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# Human-centered management in polyergatic information systems. Multi-criteria distribution of functions between operators

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**Abstract.** The article considers the problem of human factor in complex polyergatic systems with a flow of applications for functions (problem solving) arising at random moments of time. The structure of a decision support system for the operator-manager, including subsystems of monitoring, forecasting and decision- making, is justified. The system of criteria relevant to solving the tasks of functions distribution was substantiated and its multi-criteria nature was shown. The technology of multi-criteria evaluation and choice of alternatives based on the methodology of hierarchical system analysis of problems and the method of analysis of hierarchies Thomas Saaty has been proposed. The decision-making system, which has been tested in the operation of control systems of various complex technical and production objects, has been implemented. The proposed method differs from the known approaches in that this method is aimed at prompt decision-making, as well as in that it uses a multi-criteria approach and both pragmatic and ergonomic criteria are used as criteria.

## 1. Introduction

The Fourth Industrial Revolution allowed the expansion of the widespread introduction of robots and automation [1–3] . The efficiency of agricultural and industrial production has significantly increased [4–6], educational technologies and means of access to information resources have changed dramatically [7–9]. However, unfortunately, in recent years the problem of the so-called “human factor” [10–12] has become increasingly apparent. This is associated not only with expectations of catastrophic consequences of the displacement of humans by robots and artificial intelligence, but also with the increase in tension of operators’ work, stress, increase in the number of errors leading to catastrophic consequences, increase in cases of injuries and even deaths of people [13–15].

## 2. Statement of the task

Researchers of the “human factor” problems note a fundamental change [16–19] in the role of the human operator in automated systems (figure 1).

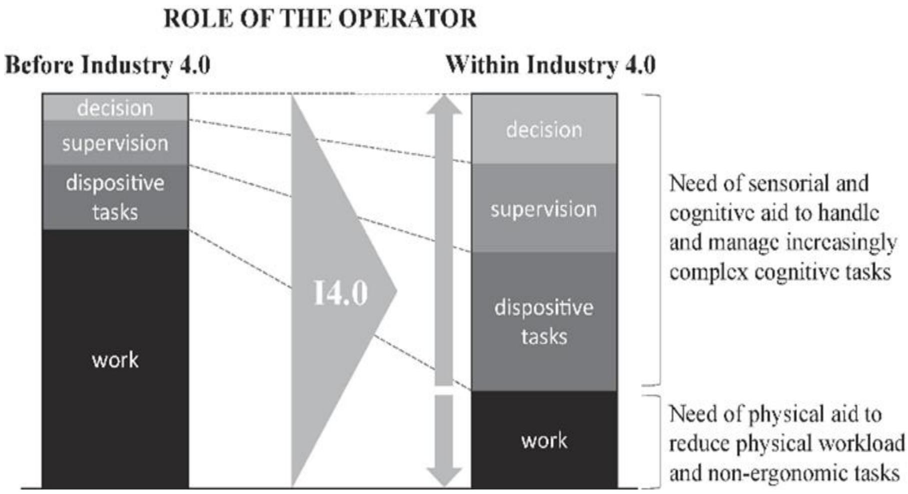


**Figure 1.** Changing the role of the human operator [18, 19].

The share of ergatic systems with the number of simultaneously working operators exceeding 1 (one operator) is increasing. Such systems are called "polyergatic" [20–24]. Executive operators work, as a rule, under the guidance of operator-managers and actively interact with each other. Operators work in a single information space under conditions of a random flow of tasks that need to be urgently solved [22–24], while for critical systems, the requirements for reliability (error-free and timely performance of functions) are significantly increasing [19, 23, 24]. In these circumstances, there is an increasing need to support the decision-making of operator-managers on the optimal operational choice of an operator (one or more), which is advisable to entrust the execution of the incoming request [18–21]. Methods for solving such problems in recent years have been proposed in a number of papers [21–26]. However, a common methodological drawback of these studies is orientation on one-criteria optimization (in most cases a problem of maximization of error-free execution probability is set) [23, 24, 27, 28], which does not allow to fully take into account the so-called "human factor" and use not only pragmatic criteria but also purely ergonomic criteria [29].

*Statement of the problem.* In connection with the described above problems we set a problem to develop an approach to rational distribution of functions with the use of both pragmatic and organizational and ergonomic criteria of optimization.

## 3. Results

The operator-manager should assign the execution of the request to the operator who will provide the maximum probability of error-free and timely execution, while taking into account many parameters and characteristics of the operator himself, as well as the conditions of his activity (characteristics of technical and software tools, exposure to harmful environmental factors, tensions, etc.) – figure 2. [28].

### *3.1. Analysis of indicators to be considered in solving the problem*

The analysis of the problem situations of the activity of the operator-manager revealed two groups of indicators, which should be used to solve the problem of allocation of functions (see examples – table 1):

- Pragmatic ($\beta$, $P$, and economic gain (loss)).
- Characterizing operators' performance and working conditions ($\Omega_1$-$\Omega_6$).

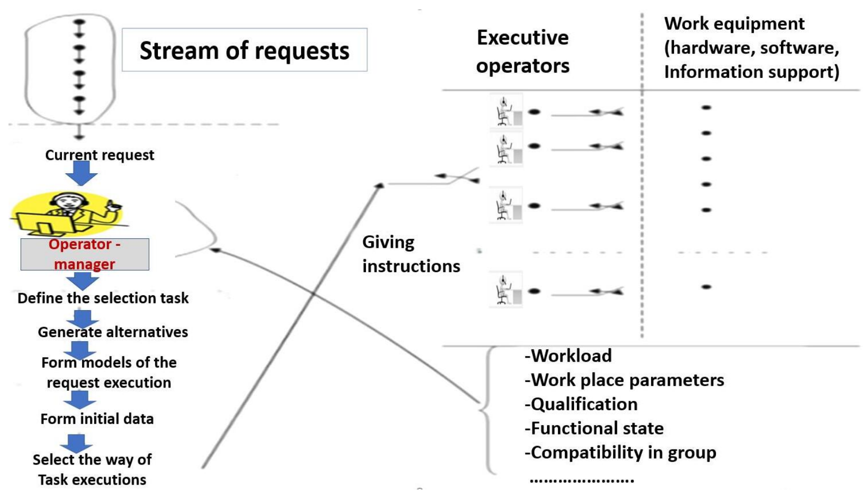


**Figure 2.** Demonstration of the problem situation of the operator-manager [28].

**Table 1.** Examples of indicators characterizing the quality of the option of fixing the function (fragment).

| **Indicator** | **Ability to use as a criterion** | **Ability to use to form a restriction** |
|---|---|---|
| $\beta$ – probability of error-free execution | In most cases (maximization) | + |
| $P$ – likelihood of timely execution | In most cases (maximization) | + |
| $\Omega_1$ – category of the current functional state (working capacity) of the operator (from 1 to 6) | Expedient (minimization) | + |
| $\Omega_2$ – category of the predicted functional state (working capacity) of the operator after the function (from 1 to 6) | Expedient (minimization) | + |
| $\Omega_3$ – severity category of working conditions (current) of the operator (from 1 to 6) | Expedient (minimization) | + |
| $\Omega_4$ – category of the predicted severity of the operator's working conditions after performing the function (from 1 to 6) | Expedient (minimization) | + |
| $\Omega_5$ – queue of requests for execution (current) | Expedient (minimization) | + |
| $\Omega_6$ – queue of requests for execution (forecast at the time of completion of the request) | Expedient (minimization) | + |

### *3.2. The task of selecting an operator to execute a request*

Obviously, in the general case the problem is multi-criteria in nature and for the example considered (table 1) can be represented as follows (in the real activity of managers the number of target functions can be larger, some indicators can be used to form constraints):

$$\begin{cases} \beta(X) \to max; \\ P(X) \to max; \\ \Omega_1(X) \to min; \\ \Omega_2(X) \to min; \\ \Omega_3(X) \to min; \\ \Omega_4(X) \to min; \\ \Omega_5(X) \to min; \\ \Omega_6(X) \to min; \\ X \in X_0. \end{cases}$$

Here $X$ is the vector characterizing the fixation of functions, $X_0$ is the set of admissible variants of the fixation of functions.

### *3.3. Developing principles for solving the problem*

We have analyzed the decision-making process of operators-managers of complex automated control systems of critical type and identified the main requirements for a decision support system. Basic requirements (principles):

- Focusing on objective quantitative indicators.
- Monitoring of the current state of operators and the environment.
- Using prediction models of the environment, ergonomics, error-free and timely implementation of functions.
- Using activity models (such as "functional network" [30–33]) to predict the reliability performance and execution time of function.
- Use of ergonomic databases (statistical data bases of operators' errors and operations execution time with all influencing factors taken into account) to form the initial data about reliability and execution time of all functional elements of functional network.
- Enabling the operator-manager to formalize ideas about the importance of criteria in a particular problem situation.
- Providing a possibility for the operator-manager to formalize the degrees of "desirability" of the values of local indicators.
- Providing a possibility to form the integral quality assessments of function distribution options.
- Enabling convenient on-line decision-making with visualization of the results.

### *3.4. Development of the conceptual structure of the decision support system for the allocation of functions*

Based on the developed principles and requirements for the decision support system, we can propose the following system structure, including a subsystem of monitoring the current states of operators and the working environment, a subsystem of forecasting the state of operators and the environment after the implementation of activities on the application, as well as a subsystem of forecasting the results of activities taking into account the individual characteristics of operators, their functional state and work environment parameters (figure 3) .

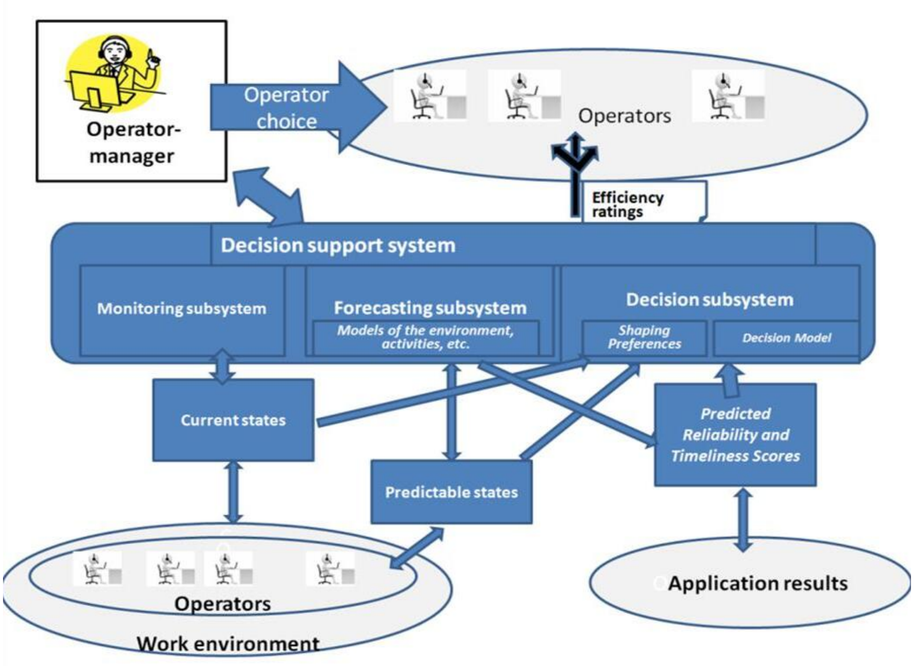


**Figure 3.** An enlargeds chematic diagram of the decision support system for the operator-manager.

### *3.5. Models for monitoring and forecasting*

To monitor the functional state of operators we propose to use the method of keyboard handwriting analysis, consisting in the analysis of key press duration when entering the text of key phrases and solving the classification problem using neural networks, as well as using special manipulators of "mouse" type with built-in sensors for evaluation of cardiac system activity. We evaluate the difficulty of work according to the system of methods [30, 34] of complex accounting of all workplace parameters (physical, psycho-emotional, activity tension) developed by us. We use a 6-point scale for evaluating working conditions. To predict the error-freeness and implementation time of the activity algorithm, we use the method of describing this activity in the form of a functioning network (SF) and application of a library of computational dependencies for typical combinations of blocks [30–32]. The software package [23, 24, 27] developed by us allows to carry out such estimation automatically. An example of reducing the dimensionality of SF necessary to carry out calculations is shown in (figure 4).

### *3.6. Model for choosing the option of fixing requests*

Based on the above substantive analysis of the problem, we can conclude that it is reasonable to apply the method of hierarchy analysis [35–40] for multicriteria evaluation of alternative variants of functions distribution. As applied to the task of ergonomic justification of the choice of variants of execution of applications, let us define the main stages of the solution of the problem:

- Structuring the problem in the form of a hierarchical structure with several levels: goals – criteria – alternatives (see the example for 3 operators in figure 5).
- Pairwise comparison of elements of each level (alternatives for each criterion and importance of criteria of quality of function distribution).

  When comparing the criteria, usually the decision support system asks the operator-head

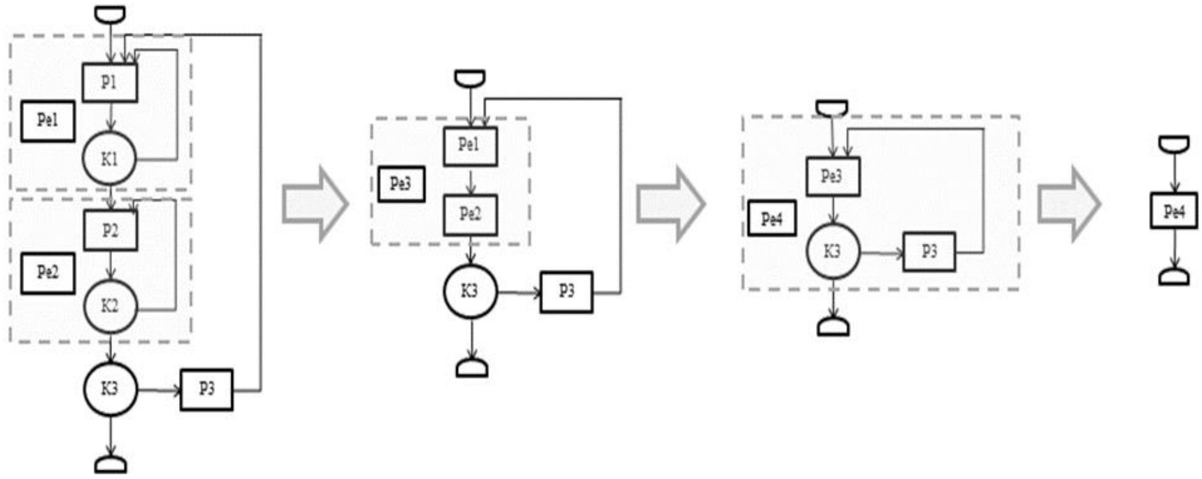


**Figure 4.** The principle of automatic reduction of the dimensionality of SF for the calculations of error-free and time of realization of activities (the identified typical blocks are replaced by an equivalent work operation with equivalent characteristics). The notations and calculation formulas are according to the generalized structural method of Anatoly Gubinsky [30–32].

which of the criteria is more important; when comparing the alternatives in relation to the criteria – which of the alternatives is more preferable. If element $E_1$ dominates over element $E_2$, the matrix cell corresponding to row $E_1$ and column $E_2$ is filled with an integer, and the cell corresponding to row $E_2$ and column $E_1$ is filled with the inverse of it. To establish the relative importance of the elements in the hierarchy, a scale of relationships is used. This scale allows the operator-manager to assign certain numbers to degrees of preference (table 2). Examples of evaluation of criteria importance under different approaches to decision making ("pragmatic" and "ergonomic") are shown in table 3 and table 4.

- Quantitative Evaluation of the Integral Indicator of Quality of Alternatives. Selection of the best alternative. (Examples of visualization of the results are shown in figure 6.)

To establish the relative importance of the elements in the hierarchy, a scale of relationships is used. This scale allows the operator-manager to assign certain numbers to degrees of preference (table 2).

**Table 2.** Examples of indicators characterizing the quality of the option of fixing the function.

| Significance | Definition |
|---|---|
| 1 | Equal importance |
| 3 | Some predominance of the importance of one action over the other |
| 5 | Significant or strong relevance |
| 7 | Obvious or very strong significance |
| 9 | Absolute significance |
| 2,4,6,8 | Intermediate values between two adjacent judgments |
| Inverse values | $a_{ij} = 1/a_{ji}$ |

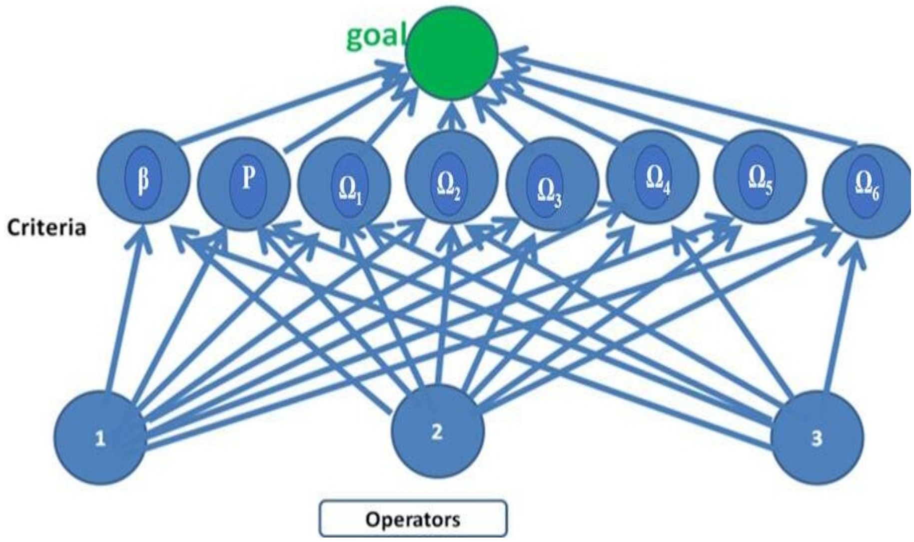


**Figure 5.** Hierarchical structure of the function allocation problem (for 3 operators – $Q_1 - Q_3$ and the system of criteria given in table 1).

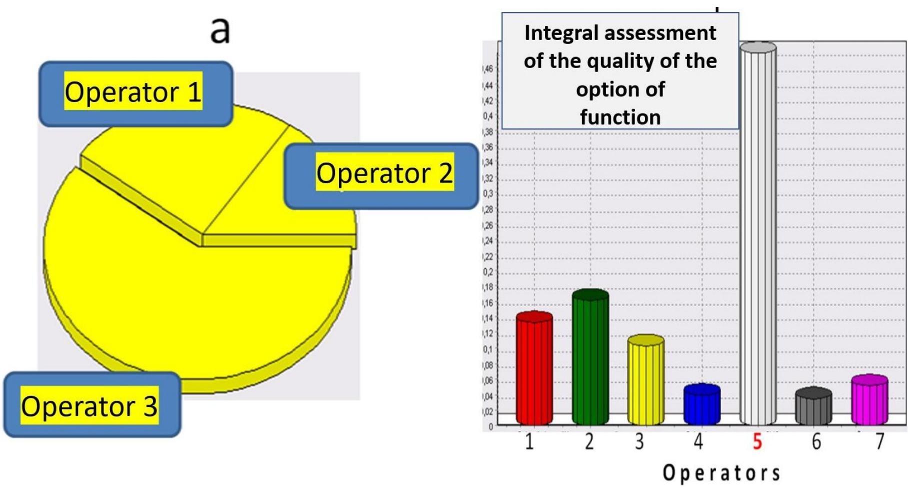


**Figure 6.** Examples of visualization of the results of solving the problem to fix operators in the control system of the main gas pipeline: a – 3 operators, b – 7 operators (prepared by the student Victor Koshara).

## 4. Testing

The results are used in pipeline control systems, e-learning and in banking and process control systems in mechanical engineering [28, 41–44].

## 5. Conclusion

In complex management systems, a single information space is usually occupied by an entire group of operators. In the context of a continuous flow of task orders, the operator-manager must make a quick decision about assigning the task to a specific operator and executor. Both pragmatic criteria and criteria related to ergonomics and the functional states of the operators are important in this process. Under these conditions, a decision can only be made if the

**Table 3.** Example of evaluation of comparative importance of criteria (Extreme approach "orientation on pragmatic indicators") with equal importance of indicators within the group.

| | $\beta$ | $P$ | $\Omega_1$ | $\Omega_2$ | $\Omega_3$ | $\Omega_4$ | $\Omega_5$ | $\Omega_6$ |
|---|---|---|---|---|---|---|---|---|
| $\beta$ | 1 | 1 | $^1/_9$ | $^1/_9$ | $^1/_9$ | $^1/_9$ | $^1/_9$ | $^1/_9$ |
| $P$ | 1 | 1 | $^1/_9$ | $^1/_9$ | $^1/_9$ | $^1/_9$ | $^1/_9$ | $^1/_9$ |
| $\Omega_1$ | 9 | 9 | 1 | 1 | 1 | 1 | 1 | 1 |
| $\Omega_2$ | 9 | 9 | 1 | 1 | 1 | 1 | 1 | 1 |
| $\Omega_3$ | 9 | 9 | 1 | 1 | 1 | 1 | 1 | 1 |
| $\Omega_4$ | 9 | 9 | 1 | 1 | 1 | 1 | 1 | 1 |
| $\Omega_5$ | 9 | 9 | 1 | 1 | 1 | 1 | 1 | 1 |
| $\Omega_6$ | 9 | 9 | 1 | 1 | 1 | 1 | 1 | 1 |

**Table 4.** Example of evaluation of comparative importance of criteria (Extreme approach "orientation on indicators characterizing working conditions and ergonomics" with equal importance of indicators within the group.

| | $\beta$ | $P$ | $\Omega_1$ | $\Omega_2$ | $\Omega_3$ | $\Omega_4$ | $\Omega_5$ | $\Omega_6$ |
|---|---|---|---|---|---|---|---|---|
| $\beta$ | 1 | 1 | 9 | 9 | 9 | 9 | 9 | 9 |
| $P$ | 1 | 1 | 9 | 9 | 9 | 9 | 9 | 9 |
| $\Omega_1$ | $^1/_9$ | $^1/_9$ | 1 | 1 | 1 | 1 | 1 | 1 |
| $\Omega_2$ | $^1/_9$ | $^1/_9$ | 1 | 1 | 1 | 1 | 1 | 1 |
| $\Omega_3$ | $^1/_9$ | $^1/_9$ | 1 | 1 | 1 | 1 | 1 | 1 |
| $\Omega_4$ | $^1/_9$ | $^1/_9$ | 1 | 1 | 1 | 1 | 1 | 1 |
| $\Omega_5$ | $^1/_9$ | $^1/_9$ | 1 | 1 | 1 | 1 | 1 | 1 |
| $\Omega_6$ | $^1/_9$ | $^1/_9$ | 1 | 1 | 1 | 1 | 1 | 1 |

manager is provided with a special decision-support system, including a monitoring, forecasting and decision-making system. The evaluation of alternative options is conveniently carried out on the basis of a systematic and hierarchical analysis of the problem and the use of the methodology of the hierarchy analysis method. The scientific novelty consists in the fact that, for the first time, the principles of decision-making support for the operator-manager have been substantiated and, in contrast to the existing single-criteria problems, the problem of multi-criteria evaluation of alternatives has been set and solved. The novelty of the results also lies in the fact that the method assumes objective quantitative indicators (including the forecast of error-free and timely execution, obtained on the basis of a model called "functional network"). Practical relevance: The method is materialized in the form of a decision-making support system that is convenient for managers of complex systems of managing critical objects.

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