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Simulating with Arena® a Control Structure for Manufacturing Systems using Petri Nets

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Abstract

Designing a control structure for discrete event systems described by Petri nets is imposed by the exigency of dealing with specific problems that impose a different approach of the control methods used for time conducted dynamic systems. Considering the discrete event system for the design of the control structure and applying the stages of the hybrid synthesis method, one has obtained the Petri network that models the control structure. The paper presents the simulation in Arena® of the respective model, emphasizing performance characteristics of the system, such as the number of processed pieces, waiting and processing times, usage degree of the resources.

Key words: *discrete event system, manufacturing systems, Petri nets, Arena® simulator.*

Introduction

Designing a control structure for discrete event systems described by Petri nets is imposed [1], [3], [5] by the exigency of dealing with problems specific to discrete event systems that require a different approach in comparison with the control methods applicable to dynamic systems time directed.

The considered discrete event system is a manufacturing system with two types of pieces. Successively applying the methods of the hybrid synthesis, one obtained the Petri net that models the control structure.

In order to perform the simulation and the study of the obtained structure, the paper developed the corresponding Arena® model. Performing the simulation, one emphasized the characteristics of the system, such as the number of performed pieces, the performed times and the degree of resources usage.

Using the *Process Analyzer* option one created operational scenarios for the system, considering as control parameters the number of paddles on each operational flow and as performance criterion the number of pieces manufactured in a fixed time interval, in order to determine the optimum number of paddles on the flow. In the same time, one determined the maximum number of pieces that may be stored in each of the two deposits, in order to perform an optimum calibration for avoiding pitching.

Manufacturing System Structure

The considered manufacturing system is presented in figure 1, having the following resources [4].

- three digital command machines M1, M2, M3
- two robots R1, R2
- two inter operational deposits D1, D2, having capacities of 2 pieces, respectively 4 pieces.

The inputs contain two types of raw pieces, **PB1** and **PB2**, and the technological operational flow for **PB1 (PB2)** pieces consists in the following consecution of operations that produces **PF1 (PF2)** finite pieces, delivered at output 1 (2):

1. The piece fitted on a paddle is automatically loaded in M1;
2. The piece is manufactured on M1;
3. The piece is unloaded from M1, by R1, in the D1 (D2) deposit;
4. The piece waits in D1 (D2);
5. The piece is taken from D1 (D2) and automatically loaded in M2 (M3);
6. The piece is manufactured on M2 (M3);
7. The piece is unloaded from M2 (M3), by R2 and taken to the output

At output 1 (2), PF1 (PF2) is taken out of the paddle, the empty paddle being sent to output 1 (2).

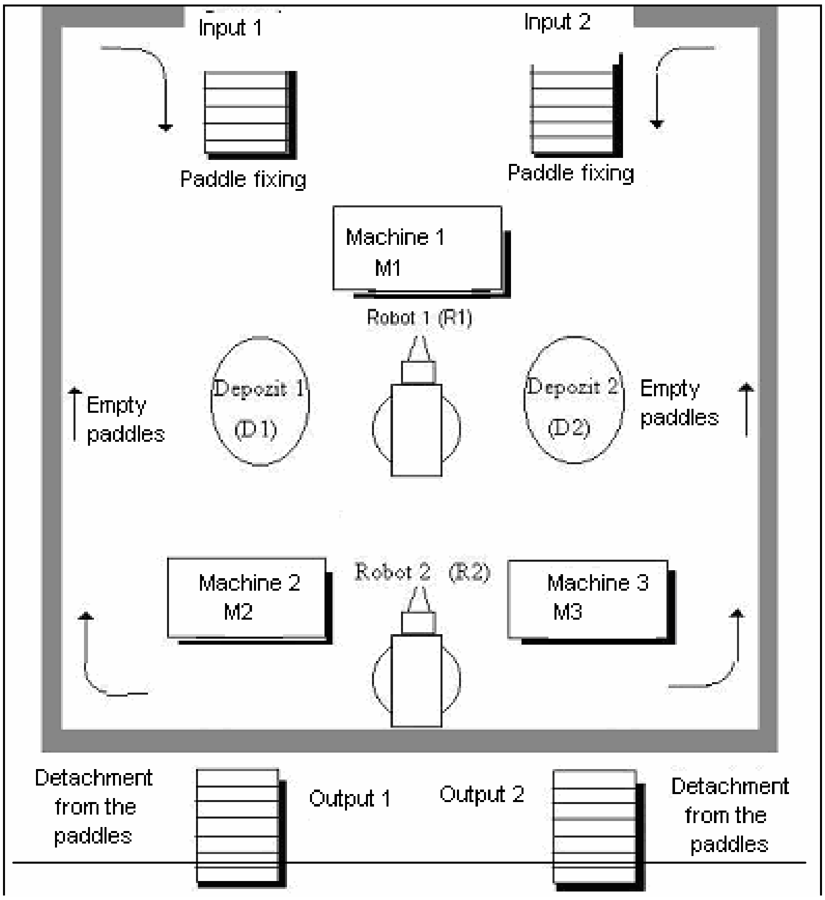

Fig.1. Manufacturing system structure

Control Structure for Discrete Event System

A technical process with event directed operation consists of a multitude of resources used for performing a sequence of operations. The accomplishment of each operation requires the assignment of one or more resources that are dismissed when the operation is finished.

The process has as input a number of *clients* (entities whose physical nature depends on the specificity of the process). Each operation performed by the process represents a certain type of *service* for a client. After performing a complete operation, *a client is fully served and may leave the process*. Thus, the output of the process consists of the number of clients completely served.

Controlling this kind of process consists in achieving the following operating conditions:
(C1) the correctness of the sequence of operations for all clients;
(C2) the correctness of allocation and dismissal of resources for each operation;
(C3) performing a certain type of service as soon as the required resources for the respective operation are available (that is, maximizing the number of clients ready to be served, in different stages).
(C4) the repeatability of performing services, without circular pitching due to shared usage of some of the resources.

A control structure (process + controller), represented in figure 2, that ensures the achievement of the operating conditions (C1)-(C4), takes into account the *logical properties* (independent of the operation duration) and, consequently, the description of this structure may be done by means of untimed Petri nets.

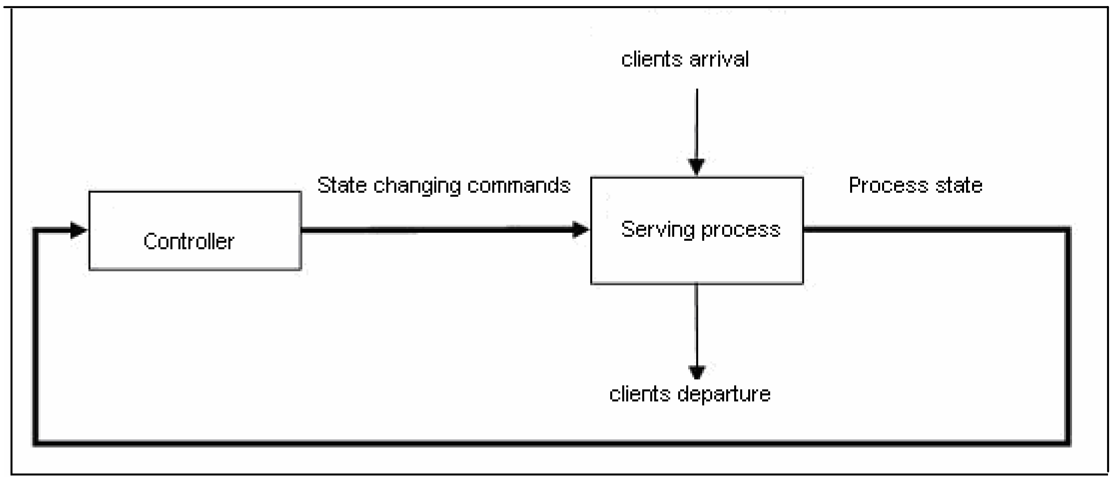

Fig. 2. Control structure for discrete event system

Hybrid Synthesis of the Control Structure

According to the above presented operational flow, in the first stage, that of the *descendent synthesis*, in order to refine the operations, one has to elaborate the *global model of the operations*, presented in figure 3. The positions p_1 and p_2, that model the availability of the paddles, represent the general resources. For an initial marking of these positions, the Petri net in figure 3 is viable, finite and reversible.

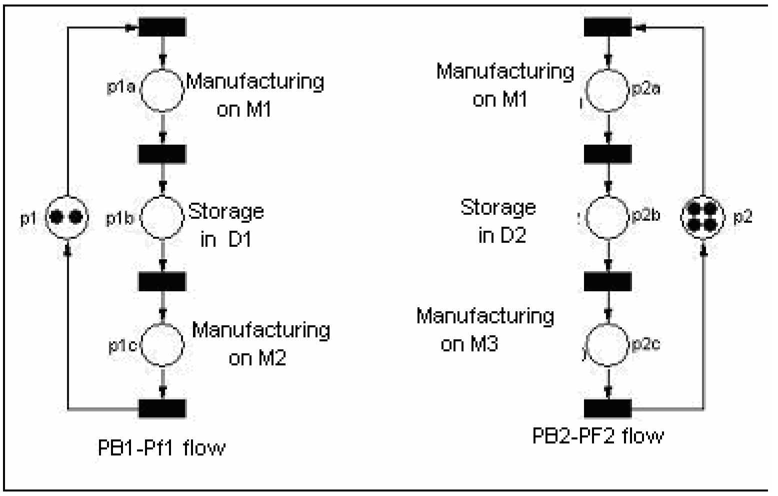

Fig.3. Global model of the sequence of operations

As a result of refining the p_{1a}, p_{1c}, p_{2a}, p_{2c} positions by replacing them by sequential and parallel operations blocks, one obtains the complete model of the sequence of operations represented by the Petri net in figure 4.

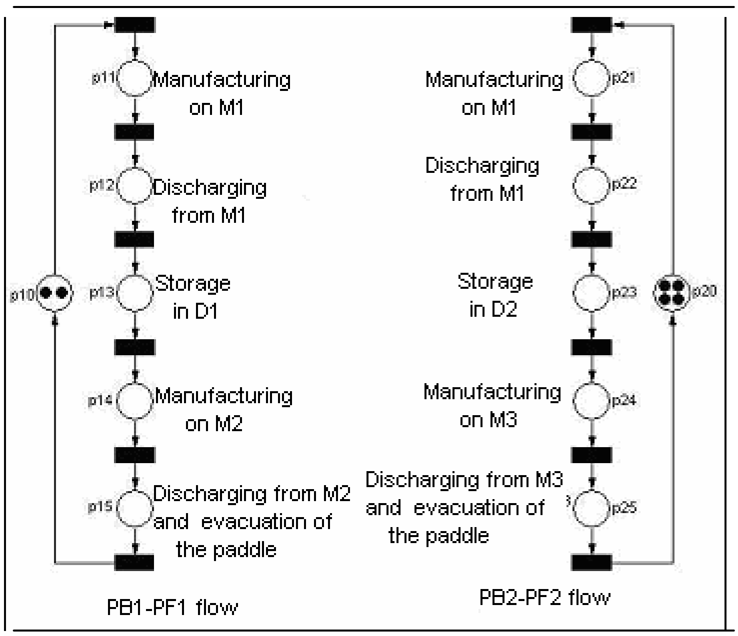

Fig.4. The complete model of the sequence of operations obtained by descendent synthesis

The second stage, of the *ascendant synthesis*, allows the attachment of the positions that model the resources, that is the specific non shared resources (PB1 → PF1: M2, modeled by p_{14r}, and PB2 → PF2: M3, modeled by p_{24r}), the non shared storage resources (D1, modeled by p_{13r} and D2, modeled byp_{23r}) and, finally, the shared resources. Thus, one obtains the Petri net represented in figure 5.

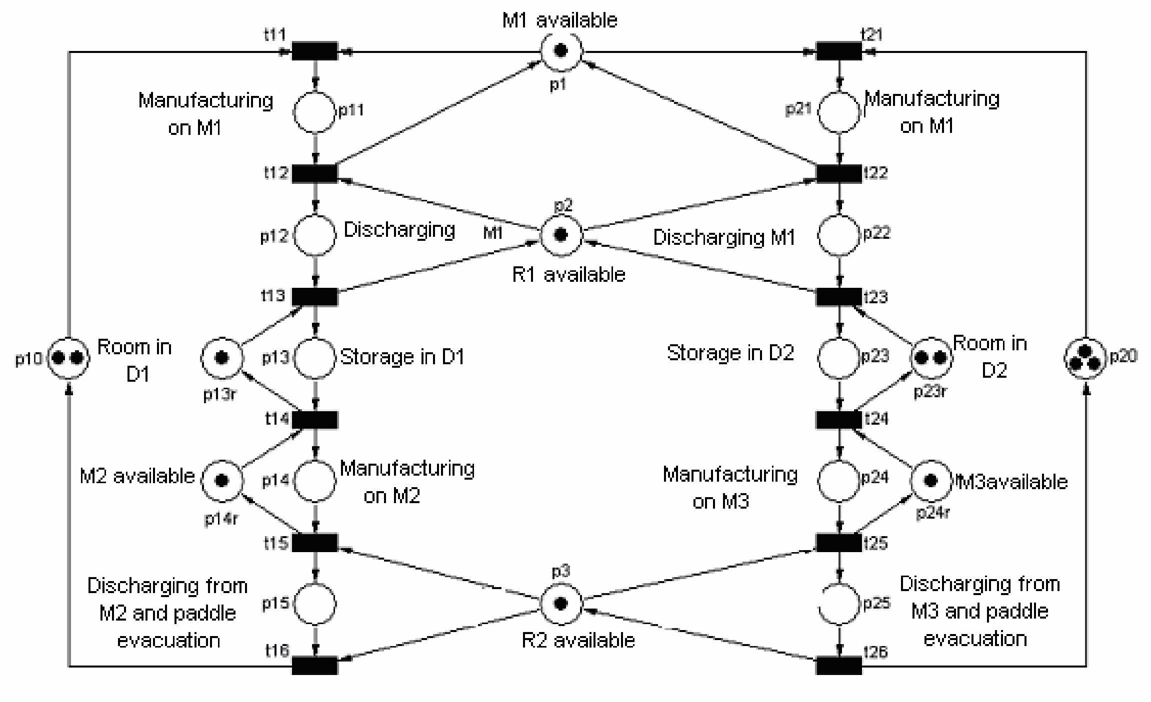

Fig.5. The complete model of the sequence of operations obtained by ascendant synthesis

Arena® Simulation of the Control Structure

In order to simulate, elaborate performance studies and optimization of the obtained control structure, one has built the Petri net based Arena® model. Arena® [2] is a powerful easy-to-use tool that allows creation and simulation of system models.

The essential steps in simulating with Arena® are:

1. **Creating a basic model –** Arena® provides an intuitive environment for building models.
2. **Model refining –** adding real data: processing times, required resources.
3. **Model simulation –**verifying if the model correspondingly reflects the system and finding out the eventual pitching.
4. **Simulation results analysis –** Arena® automatically provides reports regarding general decision criteria, such as resource usage.
5. **Selecting the optimum alternative –** one may change the model in order to emphasize the possible scenarios and to compare the results for an optimum solution identification.

Model elaboration starts with a sub-models based structure corresponding to the main operations from the global model (figure 4), presented in figure 6. *Input storage 1* and *Input storage 2* are **Create** type modules (representing the start point for the entities from the simulation model), *Paddle 1 empty* and *Paddle 2 empty* are **Release** type models (dismissing a unit from the fixed capacity resources *Paddle 1*, respectively *Paddle 2*).
The development of the *Operating p1 on M1, Operating p2 on M1, Operating on M2* and *Operating on M3* sub-models reflects the refining of the p_{1a}, p_{2a}, p_{1c}, respectively p_{2c} positions from the descendent synthesis stage.

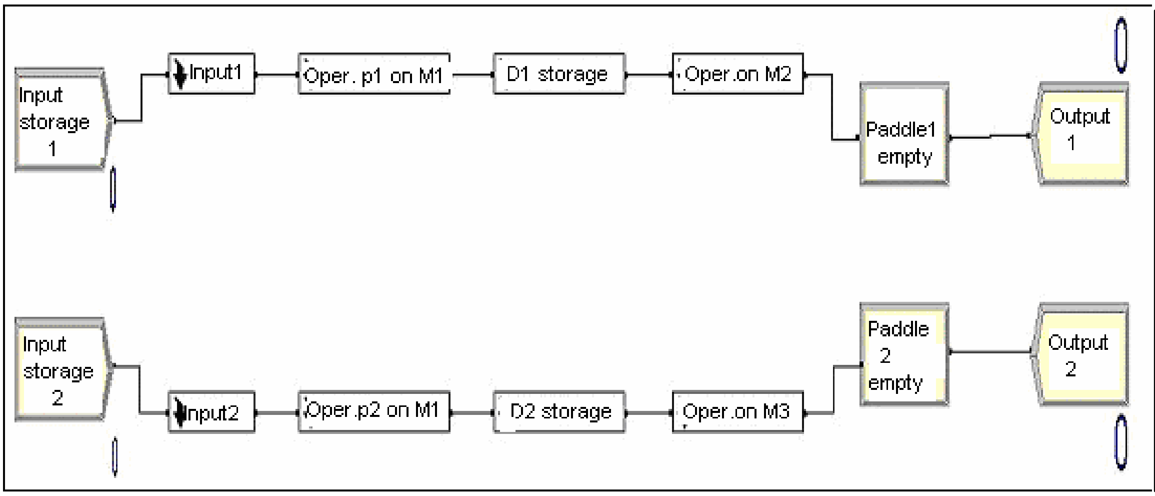

Fig.6. Sub-models built Arena® model

Figure 7 presents the state of the system in the 58th minute of operation, simulated with Arena®.

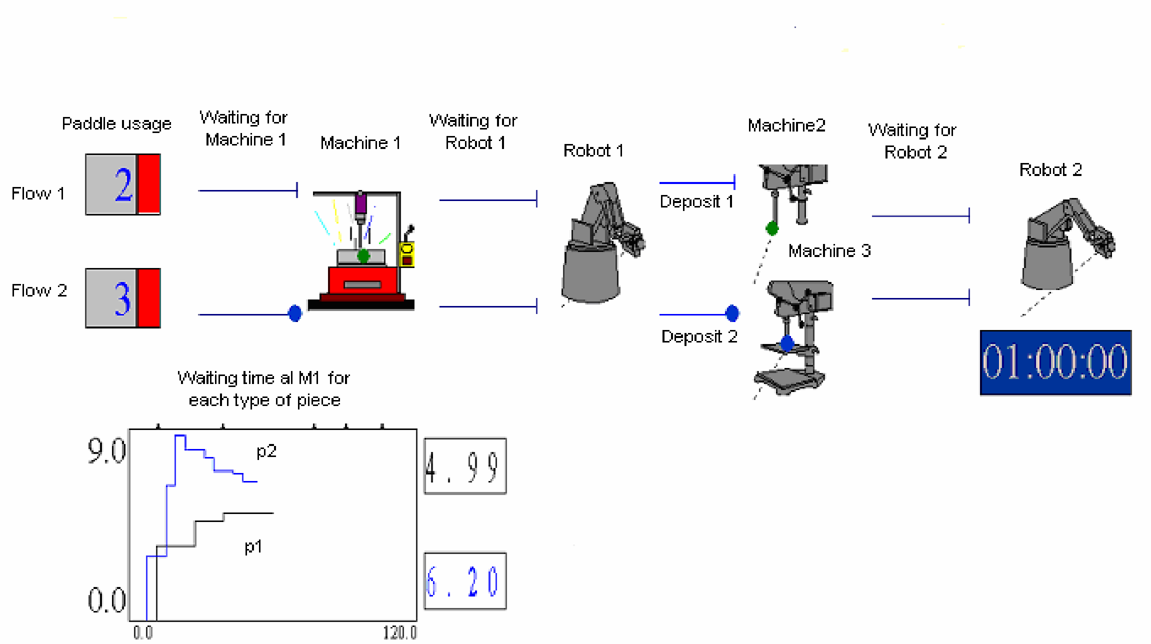

Fig.7. System operating simulation with Arena®

In order to emphasize certain specific aspects during model simulation, one added animation elements available in Arena®, so that, for example, one may observe, as presented in figure 7:

- The number of used paddles and the usage degree, corresponding to each flow;
- The number of pieces waiting to be processed on M1;
- The R1 and R2 robots state, as well as the type of handled piece;
- The number of stored pieces in each of the two deposits.

The results of the simulation are presented in reports that contain information related to time moments associated to the entities, number of processed entities, the degree of usage resources (figure 8) and time moments associated to processes.

Resource Detail Summary

Usage

	Inst Util	Num Busy	Num Sched	Num Seized	Sched Util
Masina 1	0,97	0,97	1,00	59,00	0,97
Masina 2	0,98	0,98	1,00	19,00	0,98
Masina 3	0,96	0,96	1,00	37,00	0,96
Paleta 1	1,00	2,00	2,00	20,00	1,00
Paleta 2	0,99	2,97	3,00	39,00	0,99
Robot 1	0,24	0,24	1,00	58,00	0,24
Robot 2	0,23	0,23	1,00	55,00	0,23

Fig.8. Reports available at the end of the simulation

	Scenario Properties		Controls		Responses			
	S	Name	Paleta 1	Paleta 2	Nr piese 1	Nr piese 2	Nr max in D1	Nr max in D2
1		Scenario 5	2	6	16	38	1	4
2		Scenario 3	2	4	17	37	1	3
3		Scenario 4	2	5	17	37	1	4
4		Scenario 1	2	2	18	36	1	1
5		Scenario 2	2	3	18	37	1	2
6		Scenario 6	3	2	18	35	2	1
7		Scenario 7	3	3	18	36	2	2
8		Scenario 8	3	4	18	36	2	3
9		Scenario 9	3	5	18	36	2	4
10		Scenario 10	3	6	18	36	2	4

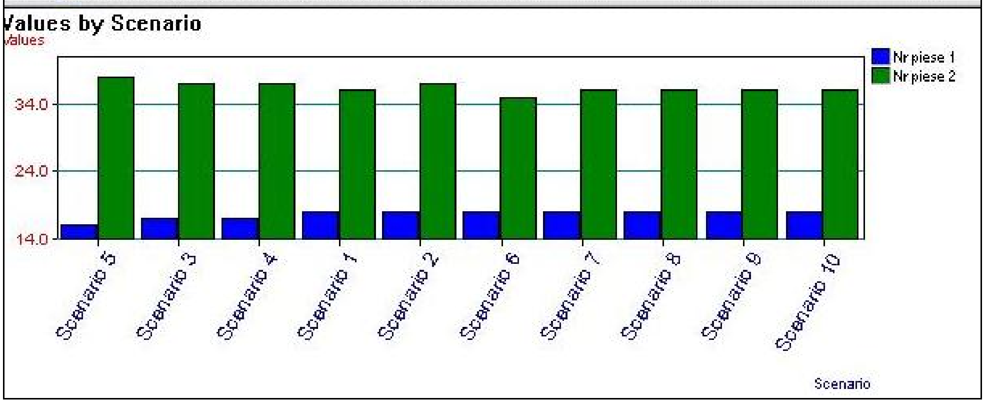

Fig.9. Scenarios run for the simulated system

In order to determine the optimum number of paddles one used the Arena® *Process Analyzer* that allows the configuration and possible scenarios creation for the considered system. For the analyzed system, one considered:

- The control variables : the capacity of *Paddle 1* and *Paddle 2* resources;
- Answers: the number of finite type1, respectively type2 pieces, obtained in a *4 hours operating time interval*.

The results obtained are presented in figure 9 that indicates an optimum number of 2 paddles on flow 1 and 3 paddles on flow 2. In the same time, the capacity of the deposits D1 and D2 has to be of minimum 1, respectively 2 pieces, as indicated in scenario 2.

Conclusion

Considering the obtained results, one may conclude that the paper has successfully achieved its proposed goals, that are presenting a control structure discrete event system type for the considered manufacturing system, elaborating of the Petri net hybrid synthesis of this structure and an Arena® simulation that allows performance and optimization studies.

A possible future research direction would have to consider the fact that the hybrid synthesis method deals with untimed Petri nets, so that the control structure solves the problem of mutual exclusion at shared resources allocation without considering the performance aspects regarding the processing times, as well as important problems such as possible failure operations and time delays generated by repairing and maintenance activities.

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Simulare cu Arena® a unei structuri de conducere pentru sisteme de fabricație folosind rețele Petri

Rezumat

Proiectarea unei structuri de conducere pentru sisteme cu evenimente discrete descrise prin rețele Petri este impusă de necesitatea rezolvării problemelor specifice care impun o abordare diferită de metodele de conducere aplicabile la sistemele dinamice pilotate de timp. In acest sens, pentru simulare şi studii ale aspectelor de performanță şi optimizare ale structurii rezultate pentru sistemul condus, lucrarea a realizat dezvoltarea în mediul Arena® a modelului care reflectă paşii de dezvoltare ai rețelei Petri finale. Prin rularea simulărilor pe un anumit interval de timp, s-au evidențiat caracteristici de performanță ale sistemului, ca: numărul de piese prelucrate din fiecare tip, timpi de prelucrare şi de aşteptare pe fiecare tip de piesă, precum şi gradul de utilizare al resurselor.