Methods of systemic management of the service life of vehicles

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Abstract. The article discusses the methods of multi-criteria assessment of the efficiency of vehicle operation according to their properties. The main difficulties in solving the issue of technical operation of vehicles when introducing these methods into the assessment process are highlighted. Algorithms of decision-making related to the choice of a vehicle in conditions of uncertainty of the external environment are analyzed. Their advantages and disadvantages are substantiated. A methodology for calculating weight coefficients for the optimization and development of the transport system is proposed.

Keywords. Technical operation of cars, multi-criteria assessment, zoning methods, transport system.

1 Introduction

The car, being an object of increased danger, does not allow violations of the regulations for its operation, leading to a decrease in the level of environmental and constructive safety. However, units, assemblies and systems that increase the safety of the car complicate the design and increase the cost of maintaining it in good condition, while the cost of spare parts and components increases significantly.

When managing the service life of cars, it is important to make a high-quality account of all factors that have a direct impact on this process. Evaluation of the efficiency of vehicle operation by means of various methods for a number of properties is the object of research, considered in a large number of works [1-5].

The tasks that arise as the number of cars that will have to be decommissioned due to non-compliance with the requirements of reliability, environmental and constructive safety multiply exponentially and require the development and implementation of a systemic state policy.

When solving this issue, two main tasks can be distinguished:

1. The complexity of the choice of the nomenclature of vehicle quality indicators. Depending on the type, operating conditions and purpose of the car, the number of assessed properties (estimated indicators) can be quite large. Naturally, with an increase in the number of quality indicators of a car, the labour intensity of their aggregate assessment increases (it is often possible to find an assessment of the quality of a car, including several dozen indicators), while the subjectivity of the decision is also increased. Therefore, it is

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recommended to enter only the most significant indicators from the point of view of vehicle explants, due to the operating environment conditions, regulatory requirements, etc., in the composition of the estimated indicators, that is, the need to identify the priority of the assessment criteria is determined.

2. Another problem of assessing the quality of a car is the procedure for correctly comparing alternative options for properties (it is almost impossible to perform this for a single indicator), therefore, a multi-criteria problem of assessing quality is formed. Here, the most vulnerable point from the point of view of the objectivity of the decision made is the determination of the weight of the criteria under consideration.

The working hypothesis consists in the assumption that the control system for the vehicle's service life should control the quality of the car for the requirements of the operating environment and develop recommendations on the need to write it off.

The search for an optimal approach requires the development of a new scientific apparatus for studying the regularities of the interaction of a complex of technical operation of vehicles (TOV) with subsystems of a higher level (external relations determined by the environment of vehicle operation) requires the adaptation of a number of existing methodological approaches to solving TOV problems necessary for the sequential implementation of the stages of the system's operation vehicle service life management (VSLMS).

2 Materials and methods

The car today is a product of public consumption or an item of demand for both individuals and industrial enterprises. On the other hand, basically, the car is operated on the infrastructure of public roads, that is, in the external environment of consumption of its quality, the operating conditions of which are regulated by state regulatory documents. Therefore, the range of requirements for a car or its quality criteria, as for a technical product, is constantly growing in quantitative and qualitative terms. Balancing a sufficiently large number of criteria (often contradictory) can only be a control system that combines the scientific principles of decision-making theory and modern information technology [6, 7].

Developments in this area have been carried out abroad for over 20 years. In world practice, the concept has now been introduced – a product lifecycle management system Product Lifecycle Management (PLM). PLM is literally defined as «product lifecycle management technology» [8, 9]. This is an organizational and technical system that ensures the management of all information about a product and about the processes performed from the moment of determining the needs of society for a particular product and until the disposal of the product after use, that is, throughout the entire individual life cycle (ILC) [10, 11]. This approach requires using a multicriterial methods of vehicle life cycle predicting.

Most often, to solve the above problems, multicriteria optimization methods are used, which can be conditionally divided into two large groups [12].

Methods, to one degree or another, based on expert judgment to obtain the values of weights or their priority in importance. The solution to this problem, as a rule, is based on determining the importance of selected particular indicators for each criterion, based on the intuitive presentation of the comparative importance of the criteria by experts. For this, a lot of different methods have been developed, which have their own advantages and disadvantages: ranking method; scoring method; MAI, etc.

Methods for removing uncertainty when solving multicriteria motor transport problems should be based on forced expert judgment. If you analyse and compare existing methods, then you should highlight the method of analysis of hierarchies (MAI). Its application does not require a survey of experts, that is, it is not necessary to know the specific values of the weight coefficients, but it is necessary to answer the question of how many times one

indicator is more important than the other in order to build a matrix of paired comparisons, and then check its consistency, which is quite time consuming, although here too there are approaches to simplify this procedure. The main disadvantage of the methods of this group is a significant degree of subjectivity of the decision made due to the fact that a person (expert) is not able to objectively assign correct numerical weights to the criteria.

For example, in the problem of choosing a car type according to several criteria:
- several types of cars - there are many possible solutions;
- several criteria are the state of the operating environment.

Let the efficiency of using any type of car be known for each of these indicators. Let us consider the case when the decision is made by the experts' ranking of the indicators of some criterion.

Let us introduce the following notation:
n is the number of indicators for which a decision is made;
m is the number of compared cars A_m;
a_{ij} is numerical value for the i-th option for the j-th indicator,
$$i = \overline{1, m}, j = \overline{1, n}$$
r_j is the rank of the j-th indicator by individual indicators, $j = \overline{1, n}$.

The most common algorithm for solving the problem of choosing a car by the ranking method is as follows:

1. The elements of the efficiency matrix δ_{ij} are determined:

Since indicators can have different dimensions and values that are not comparable in absolute value, they must be presented in relative units, it is important to remember that some indicators can tend to a maximum (for example, carrying capacity, if different types of cars are compared), and some to a minimum (for example, the cost of rolling stock). Considering the foregoing, the elements of the matrix δ_{ij} of the numerical values of indicators, presented in relative units, are calculated by the following formulas [13-15] and are formed in the form of an efficiency matrix:

$$\delta_{ij} = \begin{cases} \dfrac{a_{ij}}{\max\limits_{1 \ll i \ll m} a_{ij}}, \text{if the } i - \text{th indicator is maximized,} \\ \dfrac{\max\limits_{1 \ll i \ll m} a_{ij}}{a_{ij}}, \text{if the } i - \text{th indicator is minimized,} \end{cases} \qquad (1)$$

Matrix elements δ_{ij} numerical values are presented in table.

Table. Matrix elements δ_{ij} numerical values.

	C_1	C_2	C_3	...	C_n
	r_1	r_2	r_3	...	r_n
A_1	δ_{11}	δ_{12}	δ_{13}	...	δ_{1n}
A_2	δ_{21}	δ_{22}	δ_{23}	...	δ_{2n}
A_3	δ_{31}	δ_{33}	δ_{33}	...	δ_{3n}
...	...	...	...	...	...
A_m	δ_{m1}	δ_{m2}	δ_{m3}	...	δ_{mn}

2. Next, the quantities are being obtained:
$$d_f = \sum_{j=1}^{n} \frac{\delta_{ij}}{r_j}, i = \overline{1, m} \qquad (2)$$

3. The optimal type of the compared car is determined according to several criteria of option f from the ratio:
$$d_f = \max_{1 \ll i \ll m} d_i. \qquad (3)$$

The advantage of the described method is its simplicity. But this method also has the disadvantages listed above that are inherent in any method when using expert judgment. The main one of these drawbacks is the need to determine the numerical values of the ranks of r_o.

For example, if the ranks $r_S = 2$ and $r_t = 6$ are accepted for the sth and t^{th} criteria, then in fact this means that a strictly formalized relationship has been established between these criteria (the sth indicator is recognized as more important than the tth criterion exactly 3 times). Obviously, such a conclusion is subjective and, more often than not, cannot be substantiated.

Methods based on special procedures for obtaining weights or formal methods for obtaining weights. Let's list some of them: the method of concessions, the method of ideal point, the method of folding criteria, Fishburne estimates, Laplace's criterion, etc. Of the listed methods, the simplest and not requiring complex additional research is the method for calculating the weight coefficients using the Fishburne formulas. The main disadvantage inherent in these methods to one degree or another is that a strictly formalized relationship is established between the particular indicators (the sth indicator is recognized as more important than the tth p times). It is obvious that such a conclusion is subjective and most often cannot be substantiated [16-18]. Thus, it is possible to formulate the basic requirements for the method of analytical determination of weight coefficients in multicriteria problems of choosing a car for given operating conditions:

1) the method should consider the presence of the priority of the considered criteria;

2) the resulting solution should be as effective as possible, considering performance indicators according to the specified criteria;

3) the apparatus for obtaining the weight of a criterion must be formalized, that is, objective in terms of obtaining the weight of a separate criterion for each individual decision.

The materials used in the manufacturing process have a direct impact on the indicators that determine the service life of cars. The increasing complexity of the vehicle design contributes to an increase in costs, both for spare parts and for maintenance and repair complexes, as well as for operating materials. However, these changes are also made possible to consider when building a multi-criteria model based on the data given, for example, in [19-22] on the specifics of innovative building and machine-building materials.

3 Results and discussion

The developed method of regionalization according to the principle of observance of the hierarchical ratio of the probabilities of possible states of the external environment makes it possible to find a solution to the problem posed. The solution algorithm when applying the developed zoning method according to the principle of observance of the hierarchical ratio of probabilities of possible states of the external environment is as follows [23-25]:

1. By formulas (1), the elements of the matrix δ_{ij} are determined;

2. The value δ_{ij} is normalized by columns:

$$b_{ij} = \frac{\delta_{ij}}{\sum_{k=1}^{n} \delta_{ik}}. \tag{4}$$

3. The relative importance of the C_j indicators are ordered in the form of a sequence depending on the priorities of the vehicle operating environment:

$$c_1 \geq c_2 \geq \cdots \geq c_i \geq \cdots \geq c_{n-1} \geq c_n. \tag{5}$$

4. For each variant i being compared, the linear programming problem is solved:

$$\begin{cases} D_i = \sum_{j=1}^{n} b_{ij} c_j \to max, \\ \sum_{j=1}^{n} c_j = 1, 0 \leq c_j \leq 1, c_j \geq c_{j+1}, f = \overline{1, n-1} \end{cases} \tag{6}$$

$$c_j = \begin{cases} \frac{1}{k}, \; if \; j \leq k, \\ 0, if \; j > k, \end{cases} \tag{7}$$

where the index k is determined from the condition $b_{kj} = \overset{max}{\underset{j}{}} b_{ij}$;

5. Next, the following are calculated:

$$d_i = \sum_{i=1}^{n} b_{ij} c_j, i = \overline{1, m}. \tag{8}$$

6. Further, according to the formula (3), the optimal type of car is determined.

The advantage of the described method is the absence of a formalized connection between the estimated indicators when choosing a car, which increases the objectivity of the decision, that is, the zoning method based on the principle of observing the hierarchical ratio of probabilities of possible states of the external environment of vehicle operation is an objective means of making a subjective decision.

4 Conclusion

In the course of the study, a method was developed for calculating weight coefficients for a multi-criteria assessment of the efficiency of a car. The advantage of the technique is the absence of a formalized relationship between quality indicators in a multi-criteria assessment of a car, which increases the objectivity of the decision, that is, the zoning method based on the principle of observing the hierarchical ratio of the probabilities of possible states of the external environment in VSLMS is an objective means of making a subjective decision.

This approach allows to consider factors in conditions of uncertainty in the environment in order to form an optimal approach to the system management of vehicle operation.

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