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INVESTIGATION OF THE METHOD OF DECOMPOSITION OF A COMPLEX SCIENCE-INTENSIVE INSTRUMENT-MAKING DEVICE FOR THE FORMATION OF A RATIONAL STRATEGY FOR ITS MODERNIZATION

Запропоновано метод декомпозиції об'єктів складної техніки (ОСТ), з метою максимального використання функціонально придатних компонентів в їх складі. А також визначення тих компонентів, які підлягають заміні в ході модернізації ОСТ, в силу їх фізичного та морального старіння, для подальшого використання. Особливістю методу є те, що за допомогою аналізу можна отримати детальне уявлення системи, що дозволить визначити вимоги до неї.

Ключові слова: *складний наукоємний виріб, термін служби виробу, шляхи модернізації, об'єкт складної техніки.*

1. Introduction

Today, scientific and technological development does not stand still. Every year hundreds of scientists in the world patent their inventions. There are already processes leading to the fact that in industrial production there are fewer and fewer blue-collar workers. But more and more there are «white-collar workers» and «steel collars workers». This can cause contradictions and ambiguous processes [1].

With the growth of scientific and technological progress, more and more technology appears. Every year the world produces a huge number of complex science-intensive products, new technologies are developing [2]. This leads to the fact that outdated equipment, often goes to landfills. If one of the components of a product fails, it is considered non-working in general. This leads to problems with the environment.

Tens of tons of unusable machinery are rendered annually on suburban landfills. This equipment has in its composition materials based on phenol-formaldehyde and polyvinyl chloride, and almost all metals from the periodic table of Mendeleyev [3], which do not decompose. The emergence of this problem gives rise to the search for ways to solve it.

Such equipment should not be provided at landfills and dumps, it should be dismantled or used for recycling as much as possible. Excluding simultaneous recycling of the entire product due to failure of one of the components:

– the consumer saves money on recycling, purchase of new equipment, which is of no small importance for producers during the period of financial instability;
– the manufacturer of high-tech equipment makes a profit from the equipment during the expiration of the warranty period;
– employees are needed for the maintenance of an additional service, in other words, the provision of jobs to people [3].

All of the above confirms the relevance of this research.

2. The object of research and its technological audit

The object of research is the life cycle of the production (the object of complex equipment (OEC)) of a manufacturing enterprise.

First of all, let's map the life cycle (LC) of complex science-intensive equipment, both graphically and formally (Fig. 1).

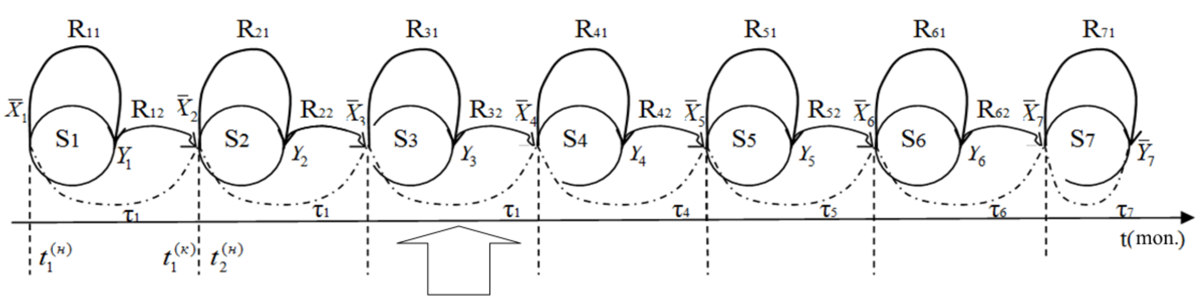

Fig. 1. Life cycle of products of complex science-intensive equipment

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The life cycle of complex science-intensive equipment consists of 7 stages such as:

– marketing;
– product design;
– pre-production;
– production;
– implementation;
– operation;
– recycling.

The conceptual model of the life cycle system is as follows:

$$A =< S,\overline{X,Y},R,T >, \tag{1}$$

where

$$S=\sum_{i=1}^{7} S_i, \quad \bar{X}i=\{xj\}, \quad \bar{X}i=\{xj\},$$

$$\bar{Y}i=\{y_k\}, \quad j=\overline{1,7}, \quad \kappa=\overline{1,7},$$

$$R\supset\{R_{l_1}\}\cup\{R_{n_2}\}, \quad l=\overline{1,7}, \quad n=\overline{1,7}, \quad \{R_{l_1}\}\cap\{R_{n_2}\}=\varnothing,$$

$$T=\{\tau_1,\ldots,\tau_7\},\forall\tau_i\in T\big|\tau_i=[t_i^{=},t_i^{k}],\forall\tau_i\in T\big|t_{i+1}^{(=)}\, i=\overline{1,7},$$

$$S_{\tau_i}:R_{\tau_i}\to\overline{X_{\tau_i}}.$$

The following designations are used in the conceptual model of the life cycle of complex science-intensive equipment at virtual instrument-making enterprise:

$S_1,\ldots,S_7$ – stages of the product life cycle;

$\overline{X_i}$ – input data at the relevant stage of the product life cycle;

$\overline{Y_i}$ – output data of the relevant stages of the product life cycle;

$t_i^{(s)},t_i^{(e)}$ – the moments respectively of start and end of each stage of the product life cycle;

R_{l_1} – data converter of the «operation-element» type for the l-th stage of the LC;

R_{n_2} – data converter of the «element-element» type for the n-th stage of the LC;

$\tau_1,\ldots,\tau_7$ – time intervals of the duration of each stage of the product life cycle.

Select all the input and output data at each stage of the LC at virtual instrument-making enterprise: (Table 1).

Each product has its own life cycle, i. e., time interval, expiration date. In Ukraine it is period of 5 years. All the problems of enterprises lie in this moment. The current situation in the country does not allow enterprises to update their production capacity every 5 years, and therefore is the most problematic place.

The process of recycling is determined by its beginning, which in most cases coincides with the end of the warranty period from the manufacturer's company or its representatives (distributors, dealers, etc.) and the time necessary for the entire scope of work (identification of ways and means, disassembly, sorting, processing, etc.), i. e., complete destruction of the product.

3. The aim and objectives of research

The aim of research is investigation of the decomposition method of a complex product and determination of the optimal ways for its implementation on the basis of research of the product life cycle. At the same time affecting the economic, environmental and social aspects, extending the life cycle of complex products by replacing or repairing failed components, , extending the product life.

To achieve this aim it is necessary to accomplish the following tasks:

1. To conduct an assessment of the OEC life cycle with the subsequent specification of the stages of the product life cycle.
2. To present science-intensive products in the form of an architecture of a distributed hierarchy.

4. Research of existing solutions of the problem

The authors of [4, 5] dealt with the problem of solid waste recycling. These studies are related to the solution of a number of scientific and practical problems, among which an important place is occupied by the determination of the volumes of generated waste that are not subject to recycling, including science-intensive products and means of their processing.

Table 1

Input and output data at each stage of the life cycle

Stages	Input	Output
1	$\overline{X_1}=\{x_1^1,\ldots x_n^1\}$, $\{x_1^1,\ldots x_n^1\}$ – set of potential customers	$\overline{Y_1}=\{y_1^{(1)},\ldots,y_n^1\}$, $\{y_1^{(1)},\ldots,y_n^1\}$ – set of applications for the manufacture of *j*-th type of equipment
2	$\overline{X_2}=\{x_1^2,\ldots x_n^2\}$, $\{x_1^2,\ldots x_n^2\}$ – set of orders for manufacturing of *m*-quantity of *j*-type equipment	$\overline{Y_2}=\{y_1^{(2)},\ldots,y_n^2\}$, $\{y_1^{(2)},\ldots,y_n^2\}$ – design and technological documentation
3	$\overline{X_3}=\{x_1^3,\ldots x_n^3\}$, $\{x_1^3,\ldots x_n^3\}$ – technological route maps	$\overline{Y_3}=\{y_1^{(3)},\ldots,y_n^3\}$, $\{y_1^{(3)},\ldots,y_n^3\}$ – production agents for the manufacture of *j*-type equipment
4	$\overline{X_4}=\{x_1^4,\ldots x_n^4\}$, $\{x_1^4,\ldots x_n^4\}$ – digital control programs for FPGA firmware of CNC processes	$\overline{Y_4}=\{y_1^{(4)},\ldots,y_n^4\}$, $\{y_1^{(4)},\ldots,y_n^4\}$ – set of manufactured units and parts
5	$\overline{X_5}=\{x_1^5,\ldots x_n^5\}$, $\{x_1^5,\ldots x_n^5\}$ – design and technological documentation of the product assembly	$\overline{Y_5}=\{y_1^{(5)},\ldots,y_n^5\}$, $\{y_1^{(5)},\ldots,y_n^5\}$ – set of manufactured equipment of the *j*-type
6	$\overline{X_6}=\{x_1^6,\ldots x_n^6\}$, $\{x_1^6,\ldots x_n^6\}$ – equipment installation	$\overline{Y_6}=\{y_1^{(6)},\ldots,y_n^6\}$, $\{y_1^{(6)},\ldots,y_n^6\}$ – service maintenance
7	$\overline{X_7}=\{x_1^7,\ldots x_n^7\}$, $\{x_1^7,\ldots x_n^7\}$ – set of orders for recycling	$\overline{Y_7}=\{y_1^{(7)},\ldots,y_n^7\}$, $\{y_1^{(7)},\ldots,y_n^7\}$ – $\varnothing$

Moreover, in the resources of the world scientific periodicals, work [6] can be singled out, which emphasizes that waste electronic complex equipment contains many recyclable elements and thus it is possible to reduce the amount of OEC waste. Unfortunately, the implementation of this approach is quite costly for Ukraine, and will not yield significant results. All the physical processes of separation in the waste recycling of electrical and electronic science-intensive equipment are disclosed in [7].

According to the authors of the works [8, 9], the modernization of science-intensive technology equipment consists in replacing parts or assemblies with more modern, high-quality ones. Their research does not take into account that the life cycle has significantly decreased with the increase in the use of electrical and electronic products, devices in our life, the speed of renewal of electrical products.

As pointed out in [10], when monitoring the work of an enterprise produced by complex science-intensive technology products, it is necessary to properly emphasize both the strengths and weaknesses of the equipment for the purpose of their modernization.

An approximate solution to the problem, as described in [11–13], suggests that the success of the OEC modernization project in improving the recovery characteristics of the environment and the resource (product) is measured by life cycle assessments and environmental impact assessment. This is not enough to solve the problem. The issue is solved by the fact that they carry out burial in the depths of the oceans. But the problem is in reducing the number of recycled science-intensive products that are difficult to recycle.

5. Methods of research

The modern architecture of complex science-intensive products contains a large number of components. With the help of decomposition it is possible to divide any product into separate components. The decomposition tree for modern complex products is a multi-level hierarchical component composition (Fig. 2).

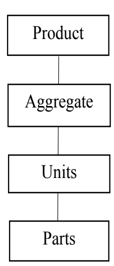

Fig. 2. Simple product decomposition

Service life of the part determines the service life of the units, which in turn determine the service life of the aggregates, and the aggregates - the service life of the product. Thus, it is a physical obsolescence. This term can be prolonged using a method of soft recycling. Along with this there is a related concept of modernization, but it does not take into account the moment of recycling. The proposed method is necessary to ensure that the beginning of the recycling phase is not the expiration of the life of the fastest wearing part, but rather prolong the life of the product to the life of the most durable part in the product.

Thus, for a comprehensive study of the problem, it is necessary to display the life stages of the product - from the origin of the idea to recycling. To do this, let's use the concept of the product life cycle, which consists of a number of stages and individual works performed to ensure its existence.

Life cycle is consistent and interrelated degrees of the product system from the acquisition or extraction of natural resources until final recycling [14].

Within the framework of the considered topic, we are interested in the design stage and the operational phase, as the research and development design is carried out at the design stage of the product and the ways of upgrading the complex product by the decomposition method are determined, as well as the ranking of the need for the modernization of a component. But at the operational stage, physical obsolescence is determined, which has a great influence on the work of the product and determines the service life.

Along with physical obsolescence, there is a moral that, for science-intensive products, as shown in world practice, trends and thanks to progress exerts a greater influence on the end of life as it acquires the property of unclaimedness [15].

To determine what impact a particular working environment will have on the system, a system study is performed (decomposition and analysis). At the stage of decomposition, a general view of the system is provided and its separation into component parts; at the analysis stage, a detailed representation of the system is provided, and it is also possible to formulate the requirements for the system.

At the analysis stage there are [3]:

1) functional and structural analysis of the system;
2) morphological analysis (interrelation of components);
3) genetic analysis (background, causes of the situation);
4) analysis of analogues;
5) formation of requirements for developed system.

Decomposition influences the decision-making and the reasonableness of the decisions made by the manager.

6. Research results

Let's imagine a complex science-technical product by decomposition into components in the form of architecture of a distributed hierarchy. This hierarchy is based on the production of a knowledge representation about an object in which a hierarchy with an inheritance relation and active slots is taken as the basis, dynamic procedures in the form of product rules are attached to request procedures and daemon procedures. This approach allows one to naturally combine in one model statistical knowledge about the subject area in the form of an inheritance hierarchy and dynamic knowledge in the form of attached procedures that control the inference.

Thus, the decomposition of products can be represented by a function of properties:

$$W : I^2 \to S,$$

where I – the set of identifiers; S – the set of slots of the form:

$$\langle \nu, d, \{Q_i\}, \{D_j\}, \{C_k\}, \leq_q, \leq_d, a \rangle,$$

including the current value of the slot and the default value, the set of request procedures and daemon procedures with

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their corresponding conflict resolution strategies in the form of full-order relationships on the set of procedures $\le_q$ and $\le_d$, a set of constraints, etc. The request procedures Q_i are expressions from some set E, and daemon procedures are the functions of change of properties:

$$D_j : W \to W,$$

where W denotes the set of functions of the hierarchy properties . The set of values of slots T can have an arbitrary nature (for example, it can be a family of types with dynamic transformation or strict typing) – to describe the output semantics, it is necessary that this set to be a complete lattice.

Inheritance relation: is induced by a slot with the reserved name parent:

$$F : G \ \left\| F(parent) \right\| = G.$$

Thus, it becomes possible to describe dynamic inheritance, in which the parent is evaluated in the inference process. Typical for decomposition, the specification operation is modeled after an implicit inclusion of the rule in the model:

$$F(parent) \leftarrow match(F, G).$$

When considering multiple inheritance, the slot *parent* is assumed to be of a list type, and $F : G \leftrightarrow G \in \left\| F(parent) \right\|$.

The definition of the semantics of inference is based on the recurrent definition of the function:

$$\|\cdot\| : C \times E \times W \to T \times W,$$

describing the process of inverse inference, as well as the functions of purposeful direct inference:

$$\Phi_{\langle f,s \rangle} : W \to W.$$

On the set of states W, the partial order relation is naturally induced in relation to which this set is a complete lattice. Since the proposed inference model is monotonous (as indicated by the monotonicity of the derivation functions over states), then there is a naturally defined semantics of the fixed point, based on the successive application of the properties functions $\|\cdot\|$ and Φ.

The combined inference process can also be illustrated as a path search in the final state bigraph factorized by the ratio of indistinguishability by the set of all hypotheses of rules.

For property functions, let's introduce the combination operator * as follows:

$$W_1 * W_2 = \lambda f,\ s \begin{Bmatrix} W_1(f,s), \text{if} \langle f, s \in \rangle I_1 \\ W_2(f,s), \text{if} \langle f, s \in \rangle I_2 \\ \perp, \text{ otherwise} \end{Bmatrix}.$$

This operator is symmetric and associative, which allows to extend it to the case of an arbitrary number of arguments. Let's call $W = *W = *_{i=1}^{n} W1$ the function of the state of the distributed frame system. In doing so, such function will define some local hierarchy, which we will call the equivalent generated system for the initial distributed system.

An inference in a distributed decomposition system can be viewed from the position of an equivalent system based on already defined semantics, or by introducing the semantic function of distributed input:

$$\|\cdot\| : C \times E \times \tilde{W} \to T \times \tilde{W},$$

operate on sets of states functions.

To calculate static and mobile links, this function will determine the interaction of the components of the distributed hierarchy:

$$\left\| \circ W_1(f,s) \right\|_{\{W1 \ldots W_i \ldots W_n\} \to \tilde{W}} = \left\| f.s \right\|_{\{W1 \ldots W_i * W_j \ldots W_n\} \to \tilde{W}},$$

$$\left\| \bullet W_1(f,s) \right\|^{F}_{\{W1 \ldots W_i \ldots W_n\} \to \tilde{W}} = \left\| f.s \right\|^{\bullet Wi(F)}_{\{W1 \ldots W_i * W_j \ldots W_n\} \to \tilde{W}}.$$

While for expressions that do not contain remote references, it will be reduced to the local semantics defined earlier:

$$\left\| E \right\|_{\{W1 \ldots \bar{W}_i \ldots W_n\} \to \tilde{W}\} \to \{W1 \ldots \bar{W}'_{i*} \ldots W_n\}} = \left\| E \right\|_{W_i \ldots W'_i}.$$

It can be said that for systems using only mobile or only statistical interaction, the semantics of distributed inference will be equivalent to the semantics of the local inference of decomposition result of a complex science-intensive instrument-making device of virtual production in the generated system of the product components.

7. SWOT analysis of research results

Strengths. The strengths of the OEC decomposition method are manifested in:

– prolongation of the life cycle of products of complex high technology;
– identification of unaccounted technical and functional characteristics of products based on the capabilities of modern technologies;
– maintaining a constant level of demand for products;
– positive influence on the ecological component of the country.

At the same time, there are a number of advantages over existing methods of overcoming the physical and moral aging of the OEC:

– time indicator: is the maximum prolongation of the life cycle of products;
– allows not losing the position of demand in the market;
– an environmental factor that is not considered in all studies relating to the modernization of complex machinery engineering.

Weaknesses. A negative factor in the implementation of decomposition method of a complex science-intensive instrument is an error in identifying the unit for modernization, since the human factor plays a role. From this, all subsequent decisions regarding the ways of modernization of the complex equipment object are depend. Thus, a wrong decision can lead to a decrease in the level of demand for OEC.

Opportunities. Further studies should be aimed at a deeper mathematical evaluation of the effect of the method considered in the article on the ecological component, not on the side of expanding the recycling possibilities, but on the part of preventing, reducing the recycling of such facilities or the lack of such necessity. The obtained results, which will be implemented at the operating enterprises of Ukraine, will enable to prolong the life cycle of the product for 3–15 years, thereby increasing the profit of the enterprise.

Threats. The negative side in the implementation of this research is that all innovative improvements to the enhancement of OEC functionality must seamlessly fit into the existing electronic and software components already available in the OEC. This adds time, inconvenience to the developer, and therefore additional costs in comparison, if the developer created a new management taking into account the latest technologies and components. With the existing control unit and the mechanical part, it is necessary to adjust, increase additional fasteners, commutation boards, etc. This can affect the quality of the OEC operation.

The method of OEC decomposition throughout its life is used by people in everyday life, as well as in offices, using a personal computer, constantly increasing not only the memory, the power of the video card, but also the functionality of the PC itself.

8. Conclusions

1. The OEC life cycle is evaluated with the subsequent specification of the stages of the product life cycle. All input and output data are revealed at every stage up to the recycling. At the same time, the main problematic stage is «operation», which directly affects the life cycle duration.

2. High-tech products are displayed in the form of distributed hierarchy architecture. Thus, the mathematical apparatus allows to make a rational choice of a particular unit for the modernization of products. Moreover, the logical inherence in the distributed decomposition system can be considered from the position of an equivalent system based on already defined semantics. The application of the OEC decomposition method allows not only to make a rational choice of a complex object unit, modernizing it, adding functionality to the equipment, but also significantly prolong the life cycle stage – «operation». Based on the results of the research, it can be concluded that, using the method discussed above, OEC recycling takes place gradually over the years (up to 15 years), and not after 5 amortized years (as predisposed in production), in other words – gently recycling some parts and components that have developed the resource or morally become outdated.

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ИССЛЕДОВАНИЕ МЕТОДА ДЕКОМПОЗИЦИИ СЛОЖНОГО НАУКОЕМКОГО ПРИБОРОСТРОИТЕЛЬНОГО ИЗДЕЛИЯ ДЛЯ ФОРМИРОВАНИЯ РАЦИОНАЛЬНОЙ СТРАТЕГИИ ЕГО МОДЕРНИЗАЦИИ

Предложен метод декомпозиции объектов сложной техники (ОСТ), в целях максимального использования функционально пригодных компонентов в их составе. А также определения тех компонентов, которые подлежат замене в ходе модернизации ОСТ, в силу их физического и морального старения, для дальнейшего использования. Особенностью метода является то, что с помощью анализа можно получить

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детальное представление системы, что позволит определить требования к ней.

Ключевые слова: сложное наукоемкое изделие, срок службы изделия, пути модернизации, объект сложной техники.

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