

AUTOMATED MANUFACTURING SYSTEMS, MODELLED BY MEANS OF COLOURED PETRI NETS WITH COMPLEX COLOURS AND FUNCTIONS

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Abstract: The automated manufacturing systems are frequent within the modern manufacturing systems. This paper shows how the coloured Petri nets are used to assess a robotic manufacturing system, considering several versions of it. The system is made of three machines, and the workpieces are moved through the system by means of a conveyor-type transferring device. Three typed of workpieces are manufactured in this system. the modelling and simulation are made by means of coloured Petri nets. Within the first version, each workpiece type is manufactured on one machine. The loading and evacuation of the workpieces is made by means of an industrial robot for each machine. Within another version, a gantry-type robot serves all the three machines. Also, this paper analyses the case when the manufacturing of one workpiece is made on two machines. These versions were modelled by means of complex coloured Petri nets. The simulations were meant to point out any bottlenecks that may occur within the operation of the system. Using the time factor allowed to assess the system versions also for efficiency. Finally, the paper confirms that modelling and simulation with coloured Petri nets are very useful to assess the performances of the robot manufacturing systems.

Key words: automated manufacturing systems, coloured Petri nets, complex colours, complex functions.

1. INTRODUCTION

The modelling and simulation of the engineering systems are more and more frequently used to design them and to assess their performance. The Petri nets in general and the coloured Petri nets in particular are effective tools for modelling and simulating flexible manufacturing systems.

Paper [1] compares the modelling with coloured and non-coloured Petri nets to assess the performances of the flexible manufacturing systems. From the structural point of view, the coloured Petri nets are simpler, with less positions, transitions and arcs. The

definition of colours and variables, however, might tend to be more difficult.

Paper [2] presents a synthesis of the research that has been carried out to study and develop the Petri nets. Two important fields are emphasized, where the modelling and simulation with Petri nets are frequently used: the performance assessment for flexible manufacturing systems and the design of automated systems.

Paper [3] underlines the fact that the development of Petri nets models allowed the incorporation of traditional techniques, such as linear programming, genetic algorithms, heuristic search, fuzzy logic.

Paper [4] proposes a Petri net model for the analysis of the required resources, and this model can be used for more general purposes. The concept of resource-oriented work networks is introduced and the rules for the transition executions are presented. An efficient resource allocation algorithm has been developed, so that the requirements should be met for a workflow in progress until completion.

The possibilities for modelling, simulation and validation with coloured Petri nets of concurrent engineering systems are described in paper [5].

Paper [6] shows the Petri net modelling of a flexible manufacturing system (FMS) from the perspective of setting the policy of avoiding the bottlenecks that may occur in the operation of the system. Finally, the policy of preventing bottlenecks for the analyzed system is based on the accessibility chart of the markings of the Petri nets model.

The modelling and simulation are methods used to increase the efficiency of the supply chains within the production systems. Paper [7] shows the timed hierarchical coloured Petri nets modelling and simulation as a method for stock management within a

series supply chain. The simulation is made for both normal operating conditions and disturbances, such as canceled orders and canceled deliveries.

There is a concern to develop models with Petri nets in which to find the techniques specific to fuzzy sets [8]. Also, hierarchical coloured Petri nets models are developed to assess the performance of flexible manufacturing systems [9, 10]. Paper [11] analyzes how the state space can be used.

The present paper describes how the coloured Petri nets models were developed for two flexible manufacturing system configurations. For the first configuration there is one version of the manufacturing process, and there are two versions of the manufacturing process for the second one.

2. COLOURED PETRI NETS MODELLING OF THE ROBOTIC MANUFACTURING SYSTEM – VERSION 1

2.1 Presentation of the Structure and of the Operation

The The first version of the fabrication system is shown in Figure 1. Three types of workpieces are manufactured, and each type is manufactured on a single machine within the system. Thus, the type 1 workpieces are manufactured on machine M2, the type 2 workpieces are manufactured on machine M2 and the type 3 workpieces are manufactured on machine M3. All three machines are in the category of CNC machining centers. The workpieces are transported throughout the system by means of a conveyor, which is divided into 12 emplacements. The workpieces input is made on emplacement 1, and their transfer inside the system is done step-by-step, from one location to another. No matter of their type, all workpieces are discharged from the system by emplacement 12.

The type 1 parts are loaded by robot R1 on machine M1 from emplacement 3 and, after manufacturing, they are unloaded on emplacement 4. The type 2 parts are loaded by robot R2 on machine M2 from emplacement 7 and, after manufacturing, they are unloaded on emplacement 8. The type 3 parts are loaded by robot R3 on machine M3 from emplacement 10 and, after manufacturing, they are unloaded on emplacement 11.

2.2 Building the Coloured Petri Nets Model – version 1

The first phase of the coloured Petri nets model building consists of defining the colour sets. A colour is assigned to each type of workpieces: *o1* for type 1, *o2* for type 2 and *o3* for type 3 (*colset object=with o1|o2|o3*)

$$object = \{o1, o2, o3\} \quad (1)$$

A simple colour set of 12 elements is assigned to the 12 emplacements (*colset settlements=with r1|r2|r3|r4|r5|r6|r7|r8|r9|r10|r11|r12*):

$$settlements = \{ri | i = \overline{1,12}\} \quad (2)$$

In order to assign a workpiece to the emplacement where it is placed, the complex colour *program* (*colset program=product object*settlements*) was defined as the Cartesian product of the sets *operation* and *settlements*:

$$program = object * settlements = \{(oj, ri) | j = \overline{1,12}; i = \overline{1,3}\} \quad (3)$$

The coloured Petri nets models built in CPN Tools are characterized by the fact that arcs are associated with variables. Two simple variables were defined for version 1. Variable *r* is defined by relation:

$$r \in \{ri | i = \overline{1,12}\} \quad (4)$$

Variable *o* is defined by relation:

$$o \in \{o1, o2, o3\} \quad (5)$$

Complex variables can be defined by means of these simple variables, such as:

$$o * r \in \{(oj, ri) | j = \overline{1,12}; i = \overline{1,3}\} \quad (6)$$

There are situations in which loads such as decision-making functions are assigned to arcs. For example, relation:

$$if\ oj=o1\ then\ 1\`o1\ else\ empty \quad (7)$$

describes the condition that on position P5 (counter for type 1 workpiece evidence) only type *o1* colours will be transferred.

The coloured Petri nets model has two types of nodes: positions and transitions. These nodes are connected by oriented arcs. The sequences that the system components are modelled by transitions: input / output of a workpiece into / out of the system, the transfer from one emplacement to another, the loading / unloading of a workpiece onto / from the machine. The execution of a transition (making of a real sequence) is possible when certain conditions are met, which are modelled by means of positions. The transitions and the positions of the model are shown in Table 1.

The coloured Petri nets model of the manufacturing system, version 1, is shown in Figure 2.

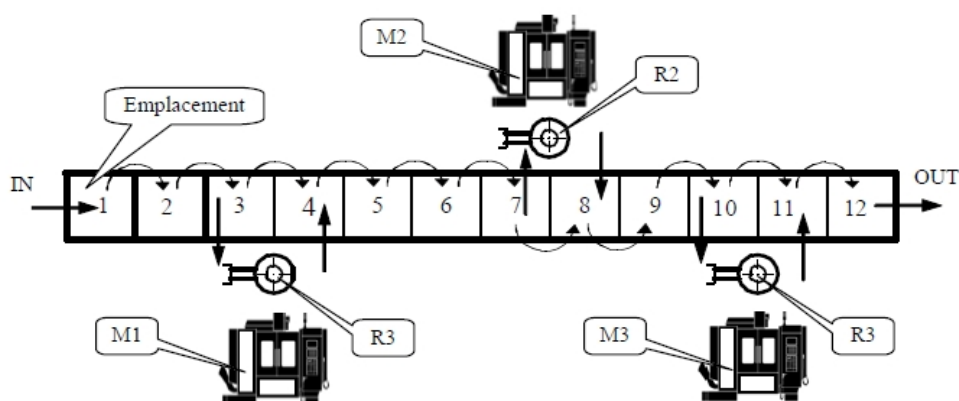


Fig. 1. Structure of the manufacturing system – version 1

Table 1. Positions and transitions of the simple coloured Petri net model – version 1

Nr. crt.	Symbol	Type	Meaning
1.	P1	Pos.	Models the free emplacements
2.	P2	Pos.	Models the occupied emplacements
3.	P3	Pos.	Models the fact that one machine is busy
4.	P4	Pos.	Models the fact that one machine is free
5.	P5	Pos.	Counter for the type 1 workpieces recording
6.	P6	Pos.	Counter for the type 2 workpieces recording
7.	P7	Pos.	Counter for the type 3 workpieces recording
8.	T1	Tr.	Models the input of a workpiece into the system
9.	T2	Tr.	Models the output of a workpiece from the system
10.	T3	Tr.	Models the transfer of a workpiece from one emplacement to another
11.	T4	Tr.	Models the loading of a machine
12.	T5	Tr.	Models the unloading of a machine

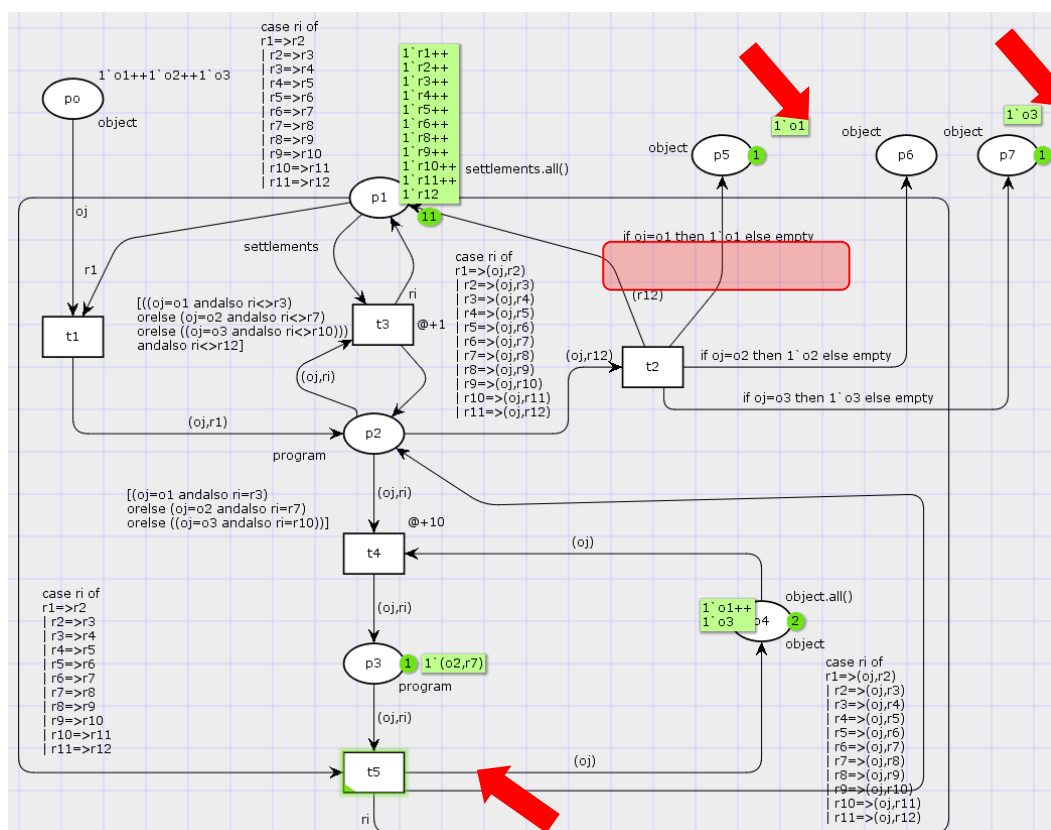


Fig. 2. The coloured Petri nets model of the manufacturing system – version 1

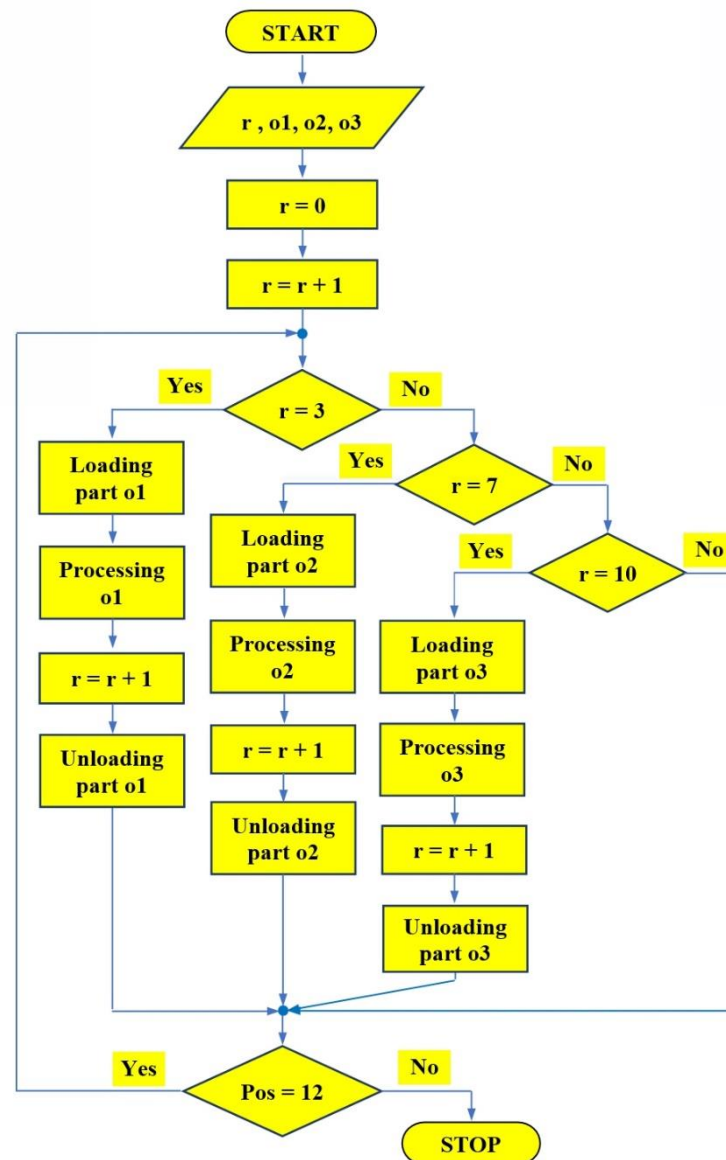


Fig. 3. The flowchart of the coloured Petri nets model, version 1

The moment of the system simulation shown in Figure 2 corresponds to one of its states within which type 1 and 2 workpieces were manufactured and discharged from the system, and the type 3 workpieces are being manufactured.

Figure 3 shows the flowchart of the coloured Petri nets model, version 1.

3. COLOURED PETRI NETS MODELLING OF THE ROBOTIC MANUFACTURING SYSTEM – VERSION 2

3.1 Structure and operation

The second version the manufacturing system is shown in Figure 4. Like the first version, the system manufactures three types of workpieces. Each type of

workpiece is manufactured on its corresponding machine within the system: type 1 workpieces are manufactured on machine M1, type 2 workpieces are manufactured on machine M2 and type 3 workpieces are manufactured on machine M3.

Also, the workpieces are moved along the system by means of a conveyer, which is divided into 12 emplacements. The workpieces are introduced into the system on emplacement 1 and are discharged from the system on emplacement 12. The transfer of the workpieces inside the system is done step-by-step, from one emplacement to another.

The loading and unloading of the workpieces onto / from the machines are carried out by a gantry-type robot (R), which is now a shared resource.

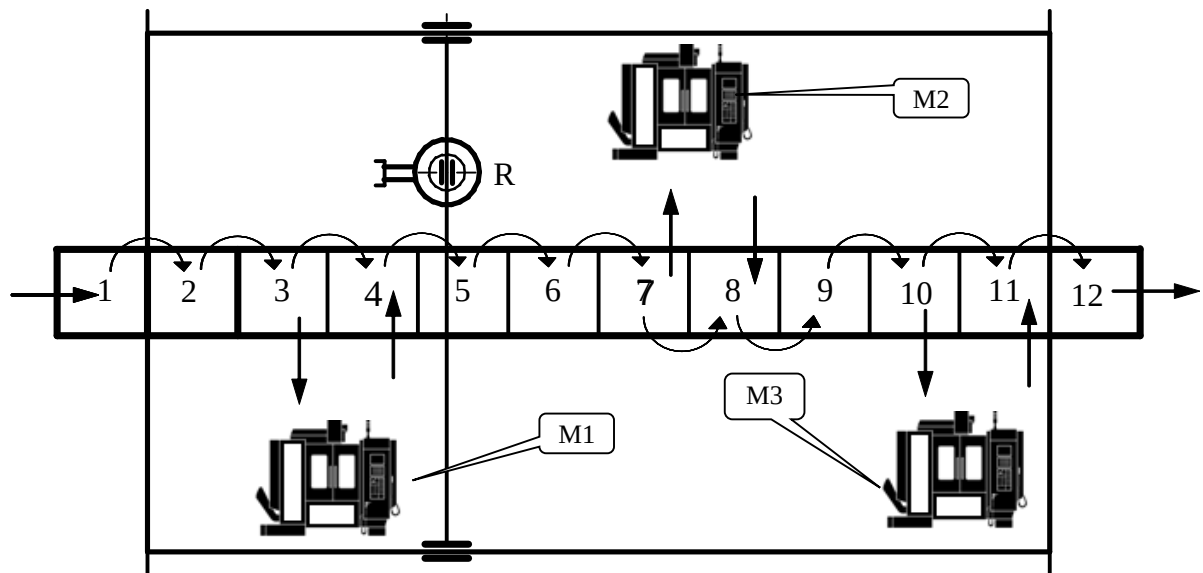


Fig. 4. Structure of the manufacturing system – version 2

Table 2. Positions and transitions of the simple coloured Petri net model – version 2

Nr. crt.	Symbol	Type	Meaning
1.	P1	Pos.	Models the free emplacements
2.	P2	Pos.	Models the occupied emplacements
3.	P3	Pos.	The workpiece has been taken by the robot
4.	P4	Pos.	Models the fact that a machine is free
5.	P5	Pos.	Machine is busy, the workpiece is not manufactured
6.	P6	Pos.	Machine is busy, the workpiece is manufactured
7.	P7	Pos.	The workpiece has been taken by the robot
8.	P8	Pos.	The robot is free
9.	P9	Pos.	Workpieces counter
10.	P10	Pos.	Counter for the type 1 workpieces recording
11.	P11	Pos.	Counter for the type 2 workpieces recording
12.	P12	Pos.	Counter for the type 3 workpieces recording
13.	T1	Tr.	Models the input of a workpiece into the system
14.	T2	Tr.	Models the output of a workpiece from the system
15.	T3	Tr.	Models the transfer of a workpiece from one emplacement to another
16.	T4	Tr.	Models the loading of the robot
17.	T5	Tr.	Models the robot unloading and machine loading
18.	T6	Tr.	Models the manufacturing of the workpiece on the machine
19.	T7	Tr.	Models the loading of the robot
20.	T8	Tr.	Models the unloading of the robot

3.2 Building the Coloured Petri Nets Model – version 2

For the second version, like the first one, the colours sets will be created: the simple colours set assigned to the parts *object* (1), the simple colours set assigned to the emplacements *settlements* (2), and the complex colours set *program* (3). Considering that robot R is a shared resource, a colour will be assigned to it *rob* (*colset robot=with rob*)

$$robot=\{rob\} \quad (8)$$

For version 2, the variable t is defined along the variables defined by relations (4), (5) and (6):

$$t \in \{rob\} \quad (9)$$

The coloured Petri nets model of the manufacturing system, version 2, is shown in Figure 5, and the transitions and positions of this model are shown in Table 2.

The moment of the system simulation shown in Figure 5 corresponds to one of its states within which all workpieces have been manufactured.

Figure 6 shows the flowchart of the coloured Petri nets model, version 2.

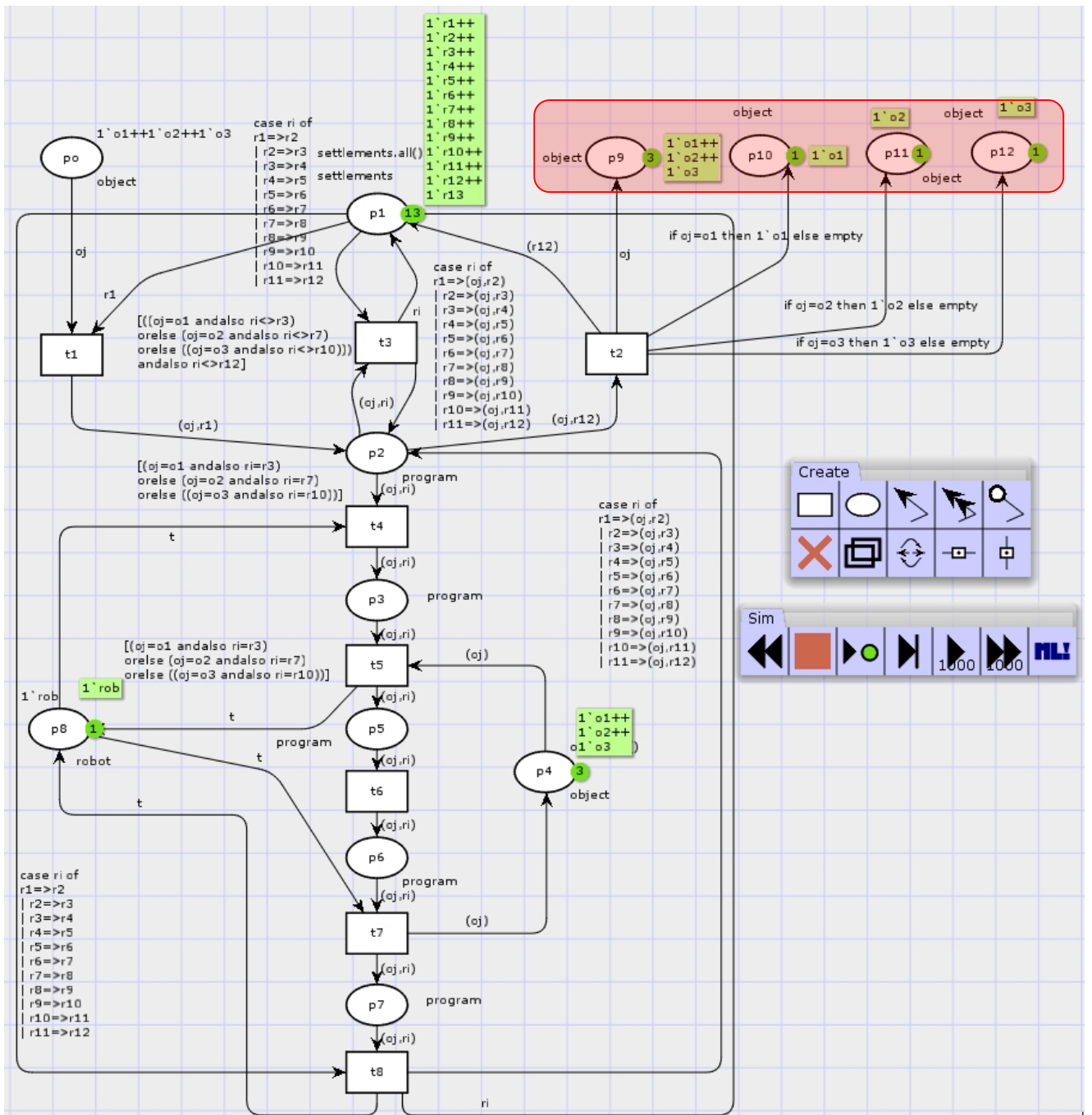


Fig. 5. The coloured Petri nets model of the manufacturing system – version 2

4. COLOURED PETRI NETS MODELLING OF THE ROBOTIC MANUFACTURING SYSTEM – VERSION 3

4.1 Structure and operation

The third version of the manufacturing system is the same as version 2 (Figure 4). Now each type of workpieces is manufactured on two machines of the system, as following:

- type 1 workpieces are manufactured on machines M1 and M2;
- type 2 workpieces are manufactured on machines M2 and M3;
- type 3 workpieces are manufactured on machines M1 and M3.

4.2. Building the Coloured Petri Nets Model – version 3

For version 3, the colours and variables sets are the same as version 2. For the modelling of the system operation – each type of workpieces being manufactured on two machines – three transitions are included in the model:

- T6-1: models the manufacturing of a workpiece (type 1 or type 2) on machine 1;
- T6-2: models the manufacturing of a workpiece (type 2 or type 3) on machine 2;
- T6-1: models the manufacturing of a workpiece (type 1 or type 3) on machine 3.

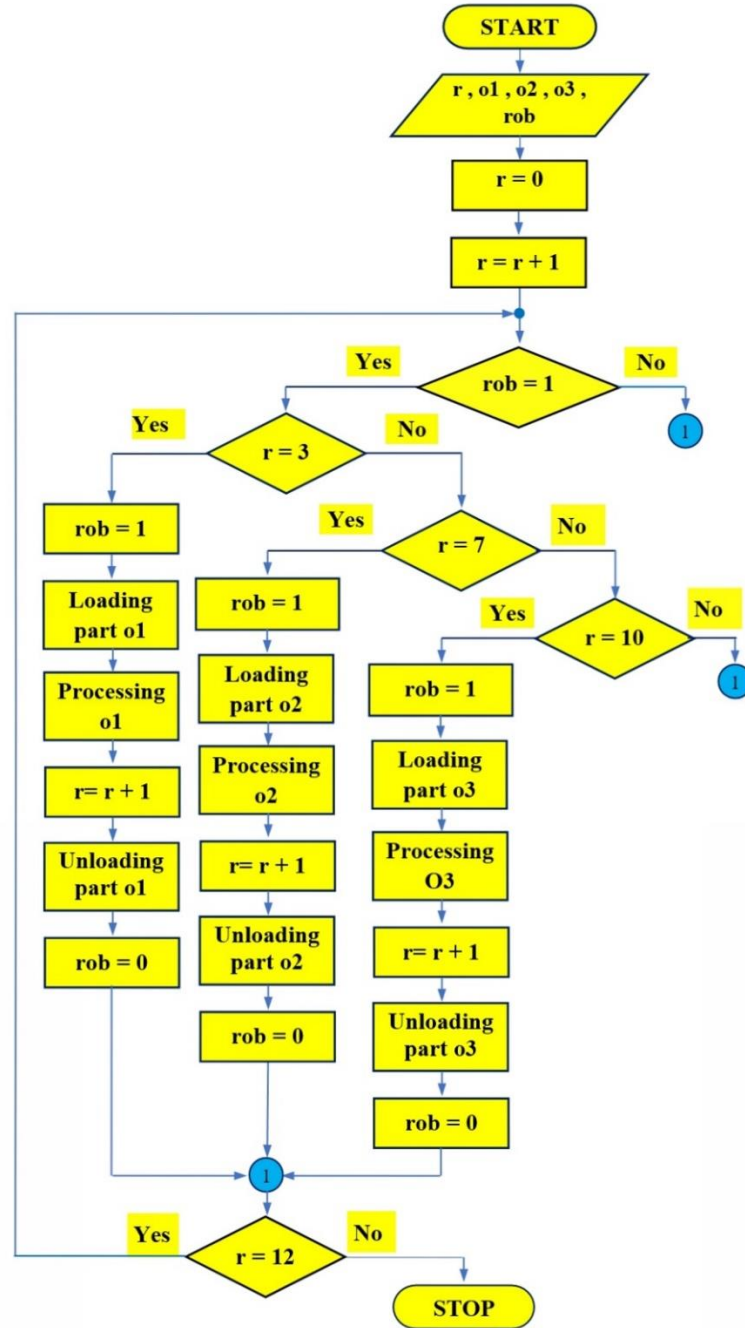


Fig. 6. The flowchart of the coloured Petri nets model, version 2

The time factor has been introduced to assess the performance of the manufacturing system. A delay that is equal to the manufacturing time of the modelled machine is assigned for each of these three transitions:

- transition T6-1 has 20 seconds delay;
- transition T6-2 has 30 seconds delay;
- transition T6-3 has 40 seconds delay.

The conditions that describe the constraints imposed by the processing of different parts on the different machines in the system are written by CPN Tools specific relations, “if”-type, which are assigned to the transitions.

The following relation is assigned to transition T6-1:

$$[(oj=o1 \text{ andalso } ri=r3) \text{ or else } (oj=o3 \text{ andalso } ri=r3)](10)$$

The following relation is assigned to transition T6-2:

$$[(oj=o1 \text{ andalso } ri=r7) \text{ or else } (oj=o2 \text{ andalso } ri=r7)](11)$$

The following relation is assigned to transition T6-3:

$$[(oj=o2 \text{ andalso } ri=r10) \text{ or else } (oj=o3 \text{ andalso } ri=r10)] \quad (12)$$

The coloured Petri nets model of the manufacturing system, version 3, is shown in Figure 7.

The state of the system shown in Figure 7 corresponds to the finalization of all three workpieces. To be specific, workpiece 1 was manufactured in 59 seconds,

workpiece 2 was manufactured in 100 seconds and workpiece 3 was manufactured in 141 seconds.

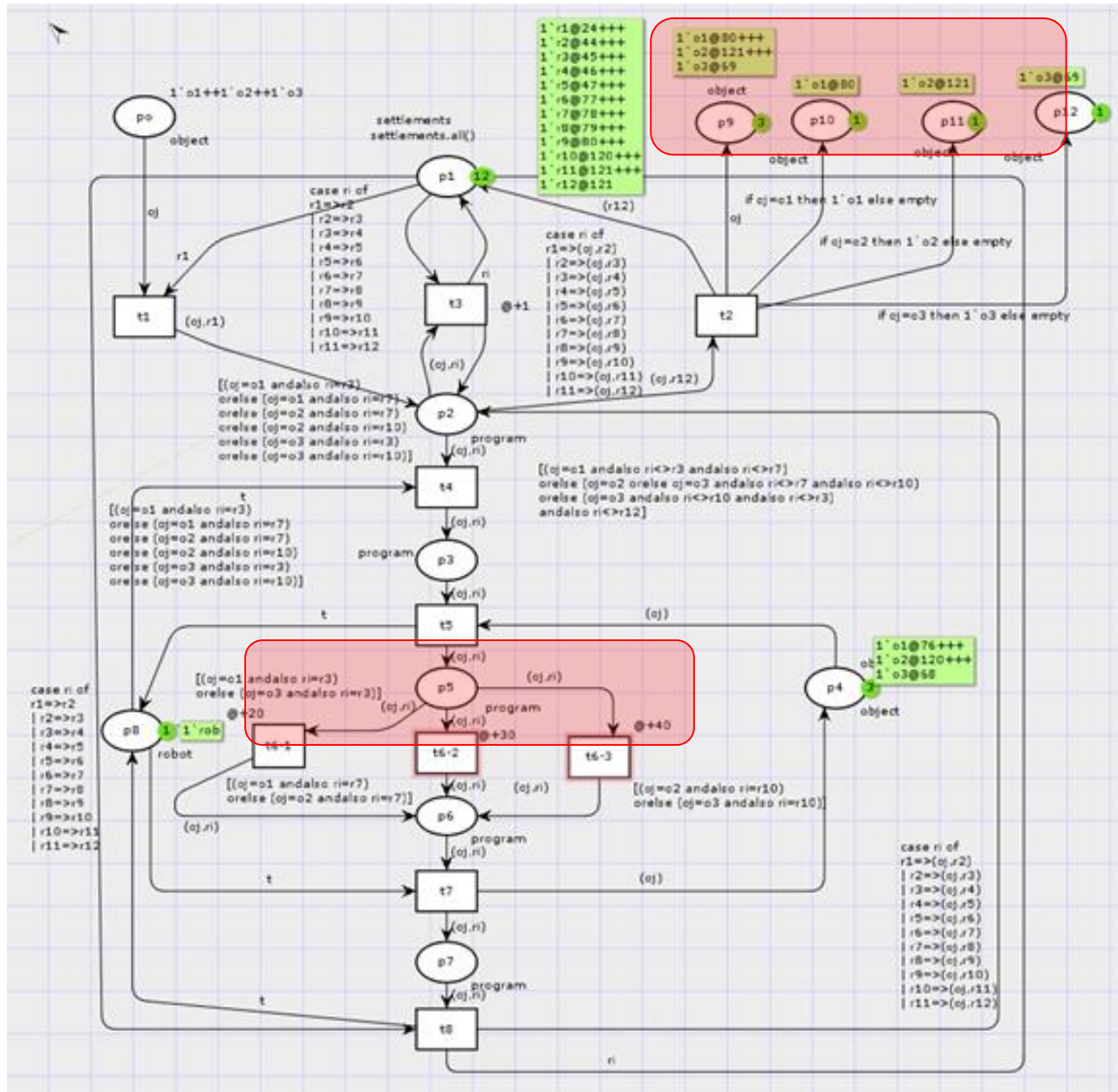


Fig. 7. The coloured Petri nets model of the manufacturing system – version 3

5. CONCLUSIONS

The modelling and simulation with coloured Petri nets are very efficient instruments to assess the performances of the technical systems in general and of robotic manufacturing systems in particular. This paper developed three coloured Petri nets models in order to assess three versions of robotic manufacturing systems.

The first version, dedicated to a manufacturing system with three machines, each of them being served by a robot, implied the use of simple colours and complex colours as well. Loads of the arcs, such as decisional

functions, were used to count one certain type of workpieces.

The specific feature of the second version consists of using a gantry-type robot to load and unload the workpieces to / from the machines, which is a shared resource. In this case, the coloured Petri nets model highlights the fact that the robot can execute only one loading / unloading sequence at a time, with a single workpiece.

Within the third version, a workpiece is manufactured on two machines. Using the coloured Petri nets model, this situation was described by assigning a timed transition for each machine and by using decisional-type relations assigned to transitions. The simulation

of this model also yields information about the manufacturing cycle of each workpiece.

The future research will concern the way that fuzzy set specific elements can be associated to coloured Petri nets models. This will be used to develop multicriterial decisional systems within the coloured Petri nets models.

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