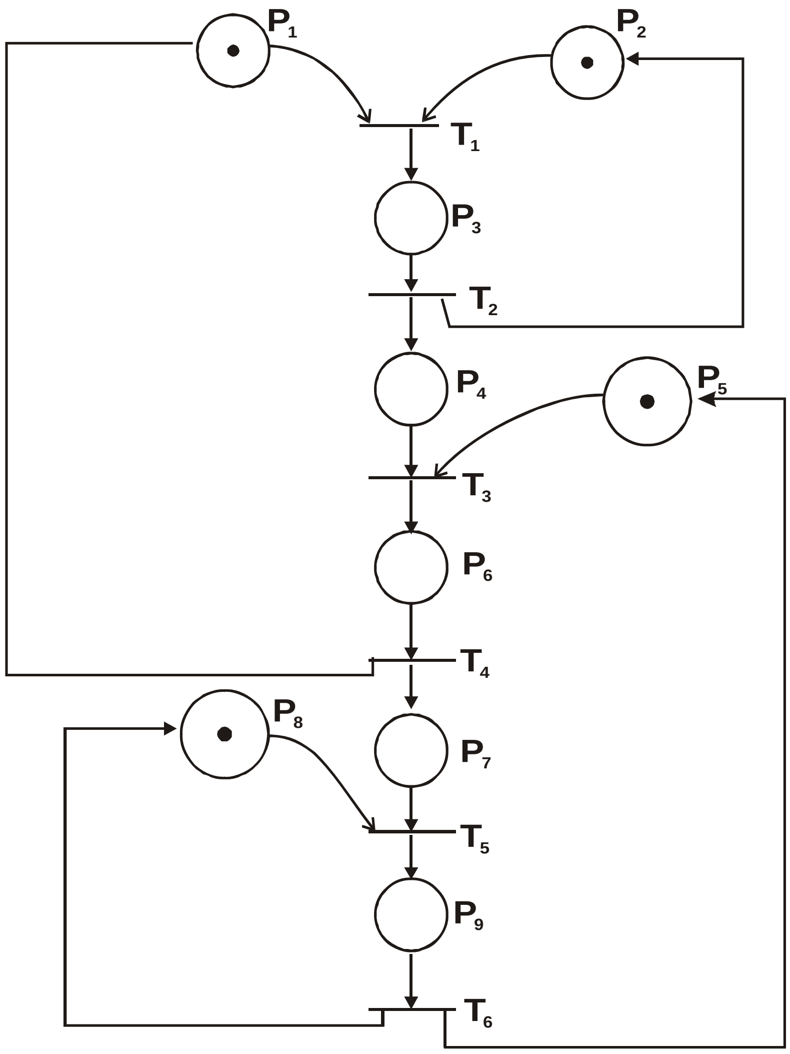


Fig.: 25 (b)
PNM OF A MFG. CELL

FOR FIG. 25 (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 wating 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.

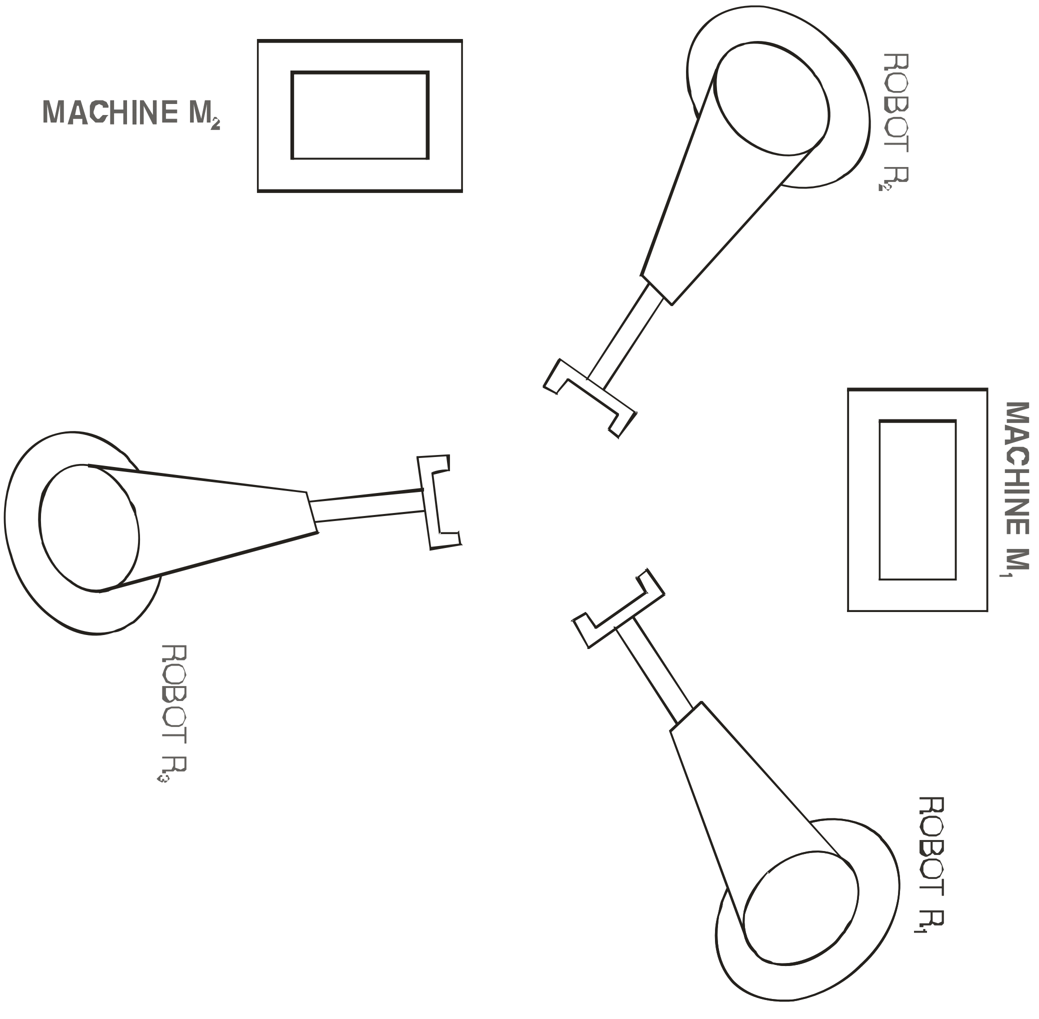
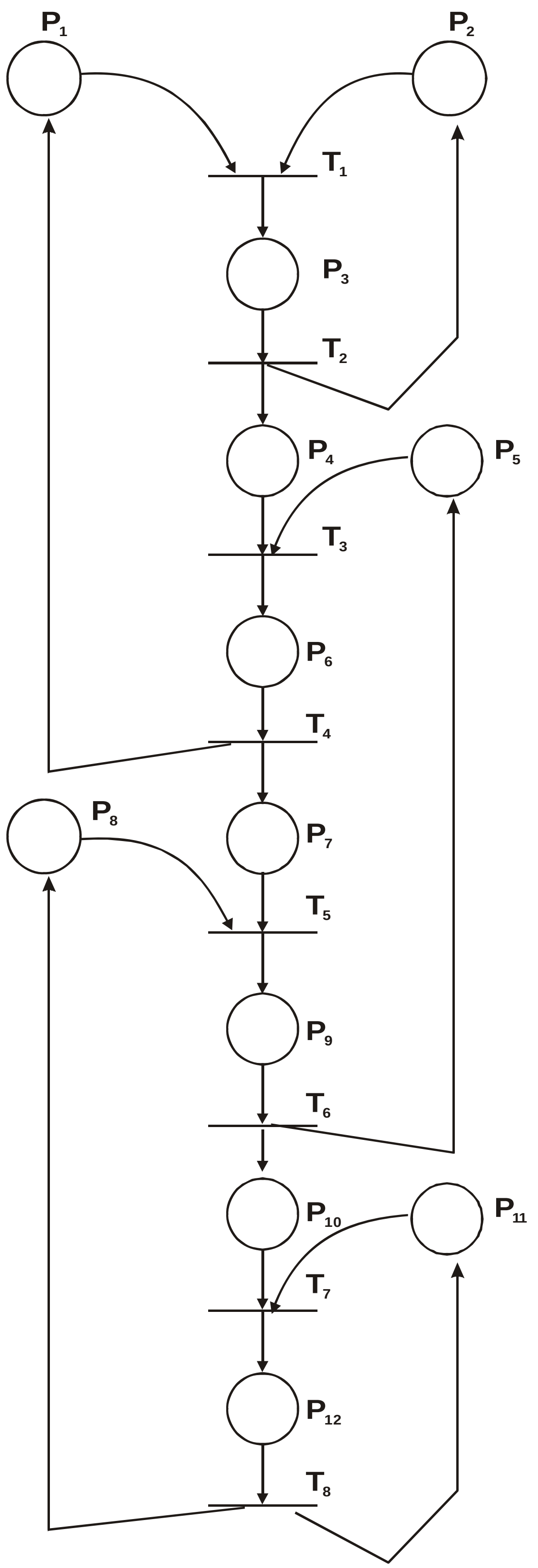


FIG. 26 (a) LAYOUT OF AN FMS CELL USING TWO MACHINES AND THREE ROBOTS



F1G. 26 (b) PNM OF FMS CELL USING TWO MACHINES AND THREE ROBOTS

FOR FIG. 26 (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 : Robot R_2 is available

P_6 : Machine M_1 is using R_2

P_7 : Robot R_2 is wating for machine M_2

P_8 : Machine M_2 is available

P_9 : M_2 using R_2

P_{10} : Machine M_2 is waiting for robot R_3

P_{11} : Robot R_3 is ready

P_{12} : Machine M_2 is busy with robot R_3.

TRANSITIONS

T_1 : M_1 starts using R_1

T_2 : Use or R_1 by machine M_1

T_3 : M_1 starts using R_2 robot

T_4 : Use of R_2 by M_1

T_5 : Machine M_2 starts using R_2

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

T_7 : M_2 starts using robot R_3.

T_8 : R_3 is engaged or busy with machine M_2.

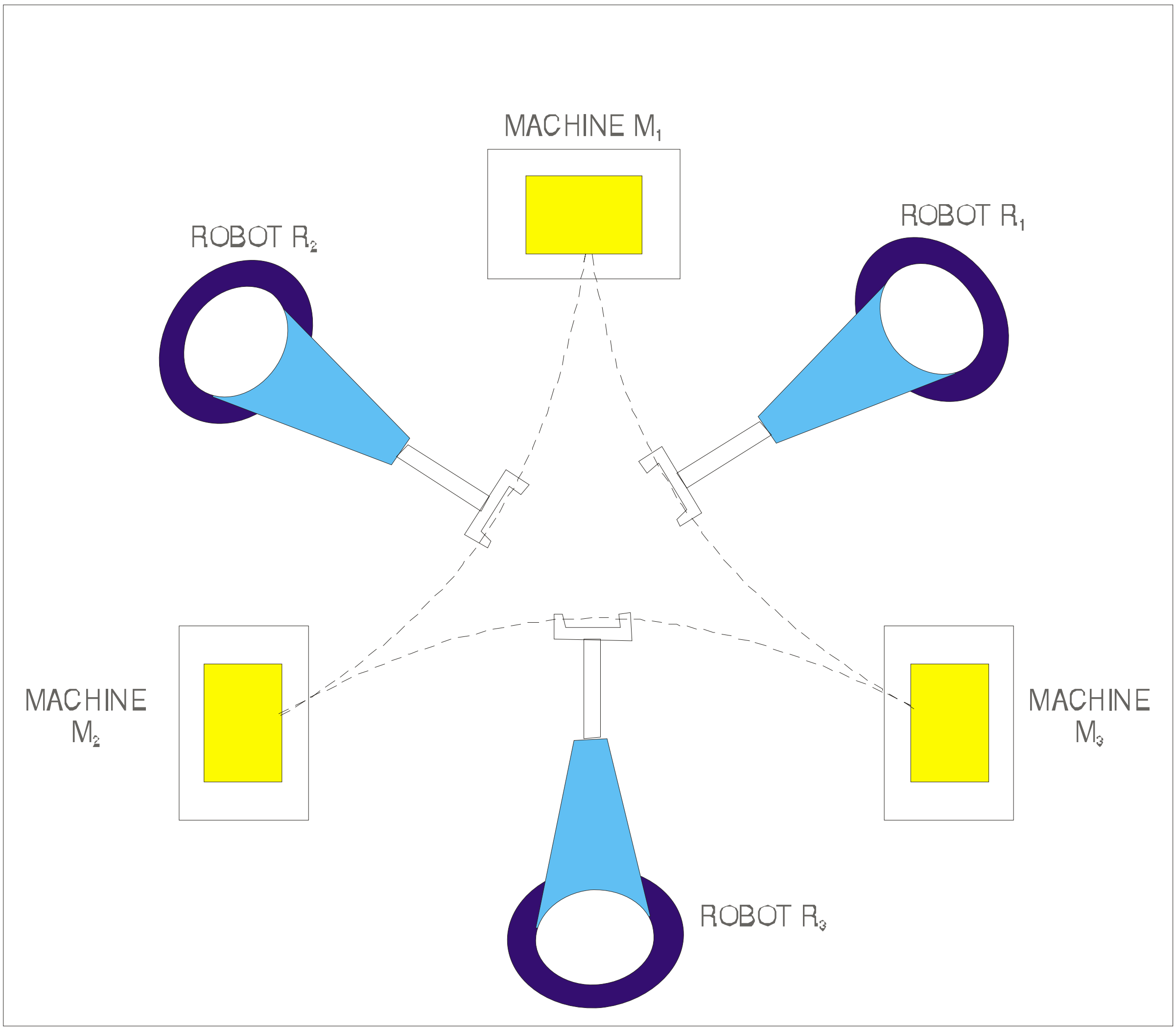
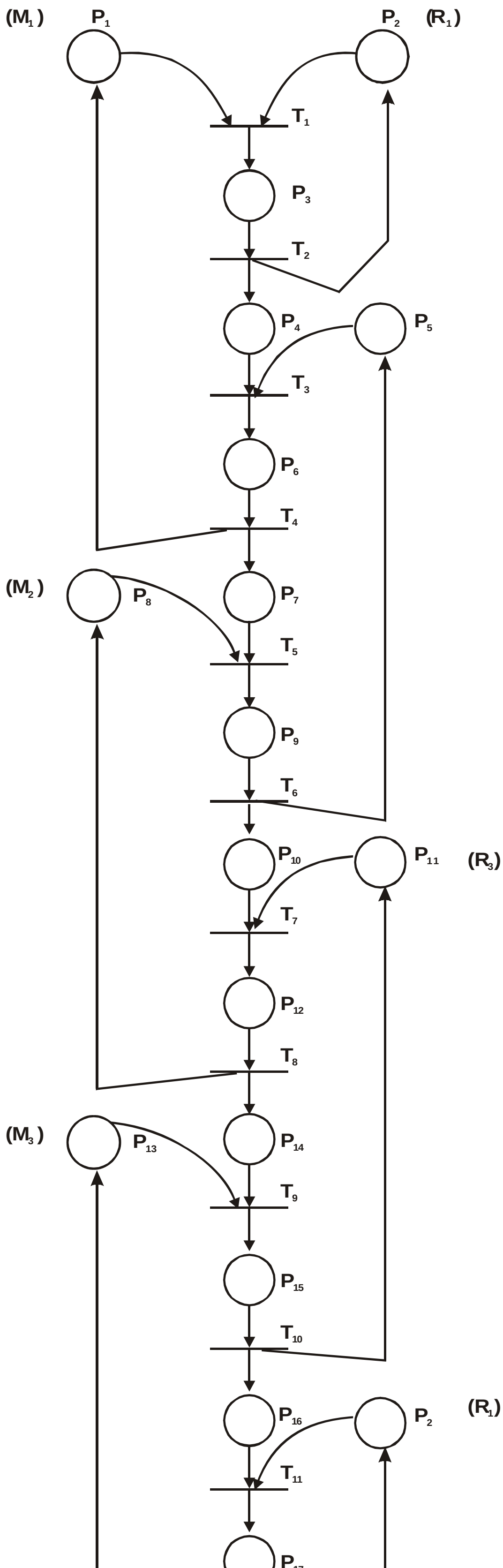


FIG. 27 (A) LAYOUT OF AN FMS CELL COMPRISING THREE MACHINES AND THREE ROBOTS



F1G. 27 (b) PNM OF AN FMS CELL COMPRISING THREE M/CS AND THREE ROBOTS

FOR FIG. 27 (b)

Description of the Petri-Net model of a manufacturing cell.

PLACES :	**TRANSITIONS**
P_1 : Machine M_1 is ready	T_1 : M_1 starts using R_1
P_2 : Robot R_1 is available	T_2 : Use of R_1 by M_1
P_3 : M_1 using R_1	T_3 : M_1 starts using R_2
P_4 : M_1 is waiting for R_2	T_4 : R_2 used by M_1
P_5 : Robot R_2 is available	T_5 : M_2 starts using R_2
P_6 : M_1 is using R_2	T_6 : R_2 used by $M_{2.}$
P_7 : R_2 is wating for M_2	T_7 : M_2 starts using R_3
P_8 : Machine M_2 is ready	T_8 : R_3 is used by M_2
P_9 : M_2 using R_2	T_9 : M_3 starts using R_3
P_{10} : M_2 is waiting for R_3	T_{10} : Use of R_3 by M_3
P_{11} : Robot R_3 is ready	T_{11} : M_3 starts using R_1
P_{12} : Machine M_2 is using R_3	T_{12} : M_3 used R_1
P_{13} : Machine M_3 is available	
P_{14} : Robot R_3 is waiting for M_3	
P_{15} : M_3 is Waiting for Robot R_1	
P_{16} : Robot R_1 is ready	
P_{17} : Machine M_3 is busy with robot R_1	

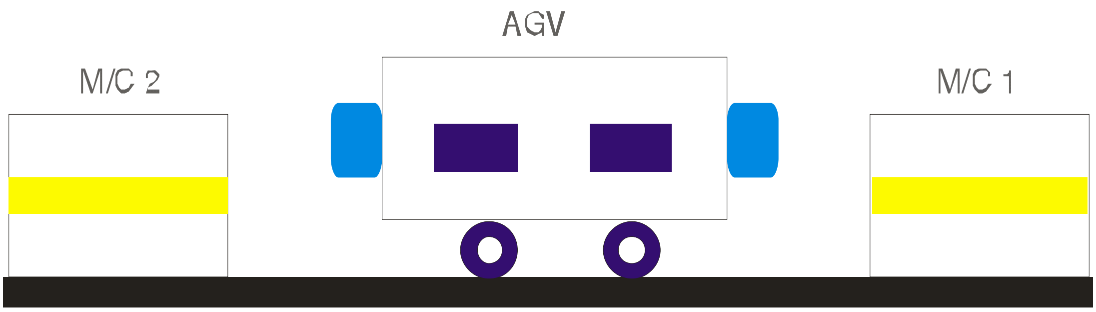


FIG. 28 (a) TWO MACHINES USING ONE AGV

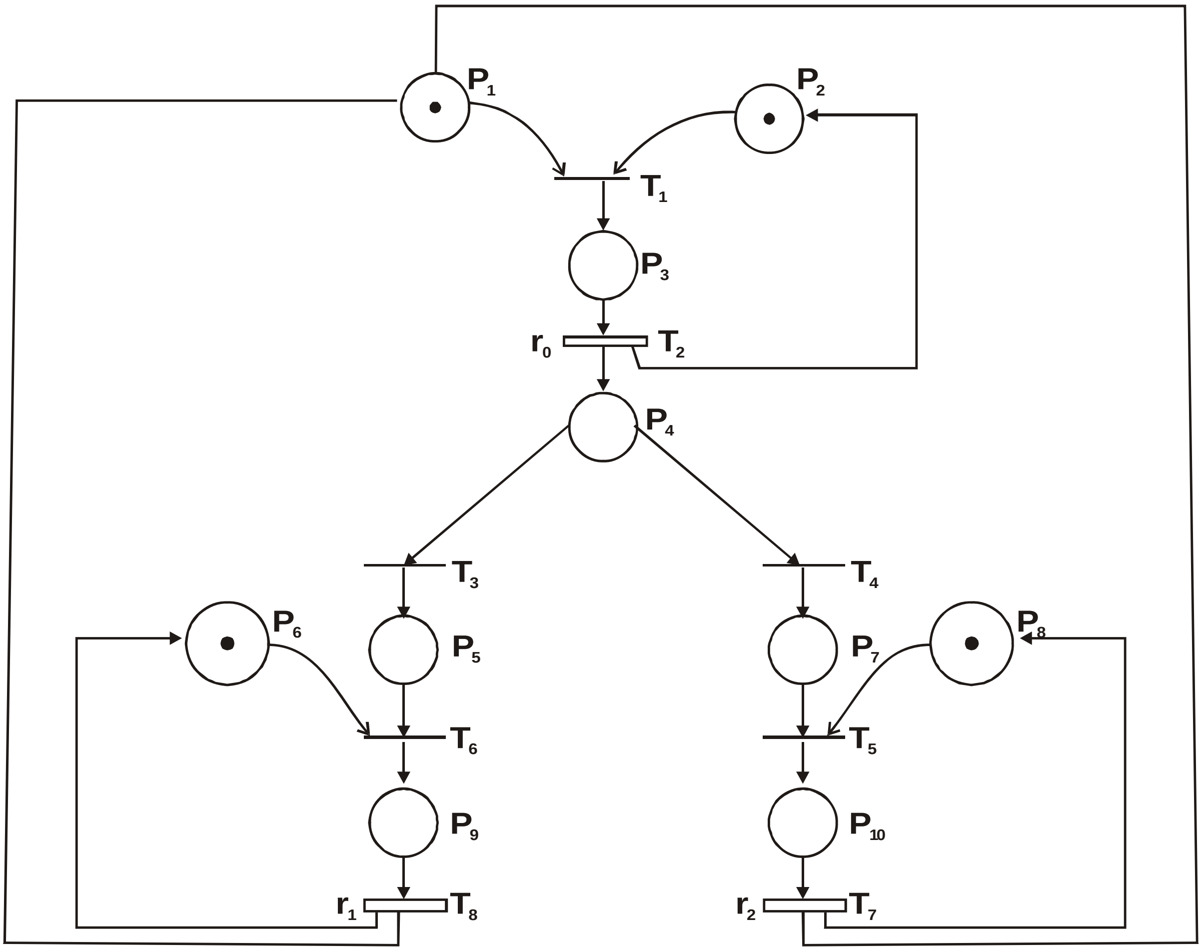


Fig. 28 (b)

A GSPN MODEL OF A SIMPLE
AMS USING AN AGV AND
TWO MACHINES

FOR FIG. 28 (b)

Interpretation of "places and Transitions"

PLACES :

P_1 : Parts in queue waiting

P_2 : AGV is available

P_3 : AGV transporting a part

P_4 : A part just transported by AGV

P_5 : Parts waiting to get processed by M_1

P_6 : Machine M_1 is available

P_7 : Parts waiting to get processed by M_2

P_8 : Machine M_2 is available

P_9 : Machine M_1 is processing a part

P_{10} : Machine M_2 is processing a part

TRANSITIONS

T_1 : AGV starts transporting a part

T_2 : Transport of part by AGV

T_3 : Part moves in queue for M_1

T_4 : Part joins the queue for M_2

T_6 : M_1 starts processing a part

T_8 : Processing of part by M_1

T_5 : M_2 starts processing a part

T_7 : Processing of part by M_2

Note :- Here T_1, T_3, T_4, T_5, & T_6 — Immediate transitions

& T_2, T_7, & T_8 — Exponential Transitions.

Rates of Processing parts — R_0, R_1 & R_2 respectively.

In the model horizontal bars are called immediate transitions (i.e. T_1, T_3, T_4 & T_6).

The rectangular bars are called exponential Transitions (ie T_2, T_7, & T_8) these represent “Timed Activites” – such as processing time by machines & transportation by the AGV.

In Immediate transitions T_3 & T_4 only one can fire at any point of time leaving the others.

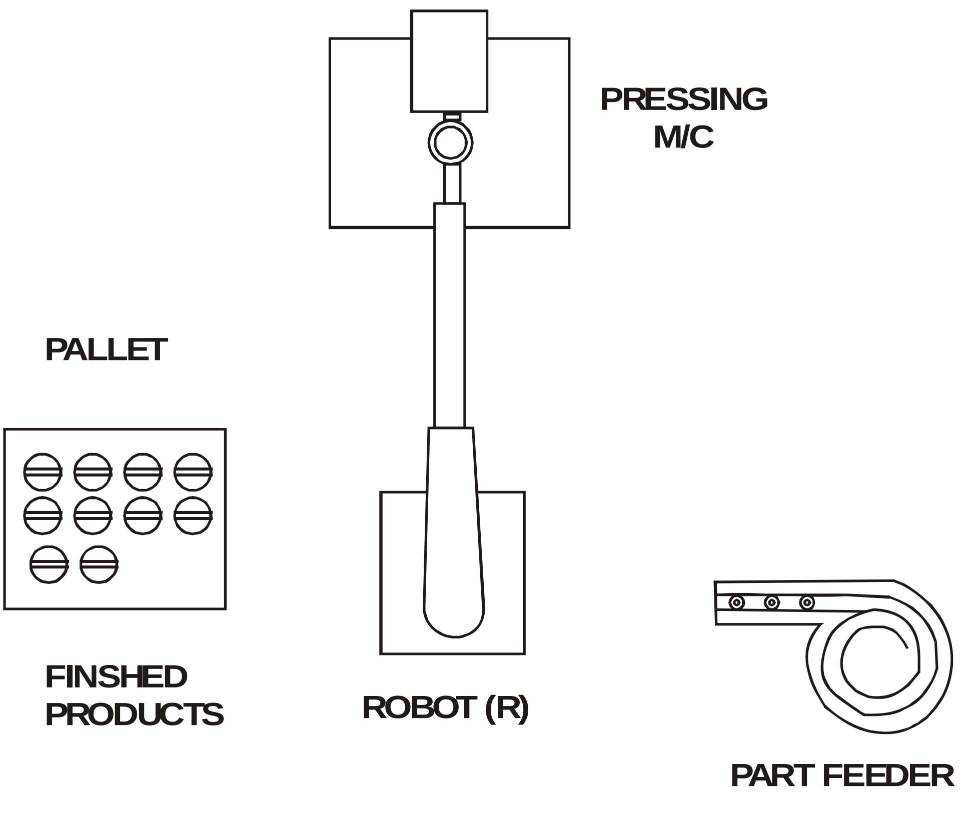


FIG. 29 (a) ROBOTIC WORK CELL FOR PRESSING OPERATIONS

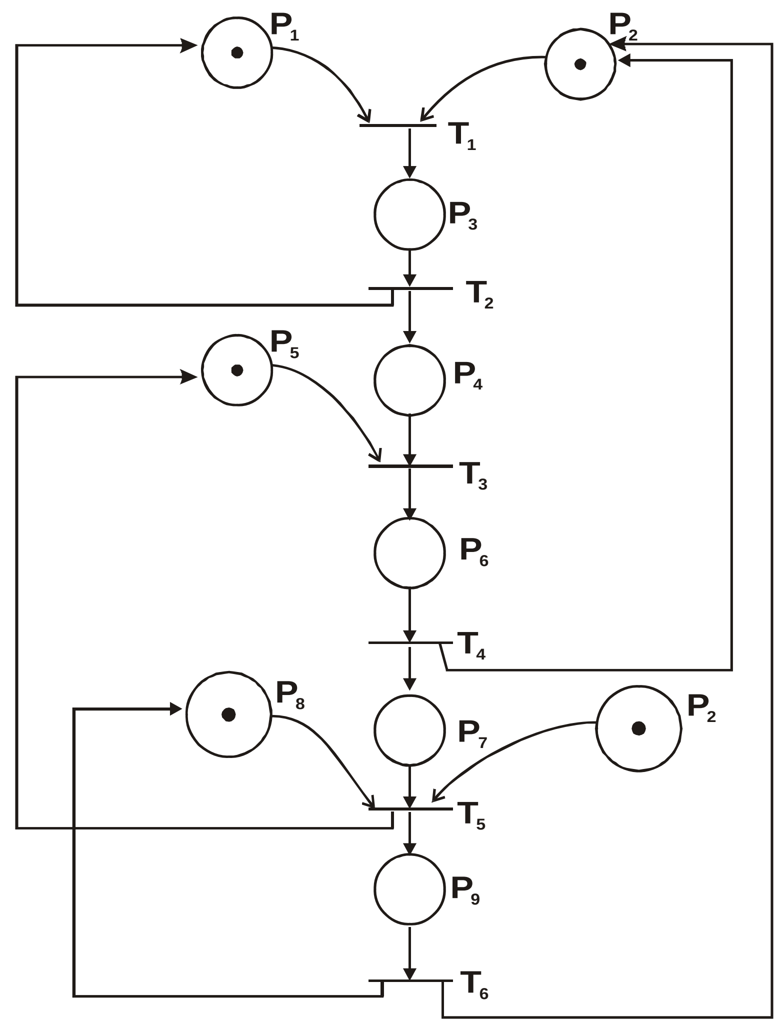


FIG. 29 (b) PNM OF A PRESSING OPERATIONS SYSTEM USING ONE ROBOT AND ONE M/C.

FOR FIG. 29 (b)

Interpretation of “places and Transitions”

PLACES :

P_1 : Parts feeder is available

P_2 : Robbot R is ready

P_3 : Transfer of part from feeder to the pressing machine ‘M’ by a robot R.

P_4 : A part is waiting to get processed by machine M.

P_5 : Pressing machine M is available.

P_6 : Pressing of part by the machine M.

P_7 : Finished part waiting to be transferred to the pallet.

P_8 : A pallet is available.

P_9 : Transfer of a finished part from machine M to a pallet.

TRANSITIONS

T_1 : Robot & Starts transferring a part

T_2 : Transfer of part by the robot

T_3 : Start of taking part by the machine M through robot R

T_4 : Part processed by the machine M

T_5 : Robot R starts transferring the finished part.

T_6 : Transfer of finished part from the pressing machine ‘M’ to the pallet.

As shown in the Fig. 30 (a), a manufacturing cell of an FMS comprising two identical machines M_1 & M_2, one material handling robot ‘R’ and two conveyor C_1 & C_2 & an unload area.

Here in coming parts arrive at the left end of conveyor C_1 and by conveyor movement react the right and of C_1. Robot ‘R’ picks up a part and places it in either macine M_1 or M_2 whichever is available.

After going to processing at a mchine, the prt is again picked up by a robot R and placed on conveyor C_2 from where it is transferred into the unload area by the same robot ‘R’.

For the operation of the above cell to obtain compact GSPN (Generalised steckastic petrinet) models certain assumptions are made such as -

(i) Unprocessed parts are always available on conveyor C_1

(ii) Each conveyor can carry only one part at a time.

(iii) Machine, conveyor & robot should not fail (i.e. there should not be any break down, or dead lock).

(iv) Robot 'R' is attaining to the three operations - such as transferring a part from C_1 to machine M_1 or M_2, transferring the part from machine M_1 or M_2 and finally from C_2 to unload area.

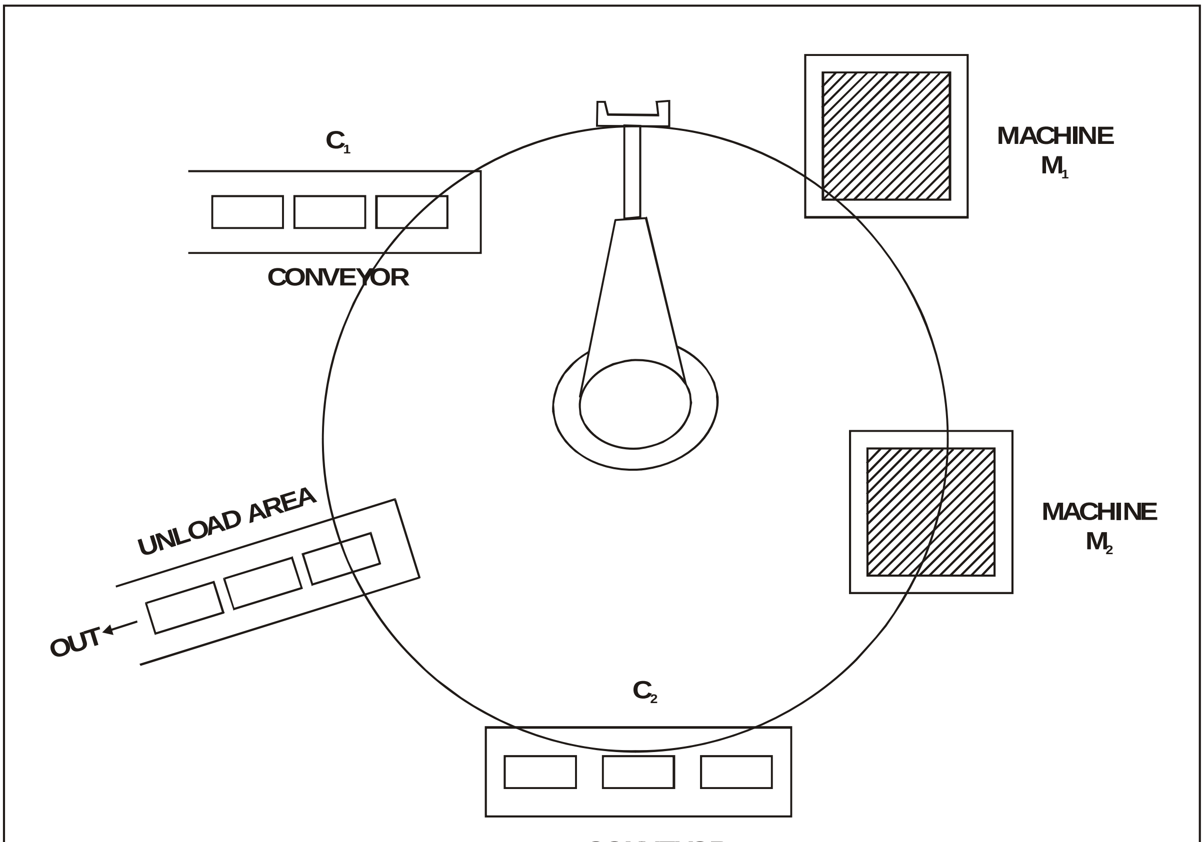


FIG. 30 (a) MFG. CELL

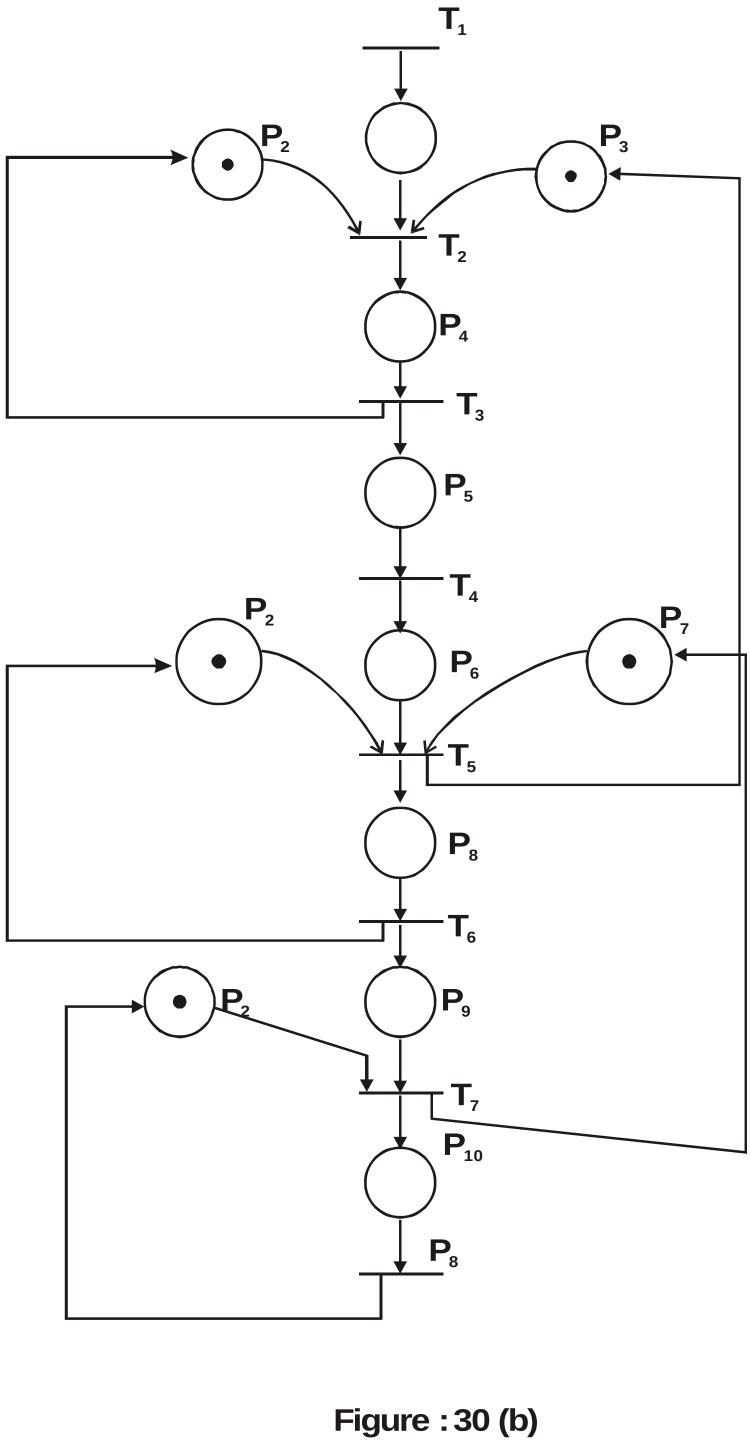


Figure : 30 (b)

FOR FIG. 30 (b)

Interpretation & places & Transitions of a GSPN model of an FMS

PLACES :

P_1 : Parts waiting on conveyor C_1.

P_2 : A Robbot 'R' is available.

P_3 : Availabe machines.

P_4 : Robot R transferring a part from convayor C_1 to one of the machines.

P_5 : Machine Procesaing the part (machine M_1, M_2 busy).

P_6 : Parts that have just been finished.

P_7 : Conveyor C_2 is available.

P_8 : Robot R transferring a part from machine to C_2.

P_9 : A part is waiting on conveyor C_2 for rotot R.

P_{10}: Robot R is unloading the finished part from conveyor C_2 to the unload area.

TRANSITIONS

T_1 : Job arrives.

T_2 : Robot R starts transferring parts from conveyor C_1 to a machine.

T_3 : Transfer of part from C_1 to a machine.

T_4 : Processing by machines.

T_5 : R starts transferring a part from a machine to conveyor C_2.

T_6 : Transfer of part from a machine to C_2.

T_7 : R starts unloading a part from C_2.

T_8 : Part unloading operation. (from conveyor C_2 to unloading area).

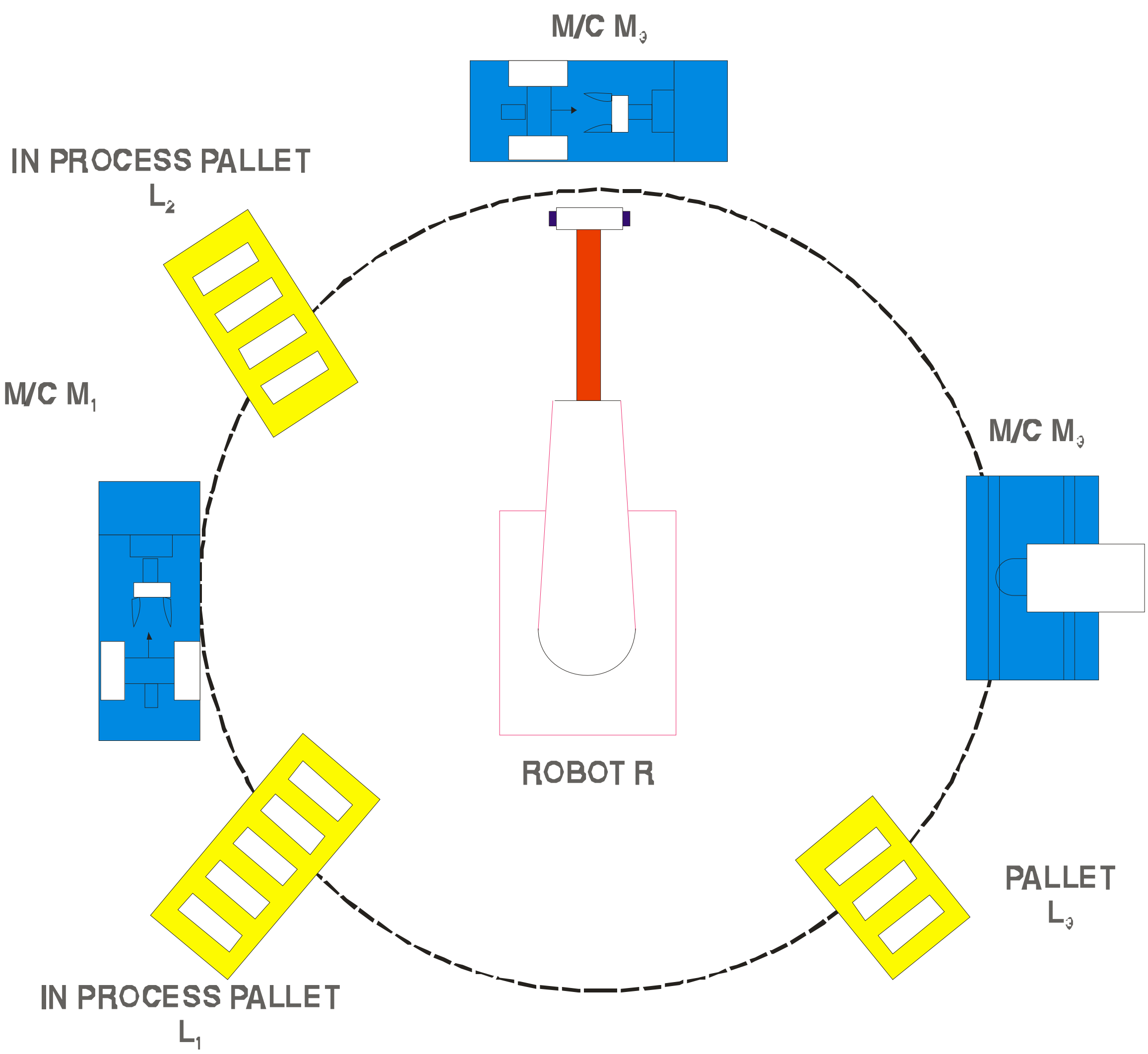


FIG. 30 (a) LAYOUT OF MFG. CELL DIA CASTING M/C IN CELL.

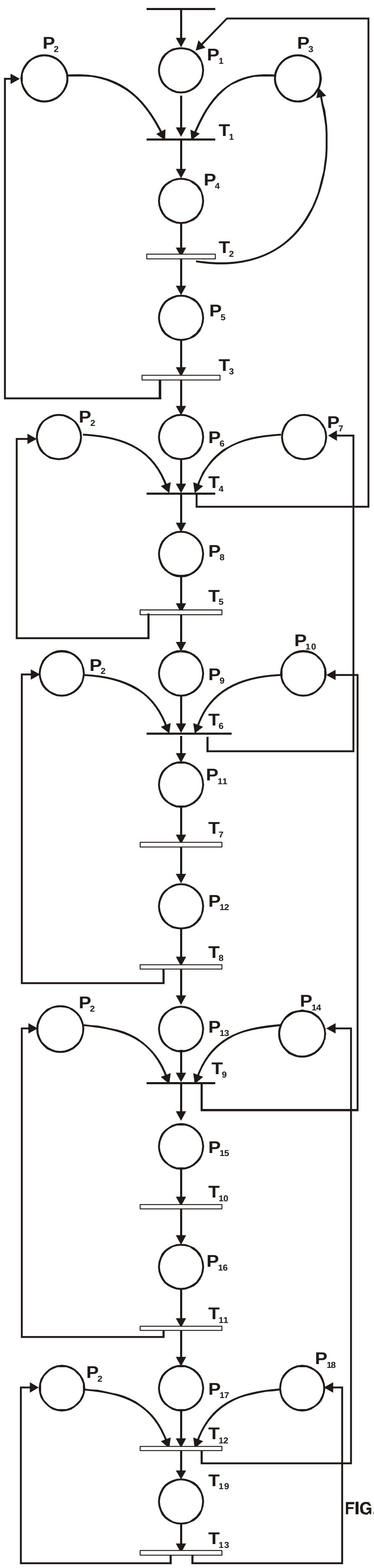


FIG. 31 (b) : EXACT GSPN MODEL OF A MFG. CELL USING THREE M/CS, THREE PALLETS AND A ROBOT.

FOR FIG. 31 (b)

Interpretation of places & Transitions in a PNM

of a DIE CASTING MANUFACTURING CELL.

PLACES :

P_1 : Parts waiting on a pallet L_1.

P_2 : Robbot R is ready.

P_3 : Machine M_1 is available.

P_4 : 'R' transfer a part from pallet L_1 to machine M_1.

P_5 : M_1 processing a part.

P_6 : Finished part just after processing on M_1.

P_7 : Pallet L_2 is available.

P_8 : Robot R transfarring a part from M_1 to pallet L_2.

P_9 : A part is waiting on pallet L_2.

P_{10}: Machine M_2 is available.

P_{11}: Robot R transferring a part from pallet L_2 to machine M_2.

P_{12}: M_2 processing a part.

P_{13} : A part just has finished processing on M_2.

P_{14} : Machine M_3 is available.

P_{15} : R transferring a part from M_2 to M_3.

P_{16} : Machine M_3 processing a part.

P_{17} : Machine M_3 just finished processing of the part.

P_{18} : A pallet L_3 is available.

P_{19} : Robot R transferring the finished part to a pallet L_3.

TRANSITIONS

T : Part arrives on a pallet L_1.

T_1 : Robot R starts transferring from L_1 to M_1.

T_2 : Part transfer from L_1 to M_1.

FOR FIG. 31 (b)

TRANSITION :

T_3 : Processing by M_1.

T_4 : Robot R starts transferring a part from M_1 to L_2.

T_5 : Part transfer from M_1 to L_2.

T_6 : Robot R starts transferring a part from pallet L_2 to M_2.

T_7 : Part transfer from L_2 to M_2.

T_8 : Processing of a part by M_2.

T_9 : Robot R starts transferring a part from M_2 to M_3.

T_{10}: Part transfer from M_2 to M_3.

T_{11}: Processing by M_3.

T_{12}: Robot ‘R’ starts transferring a finished part from machine M_3 to a pallet L_3.

T_{13}: Transfer of a finished part to a pallet L_3 for unloading.

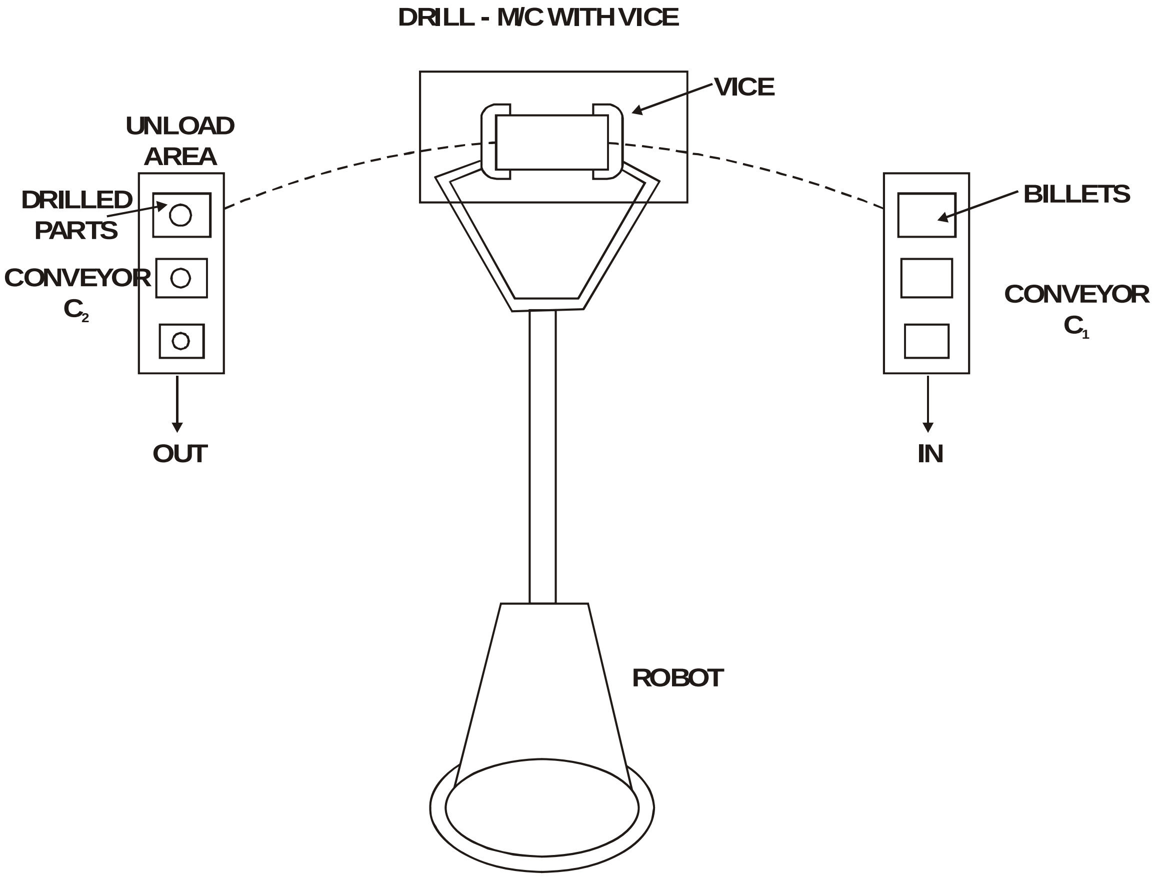
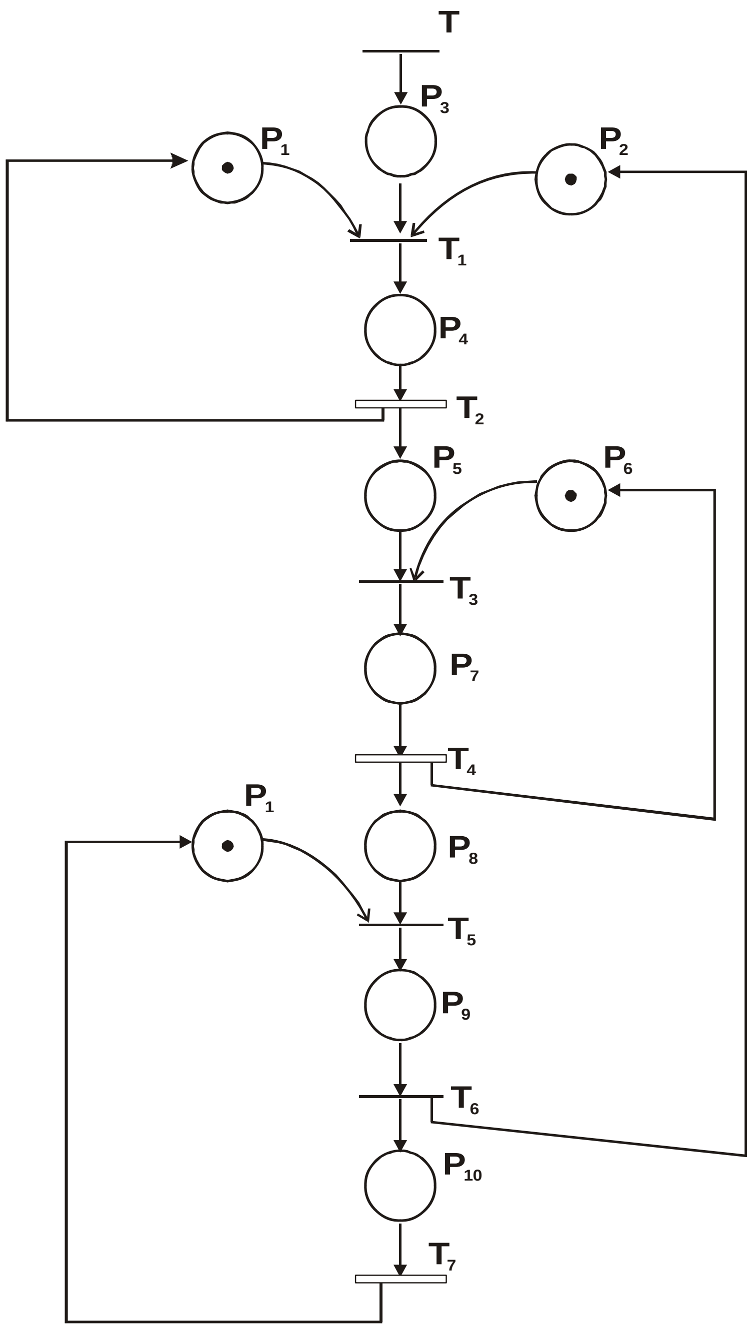


FIG. 32 (a) DRILLING OPERATION



Petri Net Model of A Drilling Work Cell

Fig. : 32 (b)

FOR FIG. 32 (b)

Interpretation of places & Transitions in a PNM of

a "DRILLING OPERATION AUTOMATED SYSTEM".

PLACES :

P_1 : Robot R is ready.

P_2 : Machine VICE is available.

P_3 : Workpiece waiting on coveyor C_1.

P_4 : Robot R transfer workpiece from convayor C_1 to vice.

P_5 : Workpiece in vice ready for drilling.

P_6 : Drilling machine available for operation.

P_7 : Drilling of a workpiece by the machine.

P_8 : Drilling workpiece waiting.

P_9 : Robot R gripping the workpiece and vice opens.

P_{10}: Robot R transferring the workpiece to unload area on conveyor C_2.

TRANSITIONS

T : Billets arrive.

T_1 : Start of transfer of workpiece.

T_2 : Workpiece transferred by R.

T_3 : Start of drilling operation.

T_4 : End of drilling operation.

T_5 : Robot R starts transferring the finished (drilled) workpiece.

T_6 : Robot R starts Gripping the drilled part.

T_7 : Transfer of finished part by robot R to the unload area C_2.

CHAPTER - 9

MODELLING OF A PCB FLEXIBLE ASSEMBLY PLANT

For the production of small batches, of surface mounted PCBs, a considerable is space saving is possible over conventionally assembled board.

Microprocessor based Intelligent equipment is becoming popular in respect of cost for assembling PCBs. This method is faster and more accurate. Here the latest generation of surface mounted devices are utilised.

9.1 PRINCIPAL FEATURES OF THE FMS :

For the purpose the FMS was developed with the following principal features:-

(i) A central processor (host computer) capable of offline date preparation; fast loading of configuration instructions to production line equipment; and line control, monitoring and fault correction.

(ii) Computer aided design (CAD) system for forward load control and part data acquisition.

(iii) A local stores to line stores and inventory control system with facilities for off-line job kitting.

(iv) Fast mechanical reconfiguration of line machines.

(v) An efficient mechanical handling system for materials transport.

(vi) A cellular line structure with facilities for independent operation of individual calls; in addition to normal integrated operation.

(vii) A typical batch size of fifteen units and maximum throughout of four hundred boarded per operating day.

9.2 Design and Operation :-

Surface mounted PCB production requires an unchangeable series of processing steps - a simple serial line design was adopted.

However to accommodate re-work and to add further flexibility, the line is divided into three processing cells, in addition to a stores cell.

FUNCTION OF THE PROCESSING CELLS :

1. Cell One - a) Substrate pre clean

b) Printing

& c) Assembly.

2. Cell Two - a) Assembly Baking

b) Soldering

& c) Defluxion.

3. Cell Three - Assembly Test.

Here fig. 33. gives a three dimensional representation of the finished line and fig. 34; an equipment layout plan, & fig. 35 shows line control and material flow.

9.3 STORES CELL :

The stores provide the following facilities :-

(i) Semi automatic kitting of jobs by an operator under control of the supervisory host computer.

(ii) Studies of job kitting feasibilities.

(iii) Stock forward planning and inventory control.

(iv) Part extraction and re-booking facilities.

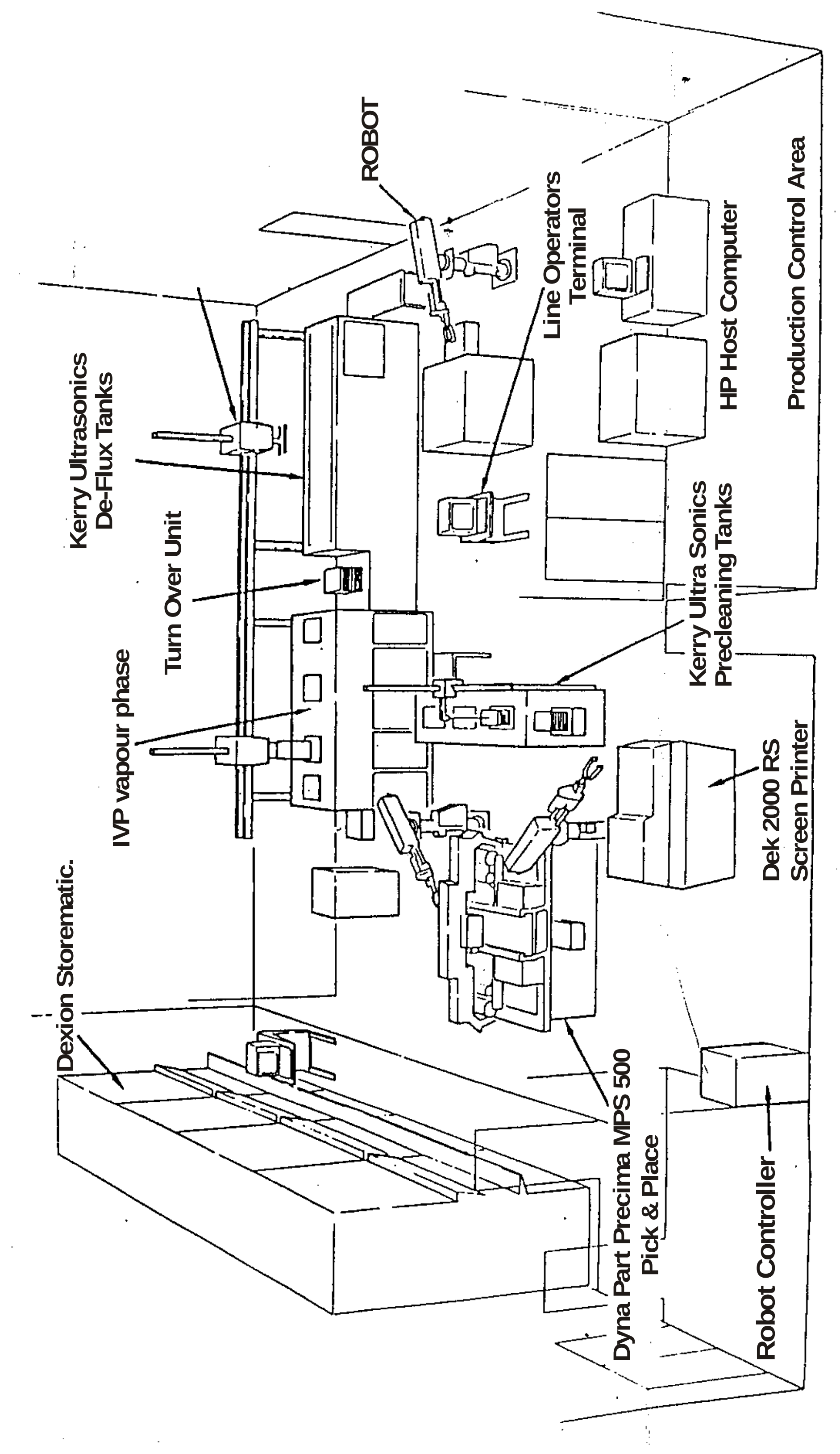


FIG. 33 PCB Flexible Assembly System

(v) A bar coded stock labelling system. In this type of stores, the stores operator is provided with an industrial visual display unit (VDU), keyboard, and bar code reader.

Parts arriving are booked into the stores system via a man - machine interface using the barcode reader and VDU. All parts have printed bar codes. Part quantities and locations are held in a database on the host computer system. Jobs may only b e kitted when the database shows that there are sufficient parts available in the stores for manufacture of the complete job.

During kitting parts are extracted by the stores operator under the supervision of the host computer. Bar coding provides correct part identification and substrate traceability.

Each substrate, which is uniquely identified by serial number is fixed in a tooling plate as it is extracted from the stores for kitting.

Tooling plates are latched into cassette containing up to seven plates.

A given job may therefore consists of one or more cassettes.

Extracted components are kitted on to pallets for use by the pick and place machine in cell one.

The positioning of parts on the pallets is monifored by the host computer for later compilation of the pick and place programme.

9.4 OPERATION IN CELL ONE

The following processes are carried out in cell one :-

(i) Substrate pre-clean (de-greasing) in an ultrasonic boiling solvent cleaning system.

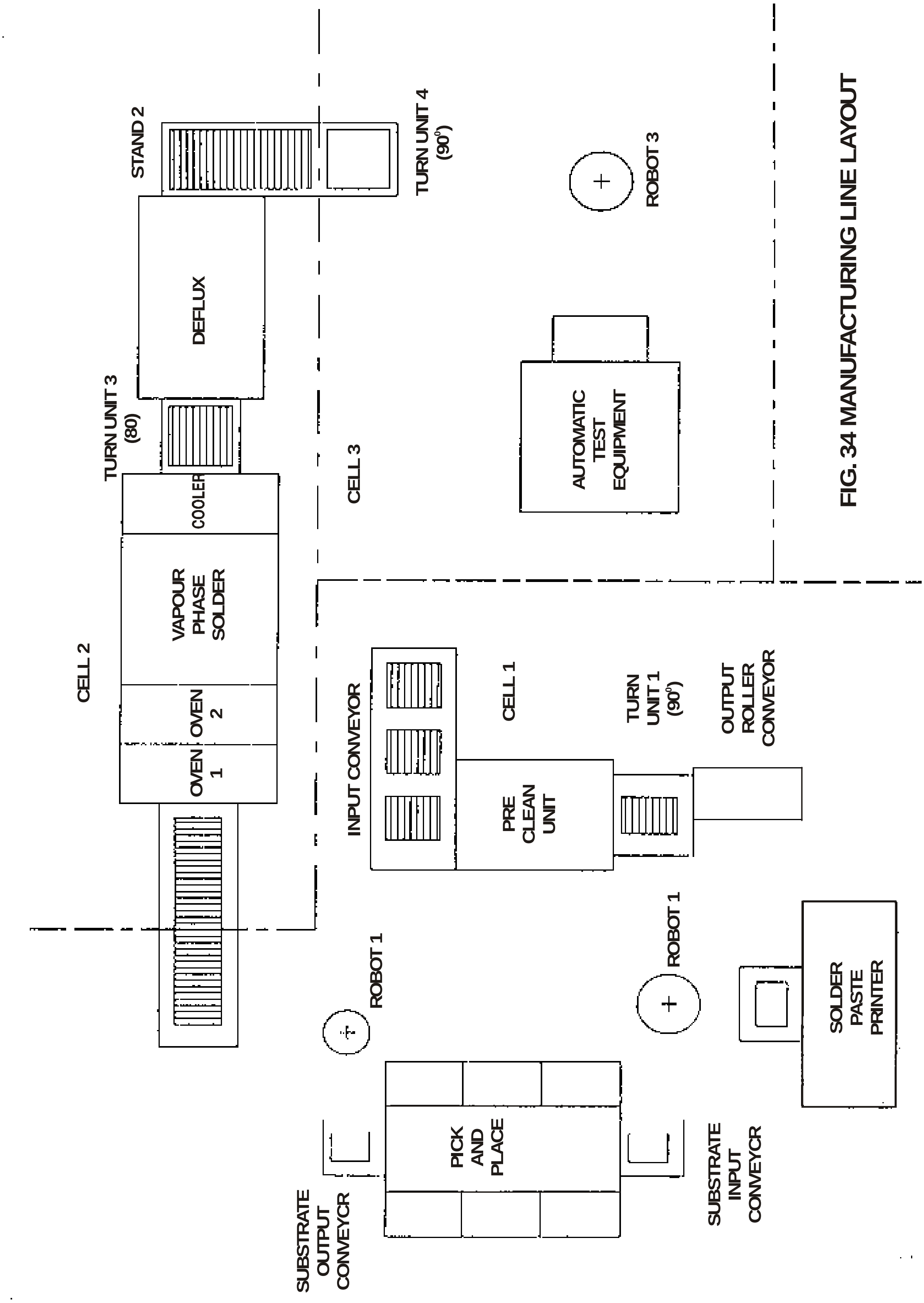


FIG. 34 MANUFACTURING LINE LAYOUT

(ii) Screen printing of the substrates with solder cream.

(iii) Assembly of the PCBs by placing of components on to the substrates.

When a job enters the cell the line operator is instructed by the host computer to configure the pick and place machine with the correct pallet set (containing components), and load the cassettes (containing substrates) on the line input conveyor.

A unique print screen for the part to be manufactured is loading into the screen printer as part of the configuration process. The pick & place machine and screen printer program are automatically downloaded by the host computer as part of the configuration sequence. Cell setup is therefore a simple task and can be achieved in minutes rather that hours.

When configuration is complete the host computer allows the cell to start processing the job. This proceeds without host intervention unless a processing error occurs.

Cassette are picked up from the impact conveyor by an overhead transport (OHT) unit which transports the batch of substrates through the three - tank pre - cleaning process. On completion of cleaning, the tooling plates are individually extracted from the cassettes by a robot (R_1) and then placed in the solder screen printer. The screen printer prints solder cream on to the contact pads for the surface mounted devices on the substrates. The robot (R_1) then moves the plats to the pick place machine (M). This unit picks up to hundreds of different component types from feeders mounted on the machine pallets and places when on to the substrate in an optimised program sequence.

Assembled board are ejected at the other side of the machine (M) where they are removed by a second robot (R_2) and re-batched into a waiting cassette. When the cassette is complete it may be moved into cell two, if the cell is free.

9.5 OPERATION IN CELL TWO :

The following processes are carried out in cell two :-

(i) Cassette pre-heat and solder cream cure.

(ii) Vapour phase soldering.

(iii) Cassette cooling.

(iv) Three stage boiling solvent deflux.

(v) Drying.

The cell is controlled by a microprocessor based single board computer which supervises the cell materials transport system and controls the operation of the processing stages.

The host computer down loads processing parameters (e.g. processing time and temps.) as each a cassette enters the cell.

Upto four cassettes, each with a different processing requirement, may be processed simultaneously. As cassettes move through the cell, monitored parameters such as temperatures are generated and upload to the host computer for archival. Thus it is possible to extract the actual processing details of a particular substrate then the need arise. Transport through the cell is affected by two intelligent overhead transportation unite which have the capability to pick up cassettes, transport them and leave them i any of the processing stages. Cassettes entering the cell are picked up by one of the overhead transport units (say OHT_1) and placed in the first of two pre - heat ovens. When the cassette has reached pre-set tempt. and a specified soak period has been observed, it is moved to the second pre-heat oven where a similar sequence of events take place. Cassettes are then transported to the vapour phase reflow solder tank where condensation of an inert fluid at a more than 200^0c cause rapid heating and thus soldering in an airless environment. On removal from this stage. After a precise pre-programmed dwell period the not cassette is transported to the cooler which allows controlled solidification of the soldered joints in a cool air stream.

The final stages of the process are a three sage solvent defluxing system, followed by hot air drying. After drying the cassettes are placed on an out station for transfer into cell three.

9.6 OPERATION IN CELL-THREE:

The cell contains the automatic test equipment (ATC), substrate tooling pates are individually removed, by a robot, from the cassette and placed in the automatic test equipment. Testing takes place via a bed or nails, test jig which makes contact with the test pads on the circuit board. On completion of testing substrates are refused to the cassette from where they were taken to deliver.

The host computer downloads test programs for the ATE as par of the cell configuration sequence.

Each type of substrate requires a unique test jig, which is mounted by the operator on orders from the host computer.

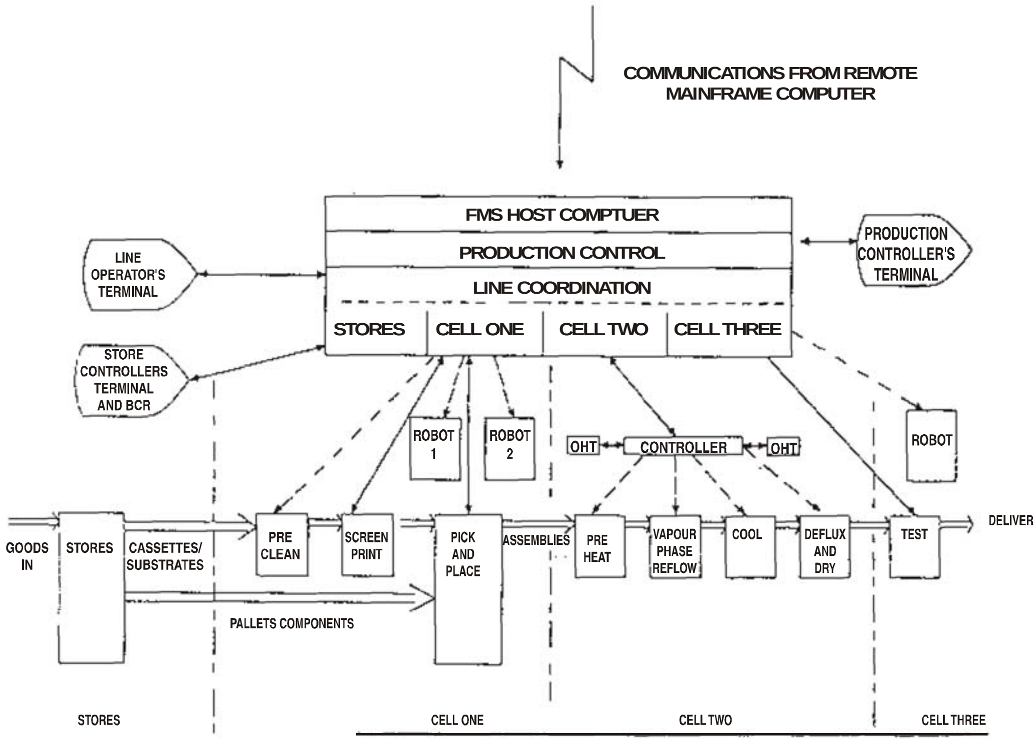

COMMUNICATIONS FROM REMOTE MAINFRAME COMPUTER
FMS HOST COMPTUER
PRODUCTION CONTROL
LINE COORDINATION
STORES
CELL ONE
CELL TWO
CELL THREE
LINE OPERATOR'S TERMINAL
PRODUCTION CONTROLLER'S TERMINAL
STORE CONTROLLERS TERMINAL AND BCR
ROBOT 1
ROBOT 2
OHT
CONTROLLER
OHT
ROBOT
GOODS IN
STORES
CASSETTES/ SUBSTRATES
PRE CLEAN
SCREEN PRINT
PICK AND PLACE
ASSEMBLIES
PRE HEAT
VAPOUR PHASE REFLOW
COOL
DEFLUX AND DRY
TEST
DELIVER
PALLETS COMPONENTS
STORES
CELL ONE
CELL TWO
CELL THREE

FIG. 35

The tool jigs are bar coded to prevent incorrect jig usage.

Test results are uploaded to the host computer for archival and interpretation by the line monitoring software.

9.7 LINE CONTROL AND INTEGRATION :

The high level control of the FMS line is carried out entirely by the host mini computer system. The production cycle, from job kitting to manufactured assembly testing, is coordinated with complete operator visibility by this machine.

The host system has an extensive move machine interface which requires only two operators and a production controller to support the production process. Each of these individual is provided with a computer terminal as shown in fig. 3.

9.8 PRODUCTION CONTROL :

A forecast jobs list of orders for the FMS is regularly downloaded from the site main frame computer list is sorted out and displayed to the production controller in due - date order, to compromise job priorities.

Before a particular job may be manufactured it is necessary for the required manufacturing data and tooling to be available.

When these conditions are satisfied the production controller may selected the job for manufacture. This causes a request to be sent to the main frame computer for the down load of production data; consisting of a kitting list, placement programmed tool program for the job.

The job the enters the jobs waiting manufacture (JAM) queue.

Jobs in the JAM queue are displayed to the operator and dispatched to the line in due - date order, provided there are sufficient components in the stores to complete manufacture. Once in manufacture, jobs are monitored by the host computer giving the production controller complete visibility of job status at any time. Stock usage data, process monitored data and test results generated by the manufacturing cycle are uploaded to the site main frame for part ordering and archival respectively.

9.9 <u>MANUFACTURING LINE COORDINATION</u> :

Cell configuration and error management is coordinated with the line operator via a VDU, keyboard and bar code reader. Owing to the stand along capability of the line equipment, one configured, manufacture takes place with little interaction from the host computer until the job is completed by the cell or an error occurs.

Downloaded assembly data is compiled into optimised placement programs for the pick and place machine. These part programs are maintained on the host computer for possible future use.

Processing parameters uploaded from the cell two equipment and test results uploaded from cell three are archived on the host computer. This data may be examined by the production controller to aid process development and study product reject rates. The host software also carries out line error analysis, which may be used by the production controller for process optimisation on the line equipment.

Operation in Cell one :-

1. Cassette picked up from the input conveyor by an overhead transport unit.
2. Transporting the batch of substrates through the three tank pre-cleaning process.
3. Completion of cleaning process
4. Tooling plates extracted from the cassette by a robot
5. Tooling plates are placed in the solder screen printer by a robot
6. Screen printer prints solder cream on the contact pads for the surface mounted devices on the substrate.
7. Robot moves the plate to the pick & place machine
8. Pick & place machine picks up 150/120/80 different components types from the feeder mounted on the pallets.
9. Machine places components on substrate in an optimised program sequence.

10. Assembled boards passes on the other side of the machine.

11. Robot 2 starts picking up the boards.

12. Robot 2 place the boards in cassette backed with (i.e. re-batched into waiting cassette)

13. Cassette packed with the board.

14. Completed cassette moved to cell two if the cell is free.

Cell-2 **<u>Following processes are carried out in this cell.</u>**

1. Cassette entering the cell no. 2.

2. Cassette pickup by one of the transport units.

3. Transport unit placed the cassette in the first of two pre-head-ovens and remains till it is reached to the pre-set-tem

4. Cassette then moved to the 2nd pre-heat oven where same process has taken place.

5. Cassette then transported to the vapor phase reflow solder tank where condensation of an inert fluid at a tamp of 216^{0}C, causes heating and soldering is done in an airless environment.

6. The hot cassette is transported to the cooler where solder solidifies the joints.

7. The final stages of the process are three stages solvent defluxing system followed by hot air drying.

8. After drying the cassettes are transferred into the third cell.

<u>(C) Third Cell :- Testing</u>

1. Each substrate tooling is transferred by a robot from the cassette and placed in the automatic test equipment (ATE).

2. Testing processes take place by a “leed of nils”, test jig which makes contact with the circuit board.

3. Testing of substrates completed.

4. Tested substrates are placed into cassette from where they were taken out.

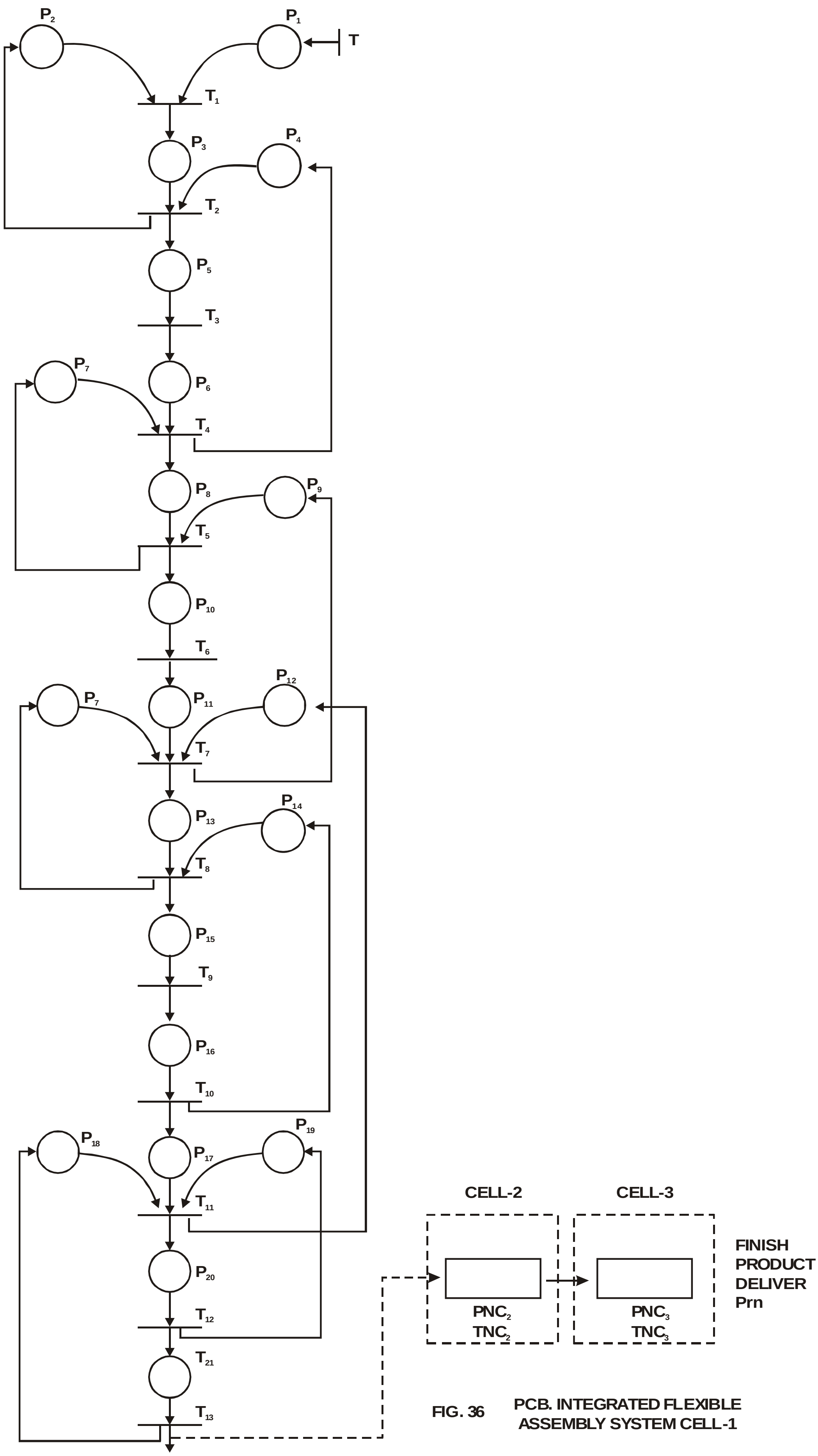


FIG. 36 PCB. INTEGRATED FLEXIBLE ASSEMBLY SYSTEM CELL-1

For PCB FLEXIBLE ASSEMBLY SYSTEM :

Interpretation of places and Transitions (For CELL-1)

P_1 : Cassette (having a batch of tooling plates) is available.

P_2 : Overhead (O.H.) Transport is ready.

P_3 : O.H. Transport transferring a Cassette from the input conveyor to the Pre-Cleaning unit.

P_4 : Pre-cleaning unit is available.

P_5 : Pre cleaning units performing cleaning operations.

P_6 : Cleaning of substrates (fixed on toolings) is complete waiting further operations.

P_7 : Robot R_1 is available.

P_8 : Tooling plates extracted from the cassette individually by the Robot R_1 and transfer them to the screen printer from pre-cleaner.

P_9 : Screen printer is available.

P_{10} : Printing process on tooling plates

P_{11} : Printing process just finished waiting further activity.

P_{12} : Pick and place machine 'M' is available.

P_7 : Robot R_1 is ready.

P_{13} : Robot R_1 transferring the printed substrates (tooling plates) to the machine 'M'.

P_{14} : Pallets containing different component types are available.

P_{15} : Machine 'M' picks up component from the feeder mounted on the Pallets, and places on the substrates in sequence.

P_{16} : Assembly of a board is just completed.

P_{17} : Assembled board ejected on the other side of the machine 'M' waiting further operation.

P_{18} : Robot R_2 is ready.

P_{19} : Cassettes waiting to be rebatched.

P_{20} : Assembled printed board rebatched into the cassette by robot R_2.

P_{21} : Rebatched cassette waiting for further activity in cell no. 2.

P_{23} : Robot R_2 transferring the cassette into cell no. 2 for further operations. Fig. 4(a)

PnC_2 : Finished products from cell one entering into cell no. 2 (Two) similarly model for operation in cell no. 2 may be drawn as shown in fig. 4(b).

PnC_3 : After completion of all operations in cell no. 2 products enter into cell no. 3 for final operation Fig. 4(c). After final operations products are taken out and delivered.

RnC_3 : Robot R_3 transferring each substrates tooling from the cassette into cell no. 3 after completion of operations in cell no. 2.

Note : Pn_1 - P - Indic-ate places of state or conditions of any process

n_1 – No. of places in cell 1.

Pn_2 – No. of places in cell 2.

Pn_3 – No. of places in cell 3.

Pnf – No. of final finished products ready for delivery.

TRANSITIONS : (CELL 1.)

T_1 : O.H.T. starting transfer of cassette from the input conveyor.

T_2 : Transfer of cassette from conveyor to pre- cleaning unit.

T_3 : Pre-cleaning of a batch of substrates

T_4 : Start of transfer of tooling plates by R_1

T_5 : Transfer of tooling place from cassette to printer

T_6 : Processing of tooling plates in printer.

T_7 : Robot R_1 starts transferring tooling plate to machine M.

T_8 : Transfer of tooling plates to the machine M.

T_9 : Transfer of components on sub startes.

T_{10} : Assembling of board.

T_{11} : Robot R_2 starts transferring the assembled board.

T_{12} : Transfer of assembled load into cassette

T_{13} : Robot R_2 starts transferring rebatched cassette into cell No. 2.

Tnc_2 : Transitions in cell No. 2.

Tnc_3 : Transitions in cell No. 3.

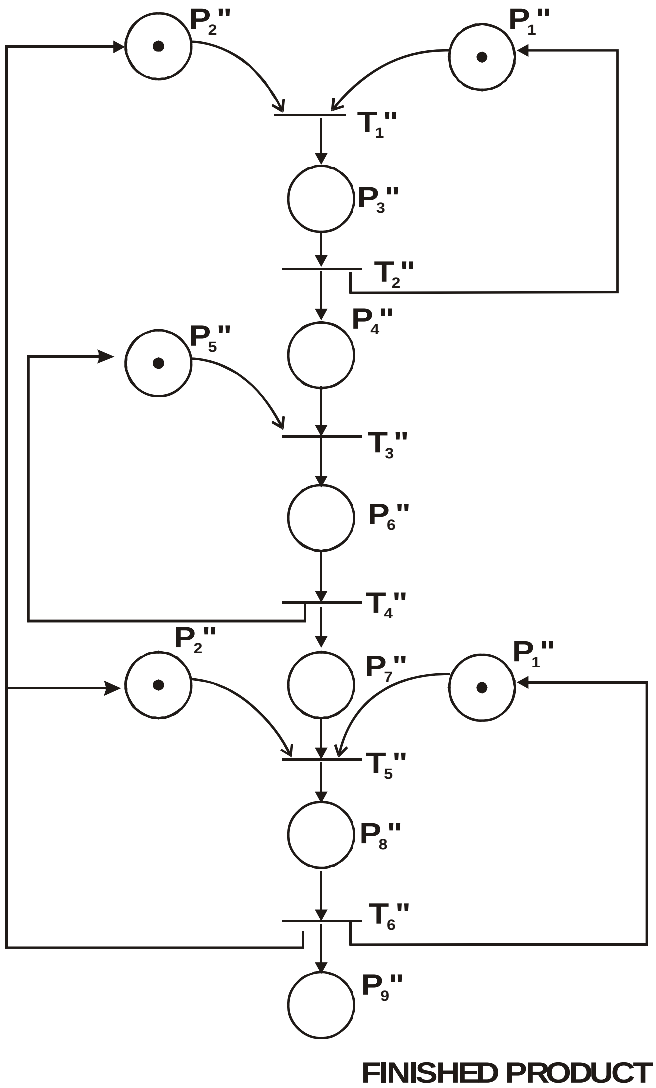


FIG. 37

PNM OF A PCB. FLEXIBLE
ASSEMBLY SYSTEM
OF CELL-3

OPERATION IN CELL - 3

Interpretation of places & Transitions.

P^{II}_1 : Robot R_3 is ready.

P^{II}_2 : Cassette waiting in the outstanding.

P^{II}_3 : Robot R_3 removing the assembled substrate toolings from the Cassette.

P^{II}_4 : Substrates tooling waiting for testing.

P^{II}_5 : Automatic Test equipment is available.

P^{II}_6 : Testing operations of circuit boards.

P^{II}_7 : Teated circuit boards waiting to be transferred.

P^{II}_1 : Robot R_3 is ready.

P^{II}_8 : Robot R_3 transferring the circuit boards (tooling substrates) into the cassette.

P^{II}_9 : Tested PCB in a cassette waiting for delivery.

TRANSITIONS :

T^{II}_1 : Robot R_3 starts extracting tooling substrate from the cassette and transfer them to ATE.

T^{II}_2 : Transfer of tooling substrates to ATE.

T^{II}_3 : ATE starts testing the circuits.

T^{II}_4 : Testing operation competed.

T^{II}_5 : Robot R3 starts transferring the tooling substrates (Assembled PCB) into the cassette.

T^{II}_6 : Transfer of tooling substrates into the cassette.

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.

- It provides useful data which helps in designing the systems thereby avoiding most of the problems of an flexible manufacturing system.

  The models for a PCB flexible assembly system presented here do not capture failures of conveyors, robots, and machines. This can however be introduced into the model easily by introducing additional places and transitions appropriately. These would be helpful in the computation of reliability and performance computations.

  As the size and complexity of the modelled (Automated PCB flexible assembly) system is growing, the PNM of each cell has been considered separately, finally the cells are integrated to give the assembled printed circuit boards.

  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.

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