The method of teaching "IT students" computer analysis of ergonomic reserves of the effectiveness of control systems for sustainable economic development

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Abstract. In the article, we consider the technology of training university students studying IT specialties to solve the problems of finding ergonomic reserves to improve the efficiency of automated systems. We describe he structure of the course “Ergonomics of automated systems”, software for evaluating and optimizing the activities of operators of human-equipment-environment systems, and methodological techniques for using ergonomic computer modeling to build effective automated control systems.

1. Introduction

Global challenges of the current state of ecology, politics and economics [1-5], an increase in the number of critical systems and industries, the growing losses from accidents and disasters, growing stress on people’s activities due to increasing responsibility and worsening mental health of the population question the prospects for sustainable development of the society [6-12].

The long-awaited automation of production, robotics, the introduction of artificial intelligence systems have largely contributed to improving the efficiency of managing production systems, however, in addition to this, they brought a number of new problems [13-15]:

- Social (unemployment, etc.)
- Moral and ethical
- Decrease in reliability of complex systems as a whole
- Risks to the life and health of people, accidents, the growth of cybercrime.

The euphoria from the ideas of unmanned production and the widespread introduction of robots is beginning to give way to a sober approach to determining the rational degree of automation, finding harmony between humans and robots, recognizing the need to pay more attention to the problems of the “human factor” [9-11]

2. Problem analysis and statement of research goals

The creation of irrational, difficult to manage and maintain machinery and equipment can lead to harmful social and economic consequences [9]. Now the majority of workers, especially young people, do not want to work where there are no normal conditions for safe and productive work.

Naturally, if comfortable conditions for human interaction with technology are not provided, then it is hardly possible to achieve a significant economic effect [10].

Experience shows that ignoring the human factor in the creation of machines and automated systems leads to a loss of about 30% of their possible effectiveness [9-11].

Non-adaptive information technologies and production management systems are the causes of accidents, colossal material losses and even deaths.

To minimize the probability of erroneous actions of personnel is possible only based on systemic considerations of ergonomic requirements [16-18].

Under these conditions, the ergonomic training of future engineers is of great importance [16-19].

Such preparation can be carried out in different ways [19]:

- Training of professional ergonomists (bachelors, masters):
  - It is carried out in many universities of the USA, Canada, Australia, Great Britain, Germany, France and other developed countries;
  - It is implemented at several universities in Russia and Belarus;

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- Not available in Ukraine;
- Not available in most developing countries
- The introduction of disciplines related to the "human factor" (of ergonomic cycle) in the training programs for bachelors and masters of technical specialties (unfortunately, often belonging to the optional disciplines).

A survey of graduate students (149 respondents from 5 universities of Ukraine) who study various specialties related to IT, automation of production processes and cybersecurity has revealed [18]:

- Lack of motivation to study the discipline, lack of understanding of its role in the formation of IT-specialists ("it is more important to learn programming languages")-89.75%
- Simplified ("common") understanding of the term "ergonomics" – 82.1%
- Lack of a clear understanding of the differences in the subjects of research on ergonomics and other sciences about "the human factor" – "engineering psychology", "labor protection", "scientific organization of labor", "design", "technical aesthetics", "cybernetics", etc. – 95.9%

The analysis of the difficulties in organizing the discipline "ergonomics" for IT specialists, among other things, is also associated with the unstable disciplinary system of science itself.

Most studies focus on local problems such as [20-26]:

- Work environment factors
- Functional state of operators
- Anthropometry
- Psychophysiological aspects of the activity
- Interface design
- Microergonomics
- Other.

If you study these particular questions in detail, you can miss the main goal - "Search for ergonomic reserves to improve the reliability and efficiency of computerized systems" [19].

In addition, typical limitations for a large number of studies are he following [19, 27-30]:

- Have a purely humanitarian descriptive nature and do not quantify the reliability characteristics of human-computer interaction
- Do not provide an answer like "what happens if?" in relation to the impact of organizational and technical measures on the effectiveness of the system
- Not focused on "organizational ergonomics" and on the formation of a program of measures to ensure an ergonomic quality system..

Obviously, the discipline can be useful and relevant if it answers questions such as "What measures to improve ergonomic quality should be implemented in the system in order to maximize profits (when fulfilling ergonomic norms and requirements)?"[31-34].

Thus, ergonomics should not be "costly" (as they say today), but "profitable" [19].

The most convenient theory, describing from the standpoint of a human-system approach, methods for assessing and optimizing the functioning of "man-technology-environment" systems based on objective quantitative indicators, is the theory of functional networks of a scientific school prof. Gubinsky, A.I. [35-39]. In addition, within the framework of this scientific school, several methods have been developed for solving computer-based assessment problems [16,40,41] and optimization [39,40] of human-machine interaction. Obviously, these developments may be the basis for this study.

Based on the foregoing, we define the task of this work.

Formulation of the problem. Describe the method of teaching the discipline "ergonomics of automated systems" for students of computer specialties, based on the principles of:

- Qualimetric modeling (on functional networks) of human-machine interaction
- Maximum use of computer variant modeling
- The business case for the benefits of ergonomics.

3. Results

3.1. Development of the concept of discipline

We define ergonomics as a science engaged in the comprehensive study and optimization of human activity in the "man-equipment-environment" system.

We offer the following level logic of discipline presentation:

- From the study of specific characteristics of a person, equipment and environment
- Up to the choice of organizational and technical solutions (through evaluation and optimization using information technology).

Level 1. System-ergonomic analysis of systems "man – equipment – environment":

- What you need to know about the characteristics of:
  - Man
  - Technology
  - Environment
- How to conduct a system ergonomic analysis.

Level 2. Modeling human-machine interaction:

- How to carry out:
  - Description of activities
  - Performance assessment
  - Optimization of activities.
- How to use IT to model human-machine interaction.

Level 3. Solving the basic tasks of ergonomics:

- How to solve tasks of:
  - Ergonomic expert examination
  - Designing working conditions
  - The choice of the level of automation (distribution of functions between the operator and the machine)
  - Determining the number of operators and their qualifications
  - Distributions of functions between operators
  - Designing information models
  - Designing activity algorithms

- Professional selection
- How to use IT to solve the main tasks of ergonomics

Level 4. Economic justification of the ergonomic quality program.

Moreover, each subsequent level of presentation uses the knowledge and skills of all previous levels.

3.2 Development of the theoretical part of the course

The following topics are revealed at the lecture classes:

1. The object, subject, goals, objectives and methods of ergonomics
2. System-ergonomic analysis. Characteristics of a person, technology and environment
3. Ergonomic requirements for the system "man - technology-environment"
4. The severity of labor and the functional state of the human operator
5. Principles of ensuring the ergonomic quality of systems "man - technology-environment"
6. Certification of workplaces
7. Ergonomic support for the design of systems "man - technology - environment"
8. Ergonomic fundamentals of the operation of systems "man - technology-environment"
9. Description and evaluation of the algorithms of the human operator
10. Optimization of human operator activity
11. Ergonomics of information technology
12. Ergonomic examination of information technology
13. Usability
14. Man in distributed information systems
15. Ergonomics of critical systems
16. Search for ergonomic reserves to increase the efficiency of automated systems
17. The economic justification of measures to ensure the ergonomic quality of automated systems.

3.3. Development of the practical part of the course

The curriculum of the practical part of the discipline consists of four Sections:

- Certification of the working conditions
- Description and evaluation of the algorithms of the human operator
- Ergonomic expert examination of information projects
- Designing a system of measures to ensure ergonomic quality.

Each of these sections provides for laboratory work.

The first section includes three laboratory works.

1-st lab:

- Analysis of factors affecting the working environment;
- Definition of point estimates of working environment factors.

2-nd lab:

- Determination of the category of labor severity
- Determination of performance indicators
- Determination of correction factors for indicators of the quality of the human operator's activity.

3-d lab:

- Development of measures aimed at improving the working environment
- Business case for certification of workplaces

The second section of the practical part of the course consists of five laboratory works that ultimetely

- Describe
- Evaluate
- Optimize

algorithms of the human operator.

The third topic involves two laboratory works:

- Justification of the selection of characteristics that affect the ergonomic quality of information technology
- Method of conducting expert examination and processing the results of expert work

The fourth topic provides two final laboratory work:

- Economic justification of ergonomic measures (taking into account the whole complex of influencing factors: technology, environment, characteristics of operators, activity algorithms, motivation) for monoergatic systems (one operator)
- Economic justification of ergonomic measures for polyergatic systems (many operators).

3.4. The use of computer technology ergonomic research

3.4.1. Computer technology for assessing working conditions at the workplace of a human operator

General characteristics of the program.

It implements the methodology [26] for assessing working conditions.

The software package consists of modules:

- Support of reference data (a directory of sanitary and hygienic factors of working conditions, a directory of psychophysiological factors, a directory of categories of labor severity, a directory of correction factors for indicators of the quality of a human operator, measures to improve working conditions)
- Description of the sanitary-hygienic and psychophysiological factors of the working environment
- Assessment of influencing factors according to a 6-point scale
- Determination of the integral point assessment of the severity of labor, indicators of fatigue and performance;
- Determination of the category of labor severity and correction factors
- Assessment of the impact of working environment factors on the quality of the human operator's activity
- Reporting.

Features of using the program in the educational process.

The laboratory work to certify the workplace is carried out in two stages. At the first stage, a description of the working environment is introduced and initial values of the influencing factors are set. In this case, it is possible to select data from the directory. Data entry forms for filling out directories and an input form for describing factors of the working environment represent the interface. For each given factor, a point score and an integral score are determined. Next, the category of labor severity is determined, which corresponds to the integral score obtained and the correction factor for assessing the influence of working environment factors on the quality of the human operator.

The possibilities of visualizing the results of the analysis of working conditions at the workplace of a human operator are shown in Fig. 12.

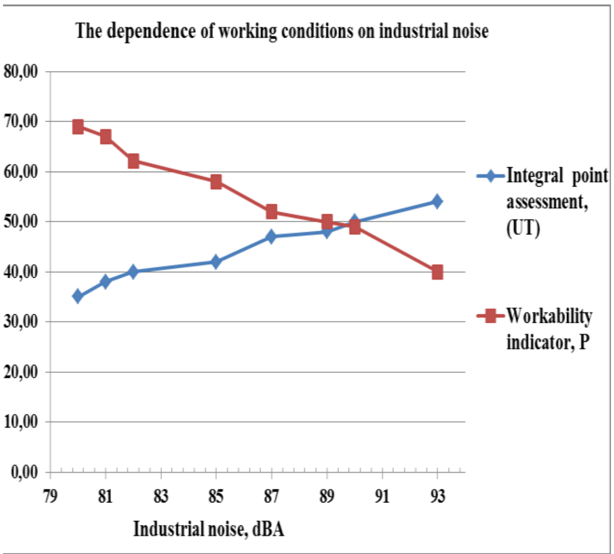


Fig. 1. An example of assessing the impact of industrial noise on indicators of labor severity

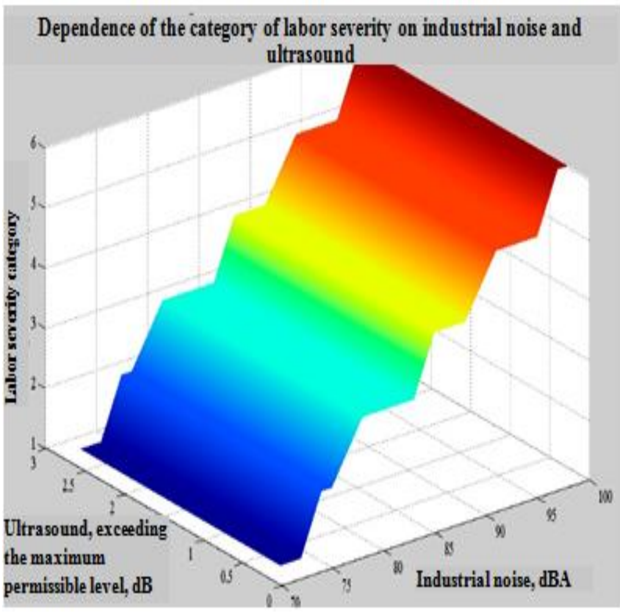


Fig. 2. An example of assessing the impact of industrial noise and ultrasound on the value of the integral scoring of the severity of labor

3.4.2. Computer technology for modeling the activities of a human operator

General characteristics of the software package.

It provides an assessment of the probability of error-free execution and the characteristics of a random value of the AF execution time

- For given
  - Structure of the functioning algorithm (FA) - is entered in the dialogue mode
  - Reliability and lead time of individual FA operations are entered or selected from the database
- For given alternatives of the FA structure and (or) methods for performing individual operations - the choice of the optimal option (24 problem statements) including:
  - Single criteria and
  - Multi-criteria.

The main modules of the software package:

- Support for reference data.
- Dialog entry of the description of the FA
- Automatic evaluation of the FA
- Variant analysis of the FA
- FA optimization.

Using the software package in the educational process

The software package is the basis of the laboratory work, the purpose of which is to acquire skills for the description, evaluation and optimization of the FA.

An example of the idea of FA estimation is shown in Fig. 3, and the results of automatic reduction and FA estimation are shown in Fig. 4.

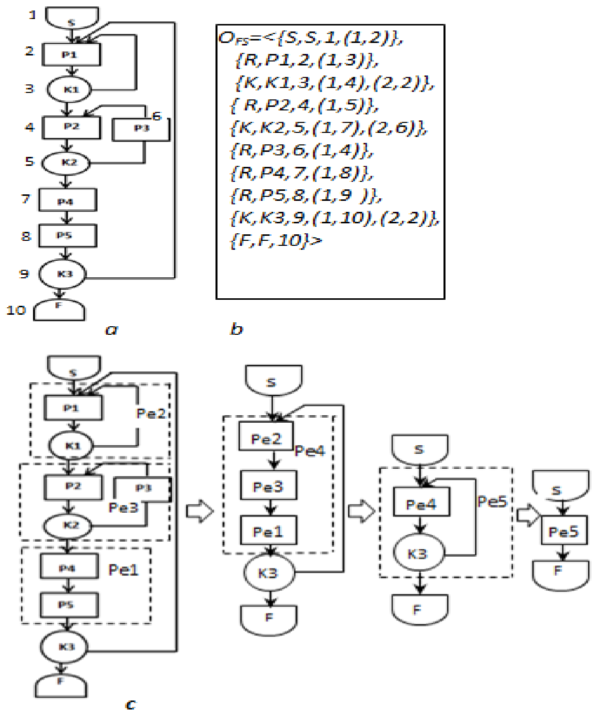
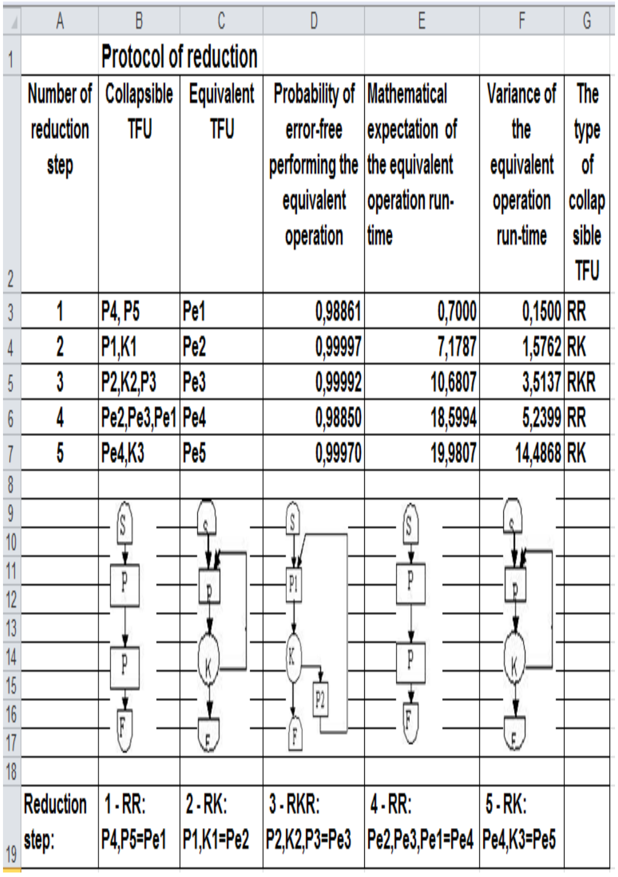


Fig.3. An example of the structure of the algorithm (fragment) of the dialogue control of a gas pumping station –a; the model for describing a functioning algorithm (generated automatically) –b; the necessary sequence of reduction steps- c; (designations according to [26-27]).



	A	B	C	D	E	F	G
1		Protocol of reduction					
2	Number of reduction step	Collapsible TFU	Equivalent TFU	Probability of error-free performing the equivalent operation	Mathematical expectation of the equivalent operation run-time	Variance of the equivalent operation run-time	The type of collapsible TFU
3	1	P4, P5	Pe1	0,98861	0,7000	0,1500	RR
4	2	P1,K1	Pe2	0,99997	7,1787	1,5762	RK
5	3	P2,K2,P3	Pe3	0,99992	10,6807	3,5137	RKR
6	4	Pe2,Pe3,Pe1	Pe4	0,98850	18,5994	5,2399	RR
7	5	Pe4,K3	Pe5	0,99970	19,9807	14,4868	RK
19	Reduction step:	1 - RR: P4,P5=Pe1	2 - RK: P1,K1=Pe2	3 - RKR: P2,K2,P3=Pe3	4 - RR: Pe2,Pe3,Pe1=Pe4	5 - RK: Pe4,K3=Pe5	

Fig.4. An example of the progress and results of evaluating the activities of the operator-technologist of a gas pumping station

Such assessment is used in solving problems:

- determination of the degree of automation,
- distribution of functions between operators,
- designing information models,
- designing activity algorithms,
- selection of measures of the system for ensuring ergonomic quality).

Consider, for example, the principle of solving the problem of choosing the optimal set of measures for an ergonomic quality system (due to measures to improve working conditions in the workplace) - a monoergic system.

Formulation of the problem

- The structure of the FA, a set of options for improving working conditions with known costs and the calculated error-response characteristics of the individual FA operations (through a system of correction factors that take into account the influence of the integral point estimate of the severity of labor)
- You must choose the option that provides the maximum profit from ergonomic activities.

Decision fundamental. Reduce the functional network corresponding to the FA and "substitute" the values obtained taking into account the influence of the environment (working conditions), operator's qualifications, technical parameters as input data and thus determine the values of indicators for each variant of the system of measures:

- The probability of error-free execution of B(k);
- Mathematical expectation M(k) and variance of runtime D(k);
- probability of timely execution of $P_{cв}(k)$ (we accept the normal distribution law).

For each option k=1,n of the system of measures, determine the value of the profit indicator from the N-fold implementation of the algorithm according to the formula

$$C(k) = [P_1 B(k) P_{cв}(k)]N - [U_1(1 - B(k) P_{cв}(k))]N,$$

where

- P_1 is the amount of profit from a single timely and error-free performance of activities
- U_1 is the amount of damage from a single performance of an activity with an error or (and) untimely performance
- N is estimated number of planned executions of the algorithm
- k is option number of a system of measures to improve working conditions
- $C(k)$ is the amount of profit from the N-fold implementation of the algorithm.
- For each version of the system of measures to determine the value of profit:

$$E(k) = C(k) - Z(k),$$

where $Z(k)$ is the amount of costs for events.

An example of a videogram with the results of an analysis of the effectiveness of measures is shown in Fig. 5.

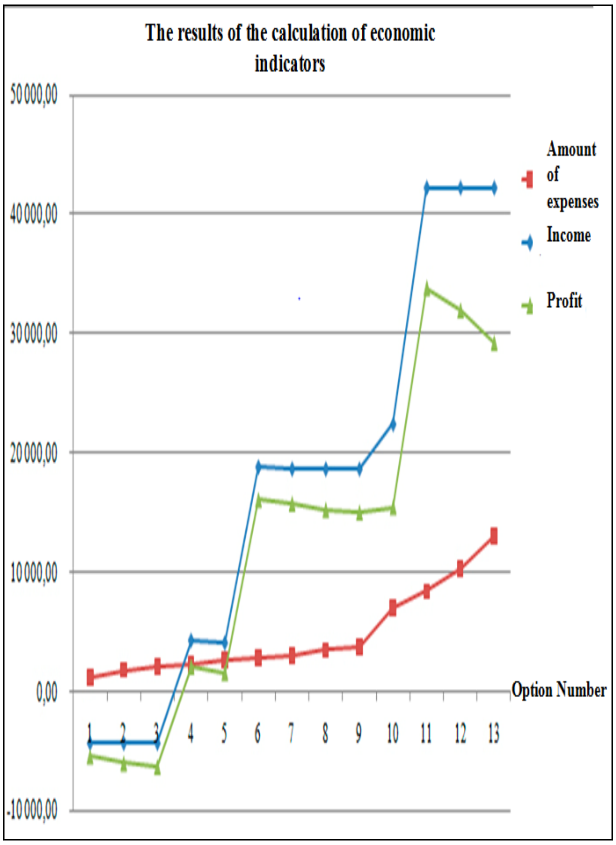


Fig. 5. An example of the results of evaluating the effectiveness of measures to improve working conditions (for a given AF structure). Values are in conventional units.

Such modeling allows convincing business managers and owners that ergonomic improvements are not only necessary to meet the standards and requirements, but are beneficial for the business.

3.4. Approbation

The developed course has been tested

- In full at the universities:
  - Sumy State University (Sumy, Ukraine);
  - Sumy National Agrarian University (Sumy, Ukraine);
- Partially at the universities:
  - National University of Life and Environmental Sciences (Kyiv, Ukraine, Kiev);
  - Ukrainian Engineering - Pedagogical Academy (Kharkiv, Ukraine)
  - St. Petersburg Electrotechnical University (St. Petersburg, Russia)
  - Belgorod Agrarian Academy (Belgorod, Russia)

4. Conclusions

The aggravating problems of finding ergonomic reserves of the effectiveness of automated systems necessitate an increased attention to teaching at universities the methods that consider the "human factor".

Ergonomic training of a modern specialist in the field of information systems should include computer simulation of "man-technology-environment" systems.

It is convenient to evaluate the reliability of the human operator's activity using models and software tools that have been developed in the framework of the theory of functional networks of a scientific school of prof. A.I. Gubinsky.

The proposed training method based on information technology for modeling human-machine interaction allows you to teach students:

- Methods for evaluating alternative options for organizing a human operator in information systems
- Techniques for solving the basic problems of ergonomics of automated systems
- Technologies for choosing a system of measures to ensure the ergonomic quality of information systems.

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