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RT&A, Special Issue No. 9 (87),
Volume 20, November 2025

INTELLIGENT MODELLING OF CONTROL SYSTEMS IN FLEXIBLE MANUFACTURING AREAS AT TECHNOPARK

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Abstract

The methods and tools of intellectual modeling of the control system at the design stage of the mechanical processing area of the flexible manufacturing system (FMS) of the technological park, selected as the object of research, were analyzed. The purpose of the work is to create expert knowledge of the control system of the mechanical processing area of the technological park and its information-measuring functions using the method of graphically determined modeling. A generalized architecture of an automated tool for modeling and studying the control of the mechanical processing area of the FMS was developed. Computer experiments were conducted to model the study of the control of the mechanical processing area of the FMS using a Petri net. The algorithm of complex coordinated and synchronized actions of the mechanical processing area of the FMS was described with a knowledge base.

Keywords: Agile manufacturing system, mechanical processing area, modeling, technopark, management system, Petri net, intelligent system, expert knowledge

I. Introduction

Based on the purpose of the work, referring to the literature sources and experience used to analyze the current state of the problem [1-6], the following three main directions have been identified for the description of control activities of the FMS with knowledge: classification of special formalisms of knowledge description models in computers; application of knowledge description models in computers in modeling technical systems; analysis of the current state of application of technical systems with Petri nets at the stage of system-technical design.

Based on the analysis of the results of research in the indicated areas, the current status and level of scientific research work carried out to solve the problem were determined, and the advantages and disadvantages were summarized through a comparative analysis, and the following main conclusions were formulated [7-11]:

- knowledge representation models in the computer, which is the basic element of intellectual systems, are formed by knowledge in the form of neural, semantic, Petri nets, expert-type production rules, logical and Frame models;

- by application area, it constitutes knowledge aimed at solving production management and economic problems, formalized by logical modeling methods and used in systems intended for decision-making;

- knowledge formalized with logical modeling and fuzzy network models in systems that advise, test, predict, and diagnose intelligent systems for solving problems.

The current state of intellectual models that provide for the design of the control system of the FMS of a technopark, which is considered a complex technical system, shows that the most common representation schemes and tools [12, 13] that describe human knowledge are the following: goal tree, "and", "or" tree (output tree), semantic network, neural network, etc. The knowledge base management system created on the basis of these models consists of software tools and performs the main functions - automated management of the goal tree, result, semantic and neural network trees, their definition, modification, sending requests to the knowledge base and receiving responses.

The selected search strategy uses not all the information in the knowledge base (KB) at all stages of solving the problem, but only the part that is relevant to it. For this purpose, the activation of knowledge by associative search with queries appropriate to the situation of the object by the expert and in dynamic expert systems is relevant. The current state of the evolution of production systems, the level of artificial intelligence of the fourth industrial revolution, the restructuring of industrial enterprises to ensure the release of high-quality products to the world market, the design of complex systems, their modeling, research and evaluation of the feasibility of their creation through computer experiments with various methods based on knowledge of specific purposes, are relevant.

[14-16] it is shown that in the process of developing of FMS control system, unlike the design of simple technical systems, it is required to solve issues such as the analysis of their functional work, the study of their properties, the determination of the operating modes of technological equipment (selection and design of mechatronic devices, layout schemes, selection and design of standard and non-standard elements, development of control and monitoring systems, organization of synchronized and coordinated activity). At the stages of design, production, testing, application and operation of FMS, the following modeling devices are widely used: finite automata; asynchronous processes with parallel operation; logical, frame and production models, semantic and Petri nets, etc. It is shown that each of the mentioned modeling devices has its own advantages and disadvantages and effective areas of application, and the properties of these devices should be taken into account in the process of designing of FMS control system.

An analysis of the current state of application of modeling tools at the stages of system-technical design (technical task, sketch and technical design) has shown that the Petri net tool is a more universal tool compared to other methods [17, 18]. This is explained by the fact that the Petri net allows you to evaluate the feasibility of creating an object without direct physical contact with it, as a result of analyzing the main properties of the network. At the same time, it is shown that Petri nets are not considered effective in modeling and studying relatively simple processes, and it is more efficient to use other modeling tools for their intended purpose.

It was noted that currently there are many extensions of Petri nets, and they have been developed into efficient software complexes for modeling and studying FMS and are widely used in design procedures, especially in studying the management, control, forecasting and other activities of FMS [19, 20]. In practice, in the study of FMS control with Petri nets, the problem of describing the FMS at three main levels - subject, mathematical and program, creation and object level with simple modeling devices, and in the subsequent stages, the transformation into a Petri net model with various purposeful transformation algorithms and the analysis of the main properties of the network at the mathematical level of FMS, and the assessment of the feasibility of the operation of the FMS control algorithm, has been solved.

Rufat Azizov, Elmira Nasirova, Arzu Aliyeva, Yusif Huseynov
INTELLIGENT MODELLING OF CONTROL SYSTEMS IN
FLEXIBLE MANUFACTURING AREAS AT TECHNOPARK

RT&A, Special Issue No. 9 (87),
Volume 20, November 2025

II. Architecture of the automated design tool
for the control system of FMS in the technopark

The modern level of development of computer technology, the use of effective modeling methods, the need to study the feasibility of designing and creating these areas at the initial design stages using computer experiments arises. In this work, a generalized structure of the interaction of the mathematical, algorithmic, software, technical, information-search support subsystems of the automated design tool, the activities of which are described by various modeling methods, in a complex manner - in the interaction of the constructive and control system, is created. From the analysis of the generalized structure of the interaction of the subsystems of the automated design tool (ADT) of the control system of the FMS, it can be seen that the complex automated design of the control system of the FMS should be carried out in two main directions: the creation of bases of non-standard mechatronic devices created on the basis of standard and constructive design; It requires the creation and study of computer model databases by modeling mechatronic devices, as well as the creation of knowledge bases of control models and algorithms for their management [21-24].
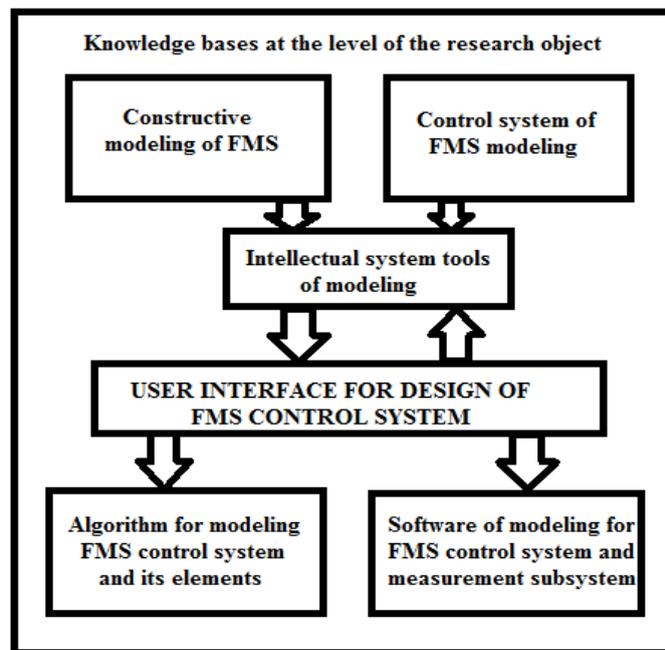

Fig. 1. *Architecture of ALA for modeling a complex study of the management system of the MIS*

The structural modeling tool of the FMS control system is formed from a set of knowledge bases at the research object and mathematical level. The knowledge base at the research object level includes: computer models of FMS in the form of layout schemes; computer models of standard and non-standard mechatronic devices; computer models of transport and storage systems; computer models of various processing equipment of FMS; technical and other characteristics of equipment and mechatronic devices of MIS; databases of the FMS control system.

At the mathematical level, the knowledge base includes computer models of the components of the control system of the FMS under study in two or three-dimensional spaces, separately, and computer models of the control system of the FMS in two or three-dimensional spaces [25].

When performing computer experiments, the computer model being studied is transferred to the working area and its control is studied through experiments.

Rufat Azizov, Elmira Nasirova, Arzu Aliyeva, Yusif Huseynov
INTELLIGENT MODELLING OF CONTROL SYSTEMS IN
FLEXIBLE MANUFACTURING AREAS AT TECHNOPARK

RT&A, Special Issue No. 9 (87),
Volume 20, November 2025

The proposed generalized architecture of the ADT management design tool for modeling the complex study of the FMS management system is given in Figure 1. As can be seen from the architecture, the knowledge of the ADT of FMS control system is described at four main levels: semantic information; subject; mathematical and software tools [26, 27].

As is known, design procedures are carried out at different stages by specialists (teams) with different qualifications, and the technical and conceptual errors of each are propagated to the next stages and ultimately detected at the testing stage of the physical model of the object. At the stages of design procedures, the selected properties of the object are described with various signs (symbols) in accordance with the technical task. The analysis shows that communication between the design organizations and the customer organization is mainly carried out in languages corresponding to the professional level of the latter. In this case, the customer can also use mathematical and logical formulas proven on empirical and scientific grounds, confirmed by various experiments.

III. Modeling the operation of the control system of the FMS in technopark

The DB of a FMS control system is created by including the types, characteristics, technical specifications, and parameters of all its components.

$$DBc \rightarrow \{DB_{ae1}, DB_{ae2}, \ldots, DB_{aen}\}$$

At the next stage, the issues of creating knewledge base (KB) and KB management system (M)S for building algorithms of the operation of the FMS of the mechanical processing flexible manufacture flexible module (FMM) in different situations and depending on the processing of various designs are considered. At both stages, the technological operations performed by the crane manipulator (CM) are accompanied by the differentiation of only the movement routes of the CM, that is, only the sequence of loading the FMM of the mechanical processing FMM is determined. Taking into account the diversity of the designs being processed mechanically, the issues of creating KB and KBMS of the software of the program-controlled machines should be considered.

In the dissertation work, in order to analyze the dynamics of the technological process of the TDM using the example of the TDM, the sequence of events (technological operations) P_i occurring in it and the calculation of the logical predicates t_j for the occurrence of events are considered.

$[(P_1 = \text{operation 1}) \vee (P_2 = \text{operation 2}) \vee$

$\vee (P_n = \text{operation n})] \wedge [((\text{end(operation 1)} < \text{start(operation 2)}) \wedge$

active element of the FMM

(For example, crane manipulator (CM) (operation 1) = $x_1 \wedge$

CM(operation 1)=$x_2 \wedge$CM(operation 2)= x_3]

$\wedge$(type(operation 1)= layout is positioned on machine (lathe))

$\wedge$(type(operation 2)= CM's handle holds the layout)

$\wedge [((\text{end(operation 2)} < \text{start (operation 3)}) \wedge$.

Here x_1 - crane manipulator (CM), x_2 - layout (Machine), x_3 - lathe (Machine).

P_i occurring in the CHIS events occur in time t_i. This dependence can be described in logical language as follows:

$(\forall P_i \in$ technological operations of the crane manipulator in the FMM)

[Positioning of T in Machine(P_1) $\rightarrow$(start(P_1) + t_1=end(P_1)]$\wedge$

[Tn in CM's capture by the holder (P_2)$\rightarrow$

(start(P_2) + t_2 = end(P_2)] $\wedge$[Selecting the type of movement of the CM ($P_3, P_{3+1}, \ldots$)$\rightarrow$

(head(P_3) + t_3=end(P_3)] $\wedge$[Processing of T to machine (P_m) $\rightarrow$(head(P_m) + t_2=end(P_{m+1})].

Here t_1 is the positioning time of the layout in machine, t_2 is the closing and opening time of the KM handle, t_3 is the duration of the movement trajectory of the CM arm.

Production rules are used in the design of the control system of the FMS. Thus, a knowledge

Rufat Azizov, Elmira Nasirova, Arzu Aliyeva, Yusif Huseynov
INTELLIGENT MODELLING OF CONTROL SYSTEMS IN
FLEXIBLE MANUFACTURING AREAS AT TECHNOPARK

RT&A, Special Issue No. 9 (87),
Volume 20, November 2025

base and a control algorithm are developed based on the production model to design the software of the control system. The main active elements in the control system of the agile production module are the transmitters and execution mechanisms of the machines. The movements of the active elements of the FMS, their transmitters and execution mechanisms are formally described in tables 1 and 2.

Table 1. Assignments of the transmitters of the CHIs's MQ

Transmitters	Technological of operations types
Positioned r ici block (MB) data	
S^1_1	Positioning the layout in the TD MB
S^2_1	Positioning the layout in the FD MB
S^3_1	Positioning the layout in the RD's MB
S^4_1	Positioning the layout in the DB of the AD
Crane manipulator (CM) transmitters	
S^1_2, $\overline{S}^1_2$	Positioning the CM handle in the closed or open position
S^2_2	Positioning the CM in the low position
S^3_2	Positioning the CM in the upper position
S^4_2	Positioning of the forward movement of the CM
S^5_2	Positioning of the CM reverse movement
Lathe (Machine) data	
S^1_3	Positioning the start of a technological operation in TD
S^2_3	Positioning the end of the technological operation in TD
Milling machine (FD) data	
S^1_4	Positioning the start of a technological operation in FD
S^2_4	Positioning the end of the technological operation in FD
Radial bending machine (RBD) specifications	
S^1_5	Positioning the start of a technological operation in RBD
S^2_5	Positioning the end of the technological operation in RBD
S^1_6	Positioning the start of a technological operation in the OB
S^2_6	Positioning the end of a technological operation in the machine tool

A control algorithm is built based on the selected transmitters and execution mechanisms of the active elements of the FMS. The control algorithm built with the help of the production model consists of the elements of the application conditions (P_i) of the production core :

$$P_i = \{P_1, P_i, \ldots., P_n\}, (4)$$

where *n* denotes the number of conditions.

The control algorithm for the process of loading and processing the workpiece onto the lathe using a crane manipulator along the technological trajectory of the lathe can be described by the following production algorithm:

1. Algorithm for loading TD FMM with CM

P1: *if* TD does not have T in MB, *then* CM is moving down;

P2: *if* the CM has moved down and the CM's grip is open, *then* the KM's grip is holding T;

P3: *if* If the CM's grip is on T, *then* CM is moving up;

P4: *if* the CM has moved up, *then* the CM is moving forward;

P5: *if* the CM arm has moved back and is in the TD working zone, *then* The handle of the CM should be opened and positioned at the MB of the T TD;

P6: *if* T is positioned at the MB of TD, *then* CM should move back and start processing T at TD;

Rufat Azizov, Elmira Nasirova, Arzu Aliyeva, Yusif Huseynov
INTELLIGENT MODELLING OF CONTROL SYSTEMS IN
FLEXIBLE MANUFACTURING AREAS AT TECHNOPARK

RT&A, Special Issue No. 9 (87),
Volume 20, November 2025

P7: *if* the processing operation of T has been started in TD, *then* the processing operation of T in TD should be executed and completed within time t_i.

Workpiece along the technological trajectory of the lathe using a crane manipulator and loading it onto the lathe and processing it can be described by the following production algorithm:

1. Algorithm for loading TD FMM with CM

P1: *if* TD does not have T in MB, *then* CM is moving down;

P2: *if* the CM has moved down and the CM's grip is open, *then* the CM's grip is holding T;

P3: *if* If the CM's grip is on T, *then* KM is moving up;

P4: *if* the CM has moved up, *then* the KM is moving forward;

P5: *if* the CM arm has moved back and is in the TD working zone, *then* The handle of the CM should be opened and positioned at the MB of the T TD;

P6: *if* T is positioned at the MB of TD, *then* CM should move back and start processing T at TD;

P7: *if* the processing operation of T has been started in TD, *then* the processing operation of T in TD should be executed and completed within time t_i.

Table 2. The IM of the CHI appointments

Execution mechanisms	Technological of operations types
Positioned on the machines block (MB) execution mechanisms	
EM $^1_1$	Implementation of TD's positioning in the MB
EM $^2_1$	Execution of FD's positioning in the MB
EM $^3_1$	In the MB of RBD positioned r loop execution
EM $^4_1$	Implementation of the positioning of the BD in the MB
Crane manipulator operating mechanisms	
EM $^1_2$, $\rceil$EM $^1_2$	Execution of positioning of the CM handle in the closed or open position
EM $^2_2$, $\rceil$EM $^2_2$	Performing the positioning of the CM in the up or down position
EM $^3_2$, $\rceil$EM $^3_2$	Execution of positioning of the forward or backward movement of the CM
Machine tools execution mechanisms	
EM $^1_3$, $\rceil$EM $^1_3$	Execution of positioning of the initial or final states of the technological operation of the TD
EM $^2_3$, $\rceil$EM $^2_3$	Execution of positioning of the initial or final states of the technological operation of the FD
EM $^3_3$, $\rceil$EM $^3_3$	Execution of positioning of the starting or final states of the technological operation of the RBD
EM $^3_4$, $\rceil$EM $^3_4$	Execution of positioning of the initial or final state of the technological operation of the machine tool

A control algorithm is constructed using logical symbols in accordance with the production conditions shown above:

$(P_1)\rceil S^1_1 \Rightarrow \rceil EM^2_2$;

$(P_2) S^2_2 \& \rceil S^1_2 \Rightarrow EM^1_2$;

$(P_3) S^1_2 \Rightarrow EM^2_2$;

$(P_4) S^3_2 \Rightarrow EM^3_2$;

$(P_5) S^5_2 \Rightarrow \rceil EM^1_2 \& EM^1_1$;

$(P_6) S^1_1 \Rightarrow EM^3_2 \& EM^1_3$;

$(P_7) S^1_3 \Rightarrow \rceil EM^1_3$.

Rufat Azizov, Elmira Nasirova, Arzu Aliyeva, Yusif Huseynov
INTELLIGENT MODELLING OF CONTROL SYSTEMS IN
FLEXIBLE MANUFACTURING AREAS AT TECHNOPARK

RT&A, Special Issue No. 9 (87),
Volume 20, November 2025

The dissertation presents a block diagram of the control algorithm for loading the lathe's MF with CM. As can be seen, production rules were used as an efficient modeling apparatus for studying the activities of all MFs of the mechanical processing FMS, and a finite automaton was used for the automatic transport manipulator. Therefore, algorithms for converting the modeling methods shown in the dissertation into a Petri net model were developed.

In the example of TD, the sequence of transition from production rules to Petri nets and the development of the FM action algorithm as a result of the analysis of the properties of the Petri net are considered.

Table 3. Predicates appropriate to the situations of CM activity

Predicates	Definition of predicates
P_1	The CM handle is open;
P_2	the presence of the layout in the layout positioning zone;
P_3	moving the CM down to the layout positioning zone;
P_4	Capture of the design by the CM holder;
$P5$	CM moving upwards;
P_6	CM moving forward;
P_7	Placing and positioning the layout on the positioning block of the TD by the CM;
P_8	CM moves back and starts processing in TD;
P_9	Completion of the design processing operation in TD;

The following active actions-transitions correspond to predicates t_j ($j = \overline{1,9}$):

t_1	The CM's handle is not working (open);
t_2	the layout positioning zone is active (there is a layout);
t_3	CM is working (moving down);
t_4	The CM's handle is working (closing);
t_5	CM is working (moving up);
t_6	CM is working (moving forward);
t_7	The positioning block of the TD is working;
t_8	TD is running (processing operation is starting);
t_9	TD is running (processing operation is ending).

In this case, the productions in the form of "condition - action" are expressed as follows.

$$P_1 \to t_1; P_2 \to t_2; P_3 \to t_3; P_4 \to t_4; P_5 \to t_5; P_6 \to t_6; P_7 \to t_1 \& t_7; P_8 \to t_8; P_9 \to t_9.$$

The numbers of predicates and transitions are equal to each other (P $_i$=9, t $_i$=9), the invariants P and T of the incidence matrix, whose number of rows and columns is equal to each other, are determined by the well-known Gauss method based on the input and output matrices, and a graph-scheme of the action algorithm in the form of a Petri net with a Petri net of the lathe FMM control system is constructed (Figure 2).
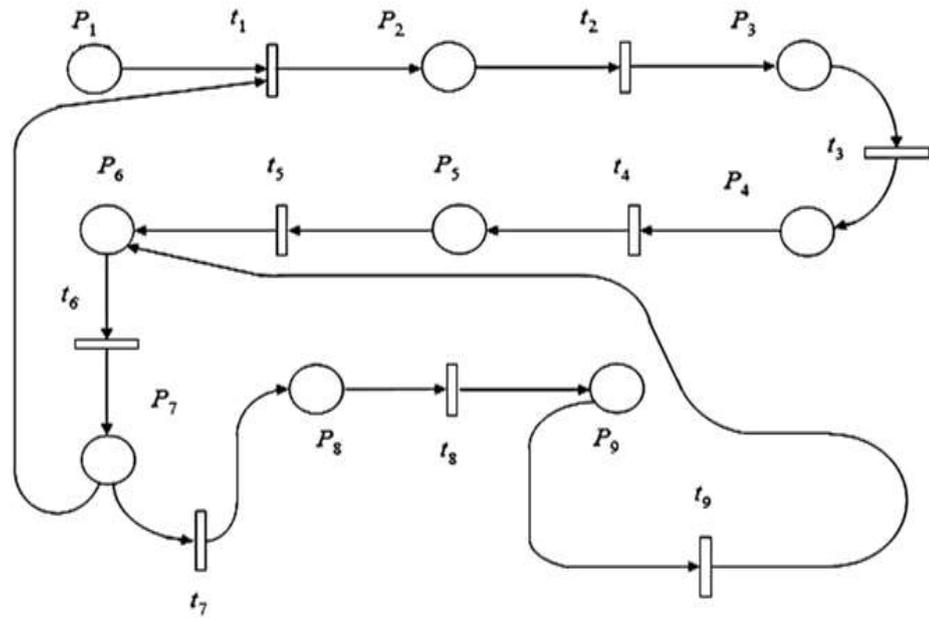
Rufat Azizov, Elmira Nasirova, Arzu Aliyeva, Yusif Huseynov
INTELLIGENT MODELLING OF CONTROL SYSTEMS IN
FLEXIBLE MANUFACTURING AREAS AT TECHNOPARK

RT&A, Special Issue No. 9 (87),
Volume 20, November 2025

Fig. 2. *Petri net graph diagram of the activity algorithm of the FMM control system with Petri net*

Conclusion

As can be seen from the architecture of the ADT of the mechanical processing FMS control system, taking into account the sequence of the FMS's activities, the control algorithm of each of its components is selected from the subject-level KB and converted into a Petri net using the appropriate Petri net transformation algorithm, and a KB is created at the mathematical level. This sequence can be shown as follows.

Algorithm

First stage

Step 1. Transform the finite automaton control algorithm of the automatic transport manipulator into a Petri net model and store it in the KB at the mathematical level (N_1).

Step 2. Converting the production rules algorithm of the loading of FMM1 (TDM) by the CM into a Petri net model and storing it in the KB at the mathematical level (N_2).

Step 3. Converting the production rules algorithm of the FMM2 (FDM) loading by the CM into a Petri net model and storing it in the KB at the mathematical level (N_3).

Step 4. Converting the production rules algorithm of the FMM3 (RBD) loading by the CM into a Petri net model and storing it in the KB at the mathematical level (N_4).

Step 5. Converting the production rules algorithm of the FMM4 (EDM) loading by the CM into a Petri net model and storing it in the KB at the mathematical level (N_5).

Step 6. Converting the production rules algorithm for automatic loading of finished products into a Petri net model by the CM and storing it in the KB at the mathematical level (N_6).

Second stage

Step 7. Evaluation of the feasibility of applying control algorithms by studying them with computer experiments as a result of analyzing the properties of each Petri net separately (N_1, N_2, N_3, N_4, N_5, N_6) sequentially

Rufat Azizov, Elmira Nasirova, Arzu Aliyeva, Yusif Huseynov
INTELLIGENT MODELLING OF CONTROL SYSTEMS IN
FLEXIBLE MANUFACTURING AREAS AT TECHNOPARK

RT&A, Special Issue No. 9 (87),
Volume 20, November 2025

CONFLICT OF INTEREST.

Authors declare that they do not have any conflict of interest.

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Rufat Azizov, Elmira Nasirova, Arzu Aliyeva, Yusif Huseynov
INTELLIGENT MODELLING OF CONTROL SYSTEMS IN
FLEXIBLE MANUFACTURING AREAS AT TECHNOPARK

RT&A, Special Issue No. 9 (87),
Volume 20, November 2025

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