# A New Approach to Assessing the Competent Use of Information and Communication Technologies by Employees of an Organization

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Abstract: This article considers the problem of finding optimal values of weighting factors for the efficient use of Information and Communication Technologies (ICT) at the stages of information processing by employees of an educational organization. The assessment is carried out by a specialist using a model for determining the basic probability of competent use of ICT as a basis for calculating the risk of using ICT. The linear programming problem is formulated and analyzed in the context of decision-making related to the use of ICT. The article uses a method of modeling computer models that imitate cognitive processes, as well as an analysis of the linear programming problem for optimizing weighting factors. A model for estimating weighting factors has been developed that takes into account the features of each stage of information processing and the time parameters of using ICT. It is shown that the transition to stochastic programming allows one to take into account the uncertainty and variability of model parameters, which is important for achieving an accurate risk assessment when using ICT. The developed approach can be applied in practice to optimize information processing and improve the efficiency of using ICT in various industries. The theoretical significance lies in expanding the methodology for risk assessment and decision-making based on computer modeling of cognitive processes.

## 1 INTRODUCTION

In the modern world, information and communication technologies (ICT) play a key role in the daily lives of people and organizations, providing access to information, improving communication and promoting efficient resource management. This is especially true for educational organizations, where efficient resource management directly affects the quality of training specialists. However, the introduction and use of ICT in educational organizations is associated with risks associated with incompetent use of technology. To minimize these risks, it is necessary to accurately determine the likelihood of competent use of ICT, which requires a deep understanding of the cognitive processes that influence decision-making and the use of technology.

The article examines the impact of cognitive definition on the assessment of risks of ICT use by an organization and develops methods for minimizing these risks, including calculating the weighting coefficients of information processing stages and conducting surveys to identify employee preferences.

This approach allows us to systematize and evaluate the significance of each stage of information processing in the context of using ICT, which helps to increase the reliability of the organization's ICT, and also forms the basis for effective management and increased labor productivity in various industries.

# 2 OVERVIEW OF CURRENT WORK

Modern approaches to risk assessment and uncertainty management are widely discussed in the literature. For example, the paper [15] analyzes the application of FMEA methods to risk management in complex telecommunication systems.

The article [5] describes the advantages and disadvantages of using ICT in education. Thus, ICT allows for individualization of learning, adaptation to different styles and needs of students, and also contributes to the development of critical and creative thinking. However, such problems as student distraction and insufficient teacher training are also highlighted.

In particular, ICT allows for individualization of learning, adaptation to different styles and needs of students, and promotes the development of critical and creative thinking. However, problems such as student distraction and insufficient teacher training are also highlighted. The problems and difficulties that teachers face after completing advanced training courses on technology integration are discussed in the article [6]. The authors analyze how teachers apply their knowledge in practice, what barriers arise when integrating technology into the educational process, and what strategies can help overcome these barriers.

The authors of the article [3] conduct an in-depth analysis of the current state of ICT integration in educational programs for future teachers. They examine key barriers such as lack of technical skills, lack of administrative support, and limited understanding of the value of ICT in the educational process, etc. A number of recommendations are offered to improve the integration of ICT in educational programs, including the development of courses for future teachers, expanding access to modern technological infrastructure, and creating a culture of support for the use of ICT in the educational process.

In the article [8] Mishra, P. and Koehler, M.J. introduce the concept of technology-based pedagogical content as a key component of teacher competence in the digital age, as a new type of knowledge required by teachers in the digital age.

In formulating linear problems, we acknowledge the significant contribution of Leonid Kantorovich, one of the founders of linear programming, to the development of linear optimization models [7].

When solving the above problems, data uncertainty arises, which in turn necessitates taking into account various scenarios and optimization under uncertainty. Therefore, in this case, to solve the linear programming problem, it is necessary to move to the stochastic programming problem.

The article [2] analyzes the process of supply chain optimization taking into account risks and failures in critical situations. The authors showed that the use of a two-stage analysis approach allows the model to be adapted to changing conditions, which is applicable to the objectives of this study, which is focused on educational institutions.

The term "stochastic programming" itself appeared in the early 1950s during the analysis of a linear programming problem with random coefficients that arose during planning in situations with uncertainty and risks. In accordance with [14, 16], the problems described above assume that the method of a two-stage linear model of stochastic programming will be used. This method involves setting and solving a basic optimization problem at the first stage using the average values of the model parameters, and using the initial solution at the second stage to assess the impact of changing the model parameters on the optimal solution. This allows for taking into account the probability coefficients and uncertainties associated with the model parameters and adapting the optimal solution to changing conditions. The linear optimization model and its transformation into a stochastic programming model described in [7] allow for taking into account the probability coefficients and uncertainties associated with the model parameters and adapting the optimal solution to changing conditions, which is the basis of the two-stage linear model of stochastic programming method.

# 3 SCIENTIFIC STATEMENT OF THE PROBLEM

The purpose of the study: to develop an approach to assessing the competent use of ICT based on the study of individual preferences of employees of educational organizations, as well as to study the increase in the effectiveness and efficiency of ICT through their correct and rational (competent) use.

Objectives of the study:

1) To consider existing methods and approaches to assessing the use of ICT in various fields, including science, business and public administration.
2) Develop a plan and survey form to obtain an assessment of the parameters of ICT use, taking into account the individual preferences

and characteristics of the work processes of employees.
3) Develop a model that takes into account the main factors influencing the efficiency and effectiveness of ICT use by employees.
4) Analyze the results of the developed model in order to improve the efficiency of ICT and the competence of their use.

The object of the study is the individual preferences of employees regarding the use of ICT at various stages of information processing in the context of preventing emergency situations.

The subject of the research is methods of expert assessment and optimization modeling of planning of employee actions when using ICT.

The scientific novelty of the study consists in:
1) consideration of the main stages of information processing from the point of view of the use of basic ICT tools;
2) cross-representation of the interaction of the specified stages and tools within the framework of the hierarchy method and construction of a system of weight indicators of their specific significance in the employee's activities based on the hierarchy;
3) formulation of a linear programming problem based on the obtained weights to obtain an optimal aggregated probabilistic assessment of the competent use of ICT tools with the transformation of this problem into a stochastic programming problem.

## 3.1 Survey Development

The study [16] identifies key factors influencing performance indicators in the telecommunications industry. The methodology presented by the authors makes it possible to objectively assess the significance of individual stages of information processing for each employee when solving his or her professional tasks.

This survey was conducted among SibSUTIS employees and was aimed at identifying the risks of improper use of ICT at each of the 7 main stages of information processing. At the same time, the implementation of these stages was studied through the prism of their implementation by 8 main ICT tools. The survey of employees was conducted as part of the retraining program for university employees. A survey of 25 employees was conducted in the form of filling out tables of cross-comparison of priorities and line-by-line distribution of time for ICT.

### 3.1.1 Pairwise Comparison of the Importance of Information Processing Stages

Each employee is asked to fill out a table of pairwise comparisons of the importance of the main stages of information processing. The table uses a three-point scale:
1) 1: one stage clearly has a higher priority than another (dominant importance);
2) 0: one stage is clearly less of a priority than the other (dominant importance);
3) 0.5: one stage has equal priority compared to another (equal importance).

### 3.1.2 Time Cost Estimation

After assessing the importance of each stage of information processing, it is necessary to estimate the time costs of using each of the ICT elements. To do this, employees indicate:

The system of constraints is a linear combination of the partial probabilities introduced above and the time costs of ICT – the specific time of costs for a specific ICT tool ($d_{ij}$). The right part of these constraints is formed by the time resource of ICT – the total time of costs for a specific ICT tool ($T_i$).

These data will allow for a detailed analysis and assessment of the impact of various ICT elements on the productivity and efficiency of employees in their professional activities.

# 4 DEVELOPMENT OF THE MODEL

It is necessary to solve an optimization problem aimed at maximizing the probability of competent use of ICT by a specialist at all stages of information processing.

## 4.1 Statement of the Linear Programming Problem

To solve an optimization problem, methodological guidelines are applied based on the approaches outlined in [1] and [12]. Furthermore, the challenges associated with solving optimization problems under uncertainty, as described in [14], are also taken into account.

It is necessary to build a system of restrictions based on the specific and total time of work with various ICT components. Data based on expert assessments are used.

To determine the probability of competent use of information resources by a specialist in the context of working with information, considered as the basis for calculating the risk of using ICT, a cognitive approach is used.

It is assumed that the specialist performs a number of stages of work with information, comparable to the functions of the information system, namely:

1) Study of the problem.
2) Choice of methodology.
3) Collection of information.
4) Filtering information.
5) Data preparation.
6) Model calculations.
7) Correction of results.

Let us denote by piw the probability of using ICT by a specialist at the i-th stage of working with information with a weighting coefficient wi, which shows the specific significance of the i-th stage for the average specialist.

Then the final probability of competent use of the entire set of ICT tools at each stage of information processing is defined as a weighted superposition of probabilities. It is assumed that the specialist strives to maximize this probability:

$$F\left(p_1^w, p_2^w, \ldots, p_7^w\right) = \sum_{i=1}^{7} w_i p_i^w \to \max .$$

The solution to this optimization problem is impossible without constructing a system of constraints based on the specific and total time of work with various ICT components.

ICT components:

1) $T_1^{MS}$ − Internet network;
2) $T_2^{MS}$ – corporate information system;
3) $T_3^{MS}$ – personal data storage;
4) $T_4^{MS}$ – database on physical media;
5) $T_5^{MS}$ – corporate workstation;
6) $T_6^{MS}$ – cloud computing servers;
7) $T_7^{MS}$ – personal computer;
8) $T_8^{MS}$ – voice mobile communication.

## 4.2 Statement of the Optimization Problem

It is necessary to maximise the probability of competent use of the ICT complex at each stage of information processing, taking into account the time constraints on working with various ICT components:

$$F(p^w) \to \max,$$

provided that:

$$\sum_{j=1}^{7} d_{ij} * p_n^w \le T_i^{MS}, \forall i = 1, 2, ..., 8,$$

where:

- $p_n^w$ − probability of using ICT at the n-th stage with weighting coefficient $w_i$, n = 1,…,7,
- $d_{ij}$- the amount of time in hours spent on one task at the j-th stage of working with information using the i-th ICT component;
- $T_i^{MS}$- the amount of time in hours spent within one task on a full cycle of working with information using the i-th ICT component (used both separately and jointly).

## 4.3 Transition to the Stochastic Programming Problem

The transition from a linear programming problem to a stochastic programming problem is due to the need to take into account the uncertainty and variability of input data and model parameters. In the context of decision-making related to the use of ICT, such a transition becomes necessary for more realistic risk modeling and effective risk management.

In linear programming, the parameters of the model are assumed to be precise and known in advance. However, in real conditions, many parameters are subject to random fluctuations and uncertainty, which can significantly affect the results of decisions made. For example, the specifics of resource use depend on the development of technologies. When transferring an organization's ICT to a cloud environment, the use of local ICT tools and the costs for them on the part of the organization are significantly reduced, being replaced by significantly lower costs for the use of cloud technologies. At the same time, the risks of their use are reduced, and the risks associated with the use of cloud technologies arise. Given the many factors influencing the adoption of such organizational decisions (personnel, security, economic indicators, legislative framework, etc.) and their variability, these processes are largely stochastic. Therefore, the transition to stochastic programming allows us to take into account this uncertainty and variability, which makes the model more adaptive and flexible to changing conditions.

The transition from a linear problem to a stochastic one by choosing a quality indicator is determined by the M-formulation, in which the objective function has the general form:

$$M(F) = M(CX) \to \max.$$

Then the mathematical model of the stochastic programming problem can be formulated as follows with the objective function:

$$\sum_{i=1}^{7} w_i * E[p_i^w] \to \max,$$

where $E[p_i^w]$ – mathematical expectation of the probability of using ICT at the i-th stage with a weighting coefficient $w_i$.

Below are the row-by-row probability constraints:

1) using $d_{ij}$ tense:

$$\sum_{i=1}^{8} d_{ij} * p_i^w \le T_j^{MS}, j = 1,...,8$$

2) weighting factors must be non-negative:

$$0 \le w_i \le 1, i = 1,...,7 \cdot$$

3) probabilities $p_i^w$ must be in the range from 0 to 1:

$$0 \le p_i^w \le 1, i = 1,...,7$$

4) restrictions on the sum of probabilities:

$$\sum_{i=1}^{7} p_i^w = 1, i = 1,...,7$$

The problem is then reduced to a deterministic one, using the mean value criterion for simplicity of solution. The desire to reduce the stochastic programming problem to a deterministic form is due to the need to increase computational efficiency and reduce the complexity of the solution.

Translation allows the use of standard optimization methods based on precise algorithms and simplifies the computational process. It also facilitates the interpretation of results and facilitates their implementation in practical solutions, since deterministic models are often more understandable and transparent:

$$\sum_{i=1}^{7} w_i * \overline{p}_i^w \to \max$$

The following restrictions apply:

1) time use restrictions:

$$\sum_{i=1}^{8} \overline{d}_{ij} * p_i^w \le \overline{T}_j^{MS}, j = 1,...,8$$

2) weighting factors must be non-negative:

$$0 \le w_i \le 1, i = 1,...,7$$

3) average probabilities must be in the range from 0 to 1:

$$0 \le \overline{p}_i^w \le 1, i = 1,...,7$$

4) restrictions on the sum of average probabilities:

$$\sum_{i=1}^{7} \overline{p}_i^w = 1, i = 1,...,7$$

For the previously described stages of working with information, it is necessary to designate the weighting coefficients: $w^{study}$ – study of the problem; $w^{choice}$ – choice of methodology; $w^{pick}$ – collection of information; $w^{filter}$ – filtering of information; $w^{prep}$ – preparation of data; $w^{seek}$ – calculations using the model; $w^{verify}$ – correction of results.

Based on the above parameters, we transform the stochastic programming problem to the following form:

$$F(p^w) = w^{study} * \overline{p}_1^w + w^{choice} * \overline{p}_2^w + w^{pick} * \overline{p}_3^w + w^{filter} * \overline{p}_4^w + \\ + w^{prep} * \overline{p}_5^w + w^{seek} * \overline{p}_6^w + w^{verify} * \overline{p}_7^w \to \max$$

To obtain these results, the total specific time expenditures (in hours per week) for using each ICT element $d_{ij}^S$ at any information stage are first found, with the calculation of the total time per element $T_j^S$, for 25 respondents:

$$d_{ij}^S = \sum_{k=1}^{n} d_{ij}^k, T_j^S = \sum_{k=1}^{n} T_j^k, i = 1,...,8, j = 1,...,7.$$

Where k – the counter of respondents, i – the counter of ICT elements, j is the counter of information stages.

And then the system of constraints for the stochastic programming problem is defined as a set of corresponding coefficients and right-hand sides:

$$d_{ij} = d_{ij}^S / n, T_j^S = T_j^S / n, i = 1,...,8, j = 1,...,7.$$

Based on the obtained data and the previously formed stochastic programming problem, we present the form of its objective function and the main system of restrictions on the time resources for using ICT elements:

$$F(p^w) = 0{,}166 * \overline{p}_1^w + 0{,}132 * \overline{p}_2^w + 0{,}142 * \overline{p}_3^w + 0{,}12 * \overline{p}_4^w + \\ + 0{,}136 * \overline{p}_5^w + 0{,}146 * \overline{p}_6^w + 0{,}159 * \overline{p}_7^w \to \max$$

An optimal solution to the system for finding the probabilities of using ICT at the i-th stage was obtained:

$p_1^w = 0.5$; $p_2^w = 0.9$; $p_3^w = 0$; $p_4^w = 0$; $p_5^w = 0$; $p_6^w = 0.14$; $p_7^w = 0.9$, $F(p^w) = 0.365$.

This shows that the probability of competent use of ICT is just over 30% - two thirds of employees' time is spent unproductively.

The average probability value can be expressed as follows:

$$\overline{p}_i^w = \int_{-\infty}^{+\infty} p_i^w * f(x)dx \cdot$$

Where $\overline{p}_i^w$ – the probability function of successful use of information resources at the i-th stage of information processing, and f(x) is the probability density of the distribution of x, characterizing the uncertainty in the model.

Limitations on the average probability $\overline{p}_i^w$ :

1) Restrictions on using $d_{ij}$ time:

$$\sum_{i=1}^{8} \overline{d}_{ij} * p_i^w \le \overline{T}_j^{MS}, j = 1,...,8$$

2) The weighting factors must be within the unit interval:

$$0 \le w^k \le 1, k \in \{study, choice, filter, prep, seek, verify\}$$

3) Probabilities $\overline{p}_i^w$ must be in the range from 0 to 1:

$$0 \le \overline{p}_i^w \le 1, i = 1,...,8$$

4) Limit of the sum of average probabilities:

$$\sum_{i=1}^{8} \overline{p}_i^w = 1$$

The Gaussian function was chosen as the distribution density:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

Where is the parameter μ–mathematical expectation, and the parameter σ–standard deviation with standard normal distribution, where μ = 0 and σ = 1, then:

$\overline{p}_1^w = 0.5$; $\overline{p}_2^w = 0.9$; $\overline{p}_3^w = 0$; $\overline{p}_4^w = 0$; $\overline{p}_5^w = 0$; $\overline{p}_6^w = 0.4$; $\overline{p}_7^w = 0.9$.

# 5 CONCLUSIONS

The results of the constructed model allow us to determine the basic probability of competent use of ICT by the organization's employees.

The probabilities of only four stages of information processing are non-zero: problem study, method selection, model calculations, and results correction. The probability of using ICT in such stages as data collection, information filtering, and data preparation turned out to be zero. This means that university employees do not have access to truly professional exclusive sources of data for research. The creation of an information center at SibSUTIS to meet the urgent needs of its teachers in data searches is becoming relevant.

However, it should be noted that the normal distribution is too rough for assessing the results of the expert survey of university employees regarding their preferences for using IT technologies in their work. In the future, it is planned to apply the division of employees into clusters, the determination of weighted average characteristics based on the division into clusters, and the use of the Student probability distribution, which is suitable for small samples, when processing the survey data.

To increase the reliability of the assessment and its applicability for practical purposes, it is necessary to use clarifying coefficients that take into account the specifics of the subject area of a particular enterprise or organization. This will allow the model to be adapted to specific conditions and increase its applicability for decision-making in practice.

Thus, further improvement of the model and taking into account the specifics of each organization will not only improve the quality of the assessment, but also ensure more accurate application of research results in the risk-resistant management educational process [11].

# REFERENCES

[1] I. L. Akulich, Mathematical Programming in Examples and Problems, 3rd ed. Moscow, Russia: Lan, 2019, p. 348.

[2] M. R. Alijanzadeh, S. A. Shayannia, and M. M. Movahedi, "Optimization of maintenance in supply chain process and risk-based critical failure situations (case study: Iranian oil pipeline and telecommunication company, north district)," Journal of Applied Research on Industrial Engineering, vol. 11, no. 1, pp. 125–142, 2024, doi: 10.22105/jarie.2022.322072.1419.

[3] Yu. M. Ermoliev, Problems and Methods of Stochastic Programming, 3rd ed. Moscow, Russia: Nauka, 2020, p. 236.

[4] G. R. Frederick, H. Schweizer, and R. Lowe, "After the inservice course: Challenges of technology integration," Computers in the Schools, vol. 23, pp. 73–84, 2020.

[5] Y. Goktas, S. Yildirim, and Z. Yildirim, "Main barriers and possible enablers of ICT integration into pre-service teacher education programs," Educational Technology and Society, vol. 12, pp. 193–204, 2022.

[6] L. V. Kantorovich, Mathematical-Economic Works. Novosibirsk, Russia: Nauka, 2019, p. 760.

[7] P. Mishra and M. J. Koehler, "Technological pedagogical content knowledge: A framework for teacher knowledge," Teachers College Record, vol. 108, no. 6, pp. 1017–1054, 2022.

[8] A. Mishra, D. Kumar, M. Shuaib, M. Tyagi, and R. Singh, "Measurement of critical factors: A case of telecommunication industry," 2021, doi: 10.1007/978-981-15-6017-0_16.

[9] UNESCO, ICT Competency Framework for Teachers. Paris, France: UNESCO, 2023, pp. 96–99.

[10] E. Smith, "How ICT is transforming education: Impact on pedagogical technologies," Journal of Educational Technology, vol. 45, no. 2, pp. 112–130, 2020.

[11] Y. Shevtsova, V. Kanev, A. Poletaikin, and N. Kuleshova, "Optimizing risk-free model of development of educational organization based on modified risk thermometer," in Proc. 15th Int. Asian School-Seminar Optimization Problems of Complex Systems (OPCS), Novosibirsk, Russia, 2019, pp. 68–72.

[12] E. V. Shikin and G. E. Shikina, Operations Research. Moscow, Russia: Prospekt, 2022, p. 281.

[13] A. N. Shiryaev, Fundamentals of Stochastic Financial Mathematics, vol. 1. Moscow, Russia: MCCME, 2022, p. 440.

[14] G. R. Sotirov and A. P. Voshchinin, Optimization under Uncertainty Conditions. Moscow, Russia: Sofia, 2020, p. 224.

[15] H. Zhang, Z. R. Wang, X. W. Wang, and F. C. Lin, "Practice and research on FMEA of telecommunication satellite system," in Signal and Information Processing, Networking and Computers, J. Sun, Y. Wang, M. Huo, and L. Xu, Eds., Lecture Notes in Electrical Engineering, vol. 917. Singapore: Springer, 2023, doi: 10.1007/978-981-19-3387-5_110.

[16] D. B. Yudin, Problems and Methods of Stochastic Programming, 2nd ed. Moscow, Russia: Krasand, 2022, p. 392.