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Abstract. In recent years, due to the uncertainty of the external environment; increasing number of functions performed; development of the element base; widespread introduction of information and communication technologies, technical systems have sharply complicated. Complication of systems has made it very difficult, if not impossible, to study them using mathematical apparatus. Analytical description led to inadequate results, which served as a basis for making bad decisions. In connection with the said, at the end of the twentieth century the creators of systems began to use more and more actively the methods of computer modeling. The experience of teaching the theory of complex systems in the higher school shows that not enough attention is paid to consideration of computer modeling methods. In conditions of economy digitalization, such situation is unacceptable, as the future specialist should know and possess these methods. The article is devoted to consideration of one of the directions of computer modeling - discrete-event (simulation) modeling, to be more exact, to one of the simulation modeling software tools - simulation research environment - GPSS Studio.

1. Introduction
The complexity and uncertainty of the external and internal environment has led to factors to be considered and studied: uncertainties, inaccuracies, under-research, and factors to be minimized and eliminated: incompleteness and inaccuracy, leading to an increased probability of risk. The presence of these factors is inherent in all areas of human activity. The aspiration to describe processes of occurrence and minimization of influencing factors by analytical methods is difficult, and sometimes even impossible. That is why more and more often they turn to computer modeling for studying processes in different spheres (technique, economics, ecology, sociology). In the present article only technical systems (section 2) and one of the directions of computer modeling - discrete-event (simulation) modeling (section 3) are considered.

2. Technical systems
There is a considerable quantity of definitions of system, let's take definition of GOST 9000-15 as a basis [1], having added its definition of specific features of technical system -TS [2]. Technical system-complexity of the interconnected and (or) cooperating elements, <u>capable independently in regular conditions to carry out consumer functions provided by its design in the conditions of environmental counteraction with necessary quality of target functioning.</u>

Let us consider some aspects of the underlined text in more detail.

2.1 Environmental counteraction

One of the defining features of the systemic nature of the environment is its resistance to human activity. As a result, the counteraction of the environment generates problems that can be solved by developing a technical system. Let's give some examples of systems development:

- thermos-regulation systems to exclude temperature influences;
- stabilization systems for steaming shock and mechanical effects;
- protection systems against radiation effects, etc.

The environment consists of many spheres influencing system simultaneously, counteracting and interacting with each other.

Let's take a short look at each of the areas:

- *The physical sphere* represents the condition established in global scales (physical, chemical, mechanical), depending on a geographical location of projected system. The universal information connection is inherent in all physical sphere, therefore interactions in it influence and on behavior of system in other spheres.
- *Biosphere.* The biological sphere is the source of many design problems: creation of protection against water and air pollution, creation of environmentally friendly technologies, etc.
- *Psychological sphere* is connected to the development of human society and influences such results of technogenic activity, which lead to overproduction, unemployment, problems of utilization of obsolete systems, etc.
- *Technosphere.* Mankind in its development has created artificial environment - technological sphere, which actively influences all other spheres. The active digitalization of the economy leads to an increase in the mismatch between the natural and artificial spheres. And this mismatch can be reduced by creating innovative projects and processes.
- *The economic spher*e defines the relations of consumer value and ownership of the elements of exchange. The economic sphere is based on a contractual basis between members of society, so the situations in it are very sensitive to situations in other spheres.
- *Social and political sphere* is, first of all, the sphere of social contracts regulating rights and obligations of community members in different spheres, the more developed a sphere is, the more it influences the social sphere. The problems generated by this sphere, in our case, lead to ensuring problems related to certification, consumer protection, etc.
- *The information sphere* closely interacts with all these spheres and it is the most stable in comparison with a number of the spheres considered above.

Such variety of spheres of the environment leads to increase of uncertainty in the course of creation of innovative processes that in turn promotes increase in probability of occurrence of risks.

2.2. Quality of target functioning

A characteristic of the quality target functioning (QTF or Q_f), which evaluates the output effect of the target functioning of the technical system - TS, must have the properties of measurability, completeness and reliability. The QTF is evaluated using the significance factor k_q (the value of the contribution of the i-th component of the TS to the total QTF value), varying from 1 (in case of full performance) to k_{qar} (allowable reduction of the output effect of the system) or to $k_q = 0$ (in case of full system failure). Functioning of the TS in the case of a given k_{al} opens new opportunities to restore the full functionality of the TS in the process of functioning. Determination of the significance factor depends on many factors: the complexity of the system and its relationships, the dependence on the parameters of the external environment, the dependence in time [3].

Technical systems, the definition of which is based on QTF, can be divided into three classes: simple, complex and SoS (System of Systems).

- *Simple systems* in concepts of the theory of reliability, irrespective of number of elements in them entering, represent the basic connection in which the factor of importance accepts two discrete values -1 at full working capacity and 0 at failure. Further in the article are not considered.
- *Complex systems*, the system becomes complex as soon as it acquires additional properties due to the hierarchical structure of the TS, multi-channel and multi-functionality, the presence of feedback and the introduction of redundancy of various types (structural, functional, temporal, code and algorithmic). At the same time, the system acquires an opportunity to function with a reduced QTF in the accumulation of violations and to recover in the process of work. Coefficient of significance of complex systems changes in the range from 0 to $k_{qar.}$. This class of systems is considered further. Figure 1 gives a general idea of a complex system.

E-efficiency

R1-reliability when introducing redundancy

E1 result Q_f performance curve
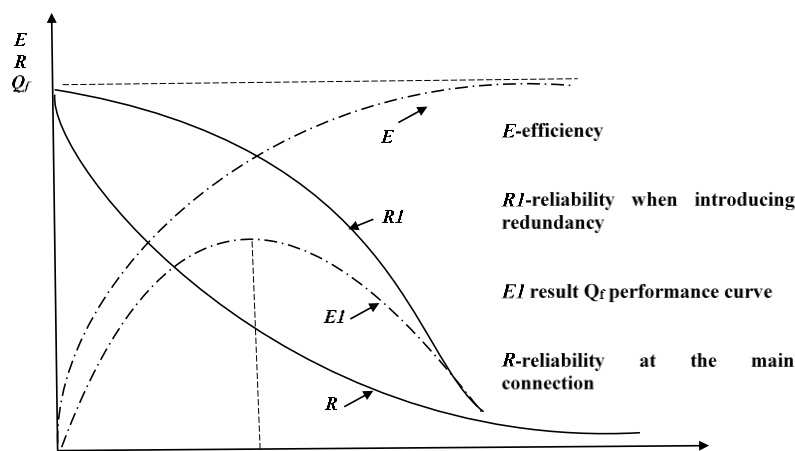
R-reliability at the main connection

Figure 1. Quality of target functioning of the complex system.

From figure 1 it is obvious that due to the multidirectional influence of efficiency and reliability the QTF has the only optimal value.

- *SoS system*. The term was introduced in 2001 by Carnegie Mellon University Software Engineering Institute specialists. SoS takes into account the integration of complex systems. The global goal of such conglomerations is to maintain and improve the consumer value of products. Each system is completely independent, but mutually complements each other in the common task of economic development of the country or region. The modelling of such conglomerations is not considered further.

3. Computer simulation of complex technical systems

Modeling processes are applied at all stages of the TS life cycle. Originally process of modeling on large, divided into two groups of methods:

- physical modeling - carrying out of tests on the object itself, or on its model (a breadboard model of the car, any construction, etc.);
- mathematical modeling (analytical description, qualitative evaluation by expert procedures, simulation modeling).

However, as the TS becomes more complex, the uncertainty of external and internal environment factors increases, and management methods are improved, the number of modeling methods increased and, accordingly, the number of different classifications of modeling methods expanded. As the present article is focused on one of directions of modeling, namely computer modeling, we shall take classification of GOST R 57412-2017 [4] as a basis.

In accordance with the 57412 standard, computer modeling is divided by:

- The properties (aspect) of the modeling object under study;
- the method used to describe the modeling object.

Let's supplement this division with the notion of complexity of abstract representation of modeling objects, conditionally highlighting the initial (0-10%), low (11-25%), medium (26-70%) and high level of complexity (71-100%).

Level of complexity C , expressed in %, depends on the way of description of the model object (analytical and/or algorithmic); number of structural blocks; number of feedback, level of uncertainty of influence of external and internal factors, leading to risks and some other components. The level of complexity is estimated mainly in an expert way. In this approach, all objects of research can be divided into two subclasses - the study of specific systems and computer modeling of systems, which includes a number of categories for which we describe their main characteristics: the type of model object, the method of description, the range of complexity level, the role of the computer in the study process.

3.1 System-specific study

- Type of the object of study - simple TS.
- Method of description - analytical.
- The range of complexity - up to 10-15%.
- The role of the computer in the research process - as a tool to accelerate the process of calculations.

3.2 Computer modeling

3.2.1 Monte-Carlo method

- Type of research object - numerical calculations of areas, volumes, statistics.
- Method of description - computational methods with elements of algorithmic representations.
- Range of complexity level - 5-35%.
- The role of the computer in the research process is a computer model based on the multiple generation of random numbers with subsequent statistical processing.

The Monte Carlo method is an excellent opportunity to solve complex numerical problems. It is known that the number of calculations required to obtain an accurate answer in the case of multi-dimensional problems (nuclear physics problems, determination of areas and volumes of complex shapes, etc.) is growing by an exponential law. With increasing computer performance and improving the quality of random number generators, the Monte Carlo method becomes an indispensable assistant in numerical calculations.

3.2.2 Discrete event (simulation) modeling - DS

- Type of study object - complex TS
- Method of description - mass service theory and algorithms of behavior.
- Range of difficulty - 26-70%
- The role of the computer in the process of research is a computer model, which allows to simulate the process of TS functioning by reproducing on the computer the process of system functioning with preservation of its logical structure and the sequence of processes in time, which allows, by multiple repetition, to gather the necessary statistical data and judge the state of the TS at various points in time, to evaluate the output characteristics, to choose the optimal behavior or to compare alternatives.

3.2.3 Agent Modeling - AM

- The type of research object is modeling of decentralized systems whose functioning depends on the behavior of individual agents (people, machines, various transport units).
- Method of description - mathematical apparatus of system approach.
- The range of complexity level - 30-85%.
- The role of the computer in the research process is a simulation model that allows describing the object under study as a set of independent agents, each of which can follow its own rules, interact with each other and with their environment.

3.2.4 System dynamics of the SD.

- Type of the research object - not specific objects, but only their numbers and generalized indicators are considered.
- Method of description - methods of non-numerical statistics.
- Range of difficulty level - 60-100%.
- The role of the computer in the research process - complex simulation and cognitive models.

The concept was proposed in the 1950s by the American scientist Jay Forrester. System dynamics is a method of studying the dynamics of processes in a system of systems. It pays special attention to accounting and modeling numerous feedbacks in the system. Systemic-dynamic models are usually set in the form of stream diagrams consisting of drives, threads between them, loops of feedback and auxiliary variables, which are then translated into the system of algebra-differential equations. Systemic-dynamic models are typically used in strategic analysis and long-term planning. Considering orientation of article we will consider only the imitation - the DC-modeling completely satisfying to problems of modeling of technical systems. In detail history of development of imitation modeling in Russia and abroad is considered in V. Devyatkov's monograph [5].

In 1975, R. Shannon's monograph [6] was published in the USA, which was translated into the USSR in 1978 and became a bestseller. However, to a certain extent, it also served a bad service, as most managers of enterprises stated that this art was not for them.

Over the years, simulation languages have been created in different countries and already in review E. Kindler's [7], which was published back in 1984, mentions more than 500 languages and systems of simulation. Some of them have brought new approaches in modeling practice and are used till now, others have disappeared for some time, some have appeared simply unsuccessful and even historians of a science do not mention them.

This abundance of languages and simulation systems has resulted in another reason for the decreasing attractiveness of simulation. So programmers, having mastered in perfection one language, tried with its help to solve problems where it simply was not adapted to the decision of new problems that led to failure and further discredit of simulation modeling.

The following principles are common for all languages:

- Generation of pseudo-random numbers that are the basis of the simulation process.
- Presentation of different times when modeling the object under study.
- Verification and validation of model adequacy.

These principles are discussed in sufficient detail in monograph A.Varzhapetyan [8].

In the article we will dwell upon the GPSS World software system for two reasons:

- Wide application of the GUAP in the educational process.
- GPSS World is the basis of the GPSS Studio modeling environment developed by Elina-Computer (Kazan) [9].

Let us briefly dwell on the history of GPSS Studio creation. In 2002 Elina Computer signed an agreement with Minuteman Software, the developer of GPSS World, to promote system GPSS World in Russia. Technical documentation was translated and the rights to distribute GPSS World were obtained in Russia and former USSR countries.

Over the years, Elina Computer   employees have been working to improve the system, and as a result, an advanced GPPS World editor was developed, which eliminated the shortcomings of the initial version and significantly improved the system's capabilities, taking into account all current trends. In early 2018, in the development of the expanded editor was released independently developed simulation modeling environment GPSS Studio, which is not worse than the best foreign counterparts, and in some respects even superior to them [10]. So, for example, in 2019 in GPSS Studio the module of parametric optimization of development of company Sigma Technology (Moscow) - IOSO (Indirect Optimization on the basis of Self-Organization), allowing to receive optimum decisions for multi-criteria, multiparametric technical systems is entered [11].

The great advantage of GPSS Studio is the availability of the student version 1.6.3.0 (the last at the time of writing this article) [12].   The student version of the system is as effective as the commercial version, only it is designed for a smaller number of blocks, which, however, enough to acquire confident skills to work with the environment.

It should be noted that version 1.6.3.0 contains not only a detailed user's guide to GPSS STUDIO, but also an equally detailed guide to GPSS World, which is the basic software support for the GPSS STUDIO modeling environment, so working in a modeling environment in no way changes the specifications of the modeling language. Model texts in the GPSS World language, written earlier, will be fully compatible with GPSS STUDIO.

4. Conclusion

Experience in teaching GPSS World has shown that students learn the principles of program creation quickly and confidently cope with control tasks. Therefore, turning to the GPSS STUDIO simulation study environment did not cause rejection. According to the authors, the significant advantages of the environment will allow it to become not only a means of teaching students, but also an effective tool for using simulation methods in the practical activities of specific enterprises.

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