Intelligent information system for supporting design solutions in the conditions of multivariate selection

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Abstract. The modeling of multivariate choice problems in the design of products within the framework of an information and software system is considered. The typical elements and functions of the information and software system of multivariate choice are given. Models of optimization problems of forming acceptable sets of alternative solutions when choosing analogs of parts and components are proposed. The formation of the initial set of alternative solutions is carried out on the basis of an assessment of the design, technological, electrical and operational characteristics of the alternatives of choice. The formalization of the problem of the final selection of the composition of parts and components according to technical and economic indicators is given. The proposed models are based on the use of Boolean variables describing the alternatives of choice. The structure of a specialized database of bathrooms for storing the characteristics of parts and components and the results of intermediate and final selection of design solutions is also given.

1. Introduction
Multivariate selection is a typical task in the design of industrial products. The design, technological, operational characteristics of the product and its technical and economic assessment are characterized by a variety and uncertainty in the evaluation of the optimal solution option.
It is advisable to carry out a multivariate choice and a multi-criteria assessment in the framework of a specialized information and software system [1].
The designed product, as a rule, has a hierarchical structure and includes its own product, components, parts and components that have a variety of design, technological, electrical and operational characteristics.
Thus, in accordance with the hierarchical structure, the product is a multi-level structure. At each level, there can be nodes, parts and complete products.
The information and software system of multivariate choice includes the following elements:

- a specialized database for storing design, technological and operational characteristics of parts and components;
- an application for maintaining a specialized database;
subsystem of multivariate selection of analogs of parts and components according to structural, technological and operational characteristics;

• subsystem of technical and economic assessment of solution options and formation of the optimal composition of parts and components;

• subsystem for visualizing the results of optimal selection.

The multivariate selection of parts and components and the technical and economic evaluation of the product are implemented with the involvement of experts in the field of design and operation of products for a specific purpose. The Group of Experts has the status of decision-makers.

2. Multi-variant selection of analogs of parts and components

The subsystem of multivariate selection of analogs of parts and components is built on the basis of optimization problems of optimal selection of objects according to their structural, technological and operational characteristics.

The multivariate choice of the structural elements of the product and the final analysis of the technical and economic indicators of the product can be carried out in two stages [2].

Initially, they implement the formation of an acceptable set of parts and components that meet the required structural, technological, electrical and operational characteristics.

At the second stage, the final composition of parts and components is formed from the permissible set based on the optimization of technical and economic indicators.

The formation of an acceptable set of parts and components can be carried out within the framework of two optimization tasks. The optimization problem of the first type can form a limited set of parts and components that are subject to borrowing. The optimization problem of the second type forms an extended group of analogues. When forming such a group, the opinions of experts in the subject area are taken into account. Experts form coefficients of importance of constructive, technological, electrical and operational indicators of the choice of analogues.

So, for each part or component product, you need to form an acceptable set of analogues. The choice of analogues comes from the existing set of parts mastered in production, or purchased components.

Let \( D_i \) (\( i = 1, \ldots, I \)) be the set of parts and components of the designed object. \( I \) is the number of parts and components in the designed object.

Each \( D_i \) has a set of design, technological or operational characteristics.

If \( D_i \) is a part, then it can have the following characteristics: the name of the group (bushing, bracket, bracket, etc.), material, main dimensions, weight, manufacturing technology (metal casting, stamping, plastic casting, etc.), etc.

If \( D_i \) is an electronic device, then electrical and operational characteristics are taken into account, for example, the characteristics of rectifier diodes, zener diodes, bipolar transistors, field-effect transistors, etc.

For each \( D_i \), it is necessary to form a valid set of analogs \( A_i = \{a_{ij}\}, (i = 1,\ldots, I; j = 1,\ldots, J_i) \). \( J_i \) is the number of analogs for \( D_i \).

Each \( D_i \) is assigned a set of characteristics \( P_{ik} \), (\( k = 1, \ldots, K_i \)). Many of the necessary characteristics are formed by experts.

To assess the compliance of the analog with the design requirements, a matrix \( B_i = \{b_{ijk}\} \) is formed. The matrix elements are calculated using the following conditions [2]:

\[
b_{ijk} = \begin{cases} 1, & \text{if } a_{ij} \in A_i \text{ meets requirement } P_{ik}; \\
0, & \text{in other case}; 
\end{cases} (i = 1,\ldots, I),(j = 1,\ldots, J_i),(k = 1,\ldots, K_i)
\]  

The search for one or a limited group of analogues that have the required characteristic values can be organized within the following task [2]:

\[
\begin{align*}
\max & \sum_{i=1}^{I} \sum_{j=1}^{J_i} b_{ijk} \\
\text{subject to} & \sum_{k=1}^{K_i} b_{ijk} \leq \alpha, \forall i \in \{1,\ldots, I\} \\
& \sum_{i=1}^{I} \sum_{j=1}^{J_i} b_{ijk} = 1, \forall k \in \{1,\ldots, K_i\} \\
& b_{ijk} \in \{0,1\}, \forall i,j,k
\end{align*}
\]

where \( \alpha \) is a parameter indicating the maximum number of analogues in the set.
\[
F_i(X) = \sum_{j=1}^{J_i} x_{ij} \rightarrow \min
\]
\[
\sum_{j=1}^{J_i} b_{ijk} \cdot x_{ij} \geq 1, \quad x_{ij} = \begin{cases} 1, & (i = 1, \ldots, I) (k = 1, \ldots, K_i) \\ 0, & \end{cases}
\]
\[
x_{ij} = \begin{cases} 1, & \text{if } a_{ij} \in A_i \text{ is included in a valid set,} \\ 0, & \text{so } a_{ij} \text{ meets requirements } P_k (k = 1, \ldots, K_i), \\ \end{cases}
\]

The search for an extended group of analogs with a set of characteristics that have the highest coefficients of importance of the selected characteristics can be carried out within the following task [2]:

\[
F(X) = \sum_{j=1}^{J} c_{ij} \cdot x_{ij} \rightarrow \max
\]
\[
\sum_{j=1}^{J} b_{ijk} \cdot x_{ij} \leq S_k, \quad x_{ij} = \begin{cases} 1, & (k = 1, \ldots, K_i) \\ 0, & \end{cases}
\]

where \(c_{ij}\) is the sum of the coefficients of importance of the characteristics of the \(v_k\) analog \(a_{ij}\).

An expert or a group of experts sets the importance coefficients for each design, technological or operational characteristic \(v_k, k=1,.., K_i\). The importance coefficients can be set from the range from 1 to 10 or from 0 to 1. The coefficients can be subjected to the normalization procedure. If you use a group of experts, you can calculate the average coefficient of importance for each characteristic. Thus, \(c_{ij}\) is calculated by the formula:

\[
c_{ij} = \sum_{k=1}^{K_i} v_{ik} \cdot b_i
\]

\(S_k\) denotes the number of analogs that have the required value of the \(P_k\) characteristic.

\[
S_k = \sum_{j=1}^{J} b_{ijk} \quad (k = 1, \ldots, K_i)
\]

The subsystem of technical and economic evaluation of solution options and the formation of the optimal composition of parts and components is implemented at the second stage of the optimal solution search.

3. The model of forming the optimal composition of parts and components

On the basis of an acceptable set of analogs, an optimization model for the formation of the composition of parts and components is built. Optimization is implemented according to the technical and economic indicator \(R_n (n=1,.., N)\); \(N\) is the number of evaluation indicators) of the projected object. The indicators can be calculated using a linear formula based on the technical and economic indicators of the selected analogues of \(r_{ijn}\). \(r_{ijn}\) is the \(n\)th indicator for the \(i\)-th part and its \(j\)-th analogue. As a technical and economic indicator, you can choose the cost of production, weight, cost, etc.

Optimization by a separate technical and economic indicator can be carried out in the framework of the following task:
\[ R_n = F_i(r_{in}) \rightarrow \text{extr} \]

\[ \sum_{i=1}^{I} y_{ij} = 1 \]

\[ y_{ij} = \begin{cases} 
1, & (i = 1, ..., I) \ (j = 1, ..., J_i) \ (n = 1, ..., N) \\
0, & \text{if } a_{ij} \text{ is included in the composition of the product; } \\
0, & \text{in other case} 
\end{cases} \]

(7)

The limitations of task (7) implement the choice of only one analog of a part or a component device to be included in the product.

The solution of the proposed optimization problems is possible with the use of random search algorithms. These search methods simulate the movement of random Boolean quantities in space along trajectories that provide optimal solutions [3].

4. Structure of a specialized database

A special-purpose database focused on a specific subject area should contain parts and components of products (electronic devices) and their characteristics.

The database may include the following tables: products, parts composition, components composition, parts, rectifier diodes, zener diodes, bipolar transistors, left transistors, etc.

The "Products" table includes the following characteristics: product code, name.

The table "Composition of parts" can include the following fields that define the product code, the part code, the number of parts included in the product. The table "Composition of components" has a similar structure.

The "Details" table can contain the following main characteristics of the parts: child code, group name, dimensions, material, weight, manufacturing technology, surface cleanliness, processing accuracy, manufacturing cost, etc.

Tables for storing the main characteristics of electronic devices may differ depending on the group of devices [4].

For example, table "Rectifier diode" can contain the following features: device ID, device type, material, average forward current, average reverse current, maximum reverse voltage, etc.

Table "Bipolar transistors" includes the following fields: device ID, device type, material, transition, maximum permissible constant collector current of the transistor, the maximum permissible surge current of the transistor, the boundary voltage between the collector and emitter of the transistor, the maximum allowable continuous power and other characteristics [4].

The results of the formation of an acceptable set of parts and components that meet the required structural, technological, electrical and operational characteristics can be stored in the tables "Analogs of parts", "Analogs of products" and have a structure containing the fields: record code, part code or device code, analog code.

The final composition of the selected parts and components contains the codes of the selected parts or components.

The application for the maintenance of a specialized database implements the input, editing, data protection and ensuring the integrity of the entered and stored information [4].

The subsystem for visualizing the results of optimal selection contains screen forms that display lists of selected parts, electronic devices and their characteristics, and the value of the selected optimal technical and economic indicator.

5. Conclusion

The proposed information and software system will provide:
• coordinated selection of analogs of parts and components with the formalization of the process of expert evaluation of multivariate design solutions;
• technical and economic assessment of the product at the early stages of design;
• storage of various structural, technological, electrical and operational characteristics of parts and components and prompt access to this information.

The results can be used, for example, when designing software for the following tasks: complex-structured objects optimization during modeling on the population algorithms adaptation [5], optimization of the forecasting neural network parameters for quality of service management tasks [6], policy control at the network edge [7], studying and characterization of the data flows in an IP-based network [8], information security risk estimation for cloud infrastructure [9].

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