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ABSTRACT

of the dissertation for a degree of doctor of philosophy

STUDY OF TECHNICAL SYSTEMS WHICH ACTIVITIES ARE DESCRIBED WITH KNOWLEDGE USING PETRI NETS

Specialty: 3338.01 – System analysis, control, and Information Processing (modeling and control)

Field of science: Technical sciences

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İMZANI TƏSDİQ EDİRƏM
ELMİ KATİB

GENERAL CHARACTERISTICS OF THE WORK

Relevance of the topic and development degree. The experience in designing Flexible Manufacturing Systems (FMS) indicates that specialists of various disciplines such as technologists, designers, automation experts, etc., should collaborate and work together at different stages of their design. Therefore, the realization of their ideas in different design stages to achieve the goal set for each of them does not justify itself in the final test stage or is accompanied by certain shortcomings. It is also important to note that medium-complexity FMS consist of multiple mechatronic devices, processing centers, software-controlled machines, transportation and storage systems, etc., which interact and are managed within common work zones. These systems comprise a set, and it is necessary to conduct comprehensive testing on them. Although it is possible to test the activities of physical models of individual components, but in their complex coordinated and synchronized control, mechatronic devices can be accompanied by situational accidents in shared working areas.

In order to prevent the identified and other unconsidered defects in the initial and subsequent design stages, it is considered a promising direction to assess the appropriateness of designing the FMS through computer experiments with the application of computer modeling methods in the stage of system-technical design (technical task, sketch and technical) .

Currently, various purpose-oriented systems have been developed that provide structural modeling and automated design of FMS. At the same time, automated design tools for FMS management models and algorithms for various purposes have been created. For the comprehensive study of complex systems, simulation modeling and animation of the results are also used. Each of the indicated systems has its superior and deficient features, and ongoing scientific research is regularly being carried out in order to improve them. The indicated research works were traditionally carried out by specialists of different purposes in two different directions - constructive and management, at the design stages, and in most cases the initial ideas did not justify themselves at the stages of testing and implementation of the complex

FMS, which was ultimately accompanied by additional costs. From this point of view, the relevance of the subject of the the FMS entitled "Research of technical systems whose activities are described by knowledge with Petri nets" can be shown, which carries out a comprehensive study of FMS using computer modeling methods at the initial design stage and allows to assess the feasibility of FMS design.

The object and subject of the research. The flexible production system in the mechanical processing domain was chosen as the object of research in the dissertation work. In the example of the FMS, at the initial design stage, the automated design and management of its components by computer modeling methods are described by various purpose modeling methods and complexly studied with Petri nets, and the issues of evaluating the feasibility of its creation are investigated and processed.

Research goals and objectives is the development of models and algorithms for the evaluation of the expediency of the creation of technical systems whose activities are described by knowledge in the initial design stages of the automated design tool and the study of computer experiments with a Petri net of the complex activity of the system.

In order to achieve the stated goal, the following issues requiring resolution were determined in the dissertation work:

✓ FMS , which belongs to the category of complex technical systems, with various modeling methods, using the Petri net, development of the generalized structure of the interconnections of the subsystems of the automated design tools (ADT) ;

✓ Development of generalized architecture of automated design tool for modeling and research of FMS management ;

✓ Analyzing of the existing composition scheme of the mechanical processing area selected as a research object and development of the composition scheme of the FMS;

✓ development of computer models of non - standard mechatronic devices (MD) with structural design methods, if required, taking into account the specific characteristics of objects ;

✓ Creation of databases and knowledge bases of mechatronic devices and equipment of FMS;

✓ Production rules for loading raw materials and semi-finished products with crane manipulator (CM) of FMS and algorithms for transformation of models of automatic transport manipulator (ATM) into a Petri net with finite automata ;

✓ Development of ADT's architecture of FMS and study of complex management with Petri net ;

✓ Creation of databases and knowledge bases of complex coordinated and synchronized activity algorithm of FMS and development of management algorithm.

Research methods. Modern modeling methods, artificial intelligence elements, data and knowledge description methods, production rules and the concept of finite automata, automatic control and Petri net theories, flexible production systems construction and management principles were used in the work.

Main clauses defended :

✓ Development of the generalized architecture of the automated design tool for the modeling, management and study of FMS, which belongs to the category of complex technical systems;

✓ Analyzing of the existing composition scheme of the mechanical processing area selected as the object of research, determination of the requirements for automation and development of the construction model in the form of the composition scheme of the FMS;

✓ Creation of databases and knowledge bases of mechatronic devices and equipment of FMS;

✓ Creating a database of algorithms for the study of the production rules of FMS mechatronic devices and automatic transport manipulators and descriptions with finite automata using the Petri net model;

✓ Of the FMS and the management of the computer model of the FMS in a complex manner with the Petri net;

✓ Creation of databases and knowledge bases of the complex coordinated and synchronized action algorithm of the mechanical processing FMS and development of the control algorithm.

Scientific novelty of the research:

✓ System technician design stage of FMS of knowledge semantic which includes informational, subject, mathematical and software bases automated design of the instrument generalized proposed and designed architecture;

- ✓ Research was conducted on the automation of mechanical processing, focusing on the selection of the research object and establishing requirements for the composition scheme of FMS. This involved creating a constructive model and a structure-cinematic scheme.;
- ✓ Data and knowledge bases were created for mechatronic devices and equipment used in mechanical processing FMS. Additionally, production rules for mechatronic devices and equipment of FMS, as well as the final ATM with automatic descriptions, were converted into algorithms using Petri networks. Their knowledge base was also developed.;
- ✓ The architecture of the ADT of mechanical processing FMS is elaborated and with a Petri net mechanical processing of FMS computer of the model complex on the picture management computer experiments with study done;
- ✓ Mechanical processing FMS is complexly coordinated and synchronizedof the action algorithm data and knowledge bases are created and FMS real in the facility complex on the picture of the activity coordinated and synchronized control algorithm has been developed.

Theoretical and practical significance of research. The obtained scientific and practical results can be used to justify that the project procedures are performed satisfactorily and at the required level at all stages of designing and creating FMS for various purposes. At the same time, it is especially important for the customer to create a vote of confidence between the customer and the executive at the initial design stage, that is, to demonstrate the final result with computer experiments in advance. Based on the results of the work, the materials developed can be successfully applied in the teaching process of appropriate specialties.

Approval and application. The results of the scientific research carried out in the dissertation are presented at international and national-level conferences and international congresses done and discussion done; Mathematics application issues and new information technologies II Republican scientific conference. (Sumgait, November 27-28, 2012); Materials of the International scientific and technical conference-Science, technology, production-2017. "Applied science as an instrument for the development of petrochemical production". (Ufa, May 23-25, 2017); Knowledge base development of an automated design tool interface of an agile manufacturing system. Materials of the International Eastern Conference on human-computer interaction (Nakhchivan, 2022); Fundamental Problems of Mathematics and Application of Intellectual Technologies in Education, II Republic Scientific conference materials (Sumgayit, 2022); Materials of the III international scientific conference on theoretical and applied problems of mathematics (Sumgayit , 2023); International scientific and technical congress "Intellectual systems and information technologies". (Russia, Gelendzhik, Divnomorskoe, September 1-7, 2023).

The name of the institution where the dissertation work was performed. The dissertation work was performed at the Department of Information Technologies and Programming of Sumgayit State University.

The scope and structure of the dissertation work. The work consists of an introduction, four chapters, a result, a list of available literature, and an appendix The main content of the work is 164 pages, 19 pictures, and 1 chart. The list of publications shows 121 sources. The volume of the main content of the work is made up of 181000 characters. Including: Introduction - 29400 characters, Chapter I - 51800 characters, Chapter II - 29,000 characters, Chapter III - 42,000 characters, Chapter IV - 27,000 characters, Results - 2165.

MAIN CONTENTS OF THE WORK

In the introduction the relevance of the topic of the dissertation is substantiated, the object and subject of the research, the purpose of the work and the issues to be solved are defined, the research methods, the main propositions defended, scientific innovations, the practical importance and approval of the work, scientific publications and a brief summary of the dissertation work by chapters are given.

The first chapter is dedicated to the investigation of the current state of the problem and the setting of the issue. For this purpose, with reference to literature sources and experience, the analysis of the modern state of description of the activities of technical systems with knowledge was carried out in three main directions: classification of special formalisms of description models of knowledge in the computer; application of computer knowledge representation models in modeling of technical systems and analysis of the modern state of application of technical systems with Petri nets at the design stage.

The purpose of the dissertation work has been formulated and the issues that need to be solved in order to achieve this goal have been defined.

The second chapter is dedicated to the issues of determining the requirements for the study of the main properties of the automated design stages of technical systems and their modeling methods . It has been shown that traditional design stages should be performed consistently regardless of whether automation methods are used in the design of any facility. Experience shows that the life of the designed object, i.e., the period of being in operation, depends on the measures taken in the direction of shortening the solution periods of the design stages up to operation. Among these measures, three main issues are of particular importance: typification, optimization and automation of design procedures. Therefore, in order to increase the efficiency of the design process, it is necessary to perform the three issues in interaction with each other, in a complex manner, at all stages.

The modern level of development of computer equipment and information technologies based on them allows the specified problem to be partially or completely fulfilled.

The design of FMS, which belongs to the category of complex systems, is carried out by specialists of different purposes in two main directions - constructive and management. Currently, a large number of typical, standard and non-standard projects and their management systems have been developed. Despite all this, these directions have developed independently of each other.

The modern level of development of computer technology, by using efficient modeling methods, by studying these directions separately and comprehensively, it is necessary to study the expediency of their creation with computer experiments at the stage of system engineering design (technical assignment, sketch and technical design).

In this work, the generalized structure of the interactions of the mathematical, algorithmic, software, technical, information-search provisioning subsystems of the automated design tool of the FMS, whose activities are described by various purposeful modeling methods, was considered.

From the analysis of the generalized structure of the interconnections of the ADT subsystems of the FMS, it appears that the complex automated design of the FMS should be carried out in two main directions: creation of databases of computer models of non-standard mechatronic devices created on the baFMS of standard and constructive design (constructive modeling); Creation of knowledge bases of control models and algorithms for the management of the computer model in the form of a FMS raw material scheme .

The dissertation shows that the knowledge base of constructive modeling at the level of the research object includes the following: FMS composition schemes; technical and other characteristics of standard and non-standard mechatronic devices, transport and storage, FMS processing equipment for various purposes and mechatronic devices; Databases of FMS.

The transformation of knowledge at the level of the research object into knowledge at the mathematical level is performed at the coPMunication interface.

At the mathematical level, the knowledge base includes separate computer models of the studied FMS components in two or three-dimensional spaces and computer models in two or three-dimensional spaces in the form of composition schemes of the FMS.

When performing computer experiments, the studied computer model is transferred to the working zone and its management is studied by experiments.

The experience of designing and implementing FMS shows that ADTs created by applying the main modeling tools (finite automata, parallel operating asynchronous processes, production rules, Frame and logic models, etc.) widely used in their modeling and management have found wide areas of application. The main missing feature of these types of ADTs is that they cannot be used in the management of FMS in facilities operating under conditions of uncertainty and fuzziness. Therefore, in the work, a generalized architecture of the ADT of FMS management, whose activities are described by knowledge of various purposes, is proposed and developed[1].

The proposed generalized architecture of the design tool for the management of ADT in a comprehensive study of FMS is given in **figure 1.**

As can be seen from the architecture, the knowledge of the ADT of FMS management is described at four main levels: semantic information; subject; mathematical and software.

As it is known, the design procedures are carried out by specialists (collective) with different qualifications at different stages, and the technical and idea errors of each of them are carried over to the next stages and finally discovered at the test stage of the physical model of the object. At the stages of the design procedures, the selected properties of the object are described with different signs (symbols) according to the technical task. The analysis shows that the communication between the project organizations and the client 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 that have been proven on empirical and scientific grounds, confirmed by various experiments. Text, audio, visual, descriptive, graphic, etc., confirmed by symbols about the selected properties of the object. type initial data set is treated as semantic information (SI). It should be noted that according to the theory of cognition, primary

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[1]Ahmadov, MA, Nasirova E.A. Development of the architecture of the automated design tool for the study of the control algorithm of the designed object.// Scientific news of SSU, -2016, -p. 71-75

SI is a fixed representation of the properties of an object selected by a person.

Therefore, there is no universal algorithm for creating the initial SI for objects of all fields of knowledge. However, man describes the logical structure-cascade of primary SI using various stable categories (goal, method, means, quality, quantity, cause, result, meaning, form, etc.).In practice, in the process of designing FMS, the initial SI is formed by the experts of the subject area and approved by agreement with the executive organizations in the form of a technical task.The flexible production area is a set of interconnected flexible manufacture modules (FMM) composed of mechatronics and other technical devices of various purposes and belongs to the category of complex discrete systems. The elements of FMM are industrial and intelligent robots, manipulators and transport devices of various purposes, positioners, etc. The mentioned devices, depending on their purpose, are known in advance or operate in environments of relative uncertainty in different situations .

As it is known, the mechatron devices of FPM interact with each other in three-dimensional space, mainly by using common working zones. Therefore, the implementation of tests on their physical models is accompanied by certain difficulties (collisions in common working areas, emergency situations, etc.) [2].

The indicated cases occur as a result of defects in the processing of control and interaction algorithms of separate mechatronic devices of the FMMs. On the other hand, the development of coordinated, complex management algorithms of the FMS PIMs to achieve any goal is also required. It is necessary to use different methods of assessing the expediency of creating a FMS at the initial design stage so that the listed shortcomings are not replicated at the stages of FMS design.

[2] Akhmedov M.A., Nasirova E.A. Tool for automated design of a computer model of a flexible production module and its complex study by computer experiments. Information, volume 2, - str. 218-223

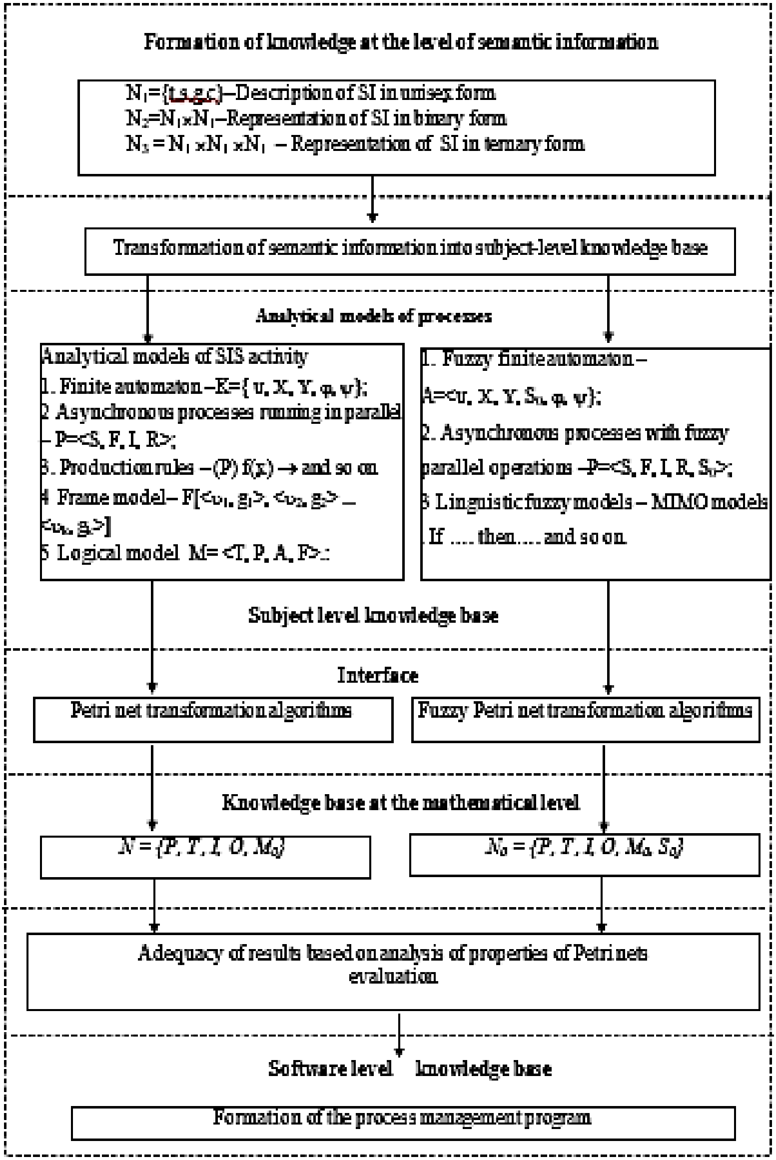

Figure 1. Generalized architecture of a FMS management automated design tool

In the dissertation work, as one of such approaches, the issue of modeling the elements of the FMM with various analytical modeling methods and performing a comprehensive study of the FMM, transforming the initial models into a Petri net model and analyzing the main properties of the latter and evaluating them. Finite automata, asynchronous processes with parallel operations, semantic and network models, Frame and logical models are widely used as methods of analytical modeling of processes.

Each of these methods has advantages and disadvantages and areas of effective application. Relatively simple processes can also be directly modeled and studied with a Petri net. Direct modeling of complex procedures with a Petri net is accompanied by certain difficulties. The main advantage of the Petri net is that the study of the object modeled with it is carried out by analyzing the main properties of the Petri net outside the object. Due to this superior feature of the Petri net, it is relevant to use it as a basic modeling tool in the evaluation of the appropriateness of the FMS in a complex study .

Algorithms for transformation of analytical models of processes whose a priori situations are identified into a Petri net have been mainly developed. Experience shows that, depending on the nature of the production processes, in the design of the FMS, it is required to use mechatronic devices that operate by making decisions under conditions of uncertainty in various situations. Therefore, the solution to the problem of complex modeling of FMS management under conditions of uncertainty, i.e. description and research in the form of ordinary and fuzzy Petri nets, is also provided in the generalized architecture. From this point of view , the description of knowledge at the subject level is carried out in two ways, analytical modeling devices (management of procedures whose a priori situations can be identified) and descriptive methods by means of fuzzy models of mechatronic devices operating under conditions of uncertainty in various situations. At the mathematical level, knowledge is described by a Petri net, and as a result of the analysis of its properties, after a comprehensive study of the FMS, a control algorithm of the FMS is formed. The transformation of the knowledge described at the subject level into the knowledge at the mathematical level is performed by the transformation algorithms formed in the interface. Forms the program of the control algorithm at the program level. One of the main issues of the (figure 2) automated design tool for the realization of the complex study of the FMS and the formation of the control algorithm is the creation of the interface. The goal is to develop algorithms for transforming the models described by various modeling devices into a Petri net model.

The third chapter is dedicated to the development of models and algorithms for the study, design and feasibility assessment of the research object mechanical processing FMS by modeling it with a Petri net in a complex system design stage with computer experiments.

It has been shown that the following main issues should be resolved in order to fulfill this task: analysis of the existing raw material scheme of the mechanical processing area and development of the raw material and structural-kinematic schemes of the proposed FMS; Creation of databases and knowledge bases of mechatronic devices, equipment and other components of FMS; Study of the algorithms for managing the loading of the FMM by CM with production rules by analyzing the properties of the Petri net; Petri net study of control algorithms of FMS with finite automata.

In the FMS work, the issues of creation of data, knowledge bases, development of models and algorithms were considered in the example of mechanical processing FMS, which was selected as a research object. The current raw material scheme of the mechanical processing area is shown in figure 3 and operates in the following sequence: The raw material is loaded by the worker on the rotary table into the working area of the lathe worktable (LW) and processed: After the operation in the LW is completed, the processed semi-finished product is transferred to the milling machine (MM) it is loaded into the working area and the processing process begins; After the operation in MM is completed, the processed semi-finished product is loaded into the working zone of the radial bending machine (RBM);

After the operation in radial drill press (RDP) is completed, the processed semi-finished product is taken from the rotary table and loaded into the working zone of the bending machine (BM); After finishing the processing process in the BM, the processed semi-finished product is placed in the product storage zone (SA of FM) in the form of a finished product.

The process continues in the specified time interval in the specified order. As can be seen from the current structure of the mechanical processing area, which was accepted as a research object, in order to organize the processing process on the machines in the field, loading them with raw materials and semi-finished products, managing and controlling the processing process is performed by four workers .

Using the theoretical and experimental results obtained in the previous chapters and modern automation tools (mechatronic devices, software-controlled equipment, transport, storage facilities, etc.) capable of increasing the efficiency of the sphere of human physical activity, in the initial design phase of the FMS in a complex manner issues of research and evaluation of feasibility of creation with computer experiments were worked out.

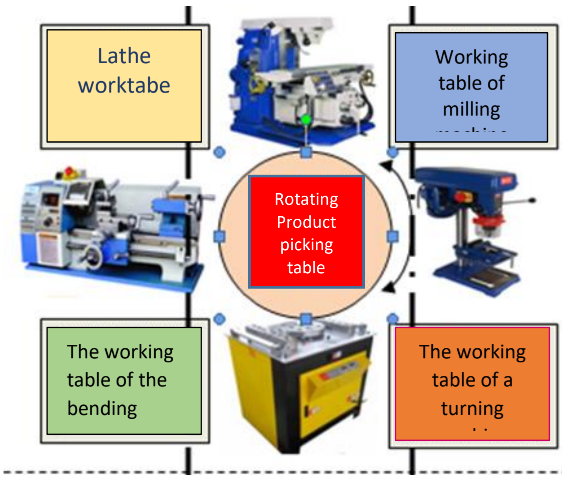

Figure 3. The existing composition scheme of the mechanical processing area

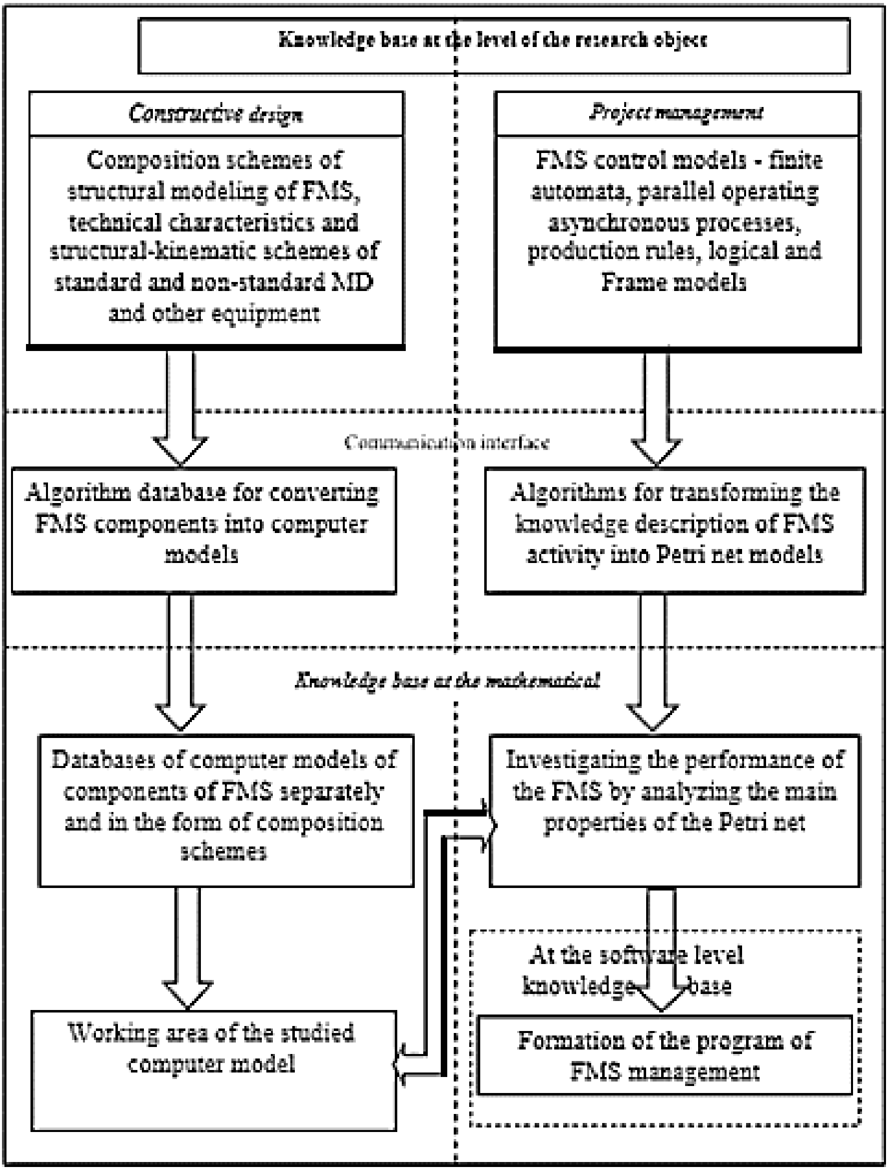

Figure 2. Generalized architecture of the ADT for the study of FMS in a complex computer experiment

The composition scheme of the mechanical processing FMS that meets the requirements of the problem setting (figure 4) was proposed and developed [3].

In addition to the machines included in the existing composition scheme of the mechanical processing FMS, there is a crane-type transport system (CTTS), a mechatronic device (MD) operating in three-dimensional space; a positioning manipulator (PM) and a transport manipulator (TM) transporting raw materials to the working zone of the PM are included.

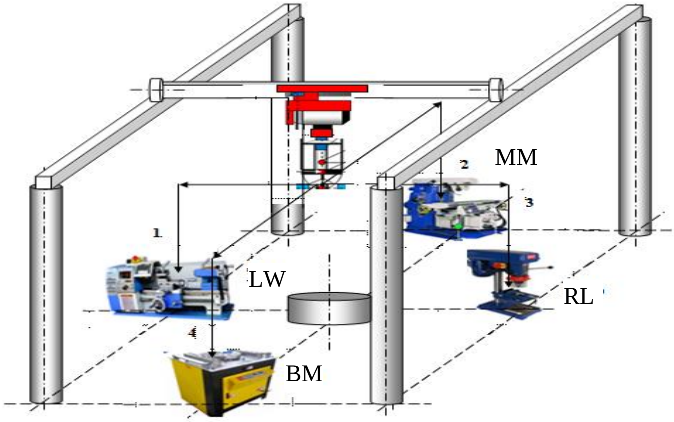

Figure. 4. Mechanical processing FMS composition scheme

Figure 5 shows the structural-kinematic scheme of the FMS's MS (mechatron set up) activity and the sequence of operations performed by the program-controlled equipment.

CM can move forward and backward on special supports. It operates with a universal-type handle on the arm of the MD installed on the CM with a trajectory of movement up and down on the vertical axis, and on the CM to the right and left.

[3] Mamedov , Dzh.F., Automatization of stages of the design of the layout of the production line for the technopark . System studies and information technologies, -Kiev:-2018, No. 3, p. 35-42.

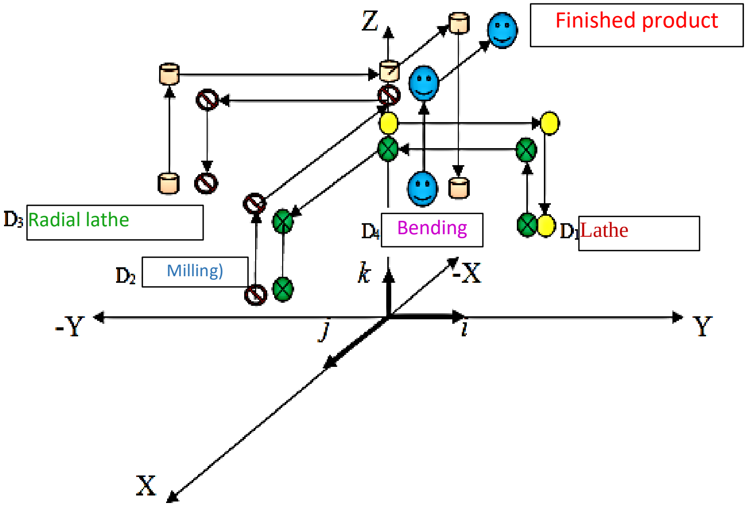

Figure 5. Motion trajectory of CM in FMS in 3-dimensional coordinate system

As can be seen from the kinematic-structural scheme of the operation of the FMS, the mechanical processing FMS to be designed passes the cylindrical mechanical part sequentially through mechanical processing procedureson four program-controlled machines PC (in processin centers-) and loads the finished product into the appropriate slot of the automated warehouse. The MS operating in three-dimensional space serves the RC in the following sequence (according to the kinematic scheme).

After being positioned on the PM (positioning manipulator) through the TM (transport manipulator), the raw material is picked up by the handle of the MS and transported to the working area of the LW; After performing mechanical processing procedures in LW, the purchased semi-finished product is transported by MD to the working area of MM; After the planned procedures in MM are performed, the newly purchased semi-finished product is transported by MS to the working area of RL, and after the planned procedures in RL are performed, the new semi-finished product purchased is transported by MS to the working area of BM, and after the procedures in BM are finished, the finished product It is taken from the working area of the BM and transported by the MS to the appropriate slot of the warehouse.

As a result of the analysis of the structural-kinematic scheme of the composition scheme and activity of the mechanical processing FMS, the following can be shown:

1. A FMS can be viewed as a set of four flexible manufacturing modules (FMM), each of which functions separately and in an integrated manner to achieve the ultimate goal.

2. Each FMM is treated as an asynchronous process, and the activity of the next FMM in the sequence of technological operations begins after the final result obtained in the previous FMM (principle of asynchrony).

3. In order to ensure the required productivity in the integrated operation of the FMS, it is allowed to operate individual FMM in the same time interval in permitted situations that do not harm the sequence of technological operations (parallelism principle).

4. As can be seen from the structural-kinematic scheme, the activity of each FMM is modeled by describing it as a finite automaton. The operation of the FMS in a complex way can be studied by modeling production rules and parallel asynchronous processes .

5. The results of the analysis show that the development of complex algorithms is required for the complex management of FMS. In most cases, they do not justify themselves in the final result, that is, in the stages of testing and application. Therefore, additional costs are required for re-design.

6. In order to solve the mentioned problem, it is relevant to study the feasibility of creation and management of FMS by computer modeling methods in a complex Petri net in the initial design stages.

For this purpose, the issues of creating databases and knowledge bases of mechatronic devices, equipment and other components of FMS were considered in the dissertation work.

The DB (database) of the FMS contains the types, characteristics, technical indicators, etc. of all its components. is created by entering parameters.

$$VB_{\text{FMS}} \in \{VB_{LW_1} \cup VB_{MM_2} \cup VB_{RL_3} \cup VB_{BM_4} \cup VB_{ATM_5} \cup VB_{SAofFP_6} \cup VB_{CM}\} \quad (1)$$

At the next stage, the issues of creating FMS and FMM are considered for the construction of algorithms of operation of KB (knowledge base) depending on the processing of KBMS (knowledge base management systems) in different situations and different raw materials.

In both stages, the technological operations performed by the CM are accompanied by the differentiation of the CM's movement routes and the calculation of logical predicates in the form (2) is performed.

$$(\forall P_i \in CM \text{ technological operations of}) \quad (2)$$

Taking into account the variety of mechanically processed designs, the issues of creating KB and KBMS software of software-controlled machine tools should be considered.

$$(\forall X_j \in \text{ Active elements of FMS of FMM}) \quad (3)$$

In order to analyze the dynamics of the technological process of the LW(lathe) FMM in the dissertation work, what happened in it P_i the sequence of events (technological operations) and the duration of occurrence of events t_j are considered for the calculation of logical predicates.

Production rules are used in the design of the FMS management system. The actions of the active elements of the FMS, their transmitters and the assignments of the execution mechanisms are formally described in tables 1 and 2.

A control algorithm is established based on selected transmitters and execution mechanisms of the active elements of the FMS [4].

The control algorithm built with the help of the production model con FMS ts of the elements of the application conditions (P_i) of the production core :

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[4] Nasirova, E.E., Issues of modeling the management functions of the flexible production system with different methods of knowledge representation.// Scientific news of SSU, Natural and Technical Sciences department, -2020, #3, -p. 63-69

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

where n is the number of terms.

The control algorithm of the process of moving the design along the technological trajectory with the help of a crane manipulator, loading it into the lathe and processing it can be described by the following production algorithm:

1. Algorithm of loading the LW FMM with CM(crane manipulator)

$P1$: ***if*** LW does not have T in PB (positioning block), ***then*** CM moves down;

$P2$: ***if*** CM has moved down and CM's handle is open, ***then*** CM's handle grabs RM;

$P3$: ***if*** the handle of CM has caught RM, ***then*** CM moves up;

$P4$: ***if*** CM moved up, ***then*** CM moves forward;

$P5$: ***if*** CM's arm has moved back and is in LW's working zone, ***then*** CM's handle should be opened and RM should be positioned in LW's PB;

$P6$: ***if*** RM is positioned in LW's PB, ***then*** CM should move back and start processing of RM in LW;

$P7$: ***if*** the processing operation of RM is started in LW, ***then*** the processing operation of RM in LW should be executed and finished in time t_i.

According to the production conditions shown in Table 2, a control algorithm is established with the help of logical symbols:

$(P_1)\rceil V_1^1 \Rightarrow \rceil IM_2^2;$

$(P_2)V_2^2 \& \rceil V_2^1 \Rightarrow IM_2^1;$

$(P_3)V_2^1 \Rightarrow IM_2^2;$

$(P_4)V_2^3 \Rightarrow IM_2^3; (P_5)V_2^5 \Rightarrow \rceil IM_2^1 \& IM_1^1;$

$(P_6)V_1^1 \Rightarrow IM_2^3 \& IM_3^1; \; (P_7)V_3^1 \Rightarrow \rceil IM_3^1.$

In the the FMS, the block diagram of the control algorithm of the loading of the lathe machine with the CM of the FMM is given.

In the example of LW, the transition sequence from the production rules to the Petri net and the development of the action algorithm of the CM as a result of the analysis of the properties of the

Petri net are considered.

For this purpose, to describe the activity of CM, dividing situations into events, appropriate for each event $P_i\,(i=\overline{1,9})$ let's define the predicates .

In this case, 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 are equal to each other, based on the input and output matrices, are determined by the well-known Gaussian method, and the Petri net of the Petri net of the activity algorithm of the lathe a graph is constructed in the form of (picture 6).

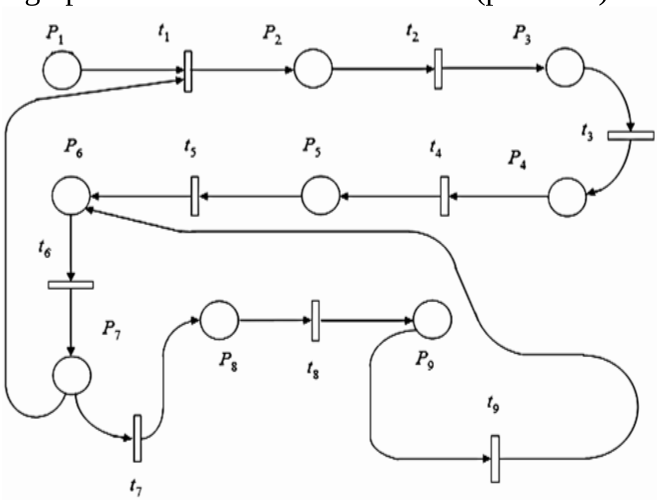

Figure 6. Petri net diagram of machining FMS activity

Table 1.
The designations of the transmitters of the MD of the FMS

Transmitters	**Types of technological operations**
Positioning block (PB) transmitters	
V_1^1	Layout positioning in PB of LW
V_1^2	Positioning of layout in PB of MM
V_1^3	Positioning of layout in PB of RL
V_1^4	Positioning of the layout in the BM of the PB
Crane manipulator (CM) transmitters	
V_1^2–V_1^2	Positioning of the CM handle in closed or open position accordingly
V_2^2	Positioning the CM in the lower position
V_2^3	Positioning of the CM in the upper position
V_2^4	Positioning of forward movement of CM
V_2^5	Positioning of the reverse movement of the CM
Lathe (LW) transmitters	
V_3^1	Positioning of the beginning of technological operation in LW
V_3^2	Positioning of the end of the technological operation in LW
Milling machine (MM) transmitters	
V_4^1	Positioning of the beginning of the technological operation in MM
V_4^2	Positioning of the end of the technological operation in MM
Radial bending machine (RL) transmitters	
V_5^1	Positioning of the beginning of technological operation in RL
$V_5^{\ 2}$	Positioning of the end of technological operation in RL
V_6^1	Positioning of the beginning of the technological operation in the BM
V_6^2	Positioning of the end of the technological operation in the BM

Table 2.
IM designations of FMS

Implementation mechanisms	**Types of technological operations**
Implementation mechanisms of the positioning block (MB) on the machines	
IM_1^1	Implementation of positioning of LW in PB
IM_1^2	Implementation of positioning of MM in PB
IM_1^3	Implementation of positioning in PB of RL
IM_1^4	Implementation of the positioning of the BM in the PB
Implementation mechanisms of the crane manipulator	
$IM_2^1, \urcorner IM^1$	Execution of positioning the handle of the CM in the closed or open position accordingly
$IM_2^2, \urcorner IM^2$	In the upper or lower position of the CM implementation of positioning
$IM_2^3, \urcorner IM^3$	Forward or backward movement of CM implementation of positioning
Execution mechanisms of machines	
$IM_3^1, \urcorner IM^1$	Implementation of the positioning of the initial or final states of the technological operation of the LW
$IM_3^2, \urcorner IM^2$	Implementation of the positioning of the initial or final states of the technological operation of the MM
$IM_3^3, \urcorner IM^3$	Implementation of the positioning of the initial or final states of the technological operation of the RL
$IM_4^3, \urcorner IM^3$	Implementation of the positioning of the initial or final state of the BM technological operation

Table 3.
Predicates corresponding to the situations of FMM activity

Predicates	Definition of predicates
P_1	- CM handle being open;
P_2	- having a layout in the layout positioning zone;
P_3	- downward movement of the CM to the layout positioning zone;
P_4	- Capturing the layout by the CM's gripper;
P_5	- CM moving up;
P_6	- CM moving forward;
P_7	- Placing and positioning of the layout on the LW positioning block by the CM;
P_8	- CM moves back and starts processing operation in LW;
P_9	Completion of the processing operation of the layout in LW;
According to the predicates, the following active actions-transitions are suitable $t_j\ (j = \overline{1,9})$:	
t_1	- The handle of the CM does not work (it is open);
t_2	- the positioning zone of the layout is active (there is a layout);
t_3	- CM works (moves down);
t_4	- CM's handle works (closes);
t_5	- CM works (moves up);
t_6	- CM is working (moving forward);
t_7	- LW positioning block works;
t_8	- LW is running (processing operation is started);
t_9	- LW is running (processing operation ends).

In the the FMS, the algorithm for converting the representation of the automatic transport manipulator, which transports raw materials to the working zone of the crane manipulator with a finite state machine, into a Petri net was also developed.

In the fourth chapter, the implementation issues of the algorithm for the study of controlling the computer model of the mechanical processing FMS with the Petri net were considered. For this purpose, in the second chapter, the architecture of ADT was developed for a specific research object - mechanical processing FMS, taking into account the requirements of the generalized architecture of ADT. Note that the generalized architecture of ADT is an open system, and depending on the properties of the research object, different structures of ADT can be flexibly formed without damaging the generalized structure.[5] (figure 7) .

As can be seen from the architecture of the ADT of mechanical processing FMS, taking into account the sequence of FMS activity, the control algorithm of each of its components is selected from KB at the subject level and transformed into a Petri net with a suitable Petri net conversion algorithm, and KB is created at the mathematical level. This sequence can be shown as follows.

Algorithm

The first stage

Step 1 . Transforming the control algorithm of the automatic transport manipulator with a finite automaton into a Petri net model and keeping it in KB at the mathematical level (N_1)[6].

Step 2. Conversion of the production rules algorithm of the loading of the FMM1 (Lathe) by CM into a Petri net model and stored in KB at the mathematical level (N_2).

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

Step 4. Conversion of the production rules algorithm of the loading of FMM3 RDP (radial drill press) by CM into a Petri net model and stored in KB at the mathematical level (N_4).

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

Step 6. Conversion of the production rules algorithm of the automatic loading of the finished product into the warehouse by CM

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[5] Ahmadov, MA, Mammadov, CF, Nasirova, E.A. Development of a comprehensive study of the architecture and activity of the automated design tool of the flexible production system with a Petri net //-Baku: News of Azerbaijan Higher Technical Schools. ADNSU, -2022. volume 19. #1, p. 4-14

[6] Akhmedov M.A., Huseynzade Sh.S., Nasirova E.A. Development of an algorithm for automating the transformation of a finite automaton into a Petri net /Automation Modern technologies Moscow, 2019, No. 3, pp. 108-112, РИНЦ

into a Petri net model and stored in KB at the mathematical level (N_6).

Subject level knowledge base

1. Database of MS and equipment of mechanical processing FMS
2.Mechanical processing FMS FMMs and FMS composition schemes
3. Knowledge base of production rules and operating algorithms of loading of finished product warehouse by CM of FMM of mechanical processing FMS
4. Knowledge Base of the Algorithm of the Finite Machine Description of the ATM Action Algorithm of Mechanical Processing GIS
5. The knowledge base of control algorithms with digital software depending on the type of design of the machines of FMM

1. Knowledge base of algorithms for transforming the description of crane manipulator activity with production rules into a Petri net model
2. Knowledge base of algorithms for transforming the description of the ATM activity into a Petri net with a finite automaton

Petri net transformation algorithms knowledge base

N_1 , N_2 , N_3 , N_4 , N_5 , N_6

Knowledge base at the mathematical

$$N = \{P, T, I, O, M_6\}$$

$$N \in \{N_1 \cup N_2 \cup N_3 \cup N_4 \cup N_5 \cup N_6\}$$

Assessment of the adequacy of management algorithms as a result of the analysis of Petri net properties

Forming management software blocks with Petri nets separately

Figure 7. Architecture of ADT of mechanical processing FMS

Step 7. As $(N_1, N_2, N_3, N_4, N_5, N_6)$ a result of the analysis of the properties of each Petri net separately, the evaluation of the appropriateness of the application of control algorithms by researching with computer experiments .In the thesis, the mechanical processing is an analysis of the working dynamics of the technological process with an animation model to study the productivity of the automated operations of the FMS. Building an animation model allows the researcher to study the issues of management, control, and planning of the product development process in more accurate ways.

In this work, a computer model of mechanical processing FMS, a complex coordinated and synchronized action algorithm with a Petri net has been developed. It has been shown that the correctness of the control algorithms proposed in the previous chapters with computer experiments and their representations with Petri nets allow to achieve the required goal, which provides an investigation at the initial design stage. At the same time, with these experiments, it is possible to confirm the possibility of the operation of the mechanical processing FMS in a complex manner in the sequence indicated in the kinematic scheme, and it is possible to assess that it is appropriate to carry out the next stages of the design process.

Other requirements are also imposed on the management algorithm of the FMS in a real object in a complex manner with a Petri net:

- MD and equipment of FMS meet in common working zones during their operation, and their mechanical nodes can create emergency situations in working modes. Therefore, it is necessary to ensure that accidents do not occur in such possible situations;
- The requirement to ensure the operation of FMMs and MDs in asynchronous modes and to have high productivity without interfering with each other, waiting for the principle of parallelism, must be met;
- If an emergency situation occurs in any FMM, the subsequent procedures should be continued until the final result and an emergency signal should be given.

Tables 4 and 5 show the designations of the execution mechanisms that perform the execution of decisions in the management of the FMS and the designations of the transmitters installed in the various nodes of the FMS. Mechanical processing is developed in the form of a knowledge base of its complex coordinated and synchronized action algorithm using the FMS database designations.

Table 4.

Designations of transmitters of mechanical processing FMS (Database)

Signal output signal of the transmitter	Determination of the output signal of the transmitter
1	2
$X1$	The presence of the raw material on the positioning manipulator
$X2$	Recent status of ATM
$X3$	Availability of raw materials in the working area of ATM
$Z1$	The CM is on the positioning manipulator (PM). (initial state)
$K1$	The handle of the CM is in the up position
$K2$	CM's handle is open.
$Y1$	Availability of raw materials in LW working are
$Y2$	The presence of semi-finished products in the working area of PM
$Y3$	The presence of semi-finished products in the working area of RL
$Y4$	The presence of a semi-finished product in the working area of the BM
$Y5$	The finished product storage slot is empty
$Y6$	FMM1 performs processing operations.
$Y7$	FMM2 performs processing operations
$Y8$	FMM3 performs processing operations
$Y9$	FMM4 performs processing operations
$Y10$	ATM works
T_{LW}	LW processing time timer
T_{MM}	MM processing time timer
T_{RL}	RL processing time timer
T_{BM}	MM processing time timer
T_{ATM}	ATM processing time timer

Table 5.
Designations of mechanical processing GIS implementation mechanisms (database)

Implementation mechanism sign	Designation of enforcement mechanism
1	*2*
$U1$	Instead of the control software block of the N1 Petri net fulfillment
$U2$	Instead of the control software block of the N3 Petri net fulfillment
$U3$	Instead of the control software block of the N4 Petri net fulfillment
$U4$	Instead of the control software block of the N4 Petri net fulfillment
$U5$	Instead of the control software block of the N5 Petri net fulfillment
UGIS	Initial state of machining GIS
$U6$	Instead of the control software block of the N6 Petri net fulfillment

Algorithm

(P1) If the raw material is not on the positioning manipulator (MM) AND there is a finished product in the working area of the automatic transport manipulator (ATM) AND the ATM is in the final position

Then connect the ATM's $N6$ Petri net control unit AND start the ATM's runtime timer.

$$(P1) \rceil X1 \& X3 \& X2 \Rightarrow U6 \& T_{ATM} = r$$

(P2) If there is raw material on the PM AND the ATM is in the final position, the crane manipulator (CM) is ready for the working position ($W = Z1 \& K1 \& K2$; $Z1 - CM$ is on the PM, $K1$ the handle is up and $K2$ -the handle is open) AND there is no raw material in the working area of the lathe (LW) AND the flexible production module 1 (FMM1) is not processing

Then the execution mechanism of the CM $N1$ Petri net block should be activated

$$(P2)\, X1 \,\&\, X2 \,\&\, Z1 \,\&\, K1 \,\&\, K2 \,\&\, \neg Y1 \,\&\, \neg Y6 \Rightarrow U1$$

(P3) If there is raw material in the working area of the LW AND the CM $N1$ has executed the Petri net-program block AND the processing operation is not executed in FMM1 AND the CM is ready for the working state

Then start the processing operation on FMM1 AND start the timer of the runtime of FMM1

$$(P3) Y1 \,\&\, \neg U1 \,\&\, \neg Y6 \,\&\, Z1 \,\&\, K1 \,\&\, K2 \Rightarrow Y6 \,\&\, T_{LW} = k$$

(P4) If the machining operation is completed in FMM 1 AND T_{LW} is zero AND there is a semi-finished product in the working zone of LW AND CM is in working state

Then the execution mechanism of the N2 Petri net software block should be activated

$$(P4) \neg Y6 \,\&\, \neg T_{LW} = 0 \,\&\, Y2 \,\&\, Z1 \,\&\, K1 \,\&\, K2 \Rightarrow U2$$

(P5) If the execution mechanism of N2 has completed its work AND there is a semi-finished product in the working zone of the FD AND the processing operation is not performed in FMM 2 AND the CM is in the working state

Then start the FMM 2 processing operation AND start the FMM 2 processing time timer

$$(P5) \neg U2 \,\&\, Y2 \,\&\, \neg Y7 \,\&\, Z1 \,\&\, K1 \,\&\, K2 \Rightarrow Y7 \,\&\, T_{MM} = i$$

(P6) If the machining operation in FMM 2 is completed AND the condition $T_{MM}=0$ is satisfied AND there is no semi-finished product in the working zone of the radial turning machine (RTM) AND the CM is ready for working state

Then the execution mechanism of the program block of the N3-Petri network should be started

$$(P6) \neg Y7 \,\&\, \neg T_{MM} = 0 \,\&\, \neg Y3 \,\&\, Z1 \,\&\, K1 \,\&\, K2 \Rightarrow U3.$$

(P7) If the execution mechanism of N3 has completed its work AND there is a semi-finished product in the working zone of the RL AND the processing operation is not performed in FMM 3 AND the CM is in the working state

Then start processing on FMM 3 AND start the FMM 3 processing timer

$$(P7)\ \rceil U3\,\&\,Y3\&\rceil Y8\,\&\,Z1\,\&\,K1\,\&\,K2 \Rightarrow Y8\,\&\,T_{RL}\ =\ j$$

(P8) If the machining operation is completed in FMM 3 AND the condition $T_{RL} = 0$ is satisfied AND there is no blank in the working zone of the bending machine AND the CM is in the working state

Then let the N4 Petri net software block execution mechanism start

$$(P8)\ \rceil Y8\&\rceil T_{RL}\ = 0\&\rceil Y4\,\&\,Z1\,\&\,K1\,\&\,K2 \Rightarrow U4$$

(P9) If the execution mechanism of N4 has completed its work AND there is a semi-finished product in the working zone of the BM AND the processing operation is not being performed in FMM4 AND the CM is in the working state

Then start the processing operation in FMM4 and start the processing period of FMM4

$$(P9)\ \rceil U4\,\&\,Y4\&\rceil Y9\,\&\,Z1\,\&\,K1\,\&\,K2 \Rightarrow Y9\,\&\,T_{BM}\ = m$$

(P10) If the processing operation in FMM4 is completed AND the condition $L_{BM} = 0$ is met AND there is no finished product in the working zone of ATM AND the ATM is in the final state

Then let the execution of production (P1) be performed

$$(P10)\ \rceil Y9\&\rceil T_{BM}\ = 0\&\rceil X3\,\&\,X2 \Rightarrow (P1)\,.$$

The texts of the models and algorithms implementation programs proposed and developed in the dissertation work are included in the appendices of the work.

As can be seen from the algorithm, the mechanical processing is realized through five logical-linguistic models (LLM) formed by the production rules of FMS management:

1. $(P)X1\rceil\,\&\,Y1\rceil\,\&\,Y2\rceil\,\&\,Y3\rceil\,\&\,Y4\rceil\,\&\,Y5\rceil\,\&\,Y10\rceil\,\&\,K1\,\&\,K2\,\&$

$\&\,Y6\rceil\,\&\,Y7\rceil\,\&\,Y8\rceil\,\&\,Y9\rceil \Rightarrow V_{\mathrm{FMS}}\,.$

2. ATM's LLM con FMS ting of P1 production rule;

$$(P1)\ \rceil X1\&\,X3\,\&\,X2 \Rightarrow U6\,\&\,T_{ATM}\ = r$$

3. LLM con FMS ting of production order P2, P3 of FMM1 (LW);

$(P2) X1 \& X2 \& Z1 \& K1 \& K2 \& \neg Y1 \& \neg Y6 \Rightarrow U1$

$(P3) Y1 \& \neg U1 \& \neg Y6 \& Z1 \& K1 \& K2 \Rightarrow Y6 \& T_{LW} = k$

4. LLM con FMS ting of production rule P4, P5 of FMM2 (FD);

$(P4) \neg Y6 \& \neg T_{LW} = 0 \& Y2 \& Z1 \& K1 \& K2 \Rightarrow U2$

$(P5) \neg U2 \& Y2 \& \neg Y7 \& Z1 \& K1 \& K2 \Rightarrow Y7 \& T_{MM} = i$

5. LLM of FMM3 (RL) con FMS ting of production rule P6, P7;

$(P6) \neg Y7 \& \neg T_{MM} = 0 \& \neg Y3 \& Z1 \& K1 \& K2 \Rightarrow U3$.

$(P7) \neg U3 \& Y3 \& \neg Y8 \& Z1 \& K1 \& K2 \Rightarrow Y8 \& T_{RL} = j$

6. LLM con FM Sting of P8, P9, P10 production order of FMM4 (AD);

$(P8) \neg Y8 \& \neg T_{RL} = 0 \& \neg Y4 \& Z1 \& K1 \& K2 \Rightarrow U4$

$(P9) \neg U4 \& Y4 \& \neg Y9 \& Z1 \& K1 \& K2 \Rightarrow Y9 \& T_{\mathrm{BM}} = m$

$(P10) \neg Y9 \& \neg T_{BM} = 0 \& \neg X3 \& X2 \Rightarrow (P1)$.

Offer which is of the algorithm main duty from him con FMS ts of that his instead of fulfillmentin the facility the head the giver to situations suitable knowledge based on to the situation suitable execution forms teams. So formed through six LLM the control algorithm periodically detects situations in the machining FMS, asynchrony and parallelism principles damage without bringing of FMS management to be instead ofgives

RESULTS

1. With Petri nets of technical systems whose activities are described by knowledge of research to experience and literature sources referring to of the overview available the purpose of the dissertation by summarizing the results of the investigation of the situation formed and at work solution demand which is issues is defined.

2. In the initial design phase of the FMS in a complex way - constructive and Computer management, modeling and feasibility of creation experiments with research automated design of the instrument proposed generalized architecture done and processed.

3. A computer of FMS whose activities are described by knowledge of various purposes of models management Petri of the network main properties analysis with The automated design tool research is summarized with experiments proposed architecture and processed.

4. Automated processing of FMS was selected as a research object subject-level production of FMMs in the architecture of the design tool the rules and automatic transport manipulator finite automaton in the form of knowledge bases created, their Petri to the network conversion algorithms offer being done processed. of the ADT mathematical level all Petri of FPMs and ATM network in the form of management program from the blocksThe computer model of the FMS was studied and designed using experiments expediency evaluated.

5. Mechanical processing is complexly coordinated in real-time FMS, I mean technological of operations in sequence next of FMM of the activity from himselfin the previous one received the end from the result after start (async principle) and synchronized, that is, permission without disturbing the sequence of technological operations given situations separately of FMMs the same time in the interval activities providedbased on the rules of production (principle of parallelism), a knowledge base was created in the form of logical-linguistic models and FMS management algorithm processed.

6. Ink character, numerous information-measurement, management and regulationfrom their connections consisting of which

is mechanical processing of FMS system technician General software developed for designing and mechanical processing of FMS automated operations of productivity the working dynamics of the technological process were studied.

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Author’s individual participation in the published works

[1] – Justification of the relevance of the problem. Creating a database on the example of a real object and creating a knowledge base based on production rules using it.

[2] – The general architecture of the study of the computer model of the FMS by animation methods was developed.

[3] – The architecture of ADT for the Petri net study of the complex management of FMS with analytical models of various purposes was proposed and developed.

[4] – An example of transforming a dynamic mechatronic device described by a finite automaton into a representation by a Petri net has been worked out.

[5] -Development of the conceptual model of the current state of the area selected as a research object and the structural-kinematic scheme of its management with modern automation tools

[6] – Realization of the algorithm of transforming the object whose action is described by a finite automaton into a Petri net

[7] – Determination and analysis of the requirements for the modeling of the operation route of the crane-manipulator in the mechanical processing flexible production system and the control algorithm

[9]-Development of the computer model and structural kinematic scheme of the mechanical processing area selected as a research object for the comprehensive investigation of the operation of the FMS with a Petri net

[12]–Establishment of the knowledge phase of the ADT interface of the FMS

Development of the software structure of the control of mechatronic devices of FMS

[14] - Setting the case and developing the architecture of the computer model of the automated design tool of the flexible production module and its realization in the complex application of mechanical processing FMS.

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