REPUBLIC OF AZERBAIJAN

On the rights of the manuscript

ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

DEVELOPMENT OF MODELS AND ALGORİTHMS FOR SELECTİNG CONTROL ELEMENTS AND BUİLDİNG AN AUTOMATİON SCHEME FOR THE FLEXIBLE MANUFACTURE

Speciality: 3338.01 - Systematic analysis, control and Information Processing (modeling and management)

Field of science: Technical sciences

Applicant: **Sabina Balakishi Aliyeva**

Sumgayit – 2026

The work was performed at Sumgayit State University, "Automation and Mechanics" department .

Scientific supervisor:	Doctor of Technical Sciences, Professor **Javanshir Firudin Mammadov**
Official opponents:	Doctor of Technical Sciences, Professor **Alakbar Ali Agha Aliyev**
	Doctor of Technical Sciences **Oleg Hajiaga Huseynov**
	Doctor of Philosophy in Technical Sciences, Assocciate Professor **Rahib Aydin Imamquluyev**

Dissertation council FD 2.48 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at Azerbaijan State Oil and Industrial University.

Chairman of the Dissertation council:	Corresponding member of ANAS, Doctor of Technical Sciences, Professor **Rafig Aziz Aliyev**
Scientific secretary of the Dissertation council:	Doctor of Technical Sciences, Assocciate Professor **Akif Veli Alizadeh**
Chairman of the scientific seminar:	Doctor of Technical Sciences, Professor **Kamala Rafig Aliyeva**

İMZANI TƏSDİQ EDİRƏM
ADNSU-nun Elmi katibi

dos. Aliyev. İ.N

GENERAL CHARACTERISTICS

Relevance and degree of development of the topic. The main areas that ensure the growth of the economy of developing countries are modern industrial enterprises that produce high-quality products. As is known, the main indicators of the high-speed development of the economies of leading Western European, US and Central Asian countries are the productivity of industrial enterprises, the compliance of the manufactured products with modern requirements, their quality with international standards and the provision of most enterprises with modern automation technologies. The current state of modern industrial sectors and their production enterprises shows that certain areas, especially machine-building enterprises, are formed by complex technological processes, providing, economic corporate structures and, accordingly, are organized by multifunctional automated control systems (ACS). By development of the flexible manufacturing area (FMA) ACS, which combines numerous elements of information-measurement, regulation, control, processing, execution and industrial networks, is carried out at the traditional design stages and with the help of existing information, technical, mathematical and software tools, which complicates the selection and design of FMA ACS and their active elements applied in individual industrial sectors.

The production areas of many industrial enterprises carry out the staged preparation and production of one product. However, as the demand for household, transport, military, etc. products increases, it becomes impractical to produce products with similar materials, structures, and application areas in separate production areas, since the scale of applied production areas and the volume of state expenditures increase. In this sense, in order to ensure the increase in the country's economic development, it is considered a scientifically relevant issue to create FMA and design its automated control system, ensuring the production of a wide range of products in a large-scale enterprise with a new approach.

In modern times, new information technologies, computer equipment and intelligent systems are being applied in more and more areas. In this regard, it is more appropriate to develop new CAD (*Computer-Aided Design*)/CAE (Computer Aided Engineering) software, information and mathematical tools for the automation of the control system of a large-scale industrial enterprise and the selection and design of active elements of the control system.

Application of algorithmic, mathematical and software solutions of automated design used for the technical task, proposal, sketch and detailed design stages, which are accepted as the main stages of the design process of the control system for FMA, the purpose of the dissertation work should be determined and the solution of the main research questions should be provided.

Object and subject of the research. In the dissertation work, the issues of selecting information-measuring elements and designing the automation scheme using computer modeling methods at the initial design stage of its control system, studying them using various modeling methods and based on graph theory, and assessing the feasibility of creating their projects are investigated using the example of a mechanical assembly plant of the machine-building industry, which was chosen as the object of research.

The purpose and objectives of the research are to develop algorithms and models that ensure the construction of an automation scheme based on the selection of information-measuring, processing and execution elements at the design stage of the control system of the mechanical engineering industry.

The following tasks have been planned to achieve the goal of the research work.

1. Comparative analysis of automated design tools for flexible manufacturing control systems by application areas;

2. Creation of automated design system tools based on the structure of the design stages of the FMA control system;

3. Establishment of hierarchical information support architecture for automated design of the management system of the FMA.

4. Development of mathematical and algorithmic support for the selection and design of information-measuring, control and execution elements based on the application area of the control system of the FMA.

5. Construction of a hierarchical automation scheme based on active elements of the information-measuring, execution, regulation and processing type of the control system of the FMA.

6. Simulation study of the control process based on the automation scheme of the FMA.

7. Development of complex software for designing the management system of the FMA.

Research methods. Based on the topic of the work, an analysis of scientific sources and Internet resources in the field of problem solving was conducted, and as a result of comparative analysis, the solution of these issues was achieved by using logical and mathematical modeling methods and computer experiments to automate the design of control systems for FMA.

The main provisions put forward for defense are as follows:

1. Setting the overall goal of the work and determining research questions based on the analysis of automated design tools for the FMA control system in application areas;

2. The issue of determining and creating automated design tools based on the structure of the defined design stages of the FMA control system;

3. Establishment of a hierarchical information support architecture for automated design of the management system of the FMA and creation of basic tools of the database management system in subsystems.

Development of mathematical and algorithmic support for the accurate selection and justification of the efficiency of information-measuring, control and execution elements of the control system of the FMA based on the application area .

5. Development of algorithmic and software tools to establish a hierarchical automation scheme based on active elements of the information-measuring, execution, regulation and processing type of the control system of FMA and to ensure its efficient operation.

6. Development of a simulation model of the management process based on the FMA automation and control scheme.

7. Development of complex software for the selection and design of active elements of the control system of the FMA and its control system design based on a centralized interface.

8. Development of software for visualization of the automation scheme of the control system of the FMA.

Scientific innovations. As a result of the work, the following scientific innovations were obtained:

1. Based on the stages of development of the control system of the mechanical engineering industry's FMA, an algorithmic support has been created that increases the efficiency of the design process.
2. The computer aide design of the contro system of the FMA and new tools for the database management system were created.
3. An algorithm has been developed that provides modeling of the process of building a control system and its automation scheme for a flexible manufacturing area in mechanical engineering.
4. A model has been developed and studied through computer experiments to substantiate the reliability and economic efficiency of creating an automated control system for flexible manufacturing system.
5. The proposed control and automation schemes of the FMA, an algorithm has been developed that provides intellectual modeling of the operational process of the MIS control system.

Theoretical and practical significance of the work and application of the results. The process of designing flexible manufacturing control system and its information-measurement, regulation, control and execution elements automation. The development of algorithms and models that ensure the principles of productivity, accuracy, openness and efficiency, modeling of the design stages of the flexible manufacturing control system, simulation of the main procedures and operations with computer experiments and development of mathematical and algorithmic models to substantiate the economic efficiency of the flexible manufacturing control system based on option of information - measurement and control elements.

Approval of work. The main results of the scientific research carried out in the dissertation work. Сборник трудов ММТТ3, (Kazan, 2020); Materials of the II International scientific conference on information systems and technologies, achievements and perspectives (Sumgayit, July 09-10, 2020); International Conference Automatics and Informatics (ICAI), Bulgaria, Varna Technical University, October 1-3, 2020; Applied mathematical problems and new information technologies IV Republic of Kanskaya scientific conference (December 09-10, 2021); International Conference, Sabanci University, (November 23-25, Erzurum, Turkey-2023) was approved.

Published scientific works. 11 on the topic of the dissertation scientific work, including 6 Republican and International conference proceedings, and 5 prestigious scientific and practical journals.

Name of the organization where the dissertation work was completed. The dissertation work was completed at the department of Automation and Mechanics of Sumgayit State University.

The structure and volume of the dissertation. The work consists of an introduction, four chapters, main conclusions, a list of used literature, and abbreviations. The main content of the work is 164 pages, The main content of the work is volume without tables, figures, and bibliography 160052 characters. Including: Introduction - 20267 characters, Chapter I - 47551 characters, Chapter II - 28460 sign, chapter III - 38548 sign, Chapter IV - 23458 signs, Conclusion - 1768 mark. The list of references lists 116 sources.

CONTENT OF THE WORK

The introduction outlines the relevance of the topic, the purpose of the work, the issues addressed, scientific innovations, the practical significance of the work, and the main provisions put forward for defense.

The first chapter examines the current state of literature sources on the development stages for the automated design of a flexible manufacturing control system, the technologies for developing information, algorithmic and software tools at these stages, and the automation of design procedures and their operations. Based on a comparative analysis of existing methods and tools, research questions were identified and the general goal of the work was set.

The second chapter is devoted to the development of information support for the selection and design of technological measurement and control tools for the flexible manufacturing area control system.

A phased analysis of the selection and design of technological and measuring means for FMA control system was carried out. Taking into account the presence of numerous information-measuring and control elements of the automation scheme of the FMA, their interconnectedness, the application areas and features of the developed enterprises, the complexity of their technological and functional characteristics, the application of the principles of intellectualization and computer network tools, it was determined that the procedures of the design stages of the FMA control system (Figure 1) are provided on the basis of the program interface to study the issues of accurate information-search, selection and application of technological measurements, technical control and the automated control system in technological processes.

In stage 1, the input data of the design task is pre-processed using the automated design interface. By analyzing the problem area, information provision of technical means of control system of FMA in various application areas is formed. In the 2nd stage based on the analysis of the existing projects, their technical and economic shortcomings are identified and a database management system is created.

At the 3rd stage**,** for planning and simulation of the functions of the information-measuring, control system of the FMA, the types of active elements of the application object, their measurement, execution, regulation, control and management tools algorithms are created in accordance with technological are selected from the database and planning and management operations[1] [2].

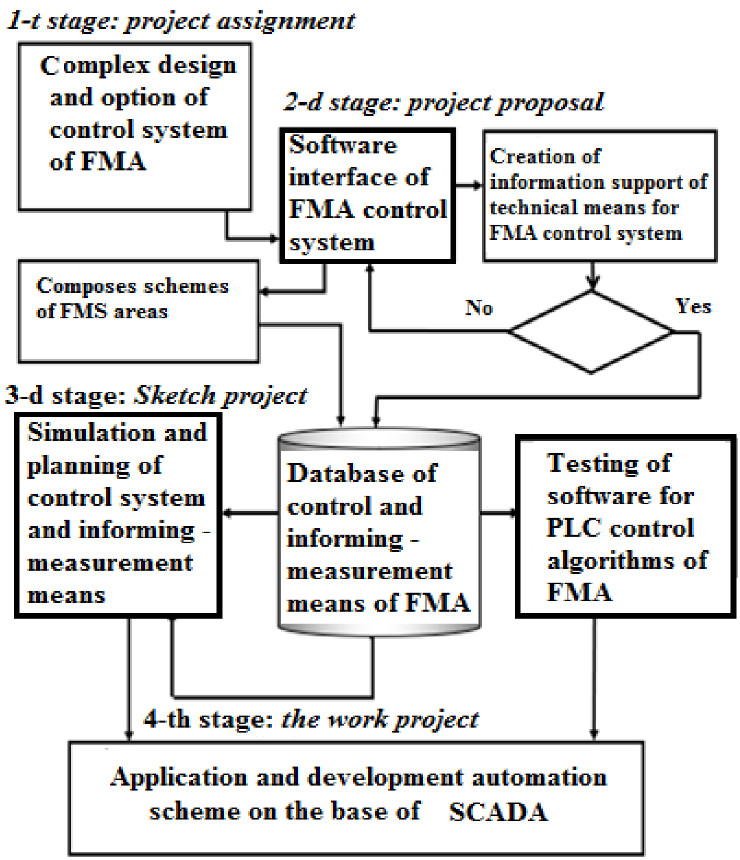

Fig. 1. Structure of the stages of designing the management and control system of an agile manufacturing system

---

[1] Orujova, G.E., Aliyeva S.B., Nasirova, E.E. Modeling the operation of a crane-manipulator in a mechanical assembly flexible production module. Scientific works of AzTU, Baku, 2019, No. 3, pp. 126-132

[2] Mammadov, J.F., Huseynov, R., Huseynova, G.H., Abdullayev, G.S., Aliyeva, S.B. Frame Modeling of Flexible Manufacture Module Selection and Expert Analysis of its Control System. 2020 International Conference Automatics and Informatics (ICAI), Bulgaria, Varna Technical University, October 1-3, p. 34-41.

Labview and TIA logic programming environment, respectively, modeling and simulation of control and control algorithms of all areas of the FMA are carried out separately and in a complex manner. For a real assessment of the performance of the management and control system of the application object , the software of the programmable logic controller (PLC) is developed and tested.

In the 4th stage, with the connection of the PLC to the industrial network, testing of programs for the automation and management of technological operations of all facilities is being carried out, and laboratory tests are being conducted[3] .

Control and monitoring system of the technological process of the FMA into the industrial network is ensured by the IEC61158 standard. For the effective organization of a flexible production management system, the justification and composition of the selection of devices that provide technological measurement, automatic determination of metrological parameters, and regulatory functions is considered (***stages 2 and 3*****).**

At the initial stage, it is justified to meet the requirements of the circular logistics structure solutions of agile production. In order to ensure the efficient operation of agile production areas, it is planned to introduce an internal and external electricity supply network, an additional distribution transformer station, organize a supply and water distribution network, organize a heat supply and sewage network, create an automated energy resources management system, organize telephone and computer network connections, and improve the areas.

Designing of an automated control system for a FMA consists of the following procedures and operations, such as searching and selecting active elements of its information-measuring and control, creating a database, and modeling the control algorithm[4] :

---

[3] Mamedov J.F., Genjelieva G.G., Aliyeva S.B., Valieva B.A. Creating coorporative network for menegament of HEI and ITS technopark. Journal of Astrakhan State Technical University.Control, Computing technicus, vol. 2020. № 3, p. 7-14.

[4] Mamedov, J.F., Abdullaev, K.S., Talybov, N.K., Aliyeva, S.B. Algorithm for searching and selecting the FMS project based on the modeling frame. International

1. Determining the types and number of transmitters and actuators according to the operations of technological equipment;

2. Determining the types and number of transmitters and actuators for the movement and loading and unloading operations of industrial robots and manipulators;

3. Determining the type and position of the technical vision system that monitors the safety operations of industrial robots.

4. Determination of the types and number of thermometers, humidity transmitters, and thermocouples that control the standard pressure, processing rate, environmental humidity, and temperature parameters in technological equipment, industrial robots, manipulators , special modules, and automatic transport lines.

5. Determining the control system for finished product quality standards on the production line.

One of the important project issues for the effective management of the active elements of the FMA is the selection of information-measuring and control means of ACS (transmitters, actuators, regulators, technical control, programmable logic controller and communication system) and the creation of a database management system for the ACS of FMA.Based on the database of active elements of the ACS of the FMA, which is structured in the form of a table, a logical model of the automation scheme is constructed in the form of frame knowledge. In the frame model, the information units of the AIS are structured in the form of protoframes as follows:

Frame name: ACS of FMA active elements ($F_{\text{ÇİS\_AİS\_AE}}$)

Slot 1 - name - Technological ACS elements of equipment (TE_{AISE}) [operation the beginning and the end note who transmitter (V_{bs}); equipment technical control system TC_a; PLC];

Slot 2 - name – Industry ACS elements of the robot [linear , angular] displacement transmitter (V_x, V_b); technical vision system (TVS); (PL)];

conference - Mathematical methods in technology and technologies. MMTTZ, Kazan, 2020, Vol. 2, p. 111-113.

Slot 3 - name - Automatic transportation line [layout positioning transmitter (V_{tm}); speed regulator (IR_s); design quality control system (QCS_t); (PL)];
Slot 4 - name - Oven [thermocouple (TC); thermostat (T); PLC];
Slot 5 - name – Compressor [air pressure measuring transmitter (V_{ht}); PLC];
Slot 6 name – Production temperature mode [mortar temperature gauge transmitter (V_t); open with PLC];
Slot 7 - name – Production tension mode [voltage regulator (VR); programmable logic controller (PLC)].

Slot i - FMA ACS's active of the elements mutual relations scheme established, where the production trust control process model was built. In figure 2, the frame name, slots (in yellow) and slots prices are in the form of circles, connections business orientator arcs picture is done.

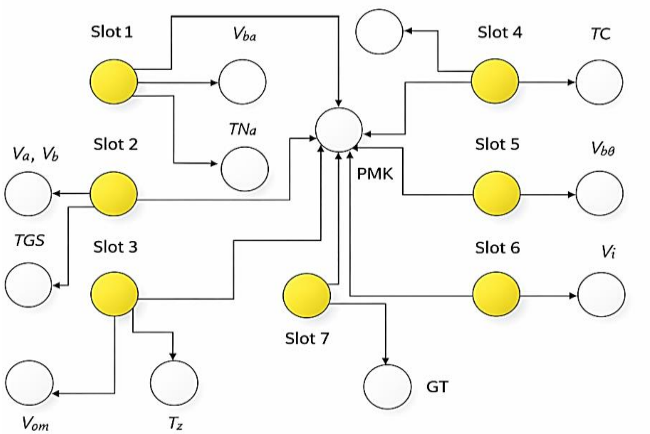

Fig. 2. Interaction diagram of active elements of the ACS of the FMA based on the frame model

By calculating the number of interconnections of individual slots and the active elements of the ACS of the FMA in general, that is, the interconnections of the automation scheme of the FMA, it is possible to determine the degree of complexity of the control system as a whole. For this, taking into account the connections of each slot, the general interconnection matrix of the graph is calculated using graph program as follows[5]:

The constructed M_q matrix, it becomes easier to analyze the management process of the research object. If we conditionally divide the M_q matrix into the fields of *Slot i*, then based on the indicators of the slot fields of that matrix, the total quantitative indicator of the ACS of the FMA (the number of inter-structural relations - the algebraic sum of the cell values in the rows of the matrix) is determined as follows:

$$R_{M_{qə}} = \sum_{i=1}^{7} Slot, \quad i=18 \qquad (1)$$

where an interconnected graph-scheme in figure 2 shows that the constructed the automated control system of the FMA and the matrix and quantitative characteristics were calculated as follows:

$$M_{\infty} = \left(\begin{array}{llllllllllll}
0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & \cdots & & & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & & & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & & & \\
\hline
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & & & \\
0 & 0 & 1 & 0 & 1 & 1 & 0 & 0 & \cdots & & & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & & & \\
\hline
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & & & \\
0 & 0 & 0 & 1 & 0 & 1 & 1 & 0 & \cdots & & & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & & & \\
\hline
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & & & \\
0 & 0 & 0 & 0 & 1 & 0 & 1 & 1 & \cdots & & & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & & & \\
\hline
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & & & \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 1 & \cdots & & \\
\hline
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & & & \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 1 & \cdots & \\
\hline
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & & & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 1 & \cdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & & &
\end{array}\right) \qquad (2)$$

A plan for the placement of equipment is drawn up for their effective selection for the purpose of further modeling of the elements

[5] Mammadov, J.F., Abdullaev, G.S., Ghasanova, E.M., Aliyeva, S.B., Muradly, Z.M. Development of frame models for the selection and design of the production system. Journal of Dagestan State Technical University. Technical sciences. Volume 47, No. 1, 2020, p. 93-101.

of the control system of the application object and building a real project of the automated scheme.

To ensure the effective functioning of the management system of the FMA, it is necessary to organize intellectual information support at the information-measurement, execution, regulation, processing and industrial network levels. The database management system (***level 1***), databases (***level 2***), information-search, selection and decision-making subsystem (***level 3***), which form the basis of information support, have a hierarchical structure. In order to control the correct use of the complex information support of the management system of the FMA and to protect the integrity of the database, the proposed hierarchical structure provides for the dynamism of the database, editing of stored data, the operation of the decision-making module, data updating and interface with other support tools of the system.

The search and selection of data is carried out based on the characteristics of the FMA of the application object and the specified characteristics. At the stage of developing the database of management elements , the type of data, the characteristics of the object, the requirements for description, the structure, the specified parameters and relationships are taken into account in the database. However, information about the objects of the structure is not fully reflected or, conversely, the management systems of most enterprises do not correspond to ready-made technical solutions.

From this it is clear that it is necessary to choose tools that can create a database based on the data to be stored in the newly created database. To solve this problem, it is required to use a database management system (DBMS), which provides input data management (search-decision-making-selection) at the 1st level of information provision[6].

The information support of the management system of the FMA is organized into DBIS: the user's DBIS and the server's DBIS. The

---

[6]Aliyeva, S.B. Creation of information support for the design of an automated control system for an agile production enterprise. Materials of the II International Scientific Conference on Information Systems and Technologies, Achievements and Prospects, July 09-10, 2020, pp. 27-31.

most widespread, user's DBIS are dBase, Paradox, Clipper, FoxPro, Access and Microsoft Data Engine.

The server database is formed from management systems such as Oracle, Informix, DB2, Sybase, Microsoft SQL Server. The “client/server” architecture in which server VBIs are designed is organized according to the “mainframe” model, where data storage and processing are organized on a central computer with special programs and services. The database formed on the basis of server data consists of files. The server DBIS ensures the integrity of information, backups, authorized access to data, recording transactions, and the execution of user requests for selecting and changing metadata. The client programs that satisfy these requests are executed on automated workstations in the network[7].

When using the server's DBIS at the 3rd level of the FMA automation scheme, queries are executed by the server itself. Therefore, client programs receive only the results of the query from the server and ensure the transfer of all indexes and tables of the relational database and the security of network traffic during query processing. In desktop DBIS, data management is implemented using the operating system's file services. DBIS includes tools aimed at working with data in a format specific to the DBIS and allowing for the creation of more and more .

IR control system's executive elements (IEE_i) , graphs of the engine's nominal torque, piston inlet-outlet diameter, length, linear displacement speeds along the *X*, *Y*, *Z* axes and required power are plotted and analyzed in Matlab (Figure 3).

[7] Aliyeva, S.B. Creation of a database of information-measuring elements of an automated production control system. Scientific News of SSU, No. 4, Vol. 21, 2021, p. 73-77.

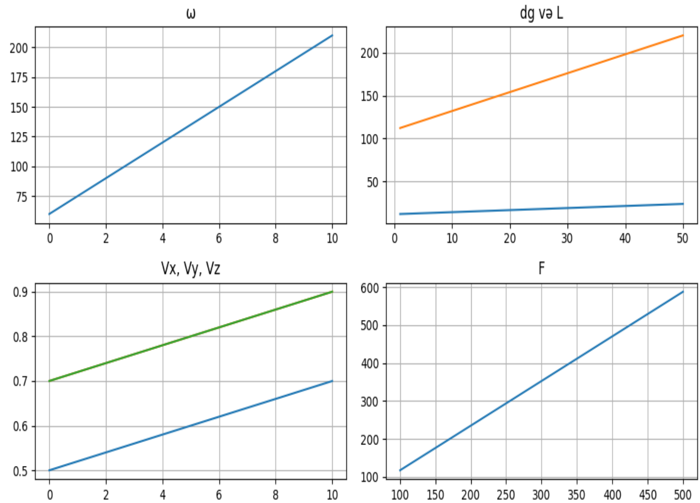

Fig. 3. Experimental graphs of indicators of the execution elements (IEE$_i$) of the IR control system

A more reliable and accurate database is formed based on the parameters determined by the given constants and formulas of the technological measurement and execution means of the control system of the active element of the collected FMA (on the example of IR).

Depending on the given fixed and specified parameters, the number of required operations of the IR servicing (loading and unloading) process is determined by the following formula:

$$n_{əm} = \frac{tK_{det}}{F_{poz}60}, \quad (3)$$

where t - is the time spent on loading and unloading operations of the IR; K_{det} - is the number of operations of loading and unloading of parts by the IR during one shift; F_{pos} – is the time allocated to IR in a production module during a day.

$$K_{det} = K_{ad} + N \quad (4)$$

where N *is* the number of parts produced during one shift K_{ad}.

The value obtained as a result of calculating the loading and unloading operations of the IR The value of is rounded up to the full maximum value. To ensure the reliability of the operation of the IR control system, it is advisable to alternate the loading and unloading positions. This approach is used so that if one position of the IR fails, the next operation continues without stopping.

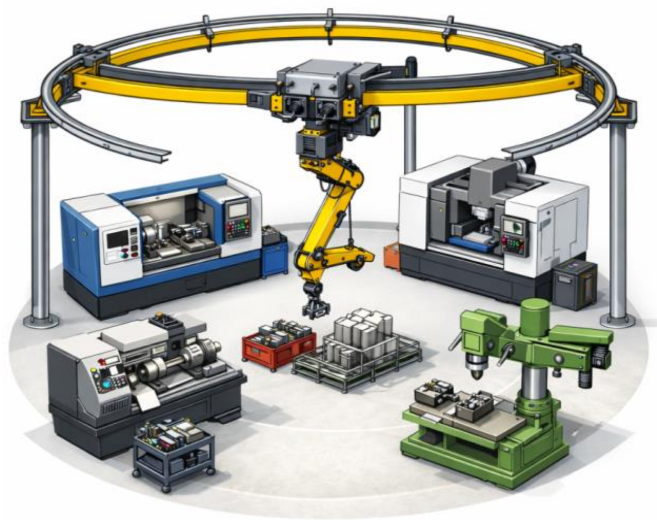

Fig. 4. 3D structure of a module serving several machines of an industrial robot in the field of agile manufacturing

To ensure the accuracy of the control system of the IR (Fig. 4) serving several machines in the modules of the agile production area, a graph-scheme is constructed based on the layout of the control system of the production modules of the FMA and its IR_i shown in figure 4.

The FMA module, the machines are placed in 4 working modules. Functional connections between the working modules are provided by an automatic transport vehicle (ANV↔X_3), a positioning manipulator (MM ↔ X_4) that ensures the positioning of the workpiece (T↔X_2), and industrial robots (IR ↔ X_{1i}) that serve the machine of each working module (TD ↔ X_5; FD↔X_6; RBD ↔X_7; ĀD↔X_8). Servicing operations for the FMA machines are performed by industrial robots IRi ↔ {X_{11}, X_{12}, X_{13}}. Finally the positioning, quality control and unloading of the workpiece are provided in the module (MKNBM ↔X_9).

Taking into account the sequence of technological operations of the FMA and functional relationships, let's build a functional diagram of the FMA[8]:

$X_{11} \to X_2 \to (X_3 \,\&\, X_2) \to (X_4 \,\&\, X_2) \to (X_{12} \,\&\, X_2) \to (X_5 \,\&\, X_{2td}) \to (X_{12} \,\&\, X_{2td}) \to (X_6 \,\&\, X_{2fd}) \to (X_{11} \,\&\, X_{2fd}) \to (X_7 \,\&\, X_{2rbd}) \to (X_{13} \,\&\, X_{2rbd}) \to (X_8 \,\&\, X_{2yd}) \to (X_{13} \,\&\, X_{2yd}) \to (X_9 \,\&\, X_{2yd})$.

X_{ij}, X_2,.....,X_9 and if we accept the presence or absence of these relationships as 0 and 1, respectively, then the following conditional expression should be written:

$$M_{ij} = \begin{cases} 1, \textit{if there is an edge from vertex } a_{ij} \textit{ to vertex } b_i, \\ 0, \quad \textit{otherwise}. \end{cases} \quad (5)$$

Based on expression (5), a matrix is constructed based on a graph-scheme (Figure 5) that provides control activities in accordance with the technological operations of the active elements of the CISh:

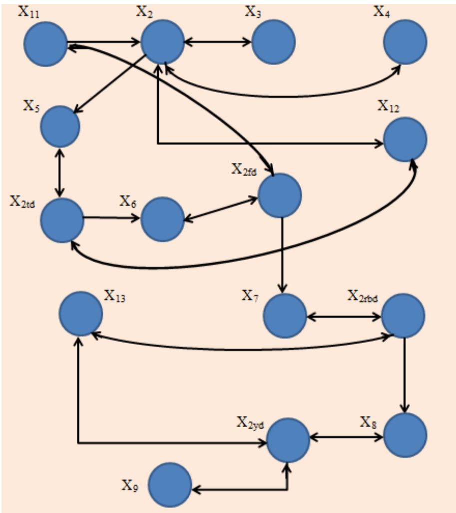

Fig. 5. Graph of the functional diagram of the sequence of technological operations of the FMA

---

[8]Aliyeva, S.B. Algorithm of selection of information-measuring elements of a flexible production module. Practical problems of mathematics and new information technologies of the IV Republican Conference. 09-10 December 2021, No. 9, p. 168-169.

$$M = \begin{pmatrix} 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \quad (6)$$

By determining the number of input and output connections of each element of the matrix, it is possible to determine the amount of information-measurements and the number of signals entering the PLC input during the technological operation of the application object.

The following formula is used to calculate the amount of technological measurements and execution based on the number of input and output connections of the active element:

$$N_{Xij} = \sum_{i}^{n} M_{ij} + \sum_{j}^{m} M_{ij} \, , \quad (7)$$

where $n=15$, $m=15$.

Depending on the information connections of each active element of the application object, the inputs X_{ij} of the control block in the example of the 2nd flexible production module of the FMA are defined. In the example of the 2nd flexible manufacturing module, the output-execution process of the control block Y_{ij} is defined.

Chapter three is dedicated to the issue of modeling the creation of an automation scheme for a flexible manufacturing control system.

The issue of structural analysis of the automation scheme of the flexible manufacturing control system was raised and for its modeling the tasks are defined:

1. Determining the general structure of the modeling tool for the control system of the FMA by collecting and presenting initial data;

2. Selection of a general automation scheme for the industrial automation system at the levels of information-measuring (IM), regulation (R), diagnostics (D), control (C), execution, processing (EP), decision-making (DM) and industrial network organization subsystems;

3. Structural modeling of the general automation scheme of the FMA to determine the information and functional relationships of the system;

4. Creation of functional and technological planning and management algorithms and software;

5. Construction, visualization, simulation of the automation scheme of the control system and integration with the industrial network.

To ensure the solution of the above issues, a general structural scheme is proposed for modeling the process of building a control system and its automation scheme for a flexible manufacturing area in mechanical engineering, which is applied at the initial stage (Figure 6). A formal structural model is compiled based on the topology of the positioning of the measurement, execution and processing elements of the automation scheme of the FMA and their mutual relationships with each other and with the external environment. To ensure automation of the management process of the applied object's FMA, the information and control relationships between subsystems are written in the form of a set as follows:

$$P_i \in \{P_1, P_2, \ldots, P_n\}, \qquad (8)$$

where P_1 is the control subsystem of the FMA; P_2 is the subsystem of the management and general system software; P_3 is the data entry subsystem of the FMA; P_4 is the subsystem of the FMA; P_5 is the technological measurement subsystem of the FMA; P_6 is the technical control subsystem of the FMA; P_7 is the execution subsystem of the FMA; P_8 is the operational management subsystem of the FMA; P_9 is the subsystem of the integration of the FMA control system with the industrial network[9].

[9]Aliyeva, S.B. Development of a functional model for information control of the trajectory of an industrial robot in a robotics complex. Proceedings of the III

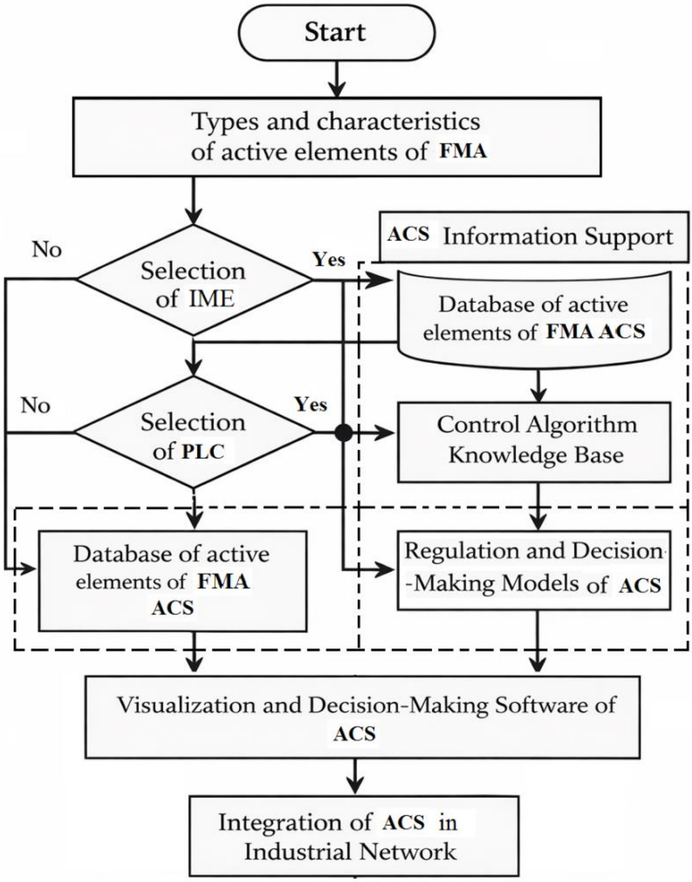

Fig. 6. Modeling the process of building an agile manufacturing site management system and its automation scheme

The values of the input relations are entered horizontally, and the values of the output relations are entered vertically. If there is no relation, the value of the matrix is taken as 0, otherwise 1 is entered.

International Scientific Conference on Information Systems and Technologies, Achievements and Prospects, Sumgayit. 2022, No. 9, pp. 225-228

Thus, the following expression is written to enter the values of the matrix:

$$M_{Pij} = \begin{cases} 1, & if\ from\ P_i\ till\ \ P_j\ there\ is\ grafical\ connection, \\ 0, & otherewise \end{cases} \quad (9)$$

where P_i – are the values of 0 or 1 obtained based on the conditions in the rows and columns of the matrix corresponding to the subsystem of the control system of the FMA.

Each subsystem of the FMA and the ranks *of* individual P_i are determined. P_i are depicted as circles, and the interactions between Pi are depicted as directed arcs (Figure 7).

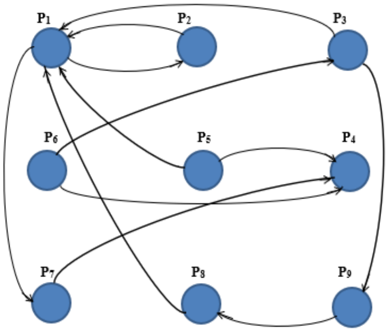

Fig. 7. Graf-scheme of the interconnections of each *P*P_i subsystem of the FMA

According to expression (9), the rank of each P_i is calculated, taking into account the number of input and output connections between the subsystems P_i

$$P_i = \sum_{i=1}^{9} P_{ij} + \sum_{j=1}^{9} P_{ji}, \quad (10)$$

where $\forall\ P_{1j}\ \in \{P_{11}, P_{12},\ \ldots, P_{19}\};\ \forall\ P_{i1}\ \in \{P_{11}, P_{21},\ \ldots, P_{91}\}$.

P_i is determined according to expression (10), allow for the creation of a more reliable management system of the application object by determining the quantitative indicators of information-measuring and execution functions.

The issue of constructing an algorithm for modeling *the* P_{ij} subsystems included in the automation scheme of the FMA is posed, depending on their functions. According to expression (9), P_i quantitative indicators of information exchange between subsystems are determined:

M_{Pij} =

	P_1	P_2	P_3	P_4	$P5$	P_6	P_7	P_8	P_9
P_1	0	1	1	0	1	0	0	1	0
P_2	1	0	0	0	0	0	0	0	0
P_3	0	0	0	0	0	1	0	0	0
P_4	0	0	0	0	1	0	1	0	0
$P5$	0	0	0	0	0	0	0	0	0
P_6	0	0	0	0	0	0	0	0	0
P_7	1	0	0	0	0	0	0	0	0
P_8	0	0	0	0	0	0	0	0	1
P_9	0	0	1	0	0	0	0	0	0

The position coordinates of the mechanical processing modules of the FMA and the applied machine tools and the dimensions of the working zones are included:

1. The working zones of the active elements of the FMA module is formed from the sum of working zones of separate geometric shapes:

1.1. V_{TD} of the lathe are determined by the following - Length L_{td} =z [s_{Ltd} , x_i]; Width B_{td} =z [s_{Btd} , x_i]; Height H_{td} =z [s_{td} , x_i], where $L_{td} \gg B_{td}$.

1.2. V_{FD} of the milling machine are determined by the following - Length L_{td} =z [s_{Lfd} , x_i]; Width B_{td} =z [s_{Bfd} , x_i]; Height H_{fd} =z [s_{fd} , x_i], where $H_{fd} \gg B_{fd}$

1.3. V_{RBD} of the radial boring machine are determined by the following - Radius R_{rbdd} =z [s_{Rrbd} , x_i]; Height H_{rbd} =z [s_{rbd} , x_i], where $H_{rbd} \gg R_{rbd}$

In order to determine the step-by-step sequence of operations of the active elements of the FMA, the following expression is written[10]:

$$P_i = \{< X_{ij}, X_{ijk}, Y_{ij}, Y_{ijk} >\}, i = 1; j = \overline{0,1}; k = \overline{1,4}, \quad (11)$$

where X_{ij}, X_{ijk}– is the signal given to the input of PLC1 for measuring

---

[10] Mammadov, J.F., Guseynova, G.H., Aliyeva, S.B., Safarova, T.A. Analysis and Modeling Automated Product Quality Control for Machine-building Industries. IECHCI2023 International Conference, Sabanci University, November 23-25, Erzurum, Turkey, p.116-119.

the technological operation of the active element of the FMMİ; Y_{ij}, Y_{ijk}– is the execution of the technological operation of the active element of the FMMI at the output of PLC1. $i = 1; j = \overline{0,1}; k = \overline{1,4}$are the indices received according to the stages of the input and output operations of the control block of the application object.

The sequence of technological operations ($i = \overline{1,22}$) is determined as follows:

<Measurement of the positioning of the active element at the input of PLC1 and its execution at the output >- $J_i \rightarrow X_{ij}, Y_{1j}$.

One of the important issues at the stages of building the architecture of the ACS of the mechanical engineering flexible manufacturing area, the selection of control elements and the design especially at the stage of the working design, is the determination of the reliability of the ACS[11]. The main indicator of the reliable operation of the proposed automation scheme is the ability of the automated control system to operate continuously, without forced interruptions, flexibly, accurately and productively during the intended period of operation. In the process of performing the functions of the control system of the applied object, let us consider that it contains a fairly large number of technological measuring, regulating, diagnostic, control, controlled processing, execution and industrial network devices and devices, which are sources that can cause random events. Cases of failure of the applied object (in the example of the mechanical processing ACS) are considered .

If we assume that there is a probability of a transaction being terminated (TT) several times in the time interval t-(t+Δt),

Then TT depends on Δ t.

All the resulting ACS are independent of each other and arise by chance. The main indicator of repairability is the probability of the system being restored $P(T_H)$ which is the probability of a given T_H time is also considered, the second criterion is the average recovery time T_b - k_i which is to restore the downtime and determine the average time

---

[11] Aliyeva, S.B. Information security of choice means of technological measurements and control of a flexible system by production Transport engineering 2024. No. 9(33). c. 12-20.

consumption in the given service conditions. In addition to the above indicators, the criterion of uninterrupted operation and repairability also includes additional complex indicators. These are the readiness factor K_h, the technical readiness factor $K\ T_H$, the readiness factor in the steady - state mode of the system, etc. These factors are determined as follows:

$$K_h = T_H / (T_H + T_b) \tag{12}$$

$$K_{TH} = T_H / (T_H + T_b + t_{pf}) \tag{13}$$

where T_H – is the time of technical preparation and use of the active element of the FMA; T_b - is the time of recovery of the malfunction of the active element of the FMA; t_{pf} - preventive maintenance time.

The parameters reflecting the reliability of the control system of active elements in the modules of the FMA are the times of technical preparation, prevention and restoration of equipment of the IR and machines T_H, t_{pf} and T_b. Taking into account these main indicators (table 2), graphic characteristics are constructed (Figure 8).

Table 2.

Experimental values of the technical preparation, prevention and equipment restoration times of IR T_H, t_{pf} and T_b

Parameter symbol	Experiment 1 indicator (hours)	Experiment 2 indicator (hours)	Experiment 3 indicator (hours)	Experiment 4 indicator (hours)
T_H	2	4	6	8
T_b	0.5	0.5	0.5	0.5
t_{pf}	0.2	0.3	0.2	0.3

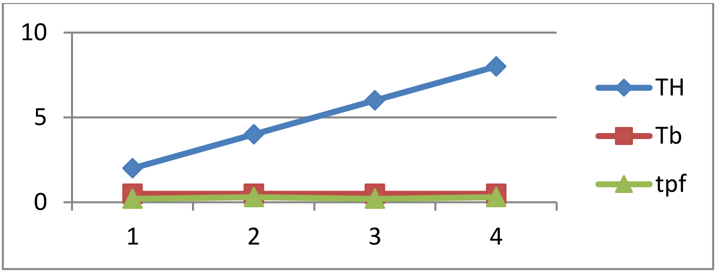

Fig. 8. Graphics of IR's T_H, t_{pf} and T_b technical preparation, prevention and equipment restoration times based on experimental indicators

The reliability coefficient is determined depending on the experimental indicators of the technical readiness, preventive maintenance and equipment recovery times of the IR T_H, t_{pf} and T_b. If the technical readiness and use of the IR T_b are assumed to be constant at 0.5 hours during one work shift and the technical readiness and use are changed in the interval of 2 ÷ 8 hours, then the corresponding changing characteristic of the K_h coefficient is obtained as in figure 9.

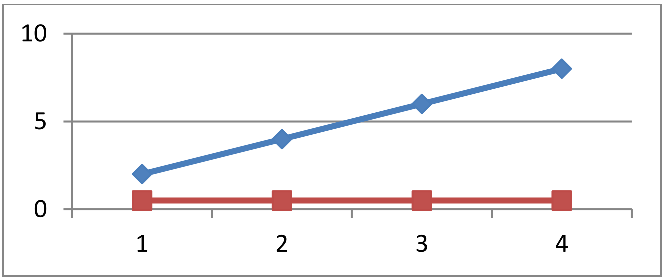

Fig. 9. Characteristics of the K_h coefficient depending on the change in the time of technical preparation and use of the industrial robot T_H in the interval of 2 ÷ 8 hours and the minimum time spent on recovery time of 0.5 hours

For the failure intensity of the active elements of the AME (in particular, IRi) and machines, the initial number of elements of the same group is i and the average failure $\lambda_{is\ i}$ and the number of such elements in the system is *N*. In many literatures, the failure intensity is given by indicating the interval of λ_i - i.

If the system is divided into *r* groups and the intensity of operation interruptions is the same in them, then the system's failure parameter λ, the operating time until failure, T_H, is determined as follows.

$$\lambda = \sum_{i=1}^{r} N_i \lambda_i ; T_H = \frac{1}{\lambda} \tag{14}$$

To calculate the reliability indicators of the system, it is necessary to know the coefficient K_i of its elements and the failure intensity λ_δ (for the base elements). In this case, the operation stoppage parameter is designated as.

$$\lambda = \lambda_\delta \sum_{i=1}^{r} N_i K_i \tag{15}$$

Where $K_i = \frac{\lambda_i}{\lambda_\delta}$, the calculation is performed using the reliability coefficient method.

This method requires knowing the reliability coefficient of the active elements of the FMA and the absolute value of the failure intensity of the base elements. Therefore, the calculation of reliability using the coefficient method is performed with comparable accuracy.

The reliability level of the control system of the application object determines the degree of economic efficiency of the system. As reliability decreases, the number of stops for the purpose of restoring the operation increases, which increases the cost of the system, and a lot of labor is spent on its operation. Therefore, in order to ensure the reliability of the system under the necessary conditions, it is necessary to optimize the technical and economic criteria of the reliability of the control system of the active element of the FMA. For this purpose, a number of structural and functional variants are expressed in the systems. The selection of the best variant, the maximum efficiency in productivity for giving and for giving annual additional yield following like reception to do can be as follows:

$$E_X = (\Delta C_e - E_n \Delta K) \rightarrow \max \tag{16}$$

$$E_T = (\Delta C_d T_e - \Delta K) \rightarrow \max \tag{17}$$

Where ΔC_e- the cost of the product being produced increases the economic efficiency by reducing the cost of production; *E* - the normative value shows the efficiency of capital investment; ΔC_d - the normative economic value is expressed as the additional capital investment; $E_H \Delta K$- the economic difference is (cost reduction).

One of the important issues for improving the performance of the control system of the FMA is to increase the reliability and productivity of the information-measuring, execution (level 1), regulation, processing (level 2) and functional elements of the industrial network, organized automated workplaces (level 3) at the levels of the automation scheme of the control system. In this regard, the choice of a method for improving the performance of the FMA at all three levels of the automation scheme (measurement-execution, regulation-processing, network management) is a question of different reliability of elements with the same reliability level.

In the case under consideration, the main criterion is to use a method that provides the maximum additional economic effect. In this case,

$$\frac{\lambda_{Hi}}{\lambda_{iopt}} = \lambda_{ui} R_i T_e / S_i^{/} = \gamma_i \quad (18)$$

is written as. Where γ_i - characterizes the increase in the optimal reliability of the element. Therefore it is written as:

$$E_{Ti\max} = \lambda_{ui} R_i T_e \left[1 - (1 + \ln \gamma_i) / \gamma_i\right] \quad (19)$$

If $1 \le \gamma i \langle \infty$ it increases monotonically in the interval $E_{Ti\max}$ γ_i is taken at the largest value of and the smallest value of S_i. $S_i^{/} / T_{ei} \to \min$ it is taken in accordance with the condition of increasing the reliability of the functional element.

The cost of creating and operating an agile manufacturing site management system and its automation scheme is divided equally, and the cost per year is determined as follows:

$$S_{il} = [(S_{iş} + S_{ob}) / T] + S_{ist} \quad (20)$$

Where S_{ish} - the cost allocated to processing, S_{ob} - the cost allocated to the purchase of machines, S_{ist} - the annual operating cost (5 ÷ 7 years) is the operating life of the automated control system of the technological process; S_{ist} - the cost includes the wages of employees, the cost of heat, electricity, water, etc. energy sources per year, materials, components (related to operation) and depreciation costs, etc. The cost is required according to the time spent by the working personnel per year, the number of employees, the average hourly rate, and the norm envisaged in the workshop.

Based on the analysis of the local control system used in the flexible production workshop with circular compo- nents of mechanical machines, it was determined that it gave a large annual economic efficiency. Due to the use of the automation scheme of the local technological process control system, the thickness of the prepared iron sheets was maintained at 1.18%. The use of technical and economic efficiency in the operation of the automated control system of metal-cutting machines allows you to correctly select the nomenclature of the processed part. In this case, the cost of preparation for operation decreases by -10 times, labor productivity increases by 2 ÷ 6 times, the amount of labor spent on the preparation of parts decreases, and quality and accuracy increase.

The fourth chapter is devoted to the visualization of the operations of the active elements of each flexible production module of the mechanical processing flexible production area, the detection of technical defects that may arise in the manufactured product, and the modeling of the complex control process.

The method and means of technical control over the quality of raw materials are selected from the initial stage of the applied production process; the technical capabilities and indicators of the active element applied in the technological line; the indicators of the manufactured product are determined.The technical control block of the FMA based on the SCADA system automatically collects current information measured from all installed sensors of the machines, industrial robots, manipulators and transport operating in the production area, thereby achieving full control based on the maximum data range. The dispatcher receives current archived information about the Gi equipment and Mi product indicators in each module.

To select the elements of the automatic control system based on the SCADA system, the specific characteristics and technical indicators of the product and technological equipment manufactured at the FMA facilities are taken into account. The indicators of the current technological status of the FMA facilities and the products manufactured here are graphically visualized on the dispatcher's monitor, allowing for visual monitoring of current parameters and prompt decision-making. Interactive communication with the dispatcher's automated workplace is provided for the collection and decision-making of current quality data (Mi) of the FMA facilities (Gi) and the products manufactured at the facilities (Fig. 10). The Gi and Mi parameters are collected on a special database server (InterBase). At the same time, a detailed report on the system's operation is stored.

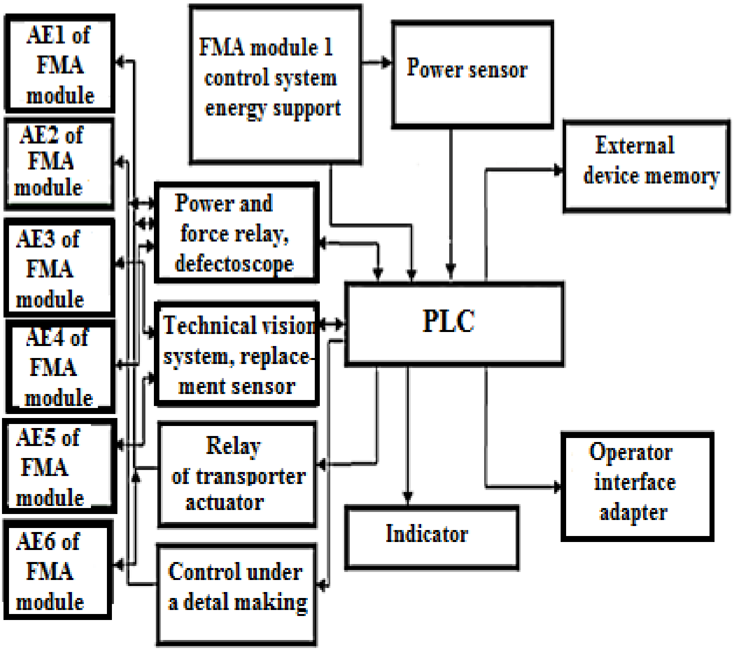

Figure 10. Automation scheme of the measuring, regulation and control system for technical control of the active elements of the FMA and product quality

The structure of the software is determined based on the functions of the management and technical control system of the FMA. The software provides the interface of the automated management and control system for the interaction of subsystems with each other. Here, the issues of monitoring current control data, data collection and archiving, statistical data analysis, quality assessment, connection to the local industrial network, and route determination are implemented.

THE MAIN RESULTS OF THE DISSERTATION WORK

1. A phased structure scheme for the selection and design of technological and measuring tools for the agile production management system has been proposed.

2. For the selection and design of the elements of the automated control system of the FMS, a scheme of the interaction of the active elements of the FMS control system was established based on the Frame model, and a large and flexible database of technological measurement and execution tools of the control system of the active element of the FMS was created.

3. Based on the proposed scheme for the assembly of machine tools and industrial robots of the FMS, a functional graph-scheme of the sequence of technological operations was constructed, and quantitative indicators of the mutual information relations of active elements were determined.

4. An algorithm has been developed for modeling the process of building an automation scheme and structural analysis at the subsystem level on the example of the 2nd flexible production module of the FMS, depending on the information connections of each active element of the application object.

5. A mathematical model ensuring the reliability of the control system based on the corresponding working zones of the IRi and the serviced machines, the automatic transport line, and the positioning manipulator was developed and analyzed through computer experiments.

6. An automation scheme of a technological measurement, regulation and control system for the working zones of the active elements of the FMA, technological operations and technical control of product quality has been proposed.

A block diagram of real-time control of the working zones and quality control process of the active elements of the production module has been established to establish a technical control system for the mechanical processing plant based on SCADA .

8. An algorithm and software have been developed to simulate the operations of active elements on the FMA's technological line and the technical control system for the quality of the manufactured product.

THE MAIN RESULTS OF THE DISSERTATION WORK ARE REFLECTED IN THE FOLLOWING PUBLISHED SCIENTIFIC ARTICLES:

1. Orujova, G.E., Aliyeva S.B., Nasirova, E.E. Modeling the operation of a crane-manipulator in a mechanical assembly flexible production module. Scientific works of AzTU, Baku, 2019, No. 3, pp. 126-132

2. Mammadov J.F., Huseynov R., Huseynova G.H., Abdullayev G.S., Aliyeva S.B. Frame Modeling of Flexible Manufacture Module Selection and Expert Analysis of its Control System. 2020 International Conference Automatics and Informatics (ICAI), Bulgaria, Varna Technical University, October 1-3, p. 34-41.

3. Mamedov J.F., Genjelieva G.G., Aliyeva S.B., Valieva B.A. Creating coorporative network for menegament of HEI and ITS technopark. Journal of Astrakhan State Technical University.Control, Computing technicus, vol. 2020. № 3, p. 7-14.

4. Mamedov J.F., Abdullaev K.S., Talybov N.K., Aliyeva S.B. Algorithm for searching and selecting the FMS project based on the modeling frame. International conference - Mathematical methods in technology and technologies. MMTTZ, Kazan, 2020, Vol. 2, p. 111-113.

5. Mammadov J.F., Abdullaev G.S., Ghasanova E.M., Aliyeva S.B., Muradly Z.M. Development of frame models for the selection and design of the production system. Journal of Dagestan State Technical University. Technical sciences. Volume 47, No. 1, 2020, p. 93-101.

6. Aliyeva, S.B. Creation of information support for the design of an automated control system for an agile production enterprise. Materials of the II International Scientific Conference on Information Systems and Technologies, Achievements and Prospects, July 09-10, 2020, pp. 27-31.

7. Aliyeva, S.B. Creation of a database of information-measuring elements of an automated production control system. Scientific News of SSU, No. 4, Vol. 21, 2021, p. 73-77.

8. Aliyeva S.B. Algorithm of selection of information-measuring elements of a flexible production module. Practical problems of mathematics and new information technologies of the IV Republican Conference. 09-10 December 2021, No. 9, p. 168-169.

9. Aliyeva, S.B. Development of a functional model for information control of the trajectory of an industrial robot in a robotics complex. Proceedings of the III International Scientific Conference on Information Systems and Technologies, Achievements and Prospects, Sumgayit. 2022, No. 9, pp. 225-228

10. Mammadov J.F., Guseynova G.H., Aliyeva S.B., Safarova T.A. Analysis and Modeling Automated Product Quality Control for Machine-building Industries. IECHCI2023 International Conference, Sabanci University, November 23-25, Erzurum, Turkey, p.116-119.

11. Aliyeva S.B. Information security of choice means of technological measurements and control of a flexible system by production Transport engineering 2024. No. 9(33). c. 12-20.

Author's individual participation in the published works:

[1] – Development of the crane manipulator operation algorithm.
[2] – Selection of elements of the agile production module and construction of an expert analysis model
[3] – Development of a control algorithm for the automation of the production process of the technopark.
[4] – Algorithms for searching and selecting a MIS project based on the frame model
[5] – Modeling of the production system design using the frame method
[10] – Development of a quality control algorithm for the production process.

The defense will be held on 26 May 2026 at 14^{00} at the meeting of the Dissertation Council ED 2.48 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at Azerbaijan State Oil and Industry University.

Address: AZ1010, Baku city, Azadlig avenue 16/21
e-mail: info@asoiu.edu.az

Dissertation is accessible at the library of Azerbaijan State Oil and of Industry University.

Electronic versions of dissertation and its abstract are available on the official website of the Azerbaijan State Oil and Industry University.

Abstract was sent to the required addresses on "24" April 2026

_______________Signature of the claimant

Signed for print: 23.04.2026
Paper format: A5
Volume: 36206
Number of hard copies: 25