Training of Specialists for Adaptive management. Techniques for Teaching Computer Analysis of Automated Production Systems in the FlexSim Environment

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Abstract

The article deals with the problem of teaching students and practitioners in methods of searching for reserves to increase the efficiency and reliability of automated control systems for various purposes. The article shows that in the conditions of the fourth industrial revolution, the requirements for the efficiency and quality of variant analysis of the "what if?" type. The necessity of using a new generation of simulation modeling environments in making management decisions has been substantiated. The analysis of the simulation modeling software used in practice and in the educational process of the universities of the world has been carried out. The advantages of the FlexSim software environment are described and the expediency of switching to the use of this environment in the practice of variant analysis of automated systems as well as in the educational process of universities and in the retraining of specialists is shown. A library of typical FlexSim models has been developed, providing training for a specialist who is able to analyze current problem situations in the design and operation of automated production and control systems. The authors have developed a methodology for the continuous use of FlexSim in the preparation of IT students. The method is designed for use in classical and technical universities, focused on training IT specialists, analysts and managers in structures for advanced training and retraining of personnel for modern automated production as well as for self-education.

Keywords

Simulation model, automated control, adaptive management, optimization, efficiency, reliability, training, professional competencies, automated system, information technology

1. Introduction

The Fourth Industrial Revolution is a modern technological strategy that improves the efficiency of production processes by achieving high flexibility and resource optimization [1]. This concept is based on the introduction of cyber-physical systems into production [2-4].

Technical objects of the production environment, which are equipped with a communication interface and integrated information processing capabilities, interacting via the Internet, optimally adapt their behavior to specific production conditions [5].

This approach is based on the technologies of data mining, the Internet of Things and augmented reality [4, 6]; it determines the emergence of production systems of a new type, which provide automatic management of production and sales processes throughout the entire life cycle of a product [7].

Often, student learning technologies do not keep pace with the modern progress of science and production[8-12]. Therefore, today more and more often they pose the problem of adaptive learning [13-16] as well as the problem of rapid variant analysis of possible ways to improve the efficiency of automated systems [1,3,17].

2. Problem Statement

The integration strategy of modern Internet technologies with physical processes in production was first initiated by German companies as the central basis of Industry 4.0 political program [4], and later was adopted by almost all industrialized countries [18]. A significant advantage of the strategy is to improve the competitiveness of enterprises in their continuous development through individual adjustment of production by increasing resource efficiency and reducing costs [19].

As part of the Industry 4.0 strategy, the simulation is one of the key technologies [1, 20-22]. For example, in [20] with the help of simulation models the influence of the properties of different architecture of decentralized production management on the duration of the production cycle is evaluated and compared. For research, a simulation model of a production system consisting of four operating complexes and a robot manipulator was built. Experiments on the model were carried out using both deterministic and stochastic input data. Based on the analysis, conclusions were made about how different architectures are suitable for Industry 4.0, and a set of actions to develop production management facilities in Industry 4.0 was obtained.

Practice has confirmed that simulation modeling is effectively used to solve such tasks [23-24]:
- production reengineering (adaptation of production processes to consumer needs, organization of production and management based on efficient computerization; uniform distribution of labor and technological resources);
- production planning (forecasting the objectives and stages of the production process in the conditions of dynamic changes, expansion of the commodity range, the introduction of new products or services, the use of new equipment; elimination of weak places in the production system);
- warehouse management (elimination of downtime in warehouse departments; identification of goods; strategy of their rational placement and grouping; efficient use of warehouse space; minimization of transportation costs);
- management of material flow and reserves (regulation, rationing, stock control and raw materials; prediction of material needs, determining the average delivery time and frequency of supplies; rational distribution of material and industrial stocks).

Currently, there is a wide selection of simulation programs: MATLAB/Simulink, Arena, Enterprise Dynamics, GPSS World, Excel/Solver, etc.[24-27] The most modern tool that is successfully used to model and analyze production processes is FlexSim software. This program supports all known modeling methods (discrete, continuous, agent, statistical), it has a three-dimensional medium of constructing models and is integrated with C^{++} programming language [28].

The authors of publications [28-29] present practical examples of using simulation models developed in the FlexSim environment as a result of working with students in higher education institutions and in the field of industry. This program is used in the educational process of universities; in particular, it has been introduced into the curricula of the Polish State Eastern European University in Przemysl [30].

Also known is the practice of its introduction in industrial enterprises. A large automobile company FIAT used FlexSim to optimize the production line of EURO 5 and EURO 6 engines [31].

It should be noted that the transformation of production sets new tasks for education. It is assumed that future graduates will be traced with complex problems in the management level [31-33].

The future specialist must have new competencies in accordance with the requirements of the Fourth Industrial Revolution [34-36].

In this regard, it is important to pay attention to the emergence of new technologies associated with Industry 4.0 and take into account them when preparing students of engineering and computer specialties in order to form the necessary professional skills and competencies. In [1], it is noted that human resources play an important role for the implementation of the Industry 4.0 concept. Studies conducted in [10, 37-40] determine the group of key competencies necessary for the development of Industry 4.0. Also, the authors prove that the use of FlexSIM software in the educational process,

research projects, diploma and course works contributes to the development of professional competencies in the direction of Industry 4.0.

Thus, obvious is the following:
- one of the most modern software media simulation of complex systems is FlexSim;
- modern automated production by rapid pace introduces approaches of variant simulation using FlexSIMtechnologies;
- building a learning process to prepare IT-Direction students in the most rating universities in the world focuses on the use of FlexSIM simulation technologies, as evidenced by individual publications;
- in Ukraine there is no practical experience of using FlexSim as well as systematic research on the methodology and methods of implementing this software technology in the educational process of universities.

In this regard, the task of this work will be defined as follows - to develop a method of end-to-end teaching of students, the purpose of which is to master modern tools for analyzing the effectiveness of the functioning of complex automated systems and finding possible ways to improve it, using the FlexSim software.

To achieve the goal, you need to solve such tasks:
- investigate the relevance of reorientation of the educational process to the use of FlexSim software;
- describe typical problem situations of decision support in automated production and training-oriented techniques for using FlexSim simulation models to solve them;
- describe the experience of introducing the methodology of the end-to-end use of the FlexSim program in the educational process in the preparation of IT students and further prospects for its use.

3. Results

3.1. Analysis of the feasibility of teaching students decision-making techniques using FlexSim in problems of managing complex automatic systems

We will analyze the feasibility of teaching students decision-making techniques using FlexSim in the management of complex automated systems.

FlexSim is an integrated environment for building and examining simulation models. At the initial stages of modeling, considerable attention is paid to establishing the probability distribution laws that characterize the input data collected from the modeled system. An incorrectly defined distribution law leads to an erroneous assessment of the parameters of the system's efficiency .FlexSim contains a built-in ExpertFit tool that automatically analyzes the input data and evaluates it according to a certain distribution law. The analysis process consists of the following stages: construction of a histogram of frequencies, selection of the distribution law, and statistical refinement of the parameters of the distribution law.

In production systems, the laws of distribution reflect stochastic processes: the speed of operations (processing, packaging, and assembly), the intensity of the supply of components and raw materials to the work site, time to repair equipment, etc. Figure 1(a) shows a frequency histogram constructed by means of ExpertFit on numerical data, describing the length of stay of parts in the intermediate zone before processing. Analysis of the graphs shows that the Beta distribution law better matches the histogram pattern.

The calculation according to the criteria of the Kolmogorov-Smirnov test and the χ-square determines the correspondence of the chosen distribution function and its parameters. If the random process cannot be described by the parametric distribution law, the FlexSim program provides for the use of data in tabular format without a functional description (Fig. 1, b).

At the stage of building a simulation model, the structure of the system is reproduced. FlexSim 3D objects are designed to build models contained in a set of standard program libraries, divided into categories by functionality and determining their ease of use for the implementation of both discrete and continuous processes. When building models, the principle of visual programming is implemented, according to which the user creates a model from a set of standard blocks and performs calculations. For each object, the corresponding parameters are set to meet the requirements of the simulated system.
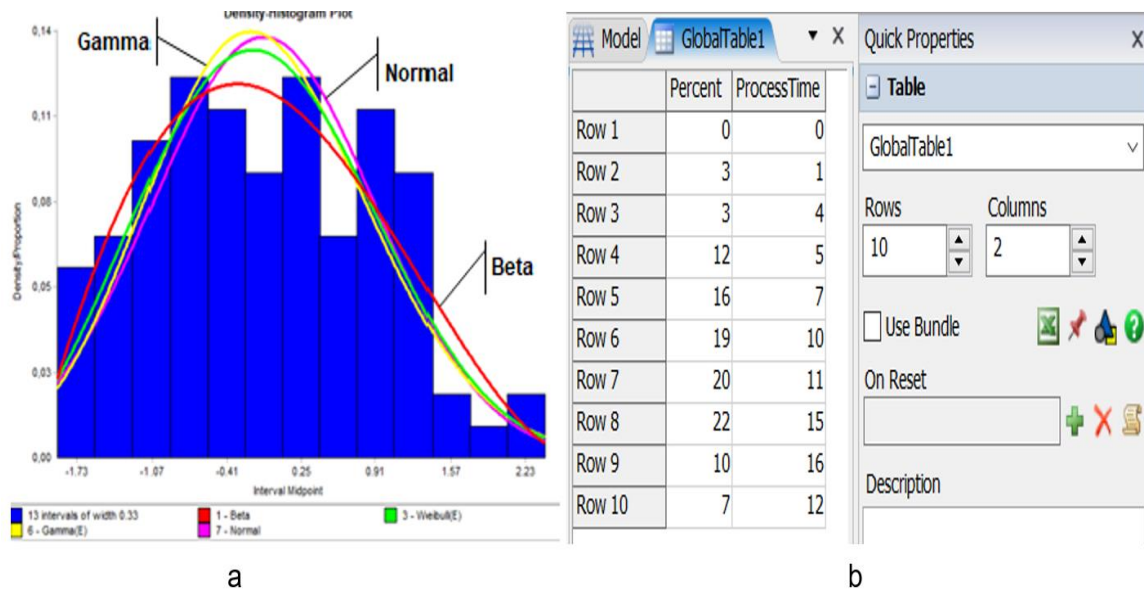
Figure 1:Identification of the law of distribution of sample data: selection of the parametric law (a); description of empirical data with a table of values (b)

Figure 2(a) shows a model consisting of a source of parts (Source); fixed resources (Processors 1 and 2 performing processing) and queues (places of waiting for the overflow of elements before performing processing operations); and a mobile resource (operator who moves parts for processing). Connections between fixed resources determine the direction of movement of material flows.
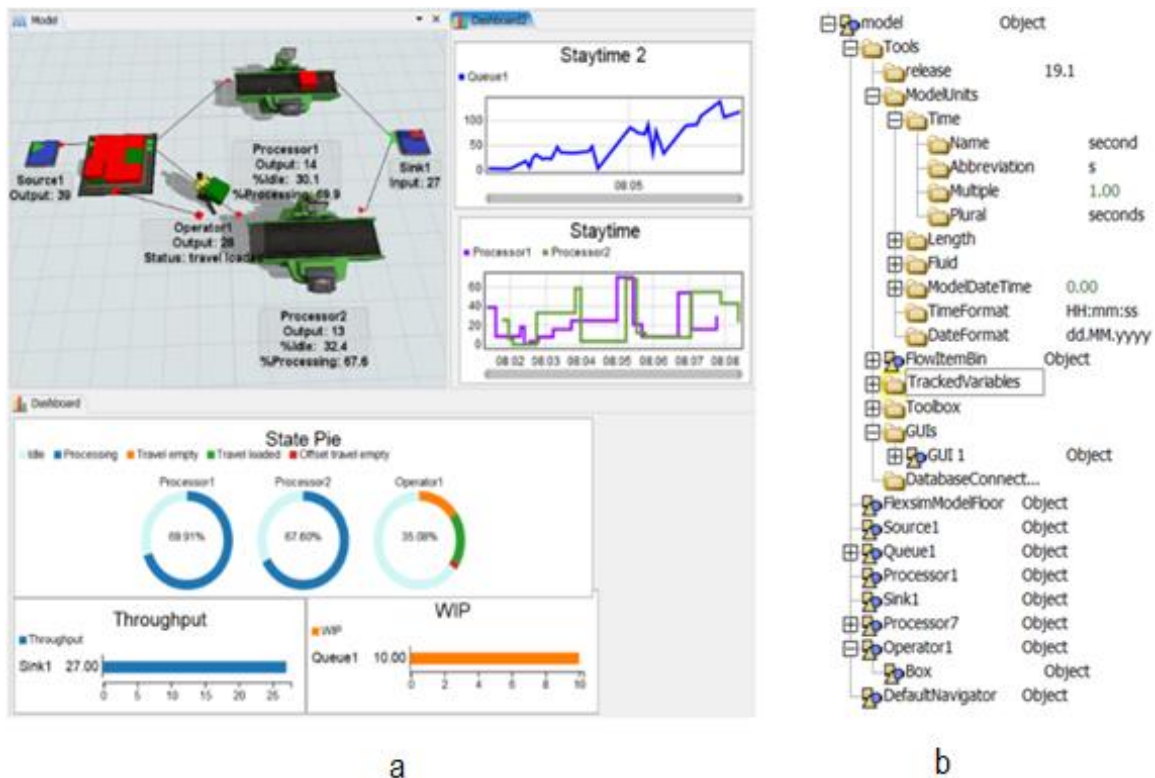

Figure 2:Example of a simulation model in the FlexSim environment: model with statistics (a), model tree (b)

Statistics for each object are displayed in text mode. More detailed statistics are shown by graphs and charts located on information panels. The types of graphs are set by the user and depend on the studied indicators of the system's efficiency.

Pie charts show resource utilization and help you identify periods with high workloads. The graphs show the average waiting time for parts in the queue (Staytime 2), processing time (Staytime), work in

progress (WIP), and system performance (Throughput). A user-friendly software interface, support for three-dimensional animation, and realistic graphics allow you to analyze production processes for risks, involve other specialists and experts in the organization to find problems, interact with project customers, take into account the proposals of experts and working groups to improve the system operation, make appropriate changes to the models, and evaluate the effectiveness of these changes.

The model is driven by data. FlexSim can import/export information from other software environments (for example, MS Excel), read from databases (MySQL, Oracle, SQLite, etc.), and create global tables with data.

It should be noted that the models of systems in the FlexSim environment are developed on the basis of object-oriented approach. So in addition to the three-dimensional view, the model can be represented as a tree structure of hierarchically subordinate objects. The tree model provides an effective tool for finding and accessing work variables used during startup, experimentation, and model optimization. Figure 2(b) shows the tree of the model shown in Fig. 2(a). The nodes of the tree model contain data and functions of objects that determine their properties and actions. The names and symbols of the nodes depend on the type of data being stored.

Support for an object-oriented approach enables the implementation of agent modeling. FlexSim does not have special library blocks that provide agent functionality. The built-in FlexScript scripting language and the C^{++} programming language are used to describe the rules of interaction and the state of the system agents. Software commands also set up messaging between objects, ensuring effective coordination and management of the model. Thus, there is a possibility of establishing information flows and feedback between the structural elements of complex systems.

Simulation models can be built for single use, for example, in solving the problem of optimal allocation of resources between departments, or for multiple use - in the development of parallel and alternative routes of manufacture and processing of products. Disposable models are usually handled by experienced users who are familiar with imitation. Specialists and experts in a particular subject area work with multi-purpose models. This creates the need to implement a graphical interface designed for easy data entry and results in a clear format. An example of a decision support system model based on a simulation model (Fig. 3) was developed by the Mississippi State University to evaluate the performance of the production system as part of the implementation of the concept of lean production (Leanproduction). The system was developed in the FlexSim environment using the GUI linker.
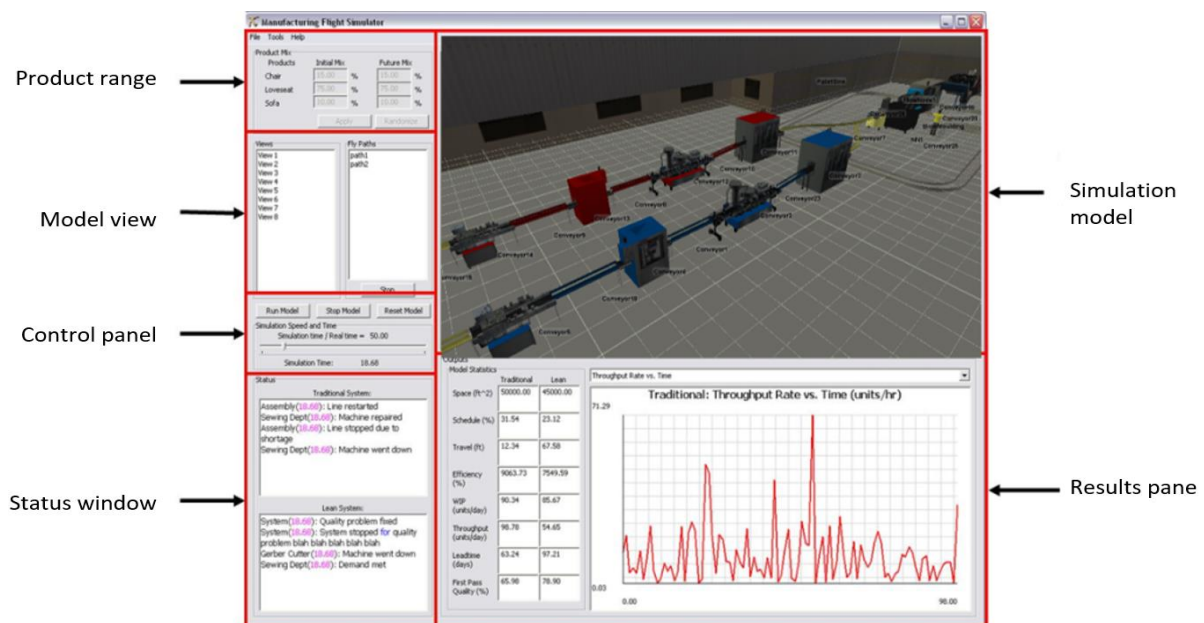

Figure 3:An example of building a DSS model in the FlexSim environment

The model is shown in the center, the input data is entered on the left side of the interface, and the lower part is intended for displaying system performance indicators in graphical and tabular formats. This model interacts with databases, analysis and optimization procedures to support the search for effective solutions.

A key aspect of the Fourth Industrial Revolution is the creation of "Digital Twin" systems that perform the function of remote monitoring and control of the production process in real time. The use

of FlexSim for the practical implementation of this approach is provided by the possibility of integrating the program with information systems of the enterprise SAP (ERP, MRP, CRM, etc.), with databases, support for standards of CALS-technologies .

The advantages of FlexSim include the availability of convenient tools for conducting experiments and calculating their results. The built-in ExpertFit module launches multiple scenarios and the model runs within each scenario in a single execution.

To conduct experiments, you need to set:
- a number of scenarios (experiments);
- a number of runs (model runs) and their duration within each scenario;
- a warm-up period of the model.

Figure 4(a) shows an example of conducting experiments with a model when investigating the effect of the number of workpiece assortment on the performance of the system. Three experiments with 20 runs were performed with the model. The warm-up period lasted 80 hours; the duration of the runs was 160 hours. The results of the experiment made it possible to establish that the highest productivity will be provided with the percentage ratios of the product range of 33% -33% -34% of the 1st, 2nd and 3rd types of parts, respectively. Thus, according to the results of the experiments carried out, the best parameters of the system are selected by analyzing possible alternatives. For organizations, this "what if ..." approach provides significant time and cost savings in decision making. If necessary, the results obtained can be exported from HTML format as CSV files to create and print reports and for their further analysis.

The FlexSim experimenter, during operation, automatically distributes program threads between the available computer processor cores, as a result of which the model runs in parallel. Therefore, the implementation of experiments for complex systems with a large amount of input data requires minimal time. Experiments designed to evaluate individual model scenarios are constructed by analysts for specified input data values. Therefore, experimental results depend on the practical experience of experts.

The OptQuest optimization tool built into FlexSim uses evolutionary algorithms to find optimal solutions based on specific criteria. Fig. 4(b) demonstrates the result of the optimizer's work
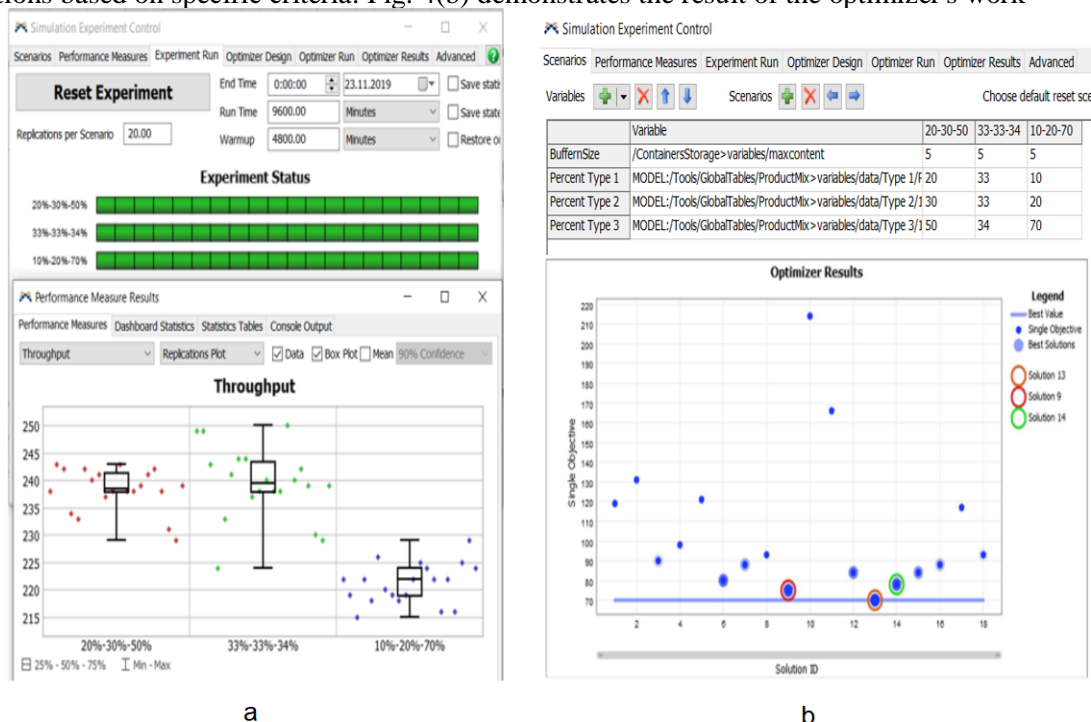

Figure 4: An example of model research: experimental results (a), optimization results (b)

The duration of the production cycle was chosen as the objective function, and the parameters of the system being investigated were the size of the buffer zone and the discipline of service in the queue. The program found 18 solutions. The graph shows the order in which they were received. The optimal solution is 13, at which the duration of the production cycle acquires a minimum value of 71 minutes.

The optimizer continues to run until one of the conditions is met :
- all possible values of the decision variables are considered;

- the time interval allotted for the search for solutions has ended;
- a given number of solutions has been received.
  The analysis shows that FlexSim is a leading software tool for modeling and research of systems. Significant functionality of FlexSim software includes:
- modeling of complex production situations;
- analysis of workload;
- support for CALS-technology standards;
- integration of models with enterprise information systems and databases;
- optimal distribution of resources between departments;
- multi-agent modeling;
- realistic 3D-animation and visualization of processes;
- availability of convenient tools for analysis, experiments, and optimization of systems.

3.2. Model of end-to-end training of students in the specialty "Computer Science" using FlexSim software

Given the need of organizations for qualified specialists capable of using modern information technology to solve production problems, Sumy State University has for the first time introduced a comprehensive curriculum that provides end-to-end training, using FlexSim software.

The Department of Computer Science has established a Training and Research Center for Simulation Modeling and Systems Analysis (TRC SMSA) whose activity is to improve the educational process of student training.

The creation of the training center became possible thanks to the grant activities of the Polish foundation InterMarium, whose representatives organized and conducted training for higher educational institutions of Ukraine and provided licensed FlexSim software for implementation in the educational process. The comprehensive program has been tested in the preparation of bachelor's and master's degree students in the specialty of computer science. The main goal is to train an IT specialist with practically oriented competencies necessary for solving problems that are relevant in production conditions.

Table 1 lists the disciplines and topics required to provide a comprehensive training program.

Table 1
Disciplines included in the program of end-to-end training by means of simulation modeling (fragment)

Disciplines	Teaching course	Topics
Organization and processing of electronic information	1	• Analysis of simulation software • Integrated environment of FlexSim simulation modeling software • The use of simulation for solving practical problems
Fundamentals of object-oriented programming	2	• Hierarchical architecture of FlexSim software • Basics of the FlexScript programming language • Object-oriented programming in the C ++ language • Programming objects and agents in the FlexSim environment
Computer graphics	2	• Development of 3D objects of simulation models and their import into the FlexSim environment
Corporate information systems	3	• Methods and tools for integrating simulation models into corporate systems SAP (ERP, MRP, CRM)
Systems modeling	3	• Modeling and analysis of queuing systems • Simulation of random events • Discrete-event modeling in FlexSim environment

|		• Modeling of continuous processes by means of FlexSim • Construction of model logic by means of ProcessFlow • Multi-scenario experiments and model optimization
Organization of databases and bases of knowledge	3	• Ways to organize the input data of the simulation model • Integration of FlexSim software environment with databases
IT project management	4	• Life cycle of simulation modelingand analysis (IMA) • Distribution of roles and responsibilities in the IMA project • Modeling project management
Decision theory	5	• Decision support systems based on simulation models

The end-to-end training model combines the key disciplines of the professional and practical direction from the 1st to the 6th year inclusive and is implemented by the following activities: complex theoretical training; comprehensive practical training; course design; diploma design; research projects.

The end-to-end training program places great emphasis on the practical component. To ensure the educational process in the FlexSim environment, a set of 25 basic simulation models of production and service systems has been developed. Fragments of the models and their brief descriptions are given in Table. 2.

Table 2
Library of FlexSim simulation models for the learning process (fragment)

Model 1

Scope of application: Service.
Description: The model reflects the complete set of products for customers, each of which has its own order profile. The supply of certain types of products and the receipts of customers are stochastic values.

Results: The mode of operation of the service resources of the system has been determined, in which the time for forming an order is minimized

Model 2
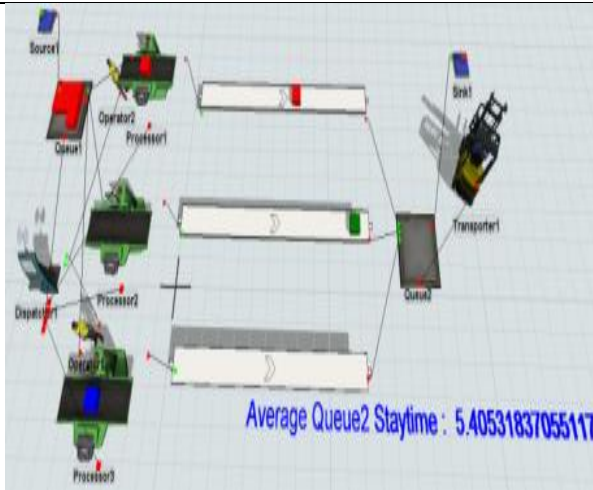
|	
Average Queue2 Staytime : 5.40531837055117	Scope of application: Production. Description: Three types of products enter the system, enter the queue zone 1, are processed by operators on the machines, through the conveyor belt they are delivered to the queue zone 2, and are removed by the conveyor from the system. Results: The influence of different methods of ordering products in the queue (LIFO, FIFO) on the system performance was investigated

Model 3
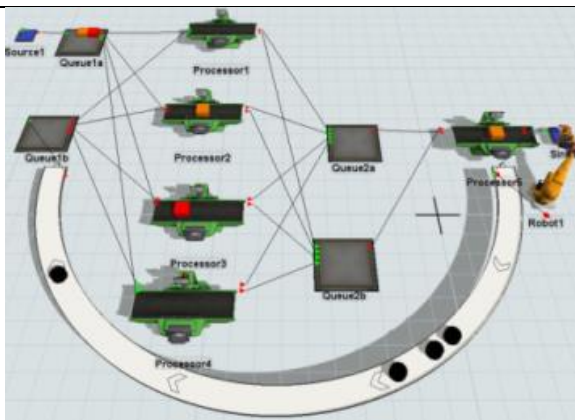
	Scope of application: Production. Description: Four types of parts enter the system, depending on the type of parts processed on one of the 4 machines. The robotic arm performs quality control of the parts. Defective parts are returned to the repetition of technological operations and are processed out of turn. Results: Identification of bottlenecks in the system operation: equipment downtime, places of accumulation of work in progress

Model 4
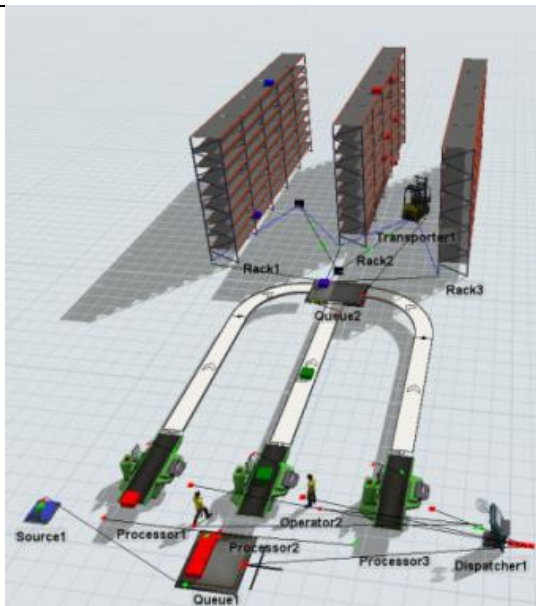
	Scope of application: Production. Description: Operators process 3 types of parts, which are transported by a conveyor belt to the queue zone, from where they are moved by a forklift to the racks of the warehouse and, depending on the type of parts, are located on the corresponding shelves. Operators and equipment are easy to operate. Results: It was determined how many work resources (operators and foprklifts) are needed to ensure the required system performance; it is investigated how the replacement of manual labor with an automated one affects the throughput of the system

The theoretical and practical parts of the program, in addition to studying development methods, building simulation models, researching and optimizing them, are also aimed at developing skills to work with customers, prepare technical and user documentation, validate, verify, and provide technical support for simulation models.

In order to ensure interdisciplinary links, work was carried out to coordinate the working programs of training courses and developed methods of organizing the educational process. This takes into account the recommendations of the Council of Employers which includes specialists from leading companies in the Sumy region. Within the framework of diploma and research works, special attention is paid to projects, the topics of which are relevant, and the results can be implemented in the practice of enterprises and organizations.

Graduates who have mastered a comprehensive training program can work as business analysts of production systems. Such a specialist is able to develop and implement a simulation model within the chosen methodology, check it for correctness and use it for analysis and optimization of production processes. Successful work in the field of business process modeling is provided by the formed practical skills. Implementation and research of simulation models related to production and service processes develop students' practical competencies related to these areas and allow them to gain the necessary skills to work with software.

In the course of the educational process, it is recommended to provide students with the opportunity to experiment with models, implement their proposals and ideas to improve the operation of systems, which may consist in changing the mutual arrangement of equipment, reducing or increasing their number, changing statistical distributions and system parameters. The high flexibility and convenience of the software environment allows them to quickly evaluate the results of the changes made and arouses interest in the learning process.

Modeling is an important tool for supporting decision-making processes in solving problems related to improving systems. Construction and research of the developed typical models in the FlexSim environment (Table 2) contributes to the development of professional competencies of students.

4. Conclusion

Due to the increasing power of computer systems, it is possible to move from complex, imperfect and little-understood analytical methods to simulation models. There are many information environments for building models. The most widespread programs among them are MATLAB/Simulink, Arena, and AnyLogic.

One of the newest and most promising tools for simulation is the FlexSim system.

Studies have shown:

- the use of FlexSim software in the educational process contributes to the forma-tion of graduates' key competencies in the field of Industry 4.0;

- in Ukraine, there is no practical experience in implementing the FlexSim program in higher education institutions.

In this regard, there is a need for effective teaching of students of different courses in basic concepts and possibilities of simulation.

At the Department of Computer Science of Sumy State University, a comprehensive program of end-to-end training in simulation tools was developed using the latest FlexSim software.

The main contribution of this work is to provide practical experience and educa-tional information on the use of modern computer simulation technologies.

The experience gained allows us to state the following:

1. The use of FlexSim is possible for end-to-end training of students of computer specialties from 1 to 5 years inclusive.

2. When preparing bachelors, it is recommended to direct the educational process to:

- methods of collecting and analyzing information about the system;

- establishing laws for the distribution of input data;

- construction of a conceptual model of the system;

- determining ways to store input data;

- development and implementation of simulation models of the system;

- development of user interfaces;

- collection of statistics and analysis of modeling results.
3. In the master's cycle it is recommended to pay more attention to:
- validation and verification of simulation models;
- planning and conducting experiments with models;
- single- and multi-criteria optimization of systems;
- interpretation of modeling results;
- development of recommendations for improving the efficiency of systems.
4. The most promising and suitable for gaining practical experience with the FlexSim program are models that reflect the production and maintenance processes.

The use of the developed basic simulation models, as an element of professional training, makes it possible to systematize knowledge, taking into account their role and place in solving applied problems of a particular industry.

There is an opportunity to build a practice-oriented training of specialists aimed at analysis and research, provides the development of analytical thinking, the formation of skills in applying the acquired skills in new conditions of activity associated with the introduction of the concepts of Industry 4.0.

The developed typical simulation models in the FlexSim environment and me-thods for their study can be recommended for mass distribution and implementation in the educational process of higher education institutions that train specialists for the IT sphere. Man-machine interaction in discrete automated systems can be well described using models, based on functional networks. Adaptive changes in man-machine interaction can be reduced to the problem of step-by-step choosing the optimal fragment of the functional network.

The method adapts the system to the peculiarities of the human-operator and environmental parameters. The combined model, which consists of a neural network for forming initial data, a functional network for modeling a dialogue and a neural network for managing the dialogue process provides a higher level of adaptation to a human operator than the known models built on the basis of unmanaged functional networks.

The computer program was used in the design process for systems of various purposes and its effectiveness was shown. Experimental studies have shown the constructiveness of the developed method.

Models will be useful for automated control in industry, agriculture and e-learning

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