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COLORED PETRI NET USED TO MODEL FLEXIBLE MANUFACTURING CELL

Sanjib Kumar SAREN[1], Florin BLAGA[2]
[1] University of Oradea, sanjibksaren@gmail.com
[2]University of Oradea, fblaga@uoradea.ro

Abstract—This paper focused on the modeling of Flexible Manufacturing Cell (FMC) using colored Petri nets without time. Using colored Petri nets, it is possible to structure of manufacturing system organization, material and data flows, concurrency and synchronization of the process and machining operation of the system. Model is constructing using CPN (colored petri net) Tools to find the connection between the place, transition and arcs of the system. For this model, we studied the FMC from the faculty of engineering Management and Technology, University of Oradea. Here we are processing two different parts: two parts for milling and two parts for turning in this FMC. Here we also discussed the modeling of the same system with two different FMC model and features of the system.

***Keywords*—**Flexible manufacturing cell, colored Petri net, modeling, simulation and comparison.

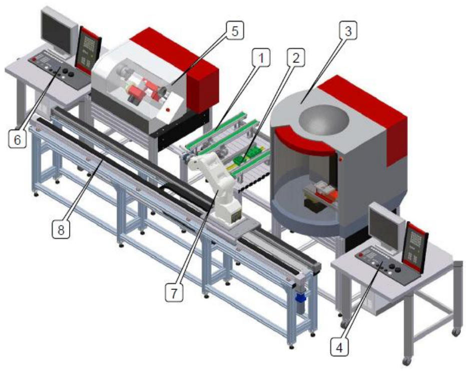
I. Introduction

FLEXIBLE manufacturing system (FMS) is a decision-making system, a discrete-event system and sets of the verity of machines, an automated transport system and has an ability to produce different products using multiple concurrent flows of job process and also reduces the production cost mentioned by Jeng and Zuberek [1]–[2]. Jensen described the concept of color in colored Petri nets. He also mentioned about each place and the transition has a color to define [3]. Jensen addressed high-level Petri nets which are a combination of predicate/transition nets and colored Petri nets [4]. Genrich mentioned the use of high-level Petri nets for system modeling [5]. Blaga focused on modeling of flexible manufacturing cell using CPN (colored petri net) tools [6]. Kristensen used Colored Petri Nets to model and simulate the concurrent systems: computer networks, communication systems [7].

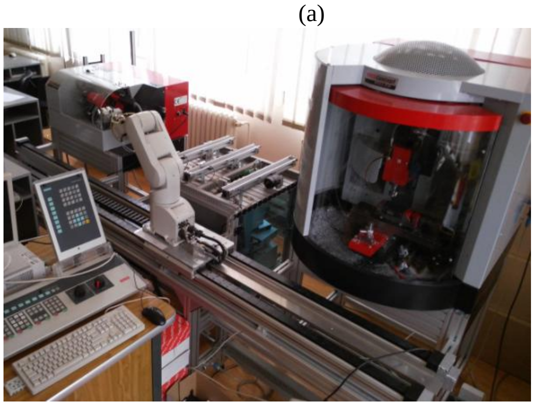
II. Description of the system

a) Components of the systems

The flexible manufacturing cell layout consisting of (1)Power station (2)Evacuation station (3)Milling machine CNC (computer numerical control) CONCEPT MILL 55 (4)Control equipment (FANUC or SIMESS) of milling machine (5)Lathe CNC CONCEPT TURN 55 (6)Control equipment (FANUC or SIMESS) (7) Mitsubishi RV-2AJ robot (8)Handle the moving robot.



(a)



(b)

Fig. 1. Flexible manufacturing cell (a) Porotype model of the Flexible manufacturing cell (b) Flexible manufacturing cell (faculty of engineering Management and Technology, University of Oradea.).

b) Flow of information and materials

In this manufacturing cell two storage parts are available for milling and turning parts. CNC concept mill 55 and Concept turn 55 CNC used for machining the desired parts. For both machine have computer control to run the program which is FANUC or SIMESS system. Mitsubishi RV-2AJ robot is used for loading and unloading the parts in the system. Two machines and robot are connected through distributed system with a master computer.

The diagram represents the material flow and information flow which mentioned below in Fig. 2.

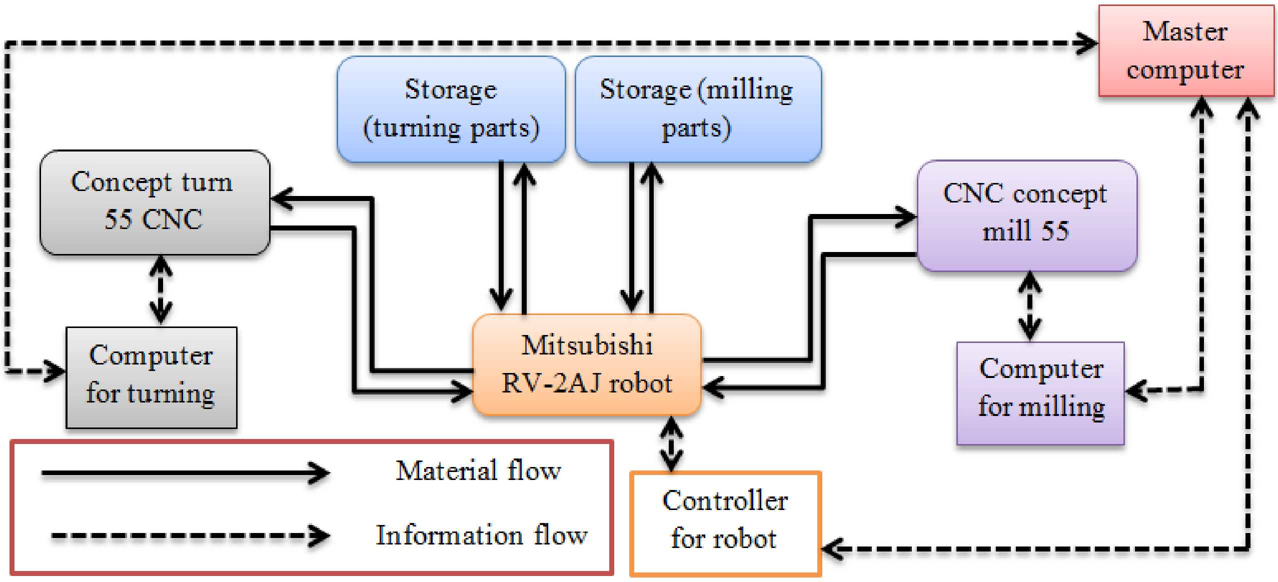


Fig. 2. Material and information flow for flexible manufacturing cell.

The information is flowing through the master computer to the both machines and robot to perform desired operations.

In this system, material (parts) is picking up by a robot (Mitsubishi RV-2AJ) from storage and loading into the desire machines which are CNC concept mill 55 and Concept turn 55 CNC. Then the machine performs machining operation (turning or milling) and the complete part is unloaded by the robot from machine and storage to the storage system. So, the master computer operates the entire system to run the program. The flow of materials observes from storage to robot, robot to the machine, machine to robot and robot to storage. This material flow is same for CNC concept mill 55 and Concept turn 55 CNC. Here basically two different milling parts and two different turning parts are produced on the desired machine. So the decision of material flow depends on the master computer because which part is flowing first, second and so on. This decision also applicable for machine too.

III. Characteristics of Parts

a) Technological operation of parts

The first parts in the figure operated in CNC turning machine. The operation of the part is stepping turning, centering and grooving. Respectively the second parts in the figure will be a machine on CNC turning, the operation for the part is facing, grooving, turning and boring. The operation of the third part of the CNC mill, the require operation will face milling, drilling, end milling, chamfering. The last part of the figure will be machining on the CNC mill, the operation will end, face, pocket milling and fillet making. These are the desired operation for the required parts on both machines.

b) CAD Model of parts

Two revolute parts and two prismatic parts will be processed on Concept turn 55 CNC and CNC concept mill respectively. Those parts are modeled using AutoCAD software. Here we show the required parts below in the figure. 3.

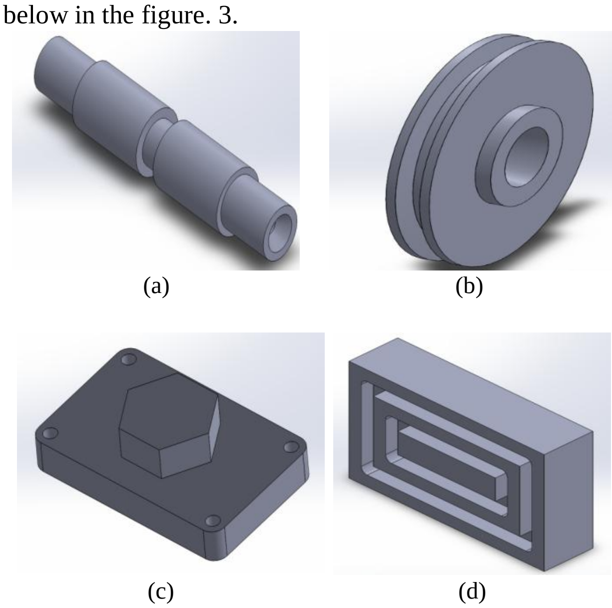


Fig. 3. Those parts will be machining on lathe and milling in FMC cell (a)first turning part (b)second turning part (c)first milling part (d)second milling part.

IV. Modeling of FMC System Using Colored Petri Nets

a) First FMC model with two different places for turning and milling machine.

In colored Petri net during modeling of the system color defined for the each parameter is necessary. Construction of flexible manufacturing model needs to define a color for each required machine, each processing parts and robots. In this case we consider CNC CONCEPT MILL 55 and CONCEPT TURN 55 CNC as a machine, processing two different parts for milling and two different parts for turning, and for loading & unloading of parts one robot (Mitsubishi RV-2AJ robot) we consider.

1) Colors define for each machine, piece and robots:

The color set for lathe CONCEPT TURN 55 CNC (colset lathe = with M1) and for milling CNC CONCEPT MILL 55 (colset Milling = with M2). So M1 and M2 is the value for machine, it defines:

Lathe = {M1} and Milling = {M2}

The color set for different parts are mentioned with the color. The milling parts are associated with color "pieceM" and the lathe parts are associated with color "pieceL". The value of the parts is: P1, P2, P3, and P4. The definitions of this value are: (colset pieceL = with P1 | P2) and (colset pieceM = with P3 | P4).

pieceL = {P1, P2} and pieceM = {P3, P4}

The robot is associated with color "robot". It has value R1. (colset robot=with R1) is the definition of robot in the model.

Robot = {R1}

The color set is defined for two different machine and different parts that cause the system is complex, for this reason color must define for each machine with the piece. For lathe the color is "colourL" and for milling "colourM".

(Colset colourL = product piece*lathe)

(Colset colourM = product piece*Milling)

While modeling the system, we define different machine and different parts. Each part is processed in the particular machine it defines in the system, the definition for the complex color for the lathe is "programL" and for milling is "programM".

(Colset programL = product piece*lathe)

(Colset programM = product piece*Milling)

The product and machine have this complex color pairs to run the system.it can be defined by:

{P1, M1}, {P2, M1} and {P3, M2}, {P4, M2}

2) Color defines for Variables:

In color Petri nets network connection between place and transition defined by arcs. In this model arc is assigned to the variables to create a connection between place and transition. The variable for turning part is defined by "pL" it has values (P1, P2) and for milling part "pM" its values are (P3, P4).

$$\mathbf{pL} \in \{\mathbf{P1}, \mathbf{P2}\} \quad (1)$$

$$\mathbf{pM} \in \{\mathbf{P3}, \mathbf{P4}\} \quad (2)$$

The variables for machine M1 and M2 are defined by respectively m2 and m1.

$$\mathbf{m1} \in \{\mathbf{M2}\} \quad (3)$$

$$\mathbf{m2} \in \{\mathbf{M1}\} \quad (4)$$

The variable for robot can be defined by "r" which has value:

$$\mathbf{r} \in \{\mathbf{R}\} \quad (5)$$

The model must be creating a connection between the parts and machine in colored Petri nets through the variables which mention in arcs to establish the system.

$$\mathbf{pL} \times \mathbf{m2} \in \{\mathbf{P1}, \mathbf{M1}\}\{\mathbf{P2}, \mathbf{M1}\} \quad (6)$$

$$\mathbf{pM} \times \mathbf{m1} \in \{\mathbf{P3}, \mathbf{M2}\}\{\mathbf{P4}, \mathbf{M2}\} \quad (7)$$

TABLE I
PLACE

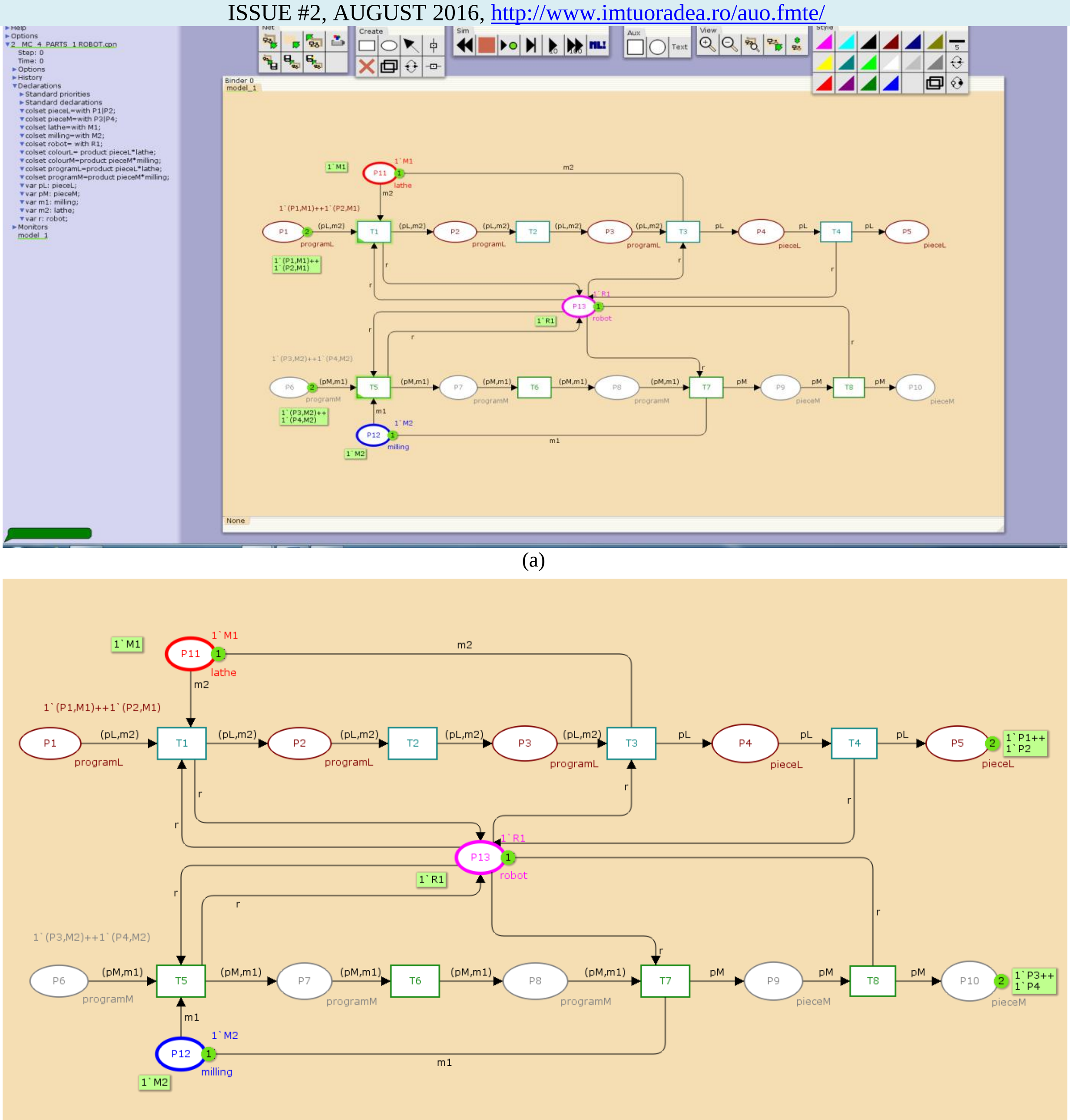
Places	*Complexity of color*	*Interpretation*
P1	complex color "programL"	Raw materials in stock for turning.
P2	complex color "programL"	Turning Parts in robot gripper (R1).
P3	complex color "programL"	Turning parts in the machine for processing (M1).
P4	complex color "pieceL"	Part is unloading from lathe by robots (R1).
P5	complex color "pieceL"	Finish turning part store in storage.
P6	complex color "programM"	Raw materials in stock for milling.
P7	complex color "programM"	Milling Parts in robot gripper (R1).
P8	complex color "programM"	Milling parts in the machine for processing (M2).
P9	complex color "pieceM"	Part is unloading from milling by robots (R1).
P10	complex color "pieceM"	Finish mill part store in storage.
P11	complex color "lathe"	Lathe (M1).
P12	complex color "milling"	Milling (M2).
P13	complex color "robot"	Robot (R1).

TABLE II
TOKEN POSITION

Initial Token position in system	*Final Token position in system*
(P1,M1);(P2,M1)	-
-	-
-	-
-	-
-	(P1;P2)
(P3,M2);(P4,M2)	-
-	-
-	-
-	-
-	(P3;P4)
M1	M1
M2	M2
R1	R2

TABLE III
TRANSITION

Transitions	*Interpretation*
T1	Turning part is load by robot (R1).
T2	Part is processing in lathe (M1).
T3	Part is unloaded by robot (R1).
T4	Part is ready to storage.
T5	Milling part is load by a robot (R1).
T6	Part is processing in milling (M2).
T7	Mill Part is unloaded by robot (R1).
T8	Mill Part is ready to storage.



(a)

(b)

Fig. 4. Flexible cell modeling with two different machine places based on Table I to III
(a) initial stage of the system (b) final stage of the system.

b) Second FMC model with compact machine place

1) Colors define for each machine, piece and robots:

The color set for lathe CONCEPT TURN 55 CNC and for milling CNC CONCEPT MILL 55. So the value for machine is (colset Milling = with M1|M2), it defines:

Machine = {M1, M2}

The color set for different parts are mentioned with the color. The value of the parts is: P1, P2, P3, and P4. The definitions of this value are: (colset piece = with P1 | P2| P3 | P4).

Piece = {P1, P2, P3, P4}

The robot is associated with color "robot". It has value R1. (colset robot=with R1) is the definition of robot in the model. Robot = {R1}.

2) Color defines for Variables:

In color Petri nets network connection between place and transition defined by arcs. In this model arc is assigned to the variables to create a connection between place and transition. The variable for parts "P" value is:

$$\mathbf{p \in \{P1, P2, P3, P4\}} \tag{8}$$

The variables for machine M1 and M2 are defined by respectively m2 and m1.

$$\mathbf{m \in \{M1, M2\}} \tag{9}$$

The variable for robot can be defined by "r" which has value**:**

$$\mathbf{r \in \{R\}} \tag{10}$$

The model must be creating a connection between the parts and machine in colored petri nets through the variables which mention in arcs to establish the system.

$$\mathbf{p\ x\ m} \in \{\mathbf{(P1,M1)\ (P2,M1)\ (P3,M2)\ (P4,M2)}\} \quad (11)$$

TABLE IV
PLACE

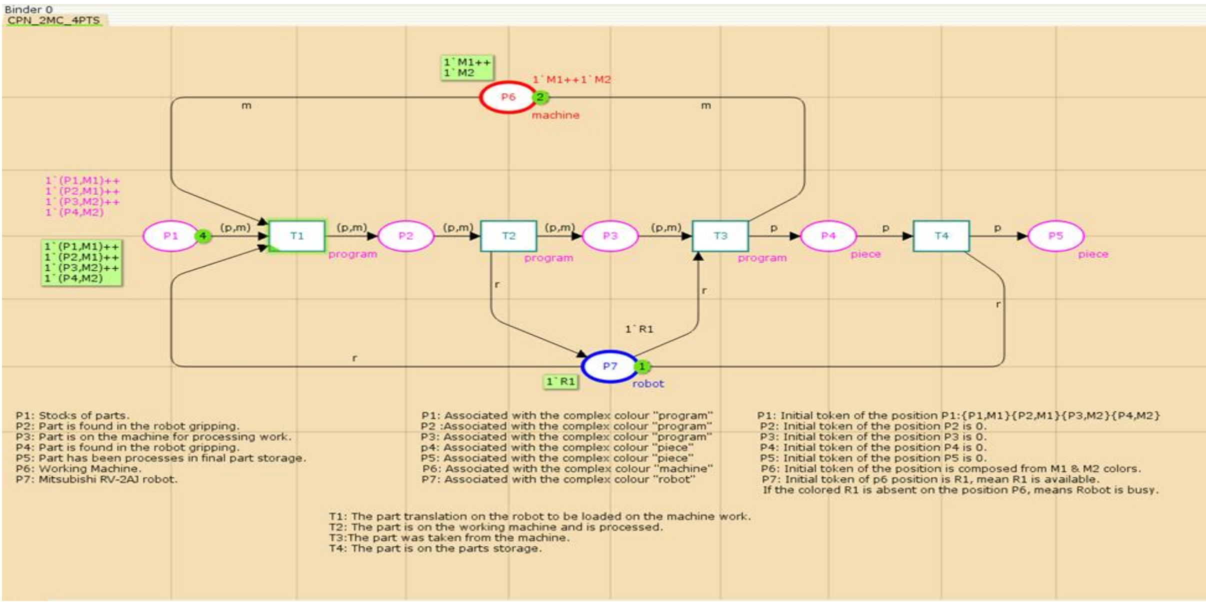
Places	Complexity of color	Interpretation
P1	complex color “program”	Raw materials in stock.
P2	complex color “program”	Parts in robot gripper (R1).
P3	complex color “program”	Part in machine for processing.(M1 & M2).
P4	complex color “piece”	Part is unloading by a robot (R1).
P5	complex color “piece”	Finish part store in storage.
P6	complex color “machine”	Working machine (M1 & M2).
P7	complex color “robot”	Robot (R1).

TABLE V
TOKEN POSITION

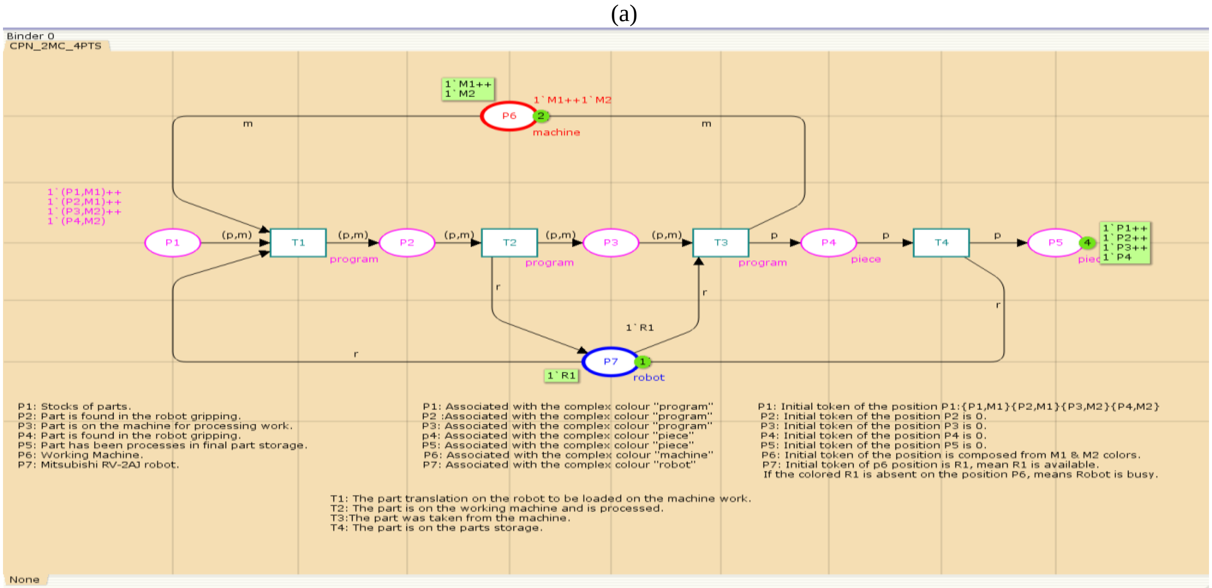
Initial Token position in system	Final Token position in system
(P1,M1);(P2,M1); (P3,M2);(P4,M2)	-
-	-
-	-
-	-
-	(P1,P2, P3, P4)
(M1,M2)	(M1,M2)
R1	R1

TABLE VI
TRANSITION

Transitions	Interpretation
T1	Part is loading by a robot (R1).
T2	Part is processing (M1 & M2).
T3	Part is unloading by a robot (R1).
T4	Part is ready to storage.



(a)



(b)

Fig. 5. Flexible cell modeling with compact machine place based on Table IV to VI
(a) Initial stage of the second system (b) final stage of the second system.

V. SIMULATION OF THE CELL

Simulation of the flexible manufacturing cell with colored Petri nets is observed without time with four different parts which are processed in milling and turning machine.

In the first model the system is simulated with two different places of machines with two different storage areas. In the model each place is connected to the transition through an arc to create a connection between the machine and robot. In the whole system the information is carrying through the arcs. If the information is in one place, then it must be firing in transition and then the information will reach in another place. For first flexible cell initial place in P1 have 2 tokens, when the information is passing through the arcs the transition will be firing and the required token will reach in next place P2, P3, P4 so on. It is found out that during simulation 2 token moves from P1 (storage 1) to P5 and 2 tokens move from the place P6 (storage) to P10 to complete the operation. Its mean the token was firing in each transition and token is moved in required place to complete the particular operation of the place. During simulation place P11 (M1) have 1 token and it moves when part is processing in the machine, after complete of the processing the token is moved to the place P11. The Same condition is applicable for the place P12 (M2). The robot R1 (P13) has 1 token, when the robot is performing some loading and unloading operation the token will move from the place, when the robot is idle it shows the token is 1. For this system the parts are selected for machining randomly by the robot.

For the second model the simulation is conducted through the compact place of the machines. In this system before simulation P1 place have 4 tokens, when the simulation is over all the 4 token moves to the place P5 (storage). Here place P6 (machines) it has 2 tokens. When M1 is performed operation 1 token moves from the position and M2 remaining in the same place it's mean 1 token remaining in the same place. When the operation is over the M1 is return back to its place then it shows the position of the token is 2 when M2 has performed the operation the token moved from the position and when the operation is over the token return back to its Place. The token position of robot R1 (P7) changes when the robot is busy. During the simulation it is found out token is changed during performing some operations. Here also part is selected by robot randomly for machining.

It observed that it would take 16 steps to complete the simulation for the both models. It has been seen that the place of the machines and robot position is different for both models but the system is same for the two models.

VI. CONCLUSION

The application area of colored Petri nets is vast. Here we discussed the application of color Petri nets to model the flexible manufacturing cell (FMC). The advantage of the colored Petri nets is the place, arcs; the transition is represented by color to construct the system. When a token is moved from place to the transition it shows replacement of token with the symbol of color in the model. As a parameters color token value changeable. Here the machine, robot and parts are defined by the different colors in the system. During simulation it is observed that movement of token represents each segment in the system. So the colored petri nets able to describe position and transitions of the system by different colors.

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