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Multicriteria Optimization Problem for the Layout of a Complex Technical System

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ABSTRACT

The article makes an attempt to perform the process of simultaneous optimization of two or more objective functions in a given domain of definition. The task of multicriteria optimization consists in finding a vector of target variables that satisfies the imposed constraints and optimizes a vector function whose elements correspond to the target functions. These functions form a mathematical description of the satisfaction criterion and, as a rule, are mutually in conflict.
This problem occurs in many areas of science and its solution can be applied to many complex mechanical assemblies and devices. Attempts to adapt existing equipment for operation in specific conditions do not allow solving the assigned tasks. The lack of scientifically grounded methods of forming the technical appearance and predicting the future values of the determining parameters hinders the development of this class of machines.

Key words*:* Unit, aviation, design, layout, technical appearance, creation, mathematical model, criterion optimization

1. INTRODUCTION

There are quite a few scientifically grounded methods of forming the technical appearance and predicting the future values of the defining parameters of complex technical systems, which undoubtedly hinders the development of a whole class of technology; for example, airplanes are excellent and complex technical systems, which are characterized by a high density of configuration [1], but there is no algorithm for constructing the movement of heavy special equipment [2]. All this poses the task of creating highly passable and maneuverable special units of a certain carrying capacity, capable of solving problems of delivering indivisible cargo [3].
Creation of methodological support for carrying out structural and parametric analysis of options for the layout of units [4] will improve the quality of design work to create objects of this type at the preliminary design stage, reduce material and time costs due to the wide use of modern materials [5] methods of mathematical modeling and computer graphics for the layout of lifting mechanisms, cargo platforms, fuselages, power plants, wheeled (caterpillar) travel and other systems, taking into account such restrictions as the reduction of sound noise [6] or the Arctic climate [7] (Fig. 1).

Figure 1 : Wheeled and tracked UAZ

2. RESEARCH METHODOLOGY

The object of research is a technical system. The subject of research is the process of assembling its equipment. Decomposition of tasks, development of models and algorithms are based on the principles of a systems approach. The identification of rational structural and layout solutions is carried out on the basis of modeling using formal heuristic procedures. The mathematical problem of finding rational values of the parameters is posed as a multi-criteria optimization problem.
The technical level of a product is a relative characteristic of product quality based on a comparison of the values of

indicators characterizing the technical perfection of the evaluated product with the base values of the corresponding indicators. The technical appearance is a complex qualitative and quantitative characteristic of the design object, reflecting the most common and significant features of the object under consideration.

The technical appearance of special units is formed in the process of developing a technical proposal. This stage plays a special role in the design process of the entire system, being one of the stages of research work and occupies a position in front of the development of technical specifications. The purpose of the process of forming a technical appearance is to substantiate the quantitative values of the main defining parameters of the designed object.

More than 70% of decisions on the project are made in the process of forming the appearance of the units, and the possibility of creating an object in a given time frame depends on the quality of these decisions, with limited funding for the program; decision making can be automated [8] but the solution of this issue can take a long period of time and the main task will cease to be relevant.

The initial data for the formation of the technical appearance of special units are the results of the analysis:

• prospective areas and conditions of use of the facility based on the main purpose;

• modern and future requirements for the operational properties of the considered class of units;

• constructive solutions for possible prototypes and main trends in the development of world mechanical engineering for units of the corresponding class.

Algorithms of direct optimal synthesis of complex technical objects are currently unknown, and their development is carried out by repeated repetition of the analysis of various options for design alternatives. The creation of new special-purpose units in this regard is no exception.

In most cases, solutions to the problems of forming a technical appearance are about processes that do not contain uncertainties. Most of the real engineering problems contain uncertainties in one form or another, associated with the fuzzy formulation of goals and objectives, blurred boundaries of restrictions, etc. An example is the uncertainty in the construction of a 3D model for the preparation of additive manufacturing technology [9] (Fig. 2).

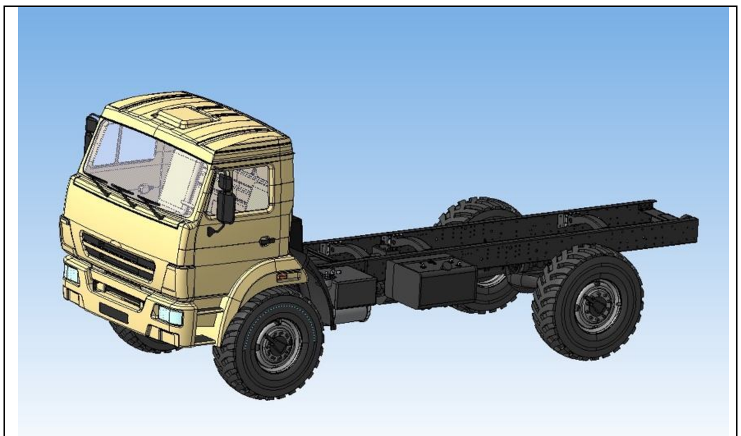

Figure 2:- KAMAZ model

Formation of the technical appearance of a family of special technical systems is a solution to a multiparameter multicriteria optimization problem with incomplete information about objects, which is due to the lack of detailed design study of units. However, due to the presence of conceptual and methodological difficulties, there is currently no single methodological approach to solving such problems.

It should be noted that the issues of design optimization and the issues of assessing the technical level of objects overlap with each other and when solving them, the same methods are often used [10].

Numerous methods for managing the quality of manufactured products at the design stage, allowing to ensure the receipt of products with optimal parameters according to the criterion "price - quality", have been developed and continue to be developed in recent decades in our country and abroad in various industries.

We understand product quality as a set of product properties that ensure its suitability to meet certain needs in accordance with its purpose [11].

3. MATHEMATICAL MODEL

Analysis of the structure of the procedures for forming the appearance of the aggregates shows that finding the vector of determining parameters $X^* \in X_{ДОП}$, where $X_{ДОП}$ is the set of acceptable design options, is a complex multicriteria task. In general, it can be formulated as follows: determine the vector of defining parameters X^*, consisting of elements that correspond to the minimum value of the objective function F(x; u), connecting these parameters and characteristics of projects on a set of constraints.

The solution of this problem as a problem of mathematical modeling does not always lead to success due to the significant dimension of the vector of defining parameters X^*, the complexity of the set $X_{ДОП}$ and U, in some cases the large amount of time required to calculate the values of the criterion F(x; u).

The following approach is used to simplify the task: the efficiency of the aggregates can be estimated by the values of a certain set of particular criteria that determine the concept of the developed model.

Based on this approach, the mathematical formulation of the problem, as a multiobjective optimization problem, in general form will be presented as follows:

$$X^{*} = \operatorname{Arg}\operatorname{Min} F(x;u).$$
$$x \in X$$
$$u \in U$$

$X=X$ ($N_{СЕЧ}$; $N_{КР}$; C; K; T) is a vector of defining parameters:$X=X$ (X_1; X_2; X_3; X_4; X_5).

where
- G1 is lifting capacity of the unit as a whole;
- G2 is lifting capacity of the boom (lifting mechanism);
- C is parameter characterizing the ratio of payload and total mass;
- K is the amount of reach of the boom or the height of the lifting mechanism;
- T is type of lifting device used.

$U=U$ ($N_{КР/Б}$; $N_{А.В}$; $V_{ПАС}$; $L_{Ф}$; $H_{П}$) is constraint vector:

where
- $N_{КР/Б}$ is limitation on carrying capacity;
- $N_{А.В}$ is restriction on the weight of the transported cargo;
- $V_{ПАС}$ is limitation on the height of the boom reach (lifting the gripper);
- L is limitation on the length of the unit as a whole;
- $H_{М}$ is limitation on the total weight of the unit.

$F=F$ (S1; $M_{Г}$) is vector of objective functions:

where S1 is cargo platform area;

$$S1 = \iint f(x, y)dxdy,$$

M is the maximum mass of the lifted and transported cargo.

The implementation of the task at hand requires the development of appropriate mathematical models, including methods of expert assessments. In this case, the main mathematical apparatus for formalizing the presentation and processing of expert assessments and statements is the theory of fuzzy sets [8]. The use of the apparatus of a fuzzy set is an attempt to mathematically formalize fuzzy (expert) estimates in the form of linguistically named functions for constructing models for processing these estimates as a composition of these functions with a simple linguistic interpretation. As a result, it becomes possible for the end user to operate with natural subject-oriented linguistic terms, represented at the level of computer calculations in the form of numbers. This approach provides approximate, but at the same time, qualitative ways of describing the behavior of complex and poorly defined organizational and technical systems. The theoretical foundations of this approach are quite accurate and rigorous in the mathematical sense and are not a source of uncertainty. The degree of solution accuracy in each specific case can be matched to the requirements of the problem.

4. DISCUSSIONS

As shown above, the defining condition for creating an optimal design of special units is a rational layout of the lifting mechanism and the loading platform from the point of view of optimal equipment placement. This circumstance requires the development of appropriate models, techniques, algorithms and programs and an independent system for the formation of their appearance based on its layout [12].

It has been established that the indispensable components of the solution of any creative task are operational elements, strategy and a static system. The named components in the process of solving the problem of designing units can be interpreted as follows:

• operational elements are functional elements that make up the unit and ensure that it performs a given task (boom, boom lifting system, load platform, power plant, etc.).

• a strategy is a system of rules that allows you to build a working version of the unit layout from a set of functional elements and optimize it according to a certain criterion;

• a static system is a specially formalized space that makes it possible to place, coordinate and move functional elements in it [13].

As shown earlier, the determining condition for the creation of technical systems is its rational layout relative to all coordinate axes in terms of obtaining stable indicators that satisfy the potential capabilities of the selected type of lifting mechanism (boom). These features do not allow to fully apply the approaches to computer-aided design described in the introduction and require modification of the design process. The solution to this problem requires the development of appropriate models, techniques, algorithms and a software package that allows the assessment of the defining parameters at the early stages of design [14] [15].

Analysis of the design procedures shows that, while maintaining the general composition inherent in mobile objects using a wheel drive, they are practically unchanged, and must have a development reflecting their inherent specificity, or be developed anew. The task of assembling its lifting mechanism when assembling the equipment of the units should be singled out as a separate subtask; decisions made within its framework largely determine the efficiency of the unit as a whole [16].

The use of materials that comply with operating conditions and government standards will also help to avoid the failure of components located at the lower levels [17].

There is an economic effect of unification for a less costly achievement of the design goal, which is formed through the use of standard, unified, purchased or borrowed components [18].

5. CONCLUSIONS

To successfully solve the problem, it is necessary to develop models for each element at the selected level, while the models of the upper levels include models of the lower levels. The model at each hierarchical level represents relationships in the form of equations that describe the relationship between parameters and characteristics.Firstly, these are mathematical models for calculating the geometric, mass and other characteristics of the assembled elements, and, secondly, structural-parametric models of the lifting mechanism (boom).

Geometric models describe the relationship between the parameters of aggregates and its components, the characteristics of their shapes and sizes. They define build volumes, and allowable build ranges. The data of these models are input information for weight, strength and other calculations, layout, development of technological processes, etc.

Mass models provide the calculation of the mass of individual elements and in general at all design levels. The models are based on the relationships between geometry, loads, structural features, equipment, power plant, fuel, and payload. Therefore, it can be imagined that the basis of mass models are geometric criteria, which are, in fact, parameters of mass models.

An efficiency model that allows evaluating the resulting design and engineering solution is used to assess the options for design solutions. The model reflects the relationship between the parameters of individual elements and the unit as a whole, with particular and general criteria of efficiency considered in the work.

It is accepted that the deviation of the characteristics of physical and mathematical models should be no more than ± 5% when developing new and using known models.

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