Multi-criteria evaluation of management decisions in the intellectual system of transportation management

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***Abstract*—In the article is proposed to use a multi-criteria quality assessment with dynamically changing significance coefficients while searching for a rational management decision in the control system of transportation process. It is proposed to compare the solutions using the theory of fuzzy sets. The fuzzy-set member function is built using direct and indirect methods. The search conditions for rational management decisions are formulated.**

***Keywords*—railway transport, transportation process, multicriteria optimization, fuzzy set theory, rational decision search model**

Traditionally, in transport, the evolution of control systems is realized through informatization and automation. However, information systems and automated control systems during performance not only collect, but also simplify the initial data. Their activities are aimed at preparing information in accordance with a predetermined template and the subsequent presentation of aggregated information to a person for making management decisions (MD). Such approaches are effective when a limited list of typical tasks is solved according to predetermined criteria. However, in conditions when there is a need to solve non-trivial tasks, with indefinite optimality criteria, solving problems in conditions of lack of time for making decisions and huge amount of data, the effectiveness of traditional systems is significantly reduced and it becomes necessary to use intelligent traffic control systems (ITCS) [1], [2].

ITCS is recomended for overcoming information barriers and for tasks that cannot be solved with the help of ordinary management tools.

The following groups of tasks can be solved using ITCS:

- the solution algorithm is unknown and it is nesessary to create a new problem solver on the basis of the available data;
- besides digital data, it is necessary to use non-formalized or poorly formalized source data (for example, bad weather conditions during cargo operations, low qualification of the locomotive crew, etc.);
- problem solving requires using of an unconventional mathematical apparatus (cognitive logic, soft computing, etc.);
- it is necessary to find a management solution (or options for management decisions) with uncertainty, incomplete or insufficiently reliable source data (for example, developing a daily cargo handling plan with an incomplete array of applications for loading and an unknown category of wagon availability);
- when a criterion for the effectiveness of a management decision is a new criterion or is a group of criteria that was not used in the original algorithms.

Management quality assesment will differ in the ITCS from ones in traditional control systems. Besides assessing of the management effectiveness (result assessment), management actions, the resources of implementation (actions assessment) and the effectiveness of the composition, structure, and number of elements in the management system (assessment of the structure) should be evaluated in the ITCS.

When solving individual problems of transportation process management, it is not always possible to figure out single optimality criterion. More often it is necessary to operate with complex criteria with different weight coefficients.

“Fig. 1”presents a diagram of the customer requirements priorities for the transportation system.

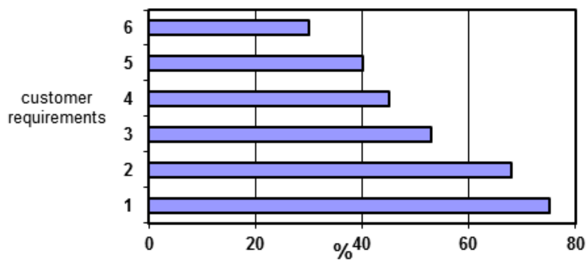

Figure 1. The priority diagram of customer requirements to the transportation system: 1 - the cost of the organization of transportation; 2 - ensuring the required time of delivery of the goods; 3 - safety of rolling stock and cargo; 5 - information support of transportation; 5 - compliance with the contractual terms; 6 - flexibility settlement system.

Since different units of measurement and different methods for their determination are used for different evaluation criteria, a technique that allows them to be integrated is proposed. Table 1 presents the criteria for assessing the transportation organization system quality, as well as methods and information sources for their determination.

Table I
QUALITY CRITERIA FOR THE TRANSPORTATION SYSTEM

Criteria	**Calculation methods**	**Source of information**
The cost of the organization of transportation	Calculation methods, contract	Operational parameters of the railway, cost meters
Ensuring the required time of delivery of the goods	Calculation methods	Delivery route, speed standards, shelf life, etc
Availability of reserves of infrastructure facilities	Calculation methods	Operational parameters of the railway
Compliance with the contractual terms between the infrastructure operator and carriers	Registration methods	Statistical data
Note: Depending on the situation, the number and the list of criteria may vary.		

As can be seen from table 1, various methods can be used for evaluation, which are applicable to clearly defined quantitative estimates of quality parameters. However, in some cases a subjective assessment can be applied - “desirable”, “within”, etc.

In the scientific literature, including the transport one [3], [4], the mathematical apparatus based on the theory of fuzzy sets [5], [6] is used as a tool for expressing unclearly defined customer expectations.

The approach to the formalization of fuzziness is as follows. A fuzzy set is formed by introducing a generalized concept of belonging, i.e. extensions of the two-element set of values of the characteristic function 0,1 to the continuum [0,1]. This means that the transition from the complete belonging of an object to a class to its complete non-belonging does not occur in jumps, but smoothly, gradually, and the belonging of an element to a set is expressed by a number from the interval from 0 to 1.

Consider the use of the specified mathematical apparatus for the evaluation of MD in ITCS.

Let X – be a set of variants of MD according to some criterion of quality in the ITCS. The fuzzy set *A* in *X* is the set of pairs of the form $(x, \mu_A(x))$, where $x \in X$, and $\mu_A(x)$ - is the level of achievement of a given fuzzy target by the variant *X*. $\mu_A(x)$ - the membership function of a fuzzy set *A*, varying from 0 to 1. The greater the value of the membership function, the greater the degree of achievement of a given goal when choosing an alternative *X* as a solution.

The membership function is set on the basis of expert assessments and can have a different look. For the conditions of the problem of choosing a rational MD in the ITCS, formalization of fuzzy consumer expectations in accordance with [7], [8] we will consider the normal fuzzy set, i.e. the upper limit of its membership function is equal to one: $\sup \mu_A(x) = 1$, and the membership function itself is inseparable.

Depending on the quality parameter under consideration and consumer preferences, the membership function may have a certain interval, where $\mu_A(x) = 1$. If the value of the quality parameter is subject to “no more” or “no less” restrictions, the membership function assumes a zero value when this condition is not met. For example, when setting infrastructure constraints $x_i <= c$, then in this case $\mu_A(x_i <= c) = 0$.

There are a number of methods for constructing, according to expert estimates, the membership functions of a fuzzy set, which can be divided into two groups: direct and indirect.

Direct methods are determined by the fact that the expert sets the rules for determining the values of the membership function $\mu_A(x)$ characterizing the concept *A*. These values are consistent with his preferences on the set of objects *U* as follows:

- for any $u_1, u_2 \in U, \mu_A(u_1) < \mu_A(u_2)$ if and only if it is u_2 preferable u_1, i.e. more characterized by the concept *A*;
- for any $u_1, u_2 \in U, \mu_A(u_1) < \mu_A(u_2)$ if and only if and are indifferent u_2 with u_1 respect to the concept *A*.

Examples of direct methods are the direct assignment of the membership function by a table, a formula, a sample.

In indirect methods, the values of the membership function are chosen in such a way as to satisfy the previously formulated conditions. Expert information is only the initial information for further processing. In the ITCS, in the process of monitoring, the values of functions dynamically change.

Additional conditions may be imposed both on the type of information received and on the processing procedure. Examples of additional conditions are the following: the membership function should reflect the proximity to a pre-allocated standard; objects of the set *U* are points in parametric space; the result of the processing procedure should be the membership function that satisfies the conditions of the interval scale, etc.

As a rule, direct methods are used to describe concepts that are characterized by measurable properties. In this case, it is convenient to directly specify the values of the degree of belonging. The procedure for constructing the membership function consists of the following steps:

determining the type of function; establishing its specific values; adequacy check.

When determining fuzzy expectations, the experts are given some values of the quality parameter and the corresponding values of the membership function, while the remaining intermediate values are determined by the interpolation method.

Multi-criteria optimization in a fuzzy setting can be represented as a system $\langle X, C_1, ..., C_n, L\rangle$, where X – is a universal set of alternatives, L –is a lattice, and ($i = \overline{1,n}$ the criterion is called L -fuzzy set

$$\mu_{C_i} in F_L(X), F_L(X) = \{\mu_{C_i} | \mu_{C_i} : X \to L\}, \quad (1)$$

where is μ_{C_i} – the membership function, fuzzy set; $F_L(X)$ – many fuzzy subsets X.

If all criteria are considered equivalent and comparable, then, in accordance with the principle of merging, we have $\langle X, D, L\rangle$, where is $D = C_1 \cap ... \cap C_n$, i.e. $\mu_D = \mu_{C_1} \cdot \mu_{C_2} \cdot ... \cdot \mu_{C_n}$ ($\cdot$ - one of the variants of the operation of intersection of fuzzy sets in $F_L(X)$).

However, in real conditions, including when choosing a rational MD, criteria of unequal significance are used. Then, if there is a set of fuzzy criteria $M = \{\mu_{C_1}, ..., \mu_{C_n}\}, \mu_{C_i} \in F_L(X)$ and a set of weights of criteria $\Pi = \{P_1, ..., P_n\}$, then a fuzzy subset Q of the fuzzy set $M : Q \subset M$

$$\mu_Q(\mu_{C_i}(x)) = \begin{cases} P_i, & \text{если } C_i \in M, \\ 0, & \text{если } C_i \notin M \end{cases} \quad (2)$$

determines the weighting criteria.

The criteria weighting procedure is considered as a mapping $v : P(N_n) \to L$, where is $P(N_n)$ the set of all subsets of criteria indices $N_n = \{1, ..., n\}, L,$ – is a grid.

The function $D : X \to L$ that represents the solutions is determined using a fuzzy integral.

$$D = \int_{N_n} v \cdot g(\cdot) = \sup_{M \in P(N_n)} \inf_{i \in M} (v_x(i) \wedge g(M)). \quad (3)$$

In the multicriteria case, the objective function is a vector function $\phi(x) = (\phi_1(x), ..., \phi_m(x))$, i.e. $\phi : X \subset R^n \to R^m$ where is R – the set of real numbers, and the strict order R^m is impossible. Any two alternatives x and y are comparable with each other if and only if $phi_i(x) \geq \phi_i(y)$, either, or $phi_i(x) \geq \phi_i(y) \forall_i$. Thus, the concept of optimality is replaced in vector optimization by the concept of non-dominance. While in a single-criterion problem, the solution is an optimum point, in a multicriteria problem it gives a lot of effective (Pareto optimal) alternatives

$$P^0 = \{x^0 \in X | \forall y \in X, \phi_i(y) \geq \phi_i(x^0 \to \phi_i(y) = \\ = \phi_i(x^0); i = \overline{1,n})\}. \quad (4)$$

In order to further narrow this set, additional information from the ITCS knowledge base is needed. The various procedures are used in this case basically boil down to explicit or implicit particular criteria folding into a single criterion.

Examples of such generic criteria include [4]:

- weighted sum of fuzzy criteria

$$C = \sum_{i=1}^{n} \omega_i C_i; \quad (5)$$

- the product of the form

$$C = \prod_{i=1}^{n} \omega_i C_i^{\omega_i}; \quad (6)$$

- minimum relationship

$$C = \min_{i=1,...,n} (C_i / \omega_i); \quad (7)$$

  where C_i - normalized criteria (unclear Bellman targets); ω_i - relative criteria weights, $i = \overline{1,n}$.

A fuzzy formulation of a multi-criteria choice problem implies that a number of compared alternatives are known.

(Version MD) $A = \{a_1, ..., a_i, ..., a_n\}$ and many comparison criteria (quality assessment parameters) $C = \{c_1, ..., c_j, ..., c_m\}$, where between each member of the set *A* and each member of the set *C* fuzzy relationship $a_i c_j$ or μ_{ij}, which reflects the level of compliance of the delivery *i* option with the *j* parameter.

$\mu_{ij} \in [0, 1]; i = \overline{1,n}; j = \overline{1,m}$

All fuzzy relations between and form a matrix of fuzzy relations of size *nm* :

$$R = \{\mu_{ij} | i = \overline{1,n}; j = \overline{1,m}\}, \quad (8)$$

and the objective function is

$$a^* = (A, C, R, M), \quad (9)$$

where *M* – used problem solving model chosen by the ITCS.

The search model for a rational MD can be defined by the following conditions:

- choice of MD in the absence of information on restrictions on the value of parameters and information on the level of their not worse than the required;
- the choice of MD when imposing desirable restrictions on some importance;
- the choice of the MD, providing the values of all parameters basic parameters;
- the choice of MD in the presence of information about the level of parameters importance and their share of influence on the overall decision.

The last condition fully characterizes the problem of choosing an option of MD. To solve such problems a compromise solution model is used. The essence of this model is that due to the impossibility of simultaneously satisfying several partial quality criteria, the decision is made using an integral (compromise) indicator obtained by folding particular parameters using formulas (5) - (7). Then problem (9) is transformed into the following form:

$$a^* = \{a_i | a_i \in A; c_i = \max\{c_i | c_i \in C; i = \overline{1,n}\}\}. \quad (10)$$

The algorithm for solving this problem is:

- to establish the level of importance of parameters $\omega_i, i = \overline{1,n}$, (takes a value from 0 - the parameter has no effect on the choice of the delivery system to 1 - the parameter has the maximum influence on the choice of the delivery system);
- to normalize of values ω_i , i.e. to calculate $\omega_i = \omega_i / \sum k = 1^n$;
- to calculate the value of an integral parameter for each variant, for example, from expression (5) ;
- determining the maximum value of integral parameter.

In real conditions it is not always possible to figure out an exhaustive group of criteria and establish their level of significance. Therefore, when developing a ITCS, it is necessary to operate not only with criteria and specified parameters, but, first of all, with the rules of their formation and change.

When solving the tasks of managing the transportation process, the significance of the evaluation criteria will vary depending on the prevailing operational environment. The intellectual function of the ITCS is the dynamic formation of a fuzzy relationship matrix (8) . n it, variables are not only the values of the coefficients of importance of the criteria, but also the size of the matrix (n variants of MD, m criteria of comparison).

The procedure for the formation of the matrix includes the following steps:

- monitoring the operational situation and the formation of a matrix of states of objects of the transportation process (for example, the values of deviations of trains from the standard schedule of movements);
- the formation of the conditions of the operational task on the basis of the knowledge base of the ITCS and the state matrix of the objects of the transportation process (if deviations from the schedule of all trains are insignificant, then we use the reserves of train times;
- of the deviations from the schedule of the majority of trains are insignificant, and for some significant ones, we adjust the train schedule threads by changing the station modes;
- if a significant number of trains have deviations from the standard schedule - we edit the entire schedule);
- selection of criteria for solving the set operational task on the basis of the ITCS knowledge base and the matrix of states of the transportation process objects (for example, for the development of a timetable, it may be the speed of a train, reliability of the schedule, timely arrival of priority trains, energy costs for train movement, the need for locomotives and so on).

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МНОГОКРИТЕРИАЛЬНАЯ ОЦЕНКА УПРАВЛЕНЧЕСКИХ РЕШЕНИЙ В ИНТЕЛЛЕКТУАЛЬНОЙ СИСТЕМЕ УПРАВЛЕНИЯ ПЕРЕВОЗОЧНЫМ ПРОЦЕССОМ

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Аннотация: установлено, что при поиске рационального управленческого решения в системе управления перевозочным процессом необходимо использовать многокритериальную оценку качества с динамически изменяющимися коэффициентами значимости. Сравнение вариантов решений предложено производить с использованием математического апппарата теории нечетких множеств. Формирование функции принадлежности нечеткому множеству предложено производить с использованием прямых и косвенных методов. Сформулированы условия поиска рациональных управленческих решений.

Ключевые слова: перевозочный процесс, организация перевозок, многокритериальная оптимизация, теория нечетких множеств, модель поиска рационального решения

Received 27.12.18