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INFORMATION TECHNOLOGY OF THE AUTOMATIZATION FORMATION OF THE NON-STANDARD PRODUCTS OPTIMAL COMPOSITION AT THE ENGINEERING ENTERPRISE

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ІНФОРМАЦІЙНА ТЕХНОЛОГІЯ АВТОМАТИЗОВАНОГО ФОРМУВАННЯ ОПТИМАЛЬНОГО СКЛАДУ НЕСТАНДАРТНОЇ ПРОДУКЦІЇ НА МАШИНОБУДІВНОМУ ПІДПРИЄМСТВІ

Purpose. Improvement of the efficiency of non-standard product design in conditions of incomplete certainty by developing information technology for the automated formation of optimal non-standard product composition.

Methodology. The following methods have been used in problem solving: methods of system analysis and general systems theory to build a set-theoretical model of subsystem of creating the optimal composition of non-standard products at the machine-building enterprise; methods of decision-making theory and optimization theory to formulate the method and the model of solving the problem of forming the optimal structure of products; a set-theoretic approach in designing the structure of subsystem and information technology.

Findings. The necessity of the development of information technology for the automated design of non-standard products optimal composition has been grounded. The analysis of mathematical methods, models and information technology of configuration control of production related to the problem of the non-standard products formation has been carried out. The approaches to the formation of non-standard products based on component reuse have been considered; the advantages and disadvantage have been analyzed. Models, methods and information technology of the automated formation of non-standard products optimal composition formation have been developed and improved that makes it possible to offer the best option for forming technical design offer for the potential customer's requirements from the existing nomenclature database of the enterprise.

Originality. The scientifically based information technology for the automated formation of optimal non-standard products composition has been suggested that includes the theoretic and multiple model of subsystem of non-standard products optimal formation, the mathematical model of the task of the product optimal variant formation and method of solving the problem of automated generation of product optimal variant that makes it possible to form the best composition in terms of integral criterion of non-standard products to each customer individually and improve the efficiency of the company.

Practical value. The models, methods and applied information technology of non-standard products selection at the engineering enterprise have been designed that includes a functional module of monitoring production readiness, as well as of customer requirements formation and a module of multi-objective optimization of production according to customer requirements.

Keywords: *multicriteria problem of selection, integral criterion of optimality, Pareto set*

Introduction. Significantly increasing competition between manufacturers has been observed at traditional markets of mechanical engineering products in recent years. If in previous years the customer had a choice between expensive European and low-cost products of Ukrainian manufacturers, now Chinese, Turkish and Russian manufacturers promote their products actively. In this situation enterprises face a challenge of transfer to manufacturing non-standard products oriented to the needs of a particular customer (individual kitting in accordance with a customer's requirements). In this connection every process of conclusion of a contract implies an expertise of the possibility of manufacturing non-standard products from the available nomenclature basis of the finished units at the enterprise. The proposed final variant, confirmed by the contract, is taken as the base of further launching into manufacture. It explains the importance of optimization of exploratory design when commercial success of new product and its life cycle is grounded.

During the expertise of the possibility to manufacture and form a preliminary composition of a non-standard product meeting the customer's requirements the personnel of the enterprise form the composition of the future product individually from the various available nomenclature base. Most often this process occurs in an operation mode without taking into account many factors influencing the quality of the product both from the point of view of its manufacturability for the manufacturing enterprise and the point of view of meeting the customer's requirements to the maximum.

The choice of the optimal composition according to the customer's requirements taking into account the enterprise restrictions, production current readiness and workload, carrying out every order under the conditions of improvement of production efficiency turn this problem into a multicriterion challenge which can only be solved using up-to-date information technologies (IT).

Hence, working out an information technology for computer-aided formation of the optimal composition of non-standard products is topical. Solution to this problem will make it possible to improve the efficiency of the enterprise operation and to meet maximum number of the customer's requirements.

Analysis of the recent research. To solve the problems of structure formation, the CAD/CAM/CAE/PDM technologies are used. They are to provide speed-up and simplification of the process of launching into manufacture. During the recent decade these technologies have been widely used at Ukrainian enterprises as well. The most popular software products bought by plants are: "Ascon", "Intermech", "1C: Mechanical engineering", "Galaxy: Mechanical engineering", "Sail", "IT-Enterprise" and others. Such software products enable reducing the number of people who control the complex cycle of product working out and manufacture, eliminating errors, taking into account many factors that were omitted before due to calculations complexity.

Considering information technologies related to this subject, it is possible to say that the technology of configuration control (CC) of product manufacture is one of the up-to-date approaches to design and manufacture of high-technology and knowledge-intensive CALS products. This scientific field has been studied by such scientists as Karasiov D. S., Sheptunov S. A., Levin A. I., Cherviakov L. M., Rybakov A. V., Yevdokymov S. A., Brodskyi L. L. et al. [1–4].

CC is a control technology related to working out, manufacturing and supporting the life cycle of complex devices produced in many variants including the variants meeting the customer's requirements.

The starting point of CC consists in determination of the contract requirements, their approval by the customer and the supplier and their formalization. The supplier must strictly adhere to this contract. The consumer receives not only the product itself but also all the documentary proofs of the fact that the product and all its components meet the assigned requirements. Configuration control at the development stage implies determination of correspondence between the values of requirements and characteristics design values in all the configuration objects (CO), in the whole product and in operative elimination of incipient deviations.

The implementation of reuse components (RUC) is another method of time reduction during preparation of multi-nomenclature products manufacture, which provides minimization of time, risks and financial expenditure of the project. It is possible to create plenty of basic RUCs according to previously known characteristics by RUC synthesis on the basis of realized projects.

When using RUC, special attention is paid to the mechanism of flexible adaptation of the basic lineups of the designs, their ability to adapt and vary (modify) during the selection of the required design for every customer even if these units are adopted from other design lineups.

Methods and approaches to formation of RUC bases from available nomenclature bases of the enterprises have been studied by such scientists as Nekrasov O. B., Shchehol V. A., Fedorovych O. Ye., Serhieiev S. V., Serhieieva Yu. I., Plokhov S. Z., Zamirets N. V. [5–6] et al. Creation of mechanisms for formation and systematization of many RUCs taking into account the accumulated experience of previous developments for the use in future projects are the basic purposes of these developments.

Unsolved aspects of the problem. When CALS- technologies, namely, systems of CAD/CAM/CAE/PDM class, related to production preparation for manufacturing complex products, are used, they do not solve complicated multicriterion problems, in particular, concerning selection of optimal combination of non-standard products.

Analysis of CC mathematical methods, models and information technologies related to solution of the problem of formation of non-standard products composition was carried out. It revealed that:

1. CC technology is comparatively new for Ukrainian industry, and its application is connected with a number of terminological, methodical and technological problems.

2. CC technology consists of the following basic procedures: configuration identification, configuration control, account of configuration status, configuration check (audit).

3. Analysis of the functional model of CC procedures description revealed the necessity for development of a method and algorithms describing the succession and interaction of CC procedures in the integrated information environment of the enterprise at different stages of the product life cycle. In this case technical requirements to CO are inherited from the previous context and are used as the basis for taking engineering (design) solutions regarding both the whole product and its components (parts, devices, assembly units, etc.), i. e. CO of lower ranges.

When the CC technology is used, either new manufactured product modification or a completely new lineup is created depending on the number of changes. These developments take rather a long time (drawing up new documents, carrying out development work) and a lot of finance on the part of both the enterprise and the customer.

The following faults were found during the analysis of the RUC technology:

- selection of RUC according to the criteria determined by developers-experts but not by the customers;

- lack of the possibility to generate the product composition according to the requirements of a particular customer and not for a general prospect;
- lack of the possibility for taking into consideration the production situation during formation of the future product composition for more efficient operation of the manufacturer.

Besides, these developments only determine the mechanism of revelation of reuse components and the method for RUC set formation, which makes it possible to form an ordered multidimensional set of RUC on the basis of the found criteria. These papers deal with the synthesis of possible future projects and not with solution to a really posed task of formation of non-standard products.

Objectives of the article. Analysis of the processes of draft proposal formation during drawing up a contract for manufacture of non-standard product composition reveals that it is necessary to regard restrictions put forth by both the customer (list of the customer's requirements with different degree of importance) and by the enterprise (account of the enterprise unfinished production and additional work, readiness of the enterprise to manufacture non-standard products at the current period of time). Besides, it is necessary to take into consideration variability of the nomenclature basis of the manufactured products, interchangeable parts and units, which will allow the optimal choice of the construction variant.

Hence, it is expedient to create models, method and information technology that will enable the specialists of the enterprise to formulate configuration of the product manufactured according to all the requirements of the customer from the available multi-nomenclature basis of the enterprise without design improvement taking into account the production capacity and reducing expenditure of time and finance.

The purpose of the paper consists in improvement of the efficiency of the process of development of non-standard products under the conditions of incomplete certainty by means of creating models, method and information technology of computer-aided formation of the optimal composition of non-standard products.

Presentation of the main research. To achieve the purpose, the research of the processes of drawing up contracts between an enterprise and a customer and formation of non-standard products composition from available nomenclature basis of the enterprise according to the customer's requirements was performed. According to the results of the research, a model of the problem of control of generating the optimal composition of non-standard products was proposed in order to write down the formal problem statement. Interrelation of the processes of formation of product composition (*FS*), formation of reuse components composition (*FK*) and the subsystem of optimization (*SSO*) is presented in Fig. 1 and the following designations are adopted.

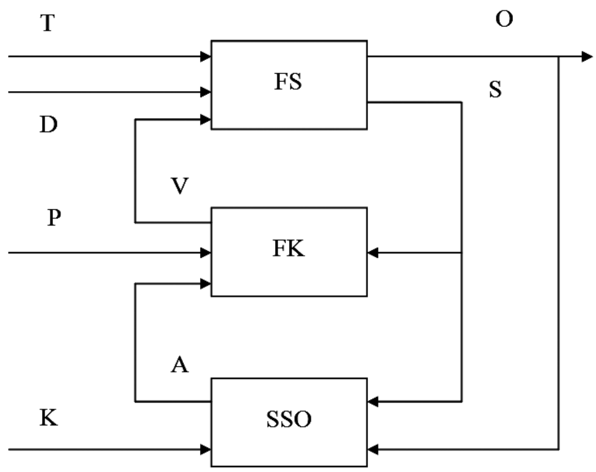

Fig. 1. Block diagram of the process of control of formation of the optimal product composition:

FS – the processes of formation of product composition; FK – the process of formation of reuse components composition; SSO – subsystems of optimization; T – set of requirements and restrictions; D – set of the data of workload and readiness for production of unfinished mutually interchangeable units and parts; O – set of resulting optimal solutions at every level of specification; S – set of the states of formation process, V – set of the solution variants; P – set of the indices of the product quality; A – set of the adapted indices of criteria significance, K – set of the quality criteria taken into consideration by the customer; $U=\{u_1, l=\overline{1,L}\}$ *– set of specification levels;* $T=\{t_i(u) | t_i(u)\in D^{T_i}, i=\overline{1,I}\}$ *– set of requirements and restrictions;* $D^T=\{D^{T_i}, i=\overline{1,I}\}$ *– range of admissible values of requirements and restrictions;* $D=\{d_i(u) | d_i(u)\in D^{D_i}, i=\overline{1,I}\}$ *– set of the data of workload and readiness for production of unfinished mutually interchangeable units and parts;* $D^D=\{D^{D_i}, i=\overline{1,I}\}$ *– range of admissible values of possible workload and readiness for production of unfinished mutually interchangeable units and parts;* $V=\{v_i(u) | v_i(u)\in D^{V_i}, i=\overline{1,I}\}$ *– set of solution variants;* $D^V=\{D^{V_i}, i=\overline{1,I}\}$ *– range of admissible values of solutions variants;* $S=\{S_u : S_u=f(S_u, D, T, V), D\in D^D, T\in D^T, V\in D^V\}$ *set of the states of formation process;* $O=\{o_j(u), j=\overline{0,J}\}, u\in U, o_j(u)=\eta_j(u,S_u), u\in U, j=\overline{0,J}$ *– set of the resulting optimal solutions at every level of specification;* $P=\{p_i(u) | p_i(u)\in D^{P_i}, i=\overline{1,I}\}$ *– set of the indices of product quality;* $D^P=\{D^{P_i}, i=\overline{1,I}\}$ *– range of admissible values of the indices of product quality;* $K=\{k_n, n=\overline{1,N}\}$ *– set of the quality criteria taken into account by the customer;* $A=\{a_m(k), m=\overline{0,M}\}$ *– set of adapted indices of criteria significance*

While developing the set-theoretic model of the subsystem, its structural and conceptual component was determined by considering capacity loading, production current state and criteria of selection of particular units determined by both the customer and the enterprise experts. Solution of these problems was the ground for development of a complex of mathematical models, a method and an information technology of computer-aided formation of optimal composition of non-standard products.

The model of the subsystem structure can be represented in the form of a sequence

$$M_{пс} = <F(MPR,\ FCR,\ PCO),\ IK,\ MK(MP,\ MT,\ MR,\ MA),\ \text{AK(AST,AS),ПК,OpK},\ R(R_1,R_2,R_3,)>,$$

where *F* stands for functional problems of *MPR*, *FCR* and *PCO* modules; *MPR* is the complex of problems of monitoring the readiness of production; *FCR* is the complex of problems of formation of requirements to manufacture of non-standard products; *PCO* is the complex of problems of optimization of the future non-standard products composition by means of selection criteria ranging; *IK* is the information complex – databases of enterprise classifiers and directories, hierarchical bases of knowledge in possible variants of products composition; *MK* is the complex of models and method (represented by *MP*, *MT*, *MR* and *MA* sets); *MP* is the model of a subsystem of computer-aided formation of the optimal composition of non-standard products; *MT* is the multicriterion model of requirements tree; *MR* is the mathematical model of the problem of formation of optimal composition of non-standard products taking into account selection criteria ranging; *MA* is the method of solution of the problem of computer-aided formation of optimal variant of non-standard products composition; *AK* is the complex of algorithms of solutions to problems of formation of the structure of future non-standard products and selection of its composition (represented by *AST* and *AS* sets); *AST* is the algorithm of formation of the structure of future non-standard products; *AS* is the algorithm of selection of non-standard products composition; ПК is the complex of software instruments realizing functional problems of the subsystem; *OpK* is the organization complex of the subsystem, i.e. organization principles, national standards and enterprise standards regulating the process of the expertize of the possibility of manufacture, making a draft proposal and setting for production, *R* stands for relations between functional problems consisting of:

- distribution of the problems by modules – $R_1 \subseteq \subseteq FM \times F$, where *FM* is the set of functional modules, *F* denotes functional problems;
- distribution of the models and the method by problems – $R_2 \subseteq MK \times F$;
- distribution of the solutions algorithms by problems – $R_3 \subseteq AK \times F$.

Solution to the mentioned functional problems needs development of requirements tree including additional information units. The model of the requirements tree is presented in the form of a sequence of input parameters that are the main branches of this tree

$$R = \langle KG,\ KD,\ U_C,\ LM,\ T,\ Z,\ TS,\ TP,\ O,\ Q,\ VZ,\ V\rangle.$$

Here *KG* is the vector of the basic signs of the construction; *KD* is the vector of additional signs depending on *KG* and signs chosen by the customer. For every mechanical engineering enterprise the signs are determined depending on the type of the manufactured product. U_C is the vector of the cost of parts and assembly units (PAU); *LM* is the vector of production workload; *T* is the vector of the terms of PAU manufacture; *Z* is the vector of accounting of developments for every PAU, its following levels contain information about types and the number of developments in every storehouse or shop at the enterprise. *TS* is the vector of the terms of resources delivery by suppliers for manufacture of the product. The branch of this category takes into consideration the factors influencing deliveries, in particular – structural factors, commercial factors, operational factors, functional factors and external factors making the sequence of vectors of the following level *TP*. *O* is the vector of maximum values of the number of reclamations by units; *Q* is the vector of minimum admissible values of reliability of the used units. It is also necessary to take into account the possibility of mutual interchange of units *VZ* and significance of units and parts *V* that can be represented in the form of matrixes for more flexible selection of the individual composition of non-standard products for the customer. U_C, *LM*, *T*, *Z*, *TS*, *TP* and *O* vectors are added to the proposed model; their significance is described in detail in the Candidate's Thesis. In paper [7] the requirements tree is analyzed in more detail.

The considered requirements, as in the known papers, represent both design context and the customer's requirements in the form of selection criteria. However, to take into account all the possibilities and capacities of the production at the present moment and to enhance the process of manufacture and efficient production operation it is necessary to take into consideration such selection criteria as:

1. Maximization of the indices of product quality.
2. Minimization of the cost of the new product.
3. Minimization of the manufacture terms.
4. Maximum realization of regional requirements.
5. Maximum use of improved units in the new product.

To write down a mathematical model of the choice of the optimal variant of the preliminary composition of non-standard product taking into account ranging of choice criteria, first of all, objective functions for all determined local criteria of choice presented below were written down.

Maximization of the indices of product quality

$$K_1 = \arg\max_j \sum_{i=1}^{n} w_i(q_i - o_i), \quad j = 1\ldots m, \tag{1}$$

where *j* is a number of the product variant; *n* is quantity of components of the new product composition; w_i denotes coefficients of importance of the indices by i^{th} unit. The parameters of the criterion include the quantity of reclamations of every unit o_i and value of reliability q_i. The parameters are normalized to range [0,1].

$$\sum_f o_f \le O_{\max}, \quad f \in F; \tag{2}$$

$$\sum_p q_p \ge Q_{\min}, \quad p \in P, \tag{3}$$

where o_f is maximum admissible quantity and character of reclamations at the present period of time for every f^{th}

assembly unit, determined by the enterprise experts; $Q_{\min}$ is minimum admissible value of reliability at the current period of time for every p^{th} PAU, determined by the enterprise experts.

Minimization of the cost of the new product

$$K_2 = \arg\min_j \sum_{i=1}^{n} C_{ij}, \quad j = 1,\ldots,m, \tag{4}$$

where C_{ij} is the cost of every i^{th} element of the construction of the j^{th} variant of the product.

This criterion includes restriction of PAU cost at the enterprise uc_h and of the cost of construction elements that cannot be excluded at such variant of the new product v_d. These restrictions are determined directly by the experts of every enterprise individually.

$$\sum_{i=1}^{n} uc_{hi} \le Uc_h; \quad h \in H; \tag{5}$$

$$\sum_{i=1}^{n} v_{di} \in V_d; \quad d \in D, \tag{6}$$

where uc_h is maximum admissible cost of h^{th} types of "variation" PAU at enterprises; H is quantity of types of variation PAU; V_d is set of required elements of the construction of the d^{th} type determined by the enterprise designers for every lineup of the product and "variation" assembly units; D is quantity of unchanged elements of the construction.

Minimization of the manufacture terms. If it is necessary for the consumer to obtain the product in the nearest time (short terms), the weight coefficient of the local criterion will be the highest. The criterion of choice is of the form

$$K_3 = \arg\min_j \left(\max \sum_{i=1}^{n} T_{ij} \right), \tag{7}$$

where T_{ij} is the term of manufacture or delivery of every i^{th} element of the construction of the j^{th} variant of the product. The choice takes place only in mutually interchangeable units, minimum values are chosen among maximum terms for every unit. For this criterion the index of production workload is the restriction

$$\sum_{i \in I} lm_{\eta i} \le Lm_{\eta}; \quad \eta \in N. \tag{8}$$

In its turn, it consists of restrictions on availability of components and materials m_b, energy resources e_c, restrictions on determined terms of delivery of materials and components t_s, free stock of time of operation of equipment r_k of the k^{th} group of PAU, available at the enterprise at the present period of time and stock of working time of workers t_g g^{th} profession. Thus, production workload includes $Lm = \{m_b, e_c, t_s, r_k, t_g\}$. This information is obtained from enterprise subsystem ERP.

Maximum realization of regional requirements to the new product

$$K_4 = \arg\max_j \sum_{i=1}^{n} R_{ij}, \tag{9}$$

where R_{ij} is quantity of requirements made to the i^{th} unit of the construction of the j^{th} variant of the product. Restrictions include only the use of the units (variants), developed according to these requirements and having relevant certificates

$$y_r \in Y_r, \quad r \in R, \tag{10}$$

where Y_r stands for required elements of the constructions of the r^{th} type developed to meet the regional requirements of the customers.

Maximum use of improved units in the new product

$$K_5 = \arg\max_j \sum_{i=1}^{n} In_{ij}, \tag{11}$$

where In_{ij} is quantity of improved units available in the i^{th} unit of the j^{th} variant of the product. Restrictions include required use of improved units, available at the enterprise, in the non-standard products

$$\sum_{i \in I} In_{il} \ne 0, \quad l = \overline{1 \ldots L}, \tag{12}$$

where L is general quantity of units in the construction.

The problem of finding the optimal solution can be solved by means of formation of an integral criterion of optimality of the following form

$$F = \sum_{i=1}^{n} \alpha_i K_i^{\prime}, \tag{13}$$

where $K_i^{\prime} = \dfrac{K_i}{K_{i\max}}$, $K_{i\max}$ is expert assessment of maximum value of this criterion and weight coefficients are to meet the condition: $\sum_i \alpha_i = 1$. The values of weight coefficients of the local criteria are determined by the method of paired comparison.

Thus, the weight coefficient assessments should:

- dynamically change with updating of the current state of the production and in the corresponding sector of the market;

- be balanced in relation to the thoughts of the representative of the customer and the representative of the enterprise.

To specify the assessment of the weight coefficient with renewal of the data and to approve the assessment of the weight coefficient of criterion K^*, received from consumer α_{*3} together with the assessment of the weight coefficient obtained from the enterprise expert α_{*n}, it is proposed to calculate coefficient α_* in the following way

$$\alpha_* = \gamma\alpha_{*3} + (1 - \gamma)\alpha_{*n}, \tag{14}$$

where $\gamma = 0.56^{0.5\beta}$; β_* is normalized assessment of the corresponding variant of product according to criterion K^*

$$\beta_* = \frac{K_*^{predic} - K_*^{bas}}{K_*^{bas}}, \tag{15}$$

where K_*^{predic} is assessment according to criterion K^* predicted for this variant of product; K_*^{bas} is basic (averaged) assessment according to criterion K^* for products of a certain class.

It provides the achievement of the property of adaptation of the integral criterion, which makes it possible to flexibly respond to changes of market conditions and prospects of production situation and to coordinate the assessments of priorities between the customer and the manufacturer.

Thus, the presented expressions form a mathematical model of the problem of formation of the optimal variant of preliminary composition of non-standard products taking into account selection criteria ranging.

On the basis of the multi-component model of requirements tree and the model of selection of the optimal variant of the preliminary composition of non-standard products, taking into account selection criteria ranging, a solution method was proposed. It provides the possibility of proposal of solution variant from the available nomenclature basis of ready PAU for the designer working out a draft proposal. Every solution is used directly for every customer according to his/her individual requirements taking into consideration restrictions and possibilities of the enterprise at the current period of time. The method includes the following stages:

Stage No. 1. Determination (formation) of the customer's requirements to the future non-standard products.

Stage No. 2. Determination of the further actions depending on the way of assigning the choice criteria.

If the customer ranges the choice criteria, search for analogous orders immediately takes place in the database (DB) of ready projects. If the customer fills in a table of weight coefficients on the basis of judgment of its advantages, judgments of consistency and admissibility are checked and he/she passes to stage No. 3.

Stage No. 3. Calculation of weight coefficients of local criteria of choice and integral criterion of optimality.

Based on formulae (1–12), the optimality criteria, (13) – integral criterion of optimality are calculated and (14, 15) – weight coefficients are specified for balancing the data of the customer and of the enterprise experts. It results in achieving the property of adaptation of the integral criterion and a set of adapted indices of criteria A importance is formed by means of mapping K set on S set and on O set described in the model of the problem of control of formation of non-standard products optimal composition: $\varphi: K \times S \times O \rightarrow A$.

Stage No. 4. On the basis of the draft proposal (DP), coordinated with the customer, analogous orders and design solutions are searched for in DB of the ready projects of the enterprises. If identical requirements are found, optimization of the product composition takes place on the basis of current production situation and priorities both on the part of the customer and on the part of the enterprise and they pass to stage No. 6. Otherwise – to stage No. 5.

Stage No. 5. On the basis of the main requirements and requirements chosen by the customer a lineup of the product composition is determined – on the basis of T, K and A sets, the designer is proposed an ordered list of possible variants of lineups in the form of V set, by means of mapping P set on A set and on S set: $\psi: P \times A \times S \rightarrow V$. Then on the grounds of additional requirements, the admissible set of variants of performance of the future product composition is reduced by determination of Pareto set. Comparison and ordering of the solution variants are made on the basis of the calculated integral criterion of optimality or ranging of the choice criteria.

Stage No. 6. Analysis of the ordering results.

Stage No. 7. Analysis of the reasons for unsatisfactory solution.

Stage No. 8. When the integral criterion of optimality or choice criteria ranging is used, which results in a partial ordering of vector assessments, it is checked if their type meets the customer's requirements. When ordering of the solution variants, obtained at some step, meets the customer's requirements, this ordering is chosen as the final one. If the person who makes decisions acts rationally, he/she must choose the solution variant in accordance with the obtained ordering. I.e. a set of resulting optimal solutions is formed at every level of specification by mapping T set on V set: $\eta: T \times V \rightarrow O$.

Stage No. 9. Check of availability of the customer's unique requirements.

Stage No. 10. Transfer to the following specification level.

Using the system approach, search and selection of variants of construction are performed "top to bottom" beginning from upper ("big") levels of specification and going down to lower ones. The method of formation of the optimal composition of non-standard product is iterated at stages No. 5…9 to the lowest level of construction specification.

Thus, a method for computer-aided formation of the optimal variant of composition of non-standard product at the mechanical engineering enterprise is proposed. It differs from the conventional methods in the fact that it uses the multi-component model of requirements tree, a mathematical model of the problem of formation of the optimal composition of product taking into account selection criteria ranging and an adaptive integral criterion of optimality. The method makes it possible to flexibly respond to variation of market conditions and prospects of production situation and to coordinate priority assessments between the customer and the manufacturer.

While developing the information technology of computer-aided formation of the optimal composition of non-standard product, its static part was determined – the data structure (*DS*) and a complex of mathematical models and a method (*CMM*), and the information technology dynamic component was also described – information processes (*IP*) and their interaction (*IPI*). On this basis the model of the information technology is presented by the set: $IT = \langle DS, CMM, IP, IPI \rangle$.

In accordance with this expression information processes (IP) were determined and the information technology scheme was created; it is shown in Fig. 2.

The complex of the mathematical models and the method used in the IT dynamic component is presented in the form of abbreviations:

M1 is the model of the subsystem of formation of the product optimal composition meeting an individual order;

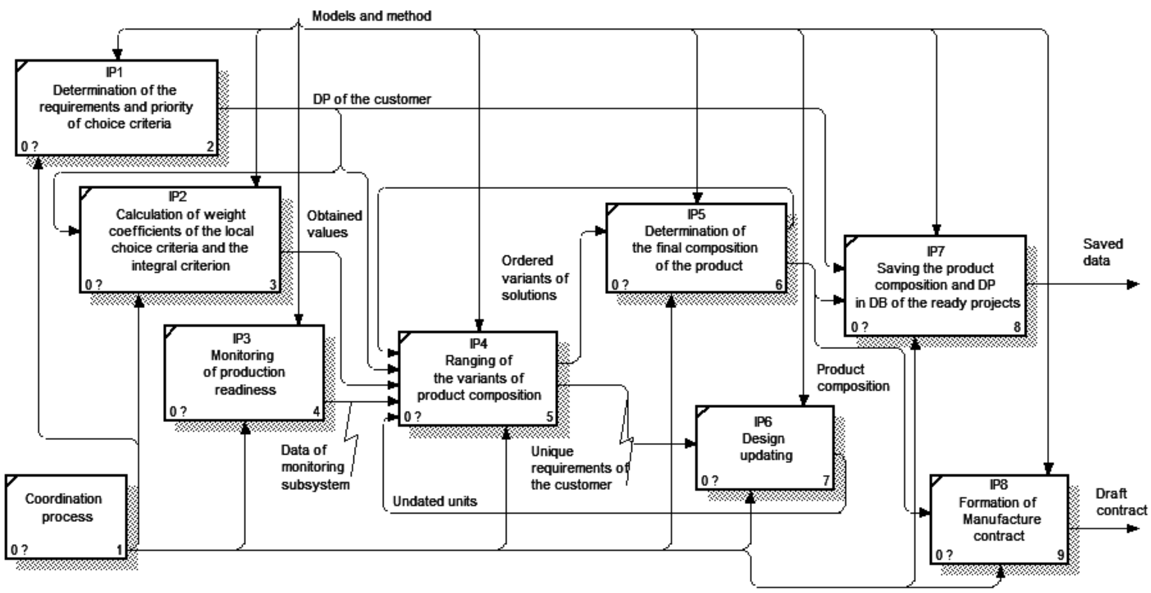

Fig. 2. Diagram of the information technology of computer-aided formation of the non-standard product optimal composition

M2 is the model of the requirements tree when non-standard product is put to production;

M3 is the mathematical model of the problem of formation of the optimal variant of the product preliminary composition taking into account the selection criteria ranging;

MF is the method for solution to the problem of formation of the product composition optimal variant.

Thus, it is the first time when a scientifically grounded information technology of computer-aided formation of the optimal composition of non-standard choice is proposed. It includes all the developed and improved models and the method enabling individual formation of the best (from the point of view of the integral criterion) composition of non-standard product for every customer and improvement of the enterprise operation efficiency.

The obtained results were practically realized and their efficiency was verified by implementation into the production process of "Kredmash" PJSC, in particular:

- information technology of computer-aided formation of the optimal composition of nonstick product was tested under the conditions of selection of the composition of asphalt-mixing plants at "Kredmash" PJSC;
- introduction of "DP formation" subsystem began in 2013 and introduction of "Composition choice" subsystem began in 2014, which made it possible to completely approbate the IT and verify its efficiency;
- IT application during 2013–2014 demonstrated improvement of the rate and quality of creating draft proposal (DP) by 1.5 times, reduction of terms and increase in efficiency of the choice of non-standard composition – by 2 times, decrease in the number of construction changes in the following production process – by 2.5 times;
- the process of DP creation, drawing up and signing a contract reduced from 10–15 days to 3–7 days.

Conclusions and recommendations for further research in this area. The necessity for development of the information technology of computer-aided formation of the optimal composition of non-standard product has been substantiated. The analysis of mathematical methods, models and information technologies of control of product manufacture configuration, which refer to solution of the problem of formation of the non-standard product composition, has been performed. Approaches to formation of the composition of non-standard product on the basis of reused components have been considered, their advantages and disadvantages have been analyzed. A scientifically grounded information technology of computer-aided formation of the optimal composition of non-standard product has been proposed. It includes a set-theoretic model of the subsystem of formation of the optimal variant of composition of the product and a method for solution to the problem of computer-aided formation of the optimal variant of product composition, which makes it possible to form the best (from the point of view of the integral criterion) composition of non-standard product individually for every customer and to improve the efficiency of the enterprise operation.

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Мета. Підвищення ефективності процесу розробки нестандартної продукції в умовах неповної визначеності шляхом створення інформаційної технології автоматизованого формування оптимального складу нестандартної продукції.

Методика. При розв'язані поставлених завдань використані: методи системного аналізу та загальної теорії систем – при побудові теоретико-множинної моделі підсистеми формування оптимального складу нестандартної продукції на машинобудівному підприємстві; методи теорії прийняття рішень і теорія оптимізації – при розробці методу й моделі вирішення завдання формування оптимального варіанта складу продукції; теоретико-множинний підхід – при розробці структури підсистеми й інформаційної технології.

Результати. Обґрунтована необхідність розробки інформаційної технології автоматизованого формування оптимального складу нестандартної продукції. Проведено аналіз математичних методів, моделей та інформаційних технологій управління конфігурацією виробництва продукції, що відносяться до вирішення завдання формування складу нестандартної продукції. Розглянуті підходи до формування складу нестандартної продукції на основі компонент повторного використання, проаналізовані переваги та недоліки. Розроблені й удосконалені моделі, метод та інформаційна технологія автоматизованого формування оптимального складу нестандартної продукції, що дозволяє з наявної номенклатурної бази підприємства запропонувати оптимальний варіант для конструктора, формуючого технічну пропозицію потенційному замовнику за його вимогами.

Наукова новизна. Запропонована науково обґрунтована інформаційна технологія автоматизованого формування оптимального складу нестандартної продукції, що включає теоретико-множинну модель підсистеми формування оптимального складу нестандартної продукції, математичну модель і метод рішення задачі формування оптимального варіанта складу продукції.

Практична значимість. Розроблені моделі, метод і прикладна інформаційна технологія вибору складу нестандартної продукції на машинобудівному підприємстві, що включає функціональний модуль моніторингу готовності виробництва, функціональний модуль формування вимог замовника й функціональний модуль багатокритеріальної оптимізації складу продукції за вимогами замовника.

Ключові слова: *багатокритеріальна задача вибору, інтегральний критерій оптимальності, множина Парето*

Цель. Повышение эффективности процесса разработки нестандартного изделия в условиях неполной определенности путем создания информационной технологии автоматизированного формирования оптимального состава нестандартного изделия.

Методика. При решены поставленных задач использованы: методы системного анализа и общей теории систем – при построении теоретико-множественной модели подсистемы формирования оптимального состава нестандартной продукции на машиностроительном предприятии; методы теории принятия решений и теория оптимизации – при разработке метода и модели решения задачи формирования оптимального варианта состава продукции; теоретико-множественный подход – при разработке структуры подсистемы и информационной технологии.

Результаты. Обоснована необходимость разработки информационной технологии автоматизированного формирования оптимального состава нестандартного изделия. Проведен анализ математических методов, моделей и информационных технологий управления конфигурацией производства продукции. Рассмотрены подходы к формированию состава нестандартного изделия на основе компонент повторного использования, проанализированы преимущества и недостатки. Разработаны и усовершенствованы модели, метод и информационная технология автоматизированного формирования оптимального состава нестандартного изделия, которая позволяет из имеющейся номенклатурной базы предприятия предложить оптимальный вариант для конструктора, формирующего техническое предложение потенциальному заказчику по его требованиям.

Научная новизна. Предложена научно обоснованная информационная технология автоматизированного формирования оптимального состава нестандартного изделия, которая включает теоретико-множественную модель подсистемы формирования оптимального состава нестандартного изделия, математическую модель и метод решения задачи формирования оптимального варианта состава изделия.

Практическая значимость. Разработаны модели, метод и прикладная информационная технология выбора состава нестандартного изделия на машиностроительном предприятии, которая включает функциональный модуль мониторинга готовности производства, формирования требований заказчика и модуль многокритериальной оптимизации состава изделия по требованиям заказчика.

Ключевые слова: *многокритериальная задача выбора, интегральный критерий оптимальности, множество Парето*

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