METHOD OF MULTI-CRITERIA EVALUATION OF INTEGRATION OPTIONS FOR LOCAL ATCS

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ABSTRACT

The methodological basis for management decisions and data transfer between local automated road traffic control systems (ATCS) is now constituted by the concept of scenarios, based on the object-relational approach. However, the disadvantage of this approach is the lack of the system's ability to adapt to changes in input information without completely reworking the structure of the original requirements. One of the options for correcting the situation is integration of existing ATCS within a single information platform. To effectively implement such a task, it is necessary to develop a methodology for multicriteria evaluation of options for integrating local control systems with the help of formal logistical analytical methods that were tested and now are used in the theory of decision making.

Keywords: *automated traffic control system, decision theory, multi-criteria task, integration, analytical methods, single information platform.*

Background. *When developing the methodology for integrating local automated road traffic control systems (ATCS) on the basis of a multi-criteria assessment of the options for creating an architecture, it is important to select and justify the methods that allow to operate the original data and obtain an optimal solution analytically.*

Objective. *The objective of the author is to develop a concept of integration of local automated traffic control systems within a single digital platform, basing on the methods of multicriteria assessment of integration versions.*

Methods. *The author uses general scientific methods, mathematical methods, comparative analysis, evaluation approach, formal logistical analytical methods.*

Results. *In real conditions, the efficiency of functioning of an integrated ATCS can be determined by a sufficiently large number of criteria. Therefore, it is expedient to form a general algorithm of the scientific and methodological approach with possible application of various methods for evaluating the effectiveness of systems. If we consider the process of integration of local ATCS as a series of specific organizational, administrative and technical measures for development of existing systems, then at least three groups of criteria must be taken into account to ensure their joint work [1, 2]:*

1. Completeness and efficiency of implementation of main functional tasks of ATCS.

2. Volume and complexity of the work on integration of local ATCS.

3. Possibility of development in the process of further functioning.

The condition for solving a multi-criteria problem is to bring the criteria to a single formal scale or to normalize the criteria. As a rule, in the presence of applied goals, the criteria are not abstract numerical functions, but have a specific non-formalized content. Therefore, at the initial stage, the necessary content corresponding to the parameters of the control actions is transformed into the values of functions with certain values, that is, they resort to one or another quantitative scale: the absolute scale, the scale of relations, the scale of differences, the scale of intervals (Table 1).

Further, the optimization indicators are formed according to the established (in our case) three groups of criteria (Pic. 1):

$$g_{ij} = \sum_{i=1}^{m} \delta_{ij},\ j = \overline{1,n}. \qquad (1)$$

To remove the objective difficulties that arise in the process of solving the multi-criteria problem of evaluating the integration of local ATCS and in the presence of a sufficiently large number of considered indicators, the Bayes' rule can be applied. Fundamentally, the developed methodology should provide solutions for the entire field of probabilities of changing the situation in the research environment, and the methods of research be applicable to factors of any degree of uncertainty. Then, in accordance with the basic theorem of elementary probability theory (Bayes' theorem), one can determine the probability of an event, provided that another statistically related event is known [3]. In other words, if there is previously known information about a process, then it is possible to more accurately name the probability of a new event in this process.

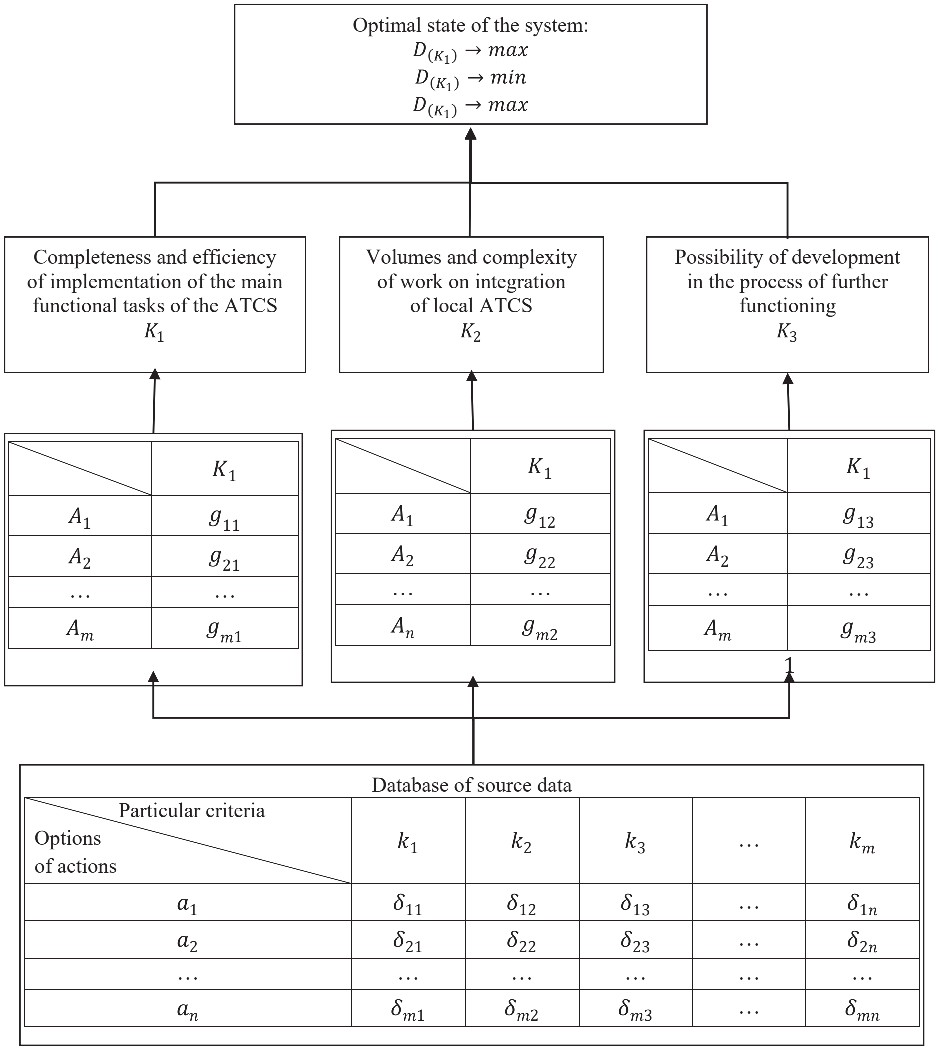
$$P(A|B) = \frac{P(B|A)P(A)}{P(B)}, \qquad (2)$$

where $P(A)$ *is a probability (a priori) of event A;*

Table 1

Criteria for evaluating the integration architecture of local ATCS

No.	Parameter of control actions	Variant / calculated value / rationale							Designation
		1bIB	1bIIB	2bIB	2cIIB	3cIIB	3cIIC	4dIIIB	
1	Completeness and efficiency of implementation of the main functional tasks of ATCS	21	12	16	11	12	12	15–13*	g_{i1}
		* provided that the newly created center is empowered to manage regional and private local ATCS							
2	Volume and complexity of works on integration of local ATCS	21	22	21	22	26	37	38	g_{i2}
		–							
3	Possibility of development during further operation	4	4	4	4	5	5	5	g_{i3}
		* provided that the newly created center is empowered to manage regional and private local ATCS							



Pic. 1. Decomposition of the hierarchy of the structure of the system for developing solutions for integration of local ATCS.

$P(A|B)$ – *probability of event A in case of event B or a posteriori probability;*

$P(B|A)$ – *probability of event B in case of occurrence of event A;*

$P(B)$ – *probability (full) of event B.*

A number of formal logistical methods are based on the Bayes' rule, allowing to analytically determine the probability of occurrence of possible events in the presence of information about previous events or the state of the system as a whole. In a number of research papers [4, 5] it was proved that, when passing from the theory of probability to the methods of solving multi-criteria problems, the probabilities of states of the system p_j *in their sense are adequate to the coefficients of relative importance (CRI) of the criteria* c_j*, that is:*

$p_j \equiv c_j$. *(3)*

Let us analyze a number of approved formal logistic methods for solving multi-criteria problems that allow us to determine, on the basis of the generated efficiency matrix of possible options for actions, the best CRI and, accordingly, the best possible solution from all possible (full probability of an event).

$$A_{ij} = \begin{pmatrix} g_{11} & g_{12} & \cdots & g_{1n} \\ g_{21} & g_{22} & \cdots & g_{2n} \\ \cdots & & & \cdots \\ g_{m1} & g_{m2} & \cdots & g_{mn} \end{pmatrix}, \quad (4)$$

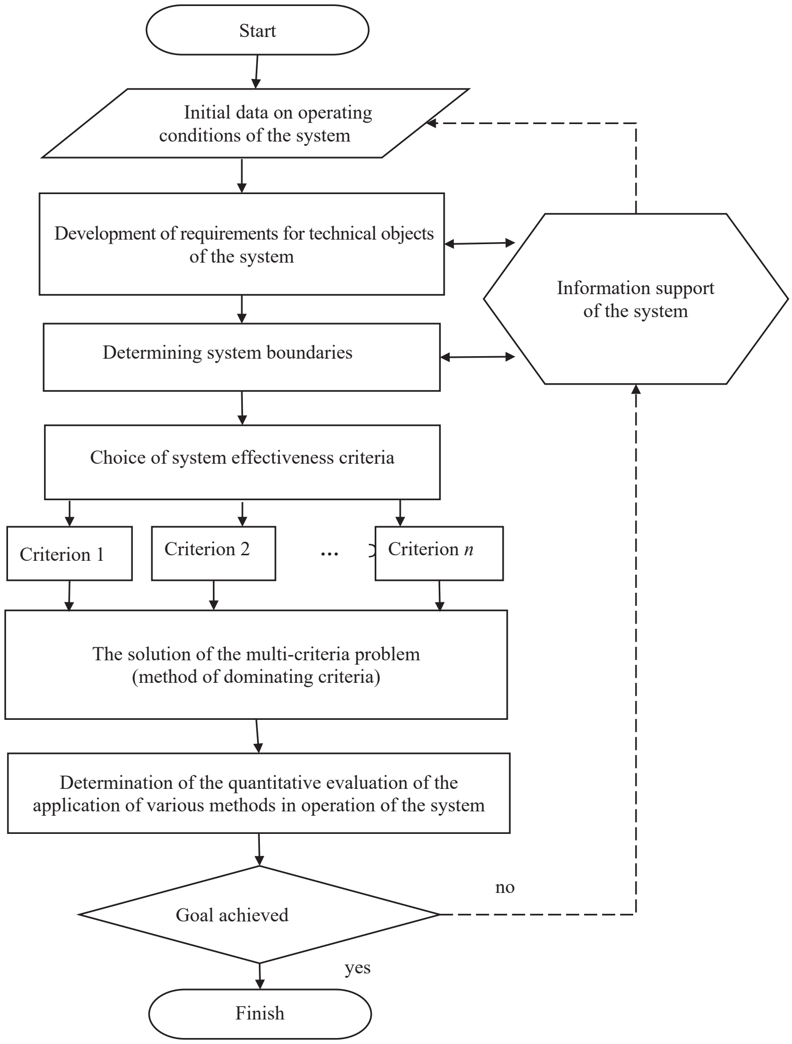
where n is the number of options considered;

m – number of criteria considered;

g_{ij} *– quantitative evaluation of the i-th action for the j-th criterion,* $i = \overline{1,m}$, $j = \overline{1,n}$.

1. The Laplace Criterion. *In accordance with the «principle of insufficient reason» developed by Laplace, it is recommended to consider the optimal decision in the conditions of insufficient information to which the probability distribution corresponds:*

$$P_j = \frac{1}{n}, \text{ or } c_j = \frac{1}{n}, j = 1, 2 \cdots n. \quad (5)$$



Pic. 2. Algorithm of the methodology of quantitative evaluation of options of integration of local ATCS.

The decision is made in accordance with the condition:

$$D_i = \max_i \frac{1}{n}\sum_{j=1}^{n} g_{ij} \,. \qquad (4)$$

This criterion is rather subjective, since the probabilities of distribution of CRI are derived from the condition of uncertainty of the possible development of the situation in the process under study. Nevertheless, a uniform distribution of the probabilities of CRI can be determined from the knowledge that certain options for action do not have a significant objective possibility of manifestation, rather than others, but not from the ignorance of the facts that some variants have a higher degree of objective possibility of manifestation than others.

2. Fishburn estimates*. In case that information about the significance of the criteria accepted as optimization parameters in the system under study is objectively present, it is possible to determine the values of CRI using the Fishburn [Peter C. Fishburn] probability estimate method [6]. According to it, the criteria are located as their importance decreases or increases:*

$$K_1 \ge K_2 \ge \ldots \ge K_m \,, \qquad (7)$$

then the 1st formula of Fishburn's estimates will have the form:

$$c_j = \frac{2(n-j+1)}{n(n+1)} \,. \qquad (8)$$

In the case of strengthening the linear ordering of priority criteria:

$$\begin{cases} c_1 \ge c_2 + c_3 + \ldots + c_n \\ c_2 \ge c_3 + c_4 + \ldots + c_n \\ \qquad \ldots \\ \qquad c_{n-1} \ge c_n. \end{cases} \qquad (9)$$

It is determined that the values of CRI are a decreasing geometric progression and are calculated according to the 2nd formula of the Fishburn estimates:

$$c_j = \frac{2^{n-i}}{2^n - 1}, j = 1, 2, \ldots, n \,. \qquad (10)$$

If certain intervals of possible values of CRI are known, the 3rd formula of the Fishburn estimates is applied:

$$c_j = a_j + \frac{1-\sum_{j=1}^{n} a_j}{\sum_{j=1}^{n}\left(a_j - b_j\right)}\left(a_j - b_j\right),\ j = 1, 2, \ldots, n, \qquad (11)$$

where

$$a_j > b_j\ ,\ i = 1, 2, \ldots, j, \sum_{j=1}^{n} a_j \le 1\ ,\ \sum_{j=1}^{n} b_j \ge 1. \qquad (12)$$

The above formulas show that the calculation of CRI by the Fishburn method of estimation is fairly simple and easy to be formalized, and there is no need for additional refinements in the process of study.

3. The method of mapping *by the principle of domination of possible options or conditions of the research environment with the subsequent choice of the optimal option [7]. The essence of the method consists in splitting the set of probabilities of effective solutions into subsets of domination, and the mapping operation is solved as an inverse parametric problem of linear programming. In particular, for a system of three criteria, CRI can be ordered in the following form:*

$$c_1 + c_2 + c_3 = 1, c_1 \ge 0, c_2 \ge 0, c_3 \ge 0\ . \qquad (13)$$

When CRI are placed according to certain criteria into an ordered sequence, the mapping method is applied according to the principle of observing the hierarchical relationship between the probabilities of possible states of the external environment or the method of dominating criteria (MDC) [8]. Then the total distribution of CRI for any number of criteria is subject to constraints

$$0 \le c_j \le 1, j = \overline{1,n}, \sum_{j=1}^{n} c_j = 1 \qquad (14)$$

and, depending on the priority of the criteria, CRI should be located in the following sequence:

$$c_1 \ge c_2 \ge \ldots \ge c_i \ge \ldots \ge c_{n-1} \ge c_n. \qquad (15)$$

When applying this method, the problem of finding the optimal action is reduced to solving the linear programming problem for each of their compared variants D_i:

$$\begin{cases} D_i = \sum_{j=1}^{n} g_{ij} c_j \to \max, \\ \sum_{j=1}^{n} c_j = 1,\ 0 \le c_j \le 1,\ c_j \ge c_{j+1},\ j = \overline{1, n-1}, \end{cases} \qquad (16)$$

and CRI are determined as

$$c_j = \begin{cases} \frac{1}{k}, if\ j \le k, \\ 0, if\ j > k, \end{cases} \qquad (17)$$

where the index k is found from the condition $g_{kj} = \max_j g_{ij}$.

The main advantages of using MDC in the methodology of multi-criteria evaluation of the integration of local ATCS is that when formulating the problem of finding the optimal solution in the case of several efficiency criteria, it is sufficient to formulate an ordered priority between them, and the analytic apparatus for obtaining CRI for each criterion is completely formalized, that is, is focused on the objects, e.g. on obtaining coefficients of relative importance for each individual criterion for all considered possible solutions.

Conclusion. *Taking into account the advantages and disadvantages of the solutions analyzed, it is possible to formulate an algorithm for quantitative assessment of the integration options for local ATCS (Pic. 2).*

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