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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

INVESTIGATION OF FLEXIBLE MANUFACTURE SYSTEM BY MEANS OF IMITATION MODELLING AND PETRI NET

Specialty: **3338.01 - System analysis, management and information processing**

Field of science**: Technical sciences**

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GENERAL CHARACTERISTICS

The actuality of the subject. As known the classical design structure of objects consists of the following basic stages: planning, scientific research, design, production, testing and operation of the object.

Experience shows that the life of the projected facility (the “life span”) depends largely on the duration of the pre-commissioning phases. The modern level of science and technology, as well as the widespread use of information and communication technologies in all areas, allows automating all or part of the design process. Therefore, the effective use of automation techniques in pre-commissioning design phases will significantly increase the life expectancy of the projected facility.

The experience of designing complex objects, including flexible manufacture systems (FMS) of this category, shows that this is more evident in their application to real objects. This is due to the fact that FMS must operate in real-time to achieve the ultimate goal, with a large number of interconnected dynamic mechatron devices. Therefore, in the initial design stages, the designers' ideas do not justify themselves in the use of physical models that are ultimately naturalized, which increases the cost of re-design and the design stages. In some cases, as a result of artificial extension of the design time, the physical and spiritual "aging" of the projected object may occur.

One of the most effective and promising areas of problem solving is the design of the object at the initial design stage, using modern modeling techniques and computer experiments, and evaluating the feasibility of the object design.

From this point of view, the theme of the thesis is dedicated to solving the urgent problem.

The purpose of the dissertation work is investigation of the feasibility of creating FMS that cutting aluminium sheets on per parts, mechanical cleaning their surfaces at the initial of its design stage to by means of investigation on imitation modelling, animation method and development of management algorithm with Petri net .

To achieve this goal the following tasks are identified in the dissertation work:

- Working out architecture of computer aided design tools (CADT) by means of research of the manufacture system with imitation modelling (IM);
- For determining, researching the requirements on computer aided design of FMS, selection of IM system and definition of the functions that need to perform;
- Development of a conceptual model of manufacture field and structural schemes of FMS which cutting aluminium sheets on per parts, mechanical cleaning their surfaces and development of CADT architecture of imitation modelling of FMS;
- Creation of databases, knowledge base and basis of animation descriptions of FMS IM, conducting computer experiments and descriptions of conclusions by means of animation methods;
- Creation of FMS imitation model by means elements of the Petri net and description of the conclusion of FMS management system with time of the Petri net;
- Creating knowledge base of the FMS management system with data and production rules and development of an applying algorithm for IM conclusions into automatic control of FMS physical model.

Research methods. To solve the presented tasks, with progressive modelling methods, concretly IM apparate for complex discrete system applieng, there were used artifical intelligence elements, the methods of data and knewleadge description, theory of automation and automatic control methods and theory of Petri net.

The main provisions for scientific protection are:

- Rationale for evaluating the feasibility of setting up a system in order to increase the design efficiency of complex discrete production systems at the initial design stage;
- Development of a generalized architecture of the CAD for the research of complex discrete manufacture system with IM;
- Development of a conceptual model and structural-kinematical scheme of selected as the research object is FMS that cutting aluminium sheets on per parts, mechanical cleaning their surfaces;
- Justifying the selection of the RAO-studio software package operating in the RDO environment in a view imitation modelling of FMS based on the proposed and improved CAD architecture of the IM;
- Development of FMS imitation modelling algorithm;
- Development and implementation of computer simulations with the creation of databases, knowledge, and animation databases of FMS and animation of imitation conclusions;
- Describe of the conclusions of the creation and management of FMS by means of the elements of the Petri net with the time of Petri net;
- Creation of databases and knowledge base for application of imitation modelling FMS conclusions at its development of management algorithm.

Scientific innovations. The scientific novelty of the dissertation work are the follows:

- CAD architecture for the researching of complex discrete manufacture system with imitation modelling has been proposed and developed;
- The requirements for computing design of FMS that consists to the category of complex discrete manufacture systems have been defined, and it was justified a sellection of the RAO-studio software complex operating in the RDO program area as imitation modelling apparate;

- At the initial design stage, feasibility of creating FMS has been substantiated with immitation model and the architecture of the FMS was proposed and developed;
- FMS for cutting aluminium sheets on per parts, mechanical cleaning their surfaces optioned as a research object, was researched with computer experiments of IM and imitation conclusions were presented with animation methods;
- Immitation model of FMS were created with elements of the Petri net and the conclusions of their management were described by time of the Petri net;
- To research automatic control of FMS worked at real time rejime, immitation modelling conclusions like data and production rules, knowledge have been created and management algorithms have been developed.

Practical significance of the work and application of results.

Dissertation work's results can be used to increase the efficiency of design stages of complex discrete systems of different purposes, to assess the feasibility of creating new designed objects in the initial design stages, to perform computer experiments using IM methods and to develop computing design or automated control algorithms for discrete processes. The results of the dissertation work used for executing of the laboratory works of the methodical aid "Research of the results of computer modeling by the animation methods" approved by the order of the Ministry of Education of the Republic of Azerbaijan dated 04.09.2014 No. 962 in the Engineering phaculty of Sumgait State University.

Approbation of the dissertation work. The results of scientific research carried out in the dissertation were presented and discussed at international and national conferences and symposiums: Riyaziyyatın tətbiqi məsələləri və yeni informasiya texnologiyaları.Respublika elmi konfransının (Sumqayıt-2007); VII Mezinarodni vedecko-prakticka conference.Aktualni vymozenosti(Praha-27.06.2011– 05.07.2011); Riyaziyyatın tətbiqi məsələləri və yeni informasiya texnologiyaları II Respublika elmi konfransı.(Sumqayıt,27-28 noyabr 2012); Avtomatika və idarəetmənin müasir problemləri. Respublika elmi-praktik konfransı (dekabr, 2012-ci il ,AzTU); II научно-практической конференции «Новые технологии и проблемы технических наук» (Красноярск, 10 октября, 2015); İqtisadiyyatın davamlı inkişafı problemləri, perspektivlər, Beynəlxalq elmi konfrans (Sumqayıt,27-28 aprel 2016); Прикладная наука как инструмент развития нефтехимических производств- Международная научно-практическая конференция посвященной дню Химика и 40-летию кафедры химико-технологических процессов филиала Уфимского государственного нефтяного технического университета в г.Салавате (Уфа-2017); Tətbiqi fizika və energetikanın aktual məsələləri.Beynəlxalq elmi konfrans (Sumqayıt−2018); 62-я Международная научная конференция Астраханского государственного технического университета (Астрахан, 23 -27 апреля 2018 года); İnformasiya sistemləri və texnologiyalar nailiyyətlər və perspektivlər beynəlxalq elmi konfrans (15-16 noyabr 2018, Sumqayıt −2018); Научно-практическая конференция с международным участием "Инженерные системы - 2019"(Москва, 03-05 апреля 2019 г); САПР и моделирование в современной электронике. III Международная научно-практическая конференция (Брянск, 24-25 октября 2019).

Name of the organization where the dissertation work is performed. The dissertation was completed at the Department of Information Technology and Programming of Sumgayit State University.

Personal presence of the author. The author indicates the main goals of the research and the tasks set to achieve them, and identifies the directions of research.

The idea of researching complex production systems with simulation and description of results by animation methods was given. The algorithm of functional research of agile production management system for supporting the raw material with the required dimensions by means of knewleadge on production model rules were developed. Using the RAO-studio software complex, the algorithm for simulation modeling of agile production system, the architecture of a generalized automated design tool for simulation of complex systems were developed. Implementation of automated design of flexible manufacture system with Petri net was carried out. The results of comparative analysis of complex systems with computer modeling and use of artificial intelligence elements were summarized and research work on simulation of computer modeling results was carried out.

The published scientific works. 23 scientific works on the topic of the dissertation including articles in 9 prestigious scientific-practical journals, tezis in 14 International and Republican conferences and symposiums were published.

The structure and scope of the dissertation. The dissertation consists of an introduction, four chapters, a list of 124 titles and appendices. The volume of the main content of the work consists of 178896 characters without tables, pictures, and bibliography. Including: Introduction - 20056 signs, Chapter - 56792 signs, Chapter II - 34190 signs, Chapter III - 42966 signs, Chapter IV - 23226 signs, Conclusion - 1666 signs.

MAIN CONTENT OF THE WORK

The introduction substantiates the relevance of the topic of the dissertation, identifies the purpose of the research and the issues that need to be addressed. Research methods, scientific innovations, main provisions of the defense, practical significance of the work and application of the results, approbation of the work, scientific publications and summary of the work by chapters are given.

The first chapter is devoted to the study of the current state of the problem and the problem statement. For this purpose, the analysis of the application of simulation modeling in the study of technology processes with reference and experience, comparative analysis of modern simulation modeling software packages, animation methods and description of the results of simulation modeling with Petri network were considered.

Imitation modeling appeared at the beginning of the computer age and has not lost its relevance to this day. But the method imitation modeling has gone through a great evolutionary process and has become one of the leading tools of scientific research for complex technical system like a flexible manufacture system that characterizes a large number of structural elements interacting functionality, informative and technological with each other.

In order to increase the efficiency of IM, to prevent the large number of errors that may occur in the stages of its creation, it is important to develop computer-aided systems that perform structural analysis of the system and describe complex systems with functional and planning diagrams.

The considered method is presented as a multivariate approach to the simulation modeling of complex systems and structurally modified models based on a common information base is proposed. The proposed approach is like to the idea of structural and object-oriented programming methods.

Thus, in the first stage, a basic imitation model of a complex system is created. Modifications to the base model are required when performing simulation experiments. Such modification is performed by maintaining the structure of the base model and adding new functional modules based on the pre-created extended interface. The high level of indicators is determined by the dynamics of increasing the amount of information obtained as a result of the experiment on the characteristics of the system.

A systematic integrated approach should be used in the design of complex discrete production systems, including FMS belonging to this category. When constructing a conceptual model, the relationship between the issues needed for research and the structure of the model must be clear. When constructing a complete model of a production process, it may not always be related to some properties of the system. In addition, depending on the nature of the problem, both the approach to modeling and the research method may change. Thus, the two aspects of FMS simulation - complexity and detail on the other hand - do not interfere with the possibility of purposeful simplification, and achieve a block configuration of the model in accordance with the structure and parameters of the object under study. During the study of FMS on the model, its various parameters are determined by the results of structural and parametric synthesis, standards and prototypes, empirical data or by expert. Then, during the modeling process, "weaknesses" in the system are identified, the defined parameters are corrected, and as a result, the final values are found. The output information of any type of model can be given in the form of text, tables, histograms, graphs, cyclograms, as well as in the form of relevant information on the screens of graphic displays.

The study of the application experience and design trends of flexible production systems shows that they have the following main features:

- mechanical control of each mechatron device (MD), as well as flexible manufacture modules (FMM) consisting of their sets, independent of each other and operating in two-dimensional or three-dimensional space interacting in common working zones considered as a dynamic system; it is purposefully planned to achieve the goal set for the FMM taken separately, and ultimately serves to achieve the goal of the FMS;

- All MD of the FMM operate on the principle of mutual agreement, ie the transition from one stable state to another can be carried out only after the completion of the previous transition;

- It is possible to have non-contradictory transitions in several mechatron devices (principle of parallelism);

- The continuity of transitions is not regulated in the MD (asynchronous principle).

It was noted that there are a number of unresolved issues in the use of artificial intelligence elements in IP, including:

- the joint work of many creative, multi-purpose and professional professionals to translate the problem in the IM process at a professional level into mathematical language is required;
- on the other hand, the control system itself which is an integral part of the modeled complex discrete production system, belongs to the category of complex systems, and there is a need to model the control system with IM and study it by computer experiments.

The creation and use of intelligent IM systems is becoming more urgent in order to eliminate such problems.

Summarizing the above, the purpose of the dissertation was formed and the issues that need to be addressed to achieve this goal were identified.

The second chapter deals with the research of complex production systems by IM methods in the initial design stages. For this purpose, the design stages of production systems and ways to increase their efficiency are considered. It is noted that the life cycle of the projected facility, ie the period of operation, depends on the implementation of the pre-operational stages. It is noted that the problems mentioned in the design of facilities in the form of FMS are even more complex at the stage of their application to real production.

A promising direction for solving the problem is to assess the feasibility of designing by computer experiments using modern automation and modeling methods at the initial design stage. It is shown that one of the effective methods for this purpose is IM. For the application of IM in complex production systems and the study of processes, the generalized architecture of IM computer aided tool is proposed and developed in this chapter (Figure 1)[1]. As can be seen from the architecture, the research with the simulation modeling of production systems is carried out as a result of joint activities of specialists of different purposes. At the level of the research object, the structural model of the object to be studied is studied by a specialist in the selected field. The structural model includes typical models of dynamic devices and auxiliary equipment included in the object, their functions, basic technical characteristics. In most cases, static analysis of the object under study is required before IM. This process should provide more knowledge about and reduce the number of errors in IM. Static analysis is performed at relatively simple facilities as a result of joint work of technologists and experts in the date field. CASE technologies are widely used at statical analysis in complex IM.

Since FMS which belongs to the category of complex production systems, was accepted as the object of research, the requirements for their automated design were determined, and for this purpose, the use of IM and the expediency of depicting the results of imitation by animation methods were shown. RAO-studio software package operating in RDO environment was selected for the study of FMS with IM and some features of the software package were clarified.

The choice of RAO-studio software package is based on the fact that this system allows you to simulate a two-dimensional space and simulate the results. On the other hand, since the management of FMS belongs to the category of complex systems, the RAO-studio software complex allows the construction of FMS with elements of

1.Əhmədov,M.A., Əhmədova,S.M. Mürəkkəb sistemlərin imitasiya modelləşdirilməsilə tədqiqinin avtomatlaşdırılmış layihələndirmə alətinin arxitekturasının işlənməsi // "Tətbiqi fizika və energetikanın aktual məsələləri" Beynəlxalq elmi-texniki konfransın materialları,- Sumqayıt: -24 may-25 may, 2018, -s.381-383.

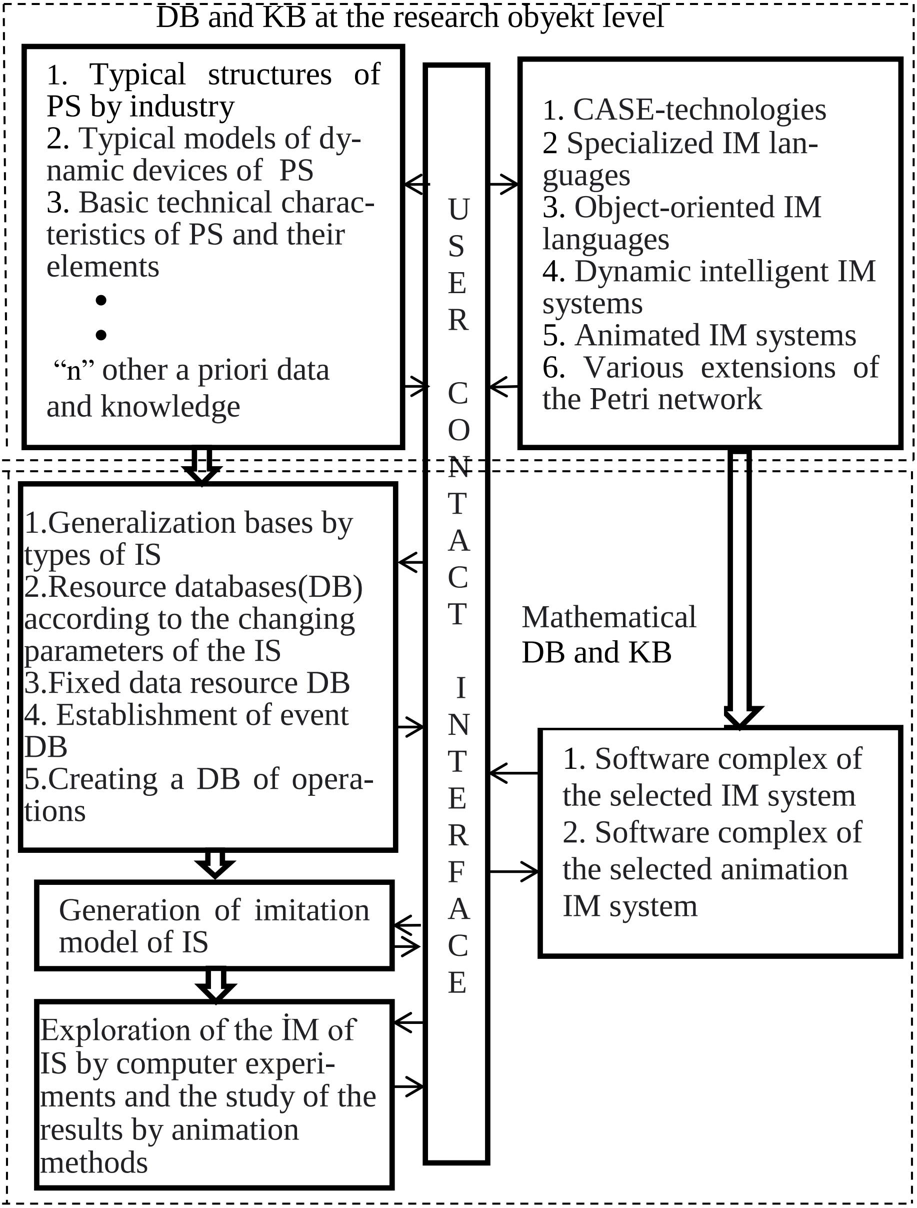

Figure 1. Architecture of computer design tool for research of the flexible manufacture system with imitation model

the Petri network of IM, the implementation of the control algorithm with the Petri network over time and its dynamics.

The third chapter is devoted to the research of FMS, which processes flat surface raw materials, by IM and computer experiments. The issues of modeling and management of the FMS selected as the object of research are considered at the initial design stage.

As a result of the analysis of the production area, a conceptual model of the processes taking place in the system was formed and the main requirements for the production area were determined: the dimensions of the layers and boards should not exceed the standard norms; it is inadmissible for personnel to touch the surface of the cleaned sheets or contaminate them with other means and it creates a basis for waste ones; the productivity of the production area should be synchronized with the work of the previous and subsequent manufacture modules and managed by coordinate manner with whole productivity supporting.

Taking into account the requirements for the conceptual model and the production area, the structural-kinematic scheme of the FMS was developed (Figure 2)[2].

The proposed structural-kinematic scheme of the investigated FMS using modern automation means consists of mechatron devices, processing machines, main and additional equipments:

- automatically controlled guillotine shears for cutting G1-raw materials into the requipment size sheets;
- transport system (TS1) that transports the raw material G1 to the working zone and the other layers to the table of the positioning manipulator (PM1) which is the working zone of the 1st industrial robot (IR);
- industrial robot (IR1) loading TS2 by turning the layer 180^0;

2.Ахмедов, М.А. Разработка архитектуры инструмента автоматизированного проектирования имитационной модели гибкого производственного модуля /М.А.Ахмедов, С.М.Ахмедова// Системы управления и информационные технологии,-Москва-Воронеж:-2015. №4.1(62), – с. 104-107

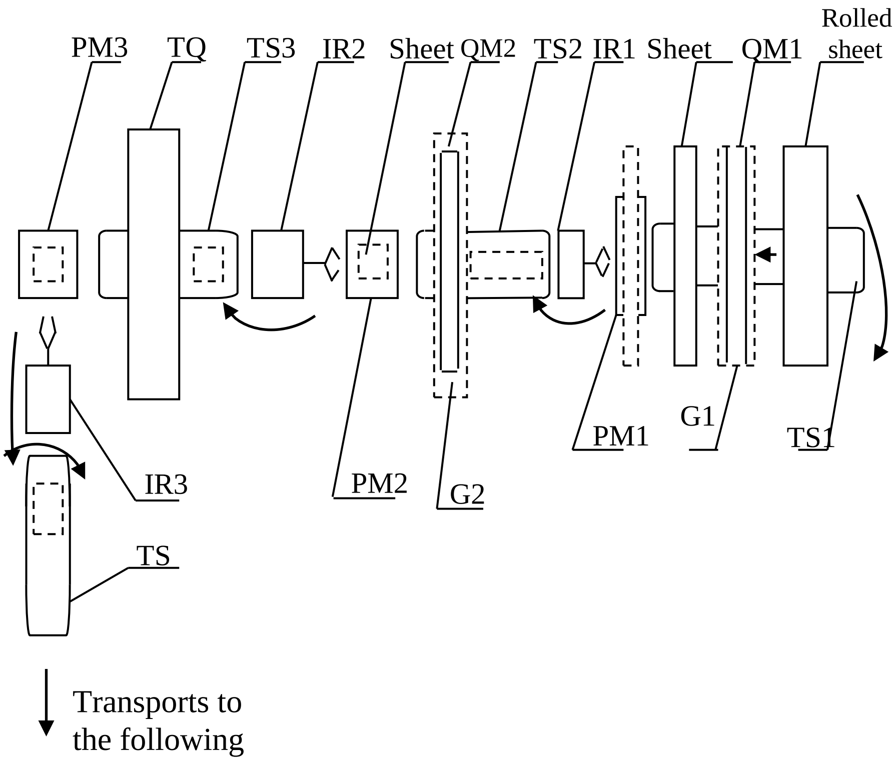

Figure 2. Structural-kinematic scheme

- TS2, which transports the sheets to the working zone of G2 and the sheets to the table of PM2;
- TS3 that loading the sheets from the PM2 desk into the working area of the cleaning device (CD) and also TS3 that loading the surface cleaned sheets from the PM3 desk;
- IR3 loading the cleaned sheets into the working area of TS4 which transports the cleaned sheets to the next manufacture module.

RAO-studio software package in RDO language was used for IM study of the selected research object. RAO-studio software complex allows to describe on a computer the problems of systematic analysis and synthesis of objects of different purposes, decision-making in a complex control system and the dynamics of the object.

In essence, the implementation of objects and control algorithms in the RAO-studio software complex is carried out using the descriptive languages of knowledge. In this case, after each event, the decision-making system checks the production rules in the knowledge base (KB) and indicates the beginning of the appropriate action by influencing the chosen rule when the condition is met. Thus, the production system, together with the block of imitation of irregular events, builds a production model and calculates the required performance of the system as a result of the analysis of the results of the imitation. The animation system displays the results of the imitation as the activity of the modeled object on the monitor screen.

Figure 3 shows the architecture of the proposed computer aided designing tool of the FMS imitation modelling operating in the environment of the RAO-studio software complex.

Taking into account the needs of the RAO-studio software complex, the following databases are created in the computer aided designing tool: a generalized database by type of MIS resources; resource base of FMS according to the values of variable parameters; events base; operations base, implementation of FMS imitation modeling and creation of FMS imitation model description bases.

In modeling in each RDO environment, the procedure for transitioning a model from one situation to another is given as follows:

$$Yi \xrightarrow{F} Y_{i+1},\ i=1,2,...,N-1,$$

where $Y_i = (y_1^i, y_2^i, ..., y_n^i)$ – the position of the model at moment i.

3.Ахмедова, С.М., Магоммедли, Х.М., Исследование гибкой производственной системы методами имитационного моделирования на этапе системотехнического проектирования // Труды научно-практической конференции с международным участием "Инженерные системы - 2019",- Москва: 03 апреля-05 апреля,- 2019, с. 493-503.

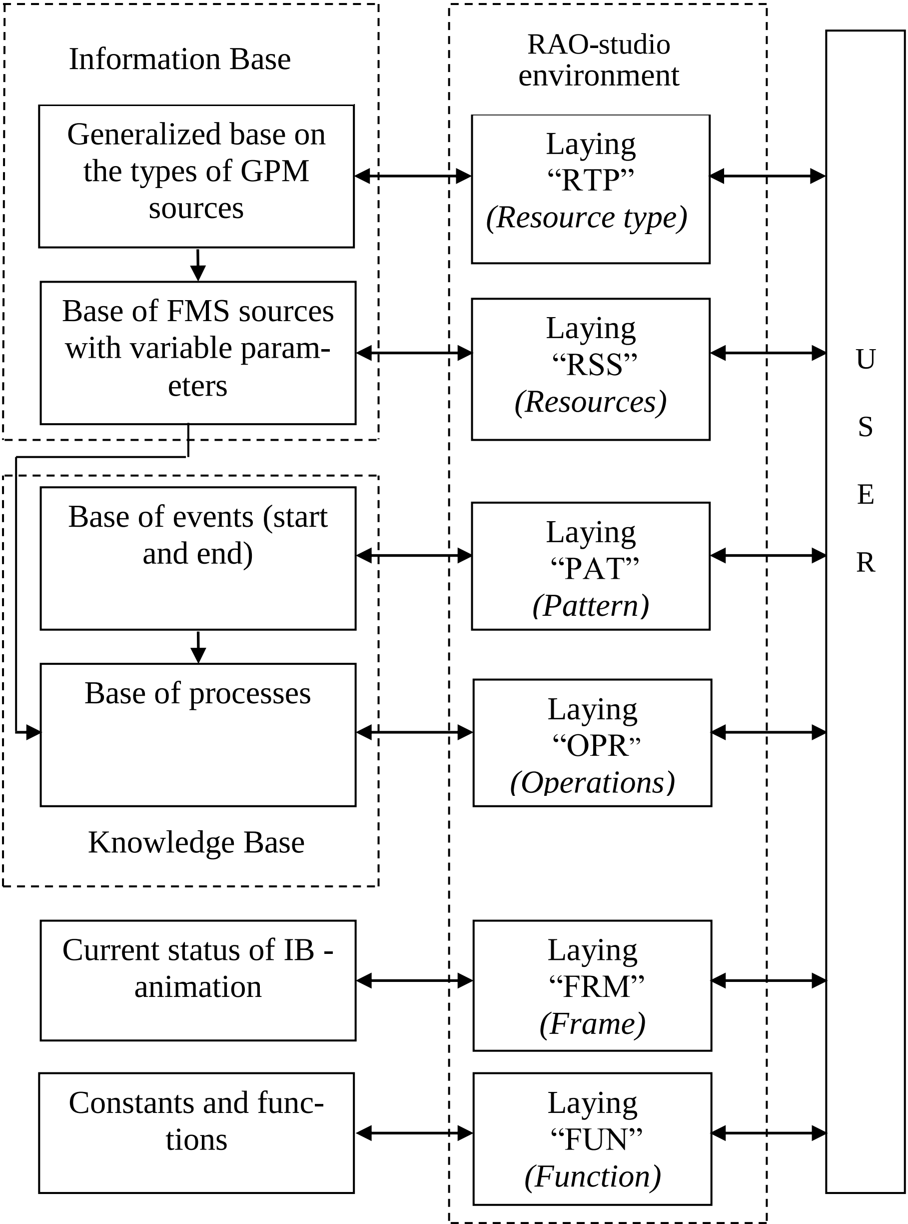

Figure 3. Computer design tool for the simulation modelling of FMS

The state of the model in the imitation modeling with the help of the operator F with the current time moment, control and external environment vectors for the next time period can be expressed as follows:

$$Y_{i+1}=F(Y_i, X_{i+1}, U_{i+1}, E_i), i=1,2,...,N-1,$$

where, $X_i=(x_1^i, x_2^i,..., x_m^i)$ – the position vectors of the external area at moment i; $Y_i=(y_1^i, y_2^i,..., y_n^i)$– the position vectors of the model at moment i; $U_i=(u_1^i, u_2^i, ... ,u_j^i)$- the control vector at moment i; $E_i=(e_1^i, e_2^i,...,e_q^i)$ – the factors vector of non controlled the external area at moment i.

The dissertation examines the study of FMS with simulation modeling using the RAO-studio software package operating in the RDO environment. The proposed IM algorithm[4] for the study of FMS is shown in Figure 4.As can be seen from the IM algorithm, in the first stage it is created by the proposed CADT using the attachments of the IM RAO-studio software complex of the FMS.

SMR performs simulation experiments by interconnecting the data, knowledge bases and animation description modules created by the corresponding attachments of RAO-studio. The frequency of repetition (simulation) of simulation experiments is determined by the experimenter. The completion of the experiments, ie the study of IM, is continued in the form of an iterative process until satisfactory results are obtained.

After setting up the IM and completing the experiments, the results are studied by animation methods in two-dimensional space.

In the next subsections of the dissertation the creation of data, knowledge and animation databases of imitation through CADT of the simulation model ofFMS using the software complex operating in the RAO-studio environment is considered.

4.Akhmedova, S.M. Research of a flexible production system by methods of imitating modeling at a stage of sistemotechnichal design // - Москва:Программные системы и вычислительные методы,- 2019. № 4. – С. 77– 86.

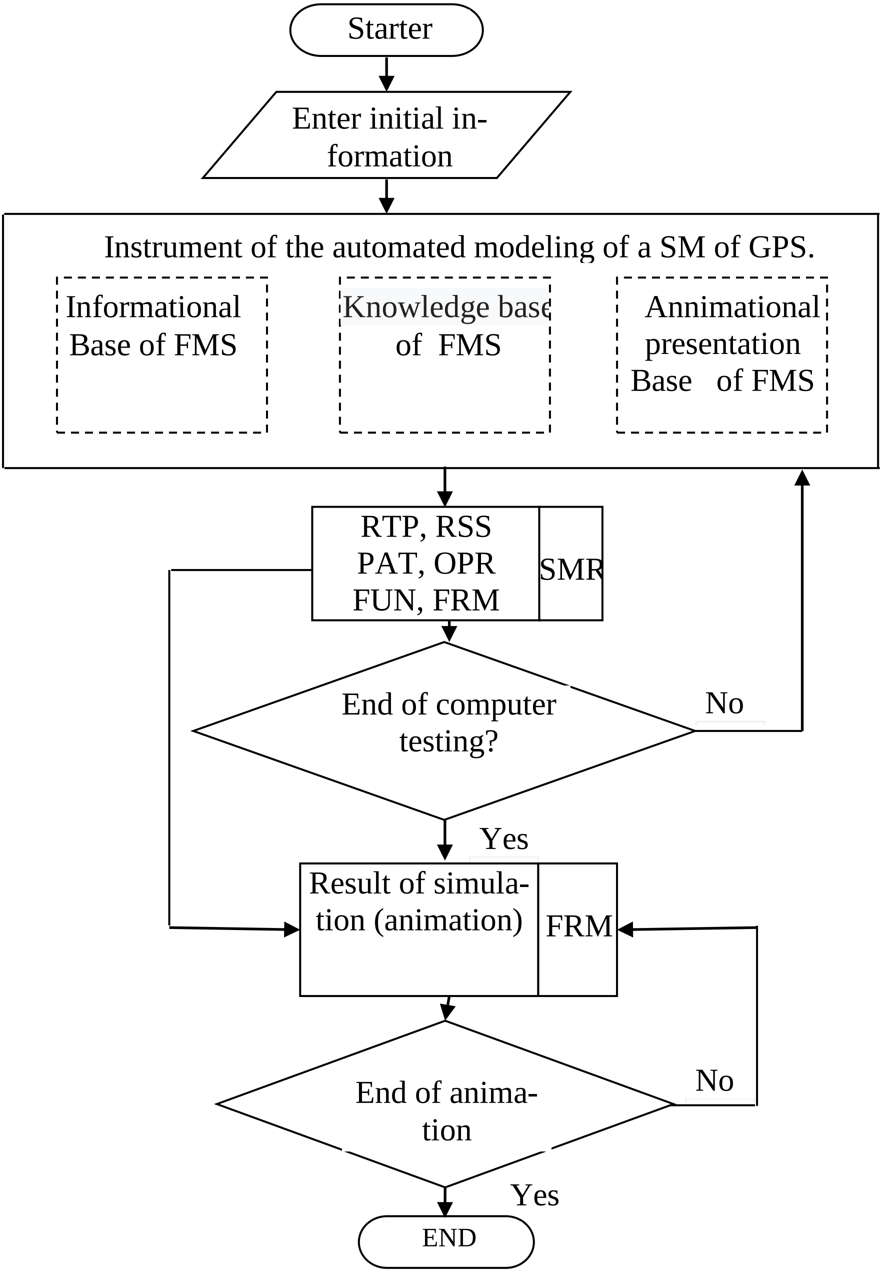

Figure 4. Algorithm of imitation modeling for investigation of FMS

SMR performs simulation experiments by interconnecting the data, knowledge bases and animation description modules created by the corresponding attachments of RAO-studio. The frequency of repetition (simulation) of simulation experiments is determined by the experimenter. The completion of the experiments, ie the study of IM, is continued in the form of an iterative process until satisfactory results are obtained.

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Let's look at an example of creating a generalized database by type of GIS resources.

The structural-functional scheme of the FMS shows that it includes the following mechatronical, the main and auxiliary equipments: 4 TS; 2 LPM; 2 G; 3 PM; 3 IR və 1 TE.

The resources specified in the IM are stable. However, it can participate in different positions of the FMS as a set of variable values of the parameters of a particular resource.

Taking into account the above, on the basis of fixed resources mentioned in the dissertation - TS, LPM, G, LM, IR, TE, FMS, a generalized database by type of resources was created.

The generalized base is implemented with RTP connection (bookmarking) operating in RAO-studio environment. The generalized database for all types of fixed resources is similarly created with the addition of RTP operating in a RAO-studio environment. Note that different types of generalized databases can be created from a fixed resource depending on the values of the parameters that vary depending on the requirements of the FMS. The example of the window for creating generalized databases is as shown in Figure 5:

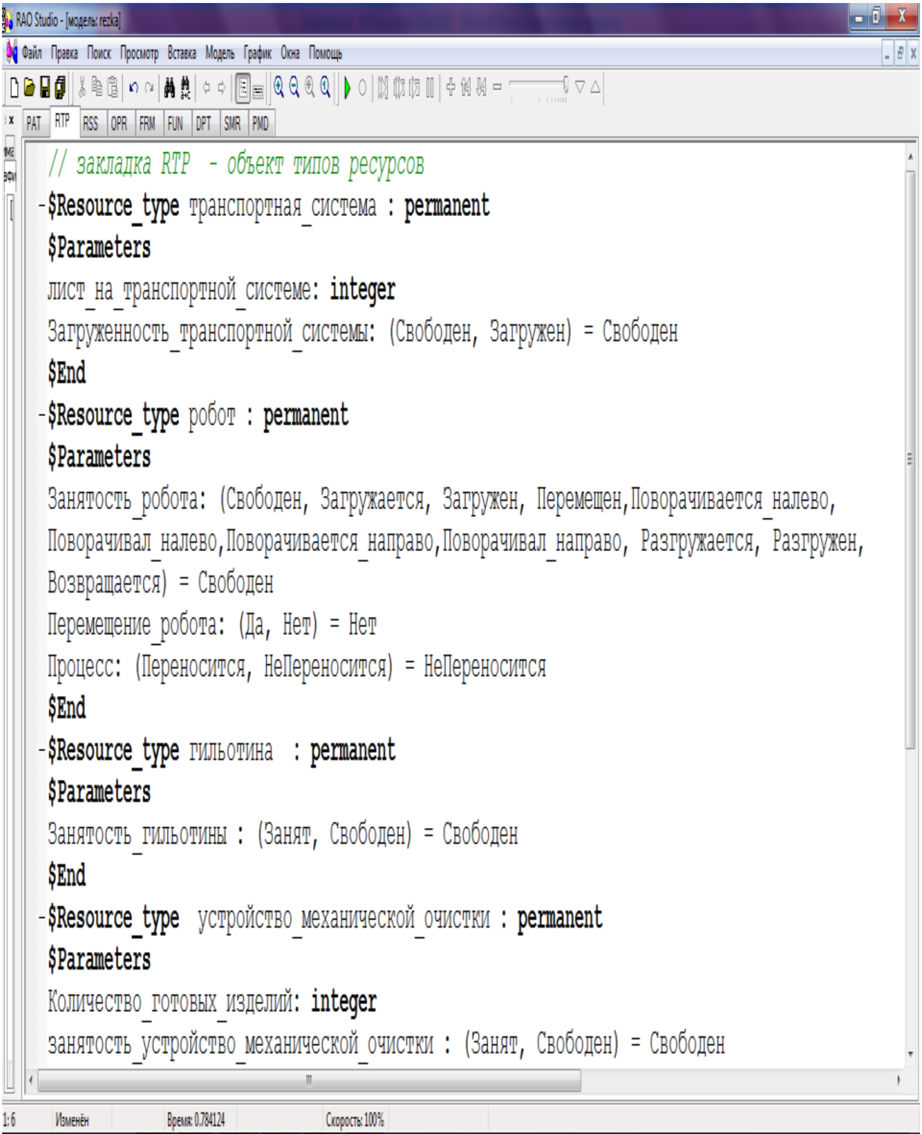

Figure 5. An example of window for creation of the common database

In this format, generalized databases for all types of fixed resources of FMS are created.

In this sequence, the creation of databases of knowledge, knowledge and animation of IM through the CADT of the IM of the FMS is considered.

The resource database of GIS is created with the addition of RSS, which operates in a RAO-studio environment. For each resource, its name, the type to which it belongs and the composition of its parameters, as well as the values of parameters not specified in the resource type object are set. Resources show the initial state of the global database of the program (model).

Knowledge of the processes of FMS is stored in the object of samples. Each sample consists of modified production rules, ordinary production rules or irregular events. For this purpose, a PAT pair operating in a RAO-studio environment is used.

Operations with samples in the RDO language are part of the procedure. The simulator receives specific values from the parameter of the samples from the object of operations. This object describes all the operations of the FMS. A transaction database is created using the OPR attachment.

Once all the databases have been created, the simulation model is set up with the SMR pair and the results are animated with the FRM pair [5]. A fragment of the animation of the results of the simulation experiments is shown in Figure 6.

The animation of the FMS with the Petri network of IM management was considered. For this purpose, the IM is described by the elements of the IM Petri net, the data of knowledge and animation databases of the simulation model are created through the CADT of the IM. According to the algorithm of the IM, the control

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5.Ахмедова, С.М., Ахмедов, М.А., Реализация алгоритма имитационной модели на примере гибкой производственной системы // Сборник научных трудов III Международной научно-практической конференции "САПР и моделирование в современной электронике",- Брянск: 24 октября-25 октября , - 2019 , с. 159-162

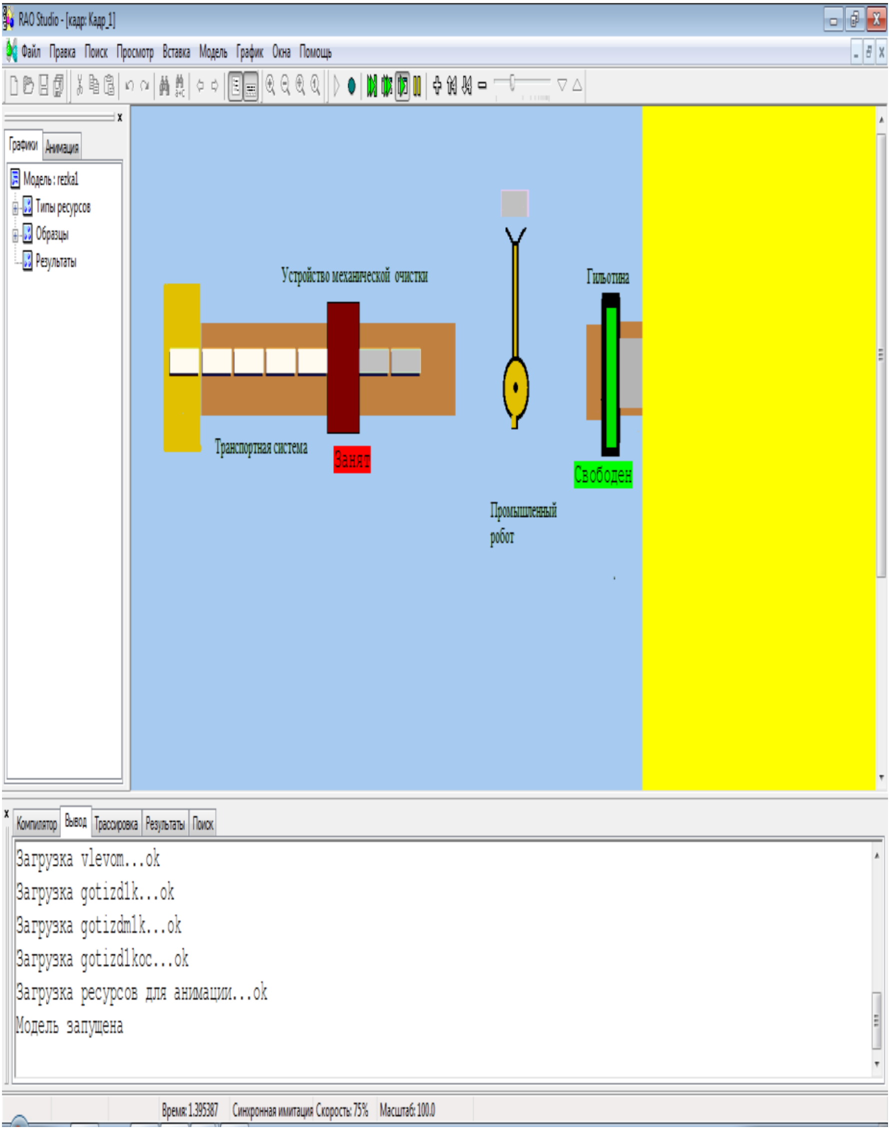

Figure 6. A fragment of animation of imitation experiment results

of computer experiments is carried out by means of graph diagrams of the operation of the Petri net.

As noted, the management of complex systems, in turn, belongs to the category of complex systems and is important in the application of systems in real objects. From this point of view, the control algorithm of the FMS in the simulation modeling should also be studied by computer experiments.

Using the capabilities of the RAO-studio software complex, the solution of this problem in the dissertation is considered by means of the Petri net. For this purpose, the simulation model of FMS is described by elements of the Petri net.

In this sequence, data, knowledge and animation image bases with descriptions of the elements of the Petri net of IM were created by means of CADT of the simulation model MS. After all the databases were created, the management of IM control was performed with the SMR connection, and animation experiments were performed with the Petri net of control time with the FRM connection.

The window for creating a generalized database by type of Petri network resources is shown in Figure 7.

A fragment of the time of the results of the simulation experiments with the Petri net is shown in Figure 8.

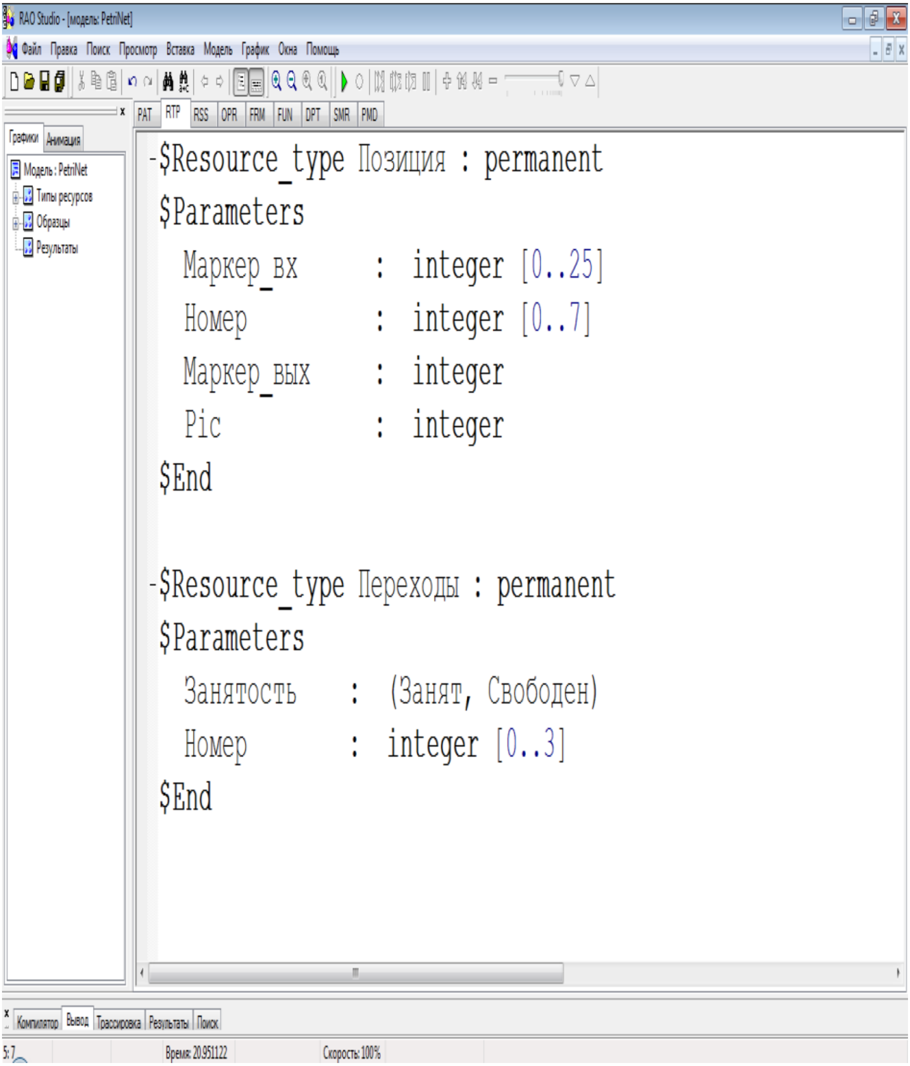

Figure 7. Window for generating a generalized database by type of Petri network resources

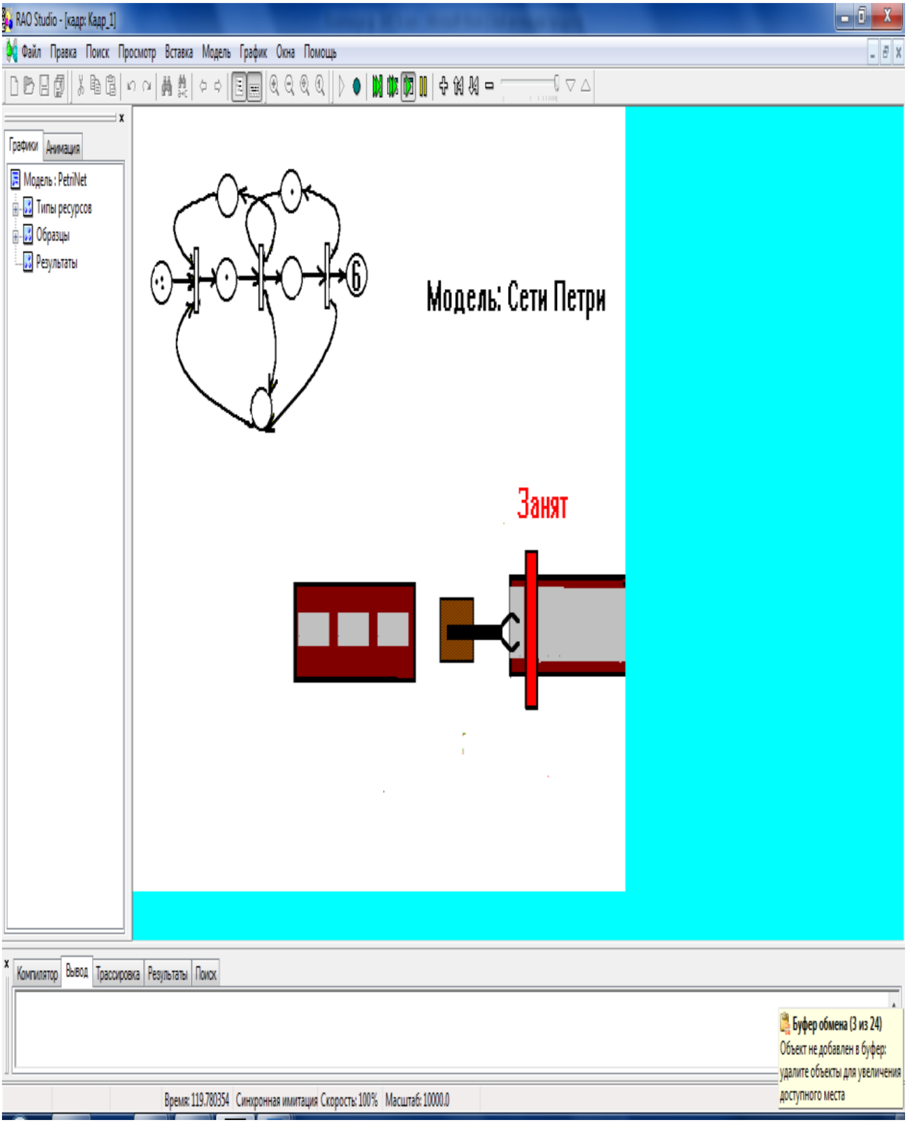

Figure 8. A fragment of IM control with time Petri net

The fourth chapter is devoted to the application of the results of the IM to the automatic control of FMS in the real object. Positional control systems are mainly used in the management of complex discrete systems, especially FMS. The trajectories of the manipulators of dynamic mechatron devices of such systems are essentially continuous, but the manipulators move according to the discrete values of the continuous function. Discrete values of the trajectory are identified by different status transmitters installed at different nodes of the FMS. The management algorithm makes adequate decisions and ensures the real-time operation of the FMS, depending on the location of the status sensors in the global database of the FMS, ie at different nodes. In a less complex FMS, this task is partially implemented and improved in practice based on the experience and intuition of professional experts. In FMS that has a complex structure, the solution to this problem is significantly complicated and in many cases it is difficult or impossible to achieve the required results.

The dissertation uses a different approach to solving this problem. Based on the results of imitation modeling of FMS, knowledge bases in the form of global data and production rules of FMS management system in different situations were developed using the time management algorithm in the form of imitation Petri net. As it is known, various situations (accidents, joint work zones, non-regular supply of raw materials and other products, etc.) are not taken into account during the operation of FMS in the Petri net and it is assumed that the required operations are usually performed at different time intervals. In order to take this problem into account in the real object, a structural-functional scheme, including the control system of the FMS, has been developed. For the management of the FMS, a global database of the control system to receive information from sensors installed at different positions of its elements and to form control teams for the appropriate execution mechanisms after processing them (output values of 45 sensors installed at different nodes and control signals generated on 24 execution mechanisms) and production rules in the form of a knowledge base (31 production rules) control algorithm was developed.

In ordinary colloquial language, the production order is formed in the following example:

IF TS1 has a flat surface layer at the initial position
AND **if** the LM1 table is in a low position
AND **if** the support point of LM1 is in the up position
AND **if** there is no a layer of the sheet in the last position of TS1
THEN the condition of activation of TS1 is executed.

The production procedure specified in the computer's internal language is described as follows:

$$\boldsymbol{(P1)\quad (X_{13} \& X_{21} \& X_{31} \& \urcorner X_{12}) \rightarrow U_{11},}$$

where P1 is the number of the production rule. Similarly, the production rules are formulated for other situations[6].

(P2) $\mathbf{(X_{21} \& X_{31} \& X_{23} \& X_{22} \& X_{33}) \rightarrow U_{13} \& \urcorner U_{15};}$
(P3) $\mathbf{(\urcorner X_{23} \& \urcorner X_{33} \& X_{32})) \rightarrow \urcorner U_{13} \& \urcorner U_{14} \& U_{26};}$
(P4) $\mathbf{(X_{41} \& X_{48})) \rightarrow U_{14};}$
(P5) $\mathbf{(\urcorner X_{48} \& X_{41} \& X_{42} \& X_{43}) \rightarrow U_{21};}$
(P6) $\mathbf{(\urcorner X_{48} \& X_{41} \& X_{47} \& X_{43}) \rightarrow U_{22};}$
(P7) $\mathbf{(\urcorner X_{48} \& X_{41} \& X_{47} \& X_{44}) \rightarrow \urcorner U_{21} \& \urcorner U_{14};}$
(P8) $\mathbf{(X_{42} \& X_{44} \& X_{45}) \rightarrow U_{23};}$
(P9) $\mathbf{(X_{47} \& X_{44} \& X_{42}) \rightarrow U_{21};}$
(P10) $\mathbf{(X_{47} \& X_{44} \& X_{46}) \rightarrow \urcorner U_{22};}$
(P11) $\mathbf{(X_{47} \& X_{43} \& X_{46}) \rightarrow \urcorner U_{21};}$

6.Ахмедова, С.М., Магоммедли, Х.М. Разработка алгоритма управления на основе продукционных правил ГПМ резки листов на карточки и очистка их поверхности// Материалы III республиканской научной конференции Прикладные задачи математики и новые информационные технологии, - Сумгаит: -15декабря-16 декабря,- 2016 ,- с.205-206.

(P12) $(X_{42} \& X_{43} \& X_{46}) \rightarrow \rceil U_{23}$;
(P13) $(X_{53} \& X_{52} \& X_{54} \& X_{56} \& X_{93}) \rightarrow U_{24}$;
(P14) $(X_{51} \& X_{61} \& X_{55} \& X_{56} \& X_{93}) \rightarrow U_{25}$;
(P15) $(X_{51} \& X_{61} \& X_{56} \& X_{94}) \rightarrow \rceil U_{25} \& \rceil U_{31} \& U_{37}$;
(P16) $(X_{61} \& X_{62}) \rightarrow U_{31}$;
(P17) $(X_{61} \& X_{62} \& X_{64} \& X_{66}) \rightarrow U_{32}$;
(P18) $(X_{61} \& X_{63} \& X_{64}) \rightarrow \rceil U_{32}$;
(P19) $(X_{63} \& X_{62} \& X_{64} \& X_{65}) \rightarrow U_{34}$;
(P20) $(X_{62} \& X_{64} \& X_{66}) \rightarrow U_{32}$;
(P21) $(X_{67} \& X_{63} \& X_{64}) \rightarrow \rceil U_{33}$;
(P22) $(X_{67} \& X_{63} \& X_{64}) \rightarrow \rceil U_{33}$;
(P23) $(X_{67} \& X_{63} \& X_{64}) \rightarrow \rceil U_{34}$;
(P24) $(X_{71} \& X_{72} \& X_{73}) \rightarrow \rceil U_{35}$;
(P25) $(X_{74} \& X_{75} \& X_{81}) \rightarrow \rceil U_{41}$;
(P26) $(X_{81} \& X_{83} \& X_{85}) \rightarrow U_{42}$;
(P27) $(X_{82} \& X_{83} \& X_{85}) \rightarrow U_{43}$;
(P28) $(X_{82} \& X_{84} \& X_{85}) \rightarrow \rceil U_{42}$;
(P29) $(X_{81} \& X_{84} \& X_{85}) \rightarrow U_{43}$;
(P30) $(X_{86} \& X_{81} \& X_{84}) \rightarrow \rceil U_{43}$;
(P31) $(X_{86} \& X_{84} \& X_{83}) \rightarrow \rceil U_{44}$;

When formulating production rules, the conditions of each management team must take into account the fact that separate mechatron devices operate in common working areas without interfering with each other. Therefore, when operating the algorithm in the form of FMS production rules, the conditions of asynchrony and parallelism of its mechatron devices are satisfied.

The control algorithm in the form of FMS production rules ensures its operation in real time as follows: the information received from the sensors installed in different positions of the FMS (global database of FMS) is checked by the appropriate expressions written in the I parts of the knowledge base. The current situation activates the execution mechanisms in accordance with all the executinge production rules, and the global database becomes a set of new situations. The process continues in automatic mode at regular intervals.

There are 18 positions and 13 transitions to manage the FMS with the Petri net:

Positions:

P1 - activation of TS1;

P2 - regulation of G1 gilyatin function;

P3 - control of cutting operation in - G1, ie 1 cut;

P4 - input of rawing materials into - G1;

P5 - perform cutting operation on - G1;

P6 - layer formed after cutting operation in G1;

P7 - regulation of G2 gilyatin activity;

P8 - activation of TS2;

P9 - layer penetration into G2;

P10 - control of cutting operation in - G2 (upor) - ie 1 cut;

P11 - perform cutting operation on - G2;

P12 - sheet formed after cutting operation in G2;

P13 - commissioning of a mechanical treatment plant;

P14 - insertion of the sheet into the mechanical cleaning device;

P15 - control of cleaning operation in the mechanical cleaning device, ie cleaning of 1 sheet;

P16 - cleaning operation in a mechanical treatment plant;

P17 - sheet cleaned after cleaning operation in mechanical cleaning device;

P18 - adjusting the operation of the mechanical treatment plant.

Links:

t1 - inclusion of raw materials in G1;

t2 - completion of the cutting operation at G1;

t3 - the release of G1;

t4 - Transfer of the layer to NS2 via SR1;

t5 - the inclusion of the layer in G2;

t6 - completion of the cutting operation at G2;

t7 - discharge of G2;

t8 - the return of IR1 from TS2 to G1;

t9 - transfer of the sheet to the mechanical cleaning device by IR2;

t10 - sheet insertion into mechanical cleaning device;

t11 - carrying out cleaning operation in the mechanical cleaning device;

t12 - Unloading of mechanical cleaning device;

t13 - Return of IR2 from the mechanical treatment plant to TS2.

İ and **O** – the set of input and output functions is set

$$\# (t_j, I(p_j)) = \# (p_j, O(t_j)), \# (t_j, O(p_j)) = \# (p_j, I(t_j)).$$

$I (p_1)=\{-\}$,
$I (p_2)=\{t_1, t_3, t_8\}$
$I (p_3)=\{t_3\}$,
$I (p_4)=\{t_1\}$,
$I (p_5)=\{ t_2 \}$,
$I (p_6)=\{t_3\}$,
$I (p_7)=\{t_5, t_7, t_{13}\}$,
$I (p_8)=\{t_4\}$,
$I (p_9)=\{t_5\}$,
$I (p_{10})=\{t_7\}$,
$I (p_{11})=\{t_6\}$,

$O (p_1)=\{t_1\}$,
$O (p_2)=\{ t_1, t_3, t_4\}$,
$O (p_3)=\{t_1\}$,
$O (p_4)=\{ t_2 \}$,
$O (p_5)=\{ t_3\}$,
$O (p_6)=\{t_4\}$,
$O (p_7)=\{ t_5, t_7, t_9\}$,
$O (p_8)=\{t_5\}$,
$O (p_9)=\{t_6\}$,
$O (p_{10})=\{t_5\}$,
$O (p_{11})=\{t_7\}$,

$I(p_{12})=\{t_7\}$, $O(p_{12})=\{t_9\}$,
$I(p_{13})=\{t_9\}$, $O(p_{13})=\{t_{10}\}$,
$I(p_{14})=\{t_{10}\}$, $O(p_{14})=\{t_{11}\}$,
$I(p_{15})=\{t_{12}\}$, $O(p_{15})=\{t_{10}\}$,
$I(p_{16})=\{t_{11}\}$, $O(p_{16})=\{t_{12}\}$,
$I(p_{17})=\{t_{12}\}$, $O(p_{17})=\{-\}$,
$I(p_{18})=\{t_9, t_{10}, t_{12}\}$, $O(p_{18})=\{t_{10}, t_{12}, t_{13}\}$.
$I(t_1)=\{p_1, p_2, p_3\}$, $O(t_1)=\{p_2, p_4\}$,
$I(t_2)=\{p_4\}$, $O(t_2)=\{p_5\}$,
$I(t_3)=\{p_2, p_5\}$, $O(t_3)=\{p_2, p_3, p_6\}$,
$I(t_4)=\{p_2, p_6\}$, $O(t_4)=\{p_7, p_8\}$,
$I(t_5)=\{p_7, p_8, p_{10}\}$, $O(t_5)=\{p_7, p_9\}$,
$I(t_6)=\{p_9\}$, $O(t_6)=\{p_{11}\}$,
$I(t_7)=\{p_7, p_{11}\}$, $O(t_7)=\{p_7, p_{10}, p_{12}\}$,
$I(t_8)=\{p_7\}$, $O(t_3)=\{p_2\}$,
$I(t_9)=\{p_7, p_{12}\}$, $O(t_9)=\{p_{13}, p_{18}\}$,
$I(t_{10})=\{p_{13}, p_{15}, p_{18}\}$, $O(t_{10})=\{p_{14}, p_{18}\}$,
$I(t_{11})=\{p_{14}\}$, $O(t_3)=\{p_{16}\}$,
$I(t_{12})=\{p_{16}, p_{18}\}$, $O(t_{12})=\{p_{15}, p_{17}, p_{18}\}$,
$I(t_{13})=\{p_{18}\}$, $O(t_{13})=\{p_7\}$,

Initial marking - M_0= (10,1,1,0,0,0,1,0,0,1,0, 0,0,0,1,0,0,1)

A graphic scheme of the management of the FMS by means of the Petri net is shown in figure 9.

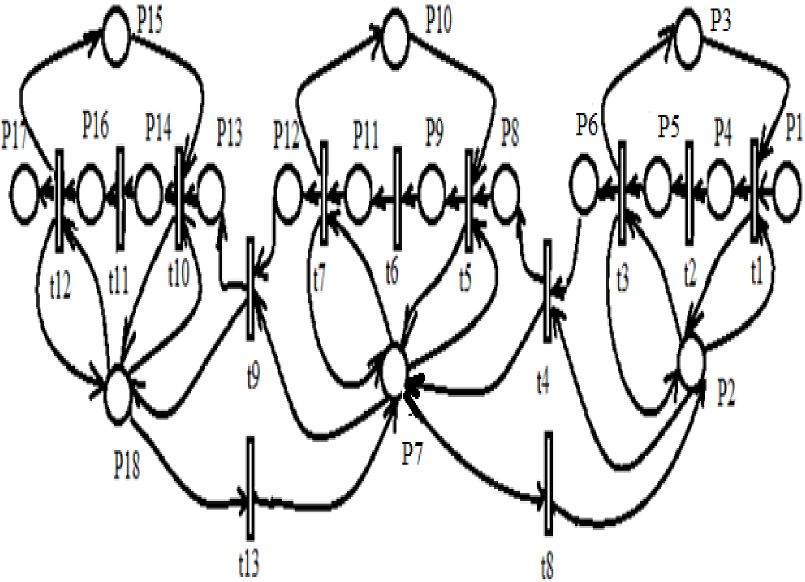

Figure 9. Graph-scheme of management of FMS by means of the Petri net

CONCLUSIONS

1. As a result of research and comparative analysis of the current state of the problem, the purpose of the dissertation was formed and the issues that need to be addressed in order to achieve this goal were identified.

2. The architecture of a generalized computer aided design tool for the investigation of complex production systems with simulation has been proposed and developed.

3. The requirements for the computer aided design of FMS belonging to the category of complex systems are defined and the expediency of the use of simulation modeling methods in its study by computer experiments and the relevance of the description of the results by animation methods are substantiated.

4. A conceptual model of the production system was formed what was selected as the object of research for the raw materials, cutting the layers into sheets and cleaning the surface of the sheet, taking into account the requirements of the production area, the structural-kinematic scheme of the FMS was developed.

5. The architecture of the computer aided design tool that creates databases, knowledge, animation descriptions of the simulation model of FMS and operates in the environment of the RAO-studio software complex was proposed and developed.

6. In accordance with the algorithm of simulation modeling of FMS, computer experiments of the simulation model were conducted, the results of the simulation were described by animation methods and the feasibility of designing the FMS was assessed.

7. In order to apply the Petri net algorithm to a real object when formed by simulation experiments, a control algorithm was developed in the form of global data and production rules based on information received from sensors installed at the positions of FMS nodes, taking into account different situations of FMS operation.

The main provisions of the dissertation are published in the following scientific works:

1. Əhmədova, S.M., Petri şəbəkələrinin tətbiqi ilə layihələndirilən obyektin fəaliyyət modelinin qurulmasının analizi// Riyaziyyatın tətbiqi məsələləri və yeni informasiya texnologiyaları.Respublika elmi konfransının materialları, -Sumqayıt: - 27 noyabr - 28 noyabr, -2007,- s. 198-199.
2. Mamedov, J.F., Akhmedova, S.M., Maghommedli, H.M. Simulation and investigation of dynamical technical system working represented by final automat by means of Petri network // VII Mezinarodni vedecko-prakticka conference.Aktualni vymozenosti.-Praha :– 27 June – 05 July,- 2011,-p. 37-39.
3. Əhmədov, M.A., Məhəmmədli, H.M., Əhmədova, S.M. Fəaliyyətləri sonlu avtomatlarla təsvir olunan dinamiki texniki sistemlərin Petri şəbəkələri ilə modelləşdirilməsi və tədqiqi // Riyaziyyatın tətbiqi məsələləri və yeni informasiya texnologiyaları II Respublika elmi konfransı, Sumqayıt: - 27 noyabr - 28 noyabr, - 2012, - s.151-152.
4. Əhmədova, S.M., Məhəmmədli, H.M.,Nəsirova, E.Ə., Əliyev E.İ. ÇİS-in struktur modelinin animasiya avtomatlaşdırmış layihələndirmə alətləri tədqiqinə qoyulan tələbatların təyini // Riyaziyyatın tətbiqi məsələləri və yeni informasiya texnologiyaları II Respublika elmi konfransı,- Sumqayıt: ,- 27 noyabr -28 noyabr, - 2012, - s.149-150.
5. Əhmədov, M.A., Əhmədova, S.M.,Məmmədova, M.R. Mürəkkəb istehsal sistemlərinin imitasiya modelləşdirilməsi ilə tədqiqinin analizi// "Avtomatika və idarəetmənin müasir problemləri" Respublika elmi-praktik konfransı,AzTU,- Bakı:-20 dekabr-21 dekabr,- 2012, - s.121-124.
6. Мамедов, Дж.Ф., Ахмедова, С.М., Амирасланов, Б.К., Джафарова ,Ш.М., Мамедова, М.Р. Разработка алгоритмического обеспечения функционального исследования системы управления гибкого производственного участка // II Международная Научно-Практическая Конференция –Новые технологии

и проблемы технических наук. Сборник научных трудов по итогам конференции, - Красноярск: -10 ноября ,- 2015, - с.21-23.

7. Ахмедова, С.М., Магоммедли, Х.М. Разработка алгоритма управления на основе продукционных правил ГПМ резки листов на карточки и очистка их поверхности// Материалы III республиканской научной конференции Прикладные задачи математики и новые информационные технологии, - Сумгаит: -15декабря-16 декабря,- 2016 ,- с.205-206.

8. Əhmədov, M.A., Əhmədova, S.M., Süni intellekt üsulları ilə çevik istehsal sistemlərinin kompüter modelləşdirilməsi // İqtisadiyyatın davamlı inkişafı problemlər, perspektivlər, Beynəlxalq elmi konfransının materialları,- Sumqayıt: -27 aprel - 28 aprel ,- 2016,- s.167-169.

9. Ахмедова, С.М. Моделирование и исследование производственного модуля с использованием временной сети Петри // Прикладная наука как инструмент развития нефтехимических производств - Материалы Международной научно-практической конференции посвященной дню Химика и 40-летию кафедры химико-технологических процессов филиала Уфимского государственного нефтяного технического университета в г.Салавате, -Уфа: 10 мая - 26 мая -2017,-с.297-299.

10. Ахмедов, М.А., Ахмедова С.М. Разработка алгоритма имитационного моделирования гибкой производственной системы с использованием программного комплекса RAO-STUDIO на языке РДО// 62-я Международная научная конференция Астраханского государственного технического университета, -Астрахан: -23 апреля -27 апреля,- 2018, - с.145.

11. Əhmədov,M.A., Əhmədova,S.M. Mürəkkəb sistemlərin imitasiya modelləşdirilməsilə tədqiqinin avtomatlaşdırılmış layihələndirmə alətinin arxitekturasının işlənməsi // "Tətbiqi fizika və energetikanın aktual məsələləri" Beynəlxalq elmi-texniki konfransın materialları,- Sumqayıt: -24 may-25 may, -2018, -s.381-383.

12. Əhmədova, S.M., Çevik istehsal modulunun RAO-studio proqram kompleksinin tətbiqi ilə imitasiya modelləşdirilməsi

// İnformasiya sistemləri və texnologiyalar: nailiyyətlər və perspektivlər,Beynəlxalq elmi konfransının materialları, -Sumqayıt: 15 noyabr-16 noyabr,-2018, s.275-277.

13. Ахмедова, С.М., Магоммедли, Х.М., Исследование гибкой производственной системы методами имитационного моделирования на этапе системотехнического проектирования // Труды научно-практической конференции с международным участием "Инженерные системы - 2019",-Москва: 03 апреля-05 апреля,- 2019, с. 493-503.

14. Ахмедова, С.М., Ахмедов, М.А., Реализация алгоритма имитационной модели на примере гибкой производственной системы // Сборник научных трудов III Международной научно-практической конференции "САПР и моделирование в современной электронике",- Брянск: 24 октября-25 октября , -2019 , с. 159-162.

15. Ахмедов, М.А. Автоматизированное проектирование ГПС с применением сети Петри / М.А.Ахмедов, С.М.Ахмедова, Х.М.Ахмедова // Научные известия СГУ, -Сумгаит: -2002.№1,-с.47-51.

16. Əhmədov,M.A. Çevik istehsalat sistemlərinin fəaliyyətinin sonlu avtomatlar şəklində təsvirinin Petri şəbəkələrinə avtomatlaşdırılmış çevrilməsi alqoritmi/ M.A.Əhmədov,Z.Ə Sadıxov, S.M. Əhmədova // SDU-nun Elmi xəbərləri, Təbiət və texniki elmlər bölməsi,- Sumqayıt: -2004.№2, - s.65-70.

17. Əhmədova,S.M. Petri şəbəkələrinin tətbiqi ilə texnoloji yığma prosesinin fəaliyyət modelinin qurulması və tədqiqi/ S. M. Əhmədova, T.A.Tağıyeva,Ş.M. Cəfərova// SDU-nun Elmi xəbərləri, Təbiət və texniki elmlər bölməsi, -Sumqayıt: -2010. № 2,-s.91-96.

18. Əhmədov, M.A. ÇİS-in verilənlər və biliklər bazalarının yaradılması və idarə alqoritminin kompüter eksperimentləri ilə tədqiqi / M.A.Əhmədov,S.M. Əhmədova, E.Ə.Nəsirova //SDU-nun Elmi xəbərləri, Təbiət və texniki elmlər bölməsi, -Sumqayıt:- 2010.№ 4 , -s.64-71.

19. Əhmədova, S.M., Məhəmmədli H.M. Xammalın tələb olunan ölçülərdə vərəqlərə doğranılması çevik istesal modulunun idarə edilməsinin produksiya qaydalarının işlənməsi/ S.M.Əhmədova,H.M.Məhəmmədli // SDU-nun Elmi xəbərləri, Təbiət və texniki elmlər bölməsi, -Sumqayıt: - 2015.№ 4, - s.73-77.

20. Ахмедов, М.А. Разработка архитектуры инструмента автоматизированного проектирования имитационной модели гибкого производственного модуля /М.А.Ахмедов, С.М.Ахмедова// Системы управления и информационные технологии,-Москва-Воронеж:-2015. №4.1(62), – с. 104-107.

21. Əhmədova, S.M. İstehsal sistemlərinin imitasiya modelləşdirilməsi ilə tədqiqinin avtomatlaşdırılmış layihələndirmə alətinin arxitekturasının işlənməsi//- Sumqayıt :SDU-nun Elmi xəbərləri,Texniki elmlər bölməsi,- 2018.№ 2,- s.51-55.

22. Əhmədova, S.M. İmitasiya modelləşdirilməsi alqoritminin işlənməsi və onun çevik istehsal sisteminin tədqiqinə tətbiqi//- Sumqayıt :SDU-nun Elmi xəbərləri,Texniki elmlər bölməsi,- 2019.№ 2,- s.64-71.

23. Akhmedova, S.M. Research of a flexible production system by methods of imitating modeling at a stage of sistemotechnichal design // - Москва:Программные системы и вычислительные методы,- 2019. № 4. – C. 77 – 86.

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