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DESIGN AND OPTIMIZATION OF AIRCRAFT ASSEMBLING BASED ON COMPREHENSIVE SIMULATION OF MANUFACTURING PROCESSES

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Abstract

A problem of design, technological and the organizational solutions optimization of aircraft manufacturing is considered. Especially topical at early steps of design is a project feasibility study, when taking place balancing of production facilities. The integrated software set, which using in assembly technology development of short-medium-haul passenger aircraft MS-21 is considered.

1. Analysis of technical and economic parameters of assembly processes in modern conditions

Implementation of "Design for defined price" concept is one of the most important directions in providing of aircraft competitiveness. Investment required for the modernization of enterprises and increasing efficiency of manufacturing systems make a significant part of aircraft prime cost. That's why creation of management system of industrial enterprise and aircraft industry innovative investment is a high priority [1].

Industry needs a specific tool aimed on prediction, planning and control of serial aircraft price, allowing calculation of labor cost, material cost and financial expenses. Especially topical at early steps of design is a project feasibility study, when choosing the scheme of cooperation, balancing of production facilities, required for execution of release program, elaborating program of plant technical modernization. Mistakes being made on this stage can be very expensive to fix later in process.

Assembly is one of the most complicated processes which determine the quality of the final product and feasibility of product manufacturing. In development of assembly technology process it's critical to take in account a large number of conflict factors that affect design, technological and the organization solutions.

Tasks of development of construction, technology, equipment and manufacturing system design perform by different groups of specialists that use specific software to create local models. It needs to develop a method of parallel engineering of construction, technology and organization of assembly processes to perform their comprehensive optimization using modern simulation technologies.

Analysis and formalization of relations between construction, technology and manufacturing organization is a complicated problem. Choose of construction-technology and organization solutions needs to be considered as a part of wider task of optimization of all production processes, which determines economic efficiency of whole project.

Necessity in development of modern automated system based on CALS-technologies and aimed on techno-economic analysis and a feasibility study of decisions, taken in design of technology and aircraft manufacturing organization, is declared by leading aircraft industry specialists. Separate components of this system implemented in few projects at last years, but volumes of apply are limited.

In Russian aircraft industry was developed an evaluation system of construction-technology and organization solutions and it was successfully used in launching aircrafts into production. It based on data and methods that have been developed by soviet scientists and aircraft industry specialists of 60s-80s of last century.

Calculation of technical and economic parameters at early steps of design (technical proposal, preliminary design) has been based on economic models, presented as formulas, nomograms, tables, charts that had been developed based on statistical investigations. Those models allow calculation of labor cost of manufacturing and technical preparation of production. Their also allow drawing of learning curve using as initial data aircraft type, airframe features, release program and etc.

At drafting step, while designing manufacturing bill of processes (MBOP) Russian aircraft producers perform calculation of aircraft technological effectiveness parameters for detailed evaluation of labor cost of manufacturing and technical preparation of production. In that case they developed aircraft parts technological classifiers, developed technological processes and calculated labor cost, performed evaluation of equipment design and production cost. The results of calculation was divided by aircraft assemblies and kinds of manufacturing and presented in directive (prescriptive) technological data.

Methods of simulation modeling, which had been developed by Russian scientists, were extensively used in investigation and design of effective high complexity manufacturing systems.

The evolution of electronic modeling methodology and systems makes quite a topical problem of integration of manufacturing systems models into simulation model. The methodology of manufacturing processes technological design and its implementation using Russian software presented in series of papers. So, one of the papers [2] presents methods of creation of manufacturing bill of materials (MBOM), MBOP and manufacturing system items. It's presenting a task list, and sequencing tasks of computer aided design of assembly and installation technology processes using "ТеМП" (simulation of technology processes) system. System based on this methodology, installed at aircraft enterprises, and is using for development of directive and operating (working) assembly technology processes.

The experience in directive technology processes development for new aircraft projects, says to us that comprehensive optimization should take into account features of modern aircraft manufacturing:

- New methods and technology processes (assembling without jigs, hole to hole indexing, allowed by CAM-systems and CNC equipment, using of automated positioners in joining, automated fastening and etc.) fundamentally change the face of manufacturing system and affect techno-economic parameters of manufacturing.
- Aircraft manufacturers are focused on customers and pay attention for its individual demands. Production plants contemporaneously build different aircrafts in few modifications and configurations. In that case they need to balance their production facilities taking into account dynamic of product release for each project. In these conditions, prediction of labor cost and production cost of new aircrafts using "learning curve" cannot ensure the necessary precision, because it means stable release of serial aircrafts excluding modifications, variance of technology processes and evolution of manufacturing system.
- During projects of new civil aircrafts development (MS-21) foreign consulting companies offer concepts of technology and organization of assembly lines, which include assembly lines layouts, assembly

stations descriptions and processing lists. In case of feasibility study they preliminary evaluate labor cost, production cycles, production capacity needs and etc. Their offers are illustrated using electronic men models, but computer animation, that simulate functioning of production system, is not a simulation model (in classic sense), because it is not sensitive for variation of model parameters, and does not allow calculating and optimization of different versions of manufacturing organization.

– In optimization of assembly processes the main criterion is production cost of assembling, because other parameters (labor cost, production cycle) are took into account in production cost calculating formulas. Evaluation of production cost needs to take into account different groups of factors, which affect design, manufacturing and operation of universal and special equipment. In this regard we need to develop a set of models for design and optimization of manufacturing systems.

The main steps of construction, technology and organization solutions of design and optimization processes are (Fig. 1):

1. Preparation of initial data. That includes choosing of general aircraft parameters, based on domestic and foreign aircraft analysis, which was chosen as prototypes.
2. Adoption of conceptual decisions of construction, technology and manufacturing organization, evaluation of their parameters, based on economic models and adapted to modern conditions.
3. Creation of product, technology and manufacturing system electronic models in parallel engineering mode. This process aided by specialized CAD/CAM-systems, which support variant design and local optimization. Completeness of models and evaluation precision determined by project step (conceptual design, preliminary design, detailed design).
4. Formation and evaluation of serial product configurations.
5. Comprehensive optimization of design, technology and organization solutions, based on simulation modeling, and calculation of techno-economical parameters of assembly program.

2. Models of assembly design and optimization

Specialists use different classes of models during construction, technology, equipment and manufacturing system development. These models must operate in integrated system environment, which performs design processes information support.

In analysis, prediction of aircraft sales and development of new technologies, other classes of models are being used, which is not a subject of this article. Take a closer look on models, which are using on stages II ÷ IV.

3. Economic and mathematical models

Preliminary evaluation methods of techno-economic parameters which is used in development of new or modified aircrafts was developed by National institute of Aviation Technologies (NIAT) and based on statistical investigation done in 50s-60s of last century. The labor cost of aircraft manufacturing was calculating by following formula:

$$T = A \cdot G^{l_1} \cdot N^{-l_2} \cdot (m + a \cdot K_M + b \cdot K_T) \cdot K_{\Pi}, \quad (1)$$

wherein

A – equation parameter, which determined by class or subclass of aircraft;

G – empty mass;

N – number of aircrafts contingently made since beginning of production;

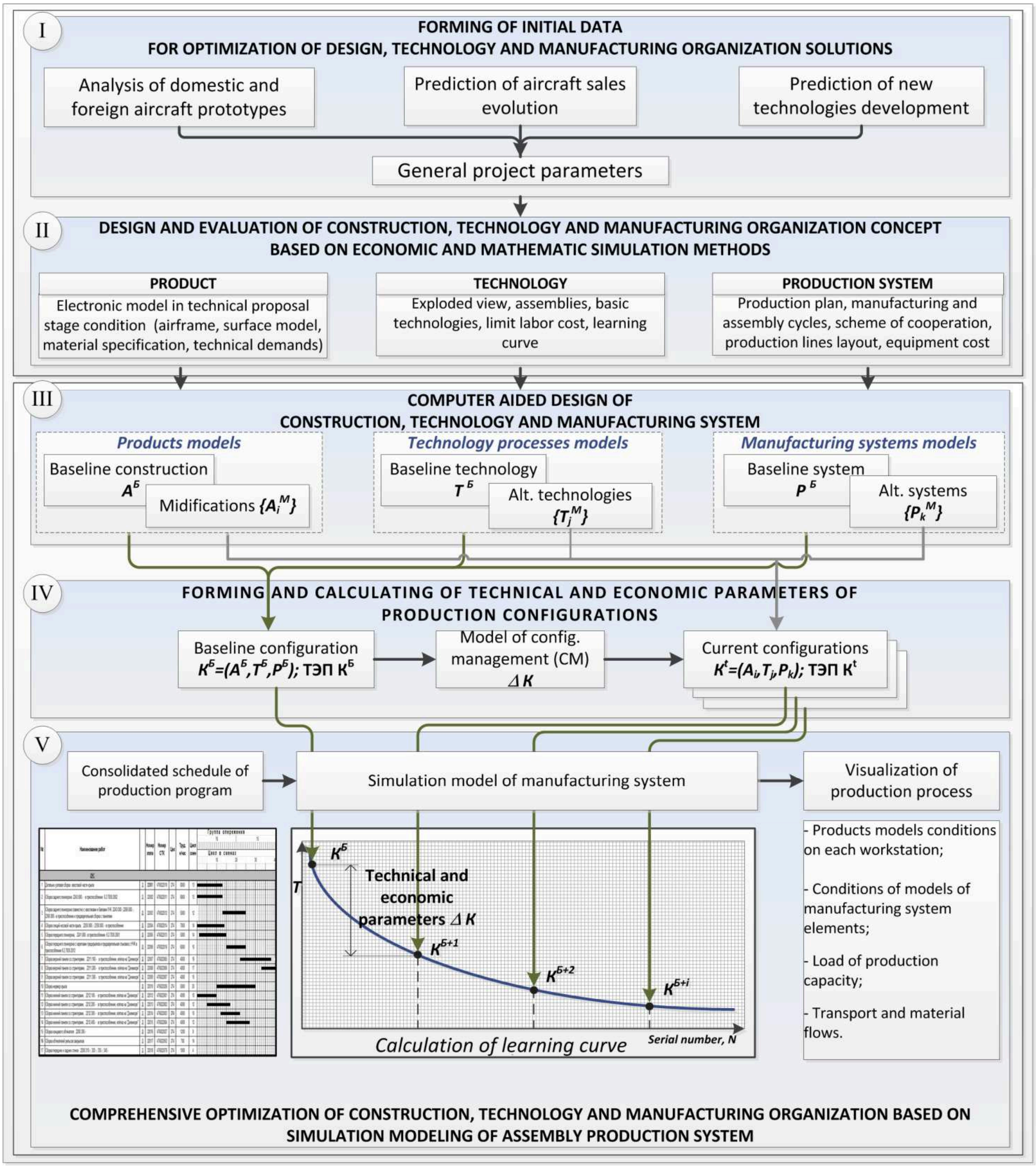

Fig.1. Scheme of making and optimization of construction, technology and manufacturing organization decisions of assembly production.

m – uncorrectable part of labor cost (tabulated value);

a – proportion of machine time in presswork, milling and locksmithing main time of aircraft manufacturing labor cost;

K_M , K_T, $K_П$ – correction factors which take in account: variation of used materials ratio, variation of joints types ratio, growth of labor productivity;

b – portion of sheets manufacturing labor cost in total aircraft manufacturing labor cost;

l_1, l_2 – equation parameters for different types of aircraft.

In recent years serial aircrafts labor cost evaluation methods based on economic and mathematical models was adapted to modern manufacturing technologies and economic circumstances by using of correction factors, which take in account variation of used materials ratio, variation of joints types, new design and manufacturing methods. But their applicability limited by following conditions:

- Correction factors used in calculation formulas defined based on expert evaluation (due to the absence of sufficient amount of statistic data about aircrafts made in conditions of computer aided design and manufacturing), which cannot ensure the necessary precision of calculation and veracity of results.
- Estimate indicators have generalized nature, so it cannot be used in analysis of production technological effectiveness (e.g. to identify "bottlenecks") and development of activities, which will lead to increase of production effectiveness.

Taking into account above limitations, we can use this class of models at stage II to develop and preliminary evaluate conceptual decisions.

4. Models of development of product, technology processes and manufacturing systems

At 3rd step we use a computer aided design methods and information environment, which uses a set of generative models to support design process.

Structure and content of integrated information and software environment, which supports construction and technology design [2] developed using basic formula of parallel engineering [3]:

$$S(A)\ \rho\ S(P) \rightarrow S(T) \qquad (2)$$

wherein:

$S(A)$ – model of initial object (product);

$S(P)$ – model of generative environment (technological design);

$S(T)$ – model of designing object (technology process);

ρ – procedural-algorithmic models, implemented by basic functionality of CAx-systems (models synthesis, calculation of parameters, interpretation and visualization of resulting models).

Set of models of development of construction and technology provides formation of manufacturing model of product $S^P(A_I^T)$ (manufacturing bill of materials (MBOM) supported by different conditions of product model, which occur in the manufacturing process), models of equipment $S^P(P_I^T)$ and using it in creation of technology processes models $S^P(T_I^A)$. Here technology process presents as array of technological operators (operations, actions), which cause variation of conditions of product and equipment models. Valuation unit perform labor cost calculation of technology operations and process at all, but do not perform analysis of designed technology process by criteria of production cost (including cost of equipment) and manufacturing organization effectiveness.

We introduce an additional unit into information and software environment for optimization of production process and take into account of above criteria. This unit performs design of manufacturing systems (Fig. 2).

Herewith was retained basic class of models: generative and resulting models of designing objects (product, technology processes, manufacturing systems), as well as relations between different development environments. So, manufacturing model of product, on the one hand, is a part of product model (A), and on other hand is a component of technology process model (T). Equipment models (P^T), which designing for particular technology and product, on other hand are the components of manufacturing system models (P^A).

Generative environment $S(P^A)$ contains parametric models of development for workstation, sites, assembly lines, transport communications, storage equipment etc. Calculating algorithms must be developed based on assembly plants design methods. Initial data forming and transmitting from generative environment of technology processes and equipment, as well as from unit I and II (Fig.1). In result we obtain electronic model of production division (3D-layout), which configuration may vary according to schedule of technical upgrade.

Horizontal arrows on scheme between generative models (first and second level) shows relations (generally variant) between elements of different environments. This level is a library of integrated construction-technology solutions, because for standard construction-technology elements of details and assemblies it describes variants of their technical implementation using elements of manufacturing system.

The set of parallel engineering models provides formation of harmonized construction-technology and manufacturing organization solutions of assembly production. These solutions are ranged by extent of detailing according to steps of development.

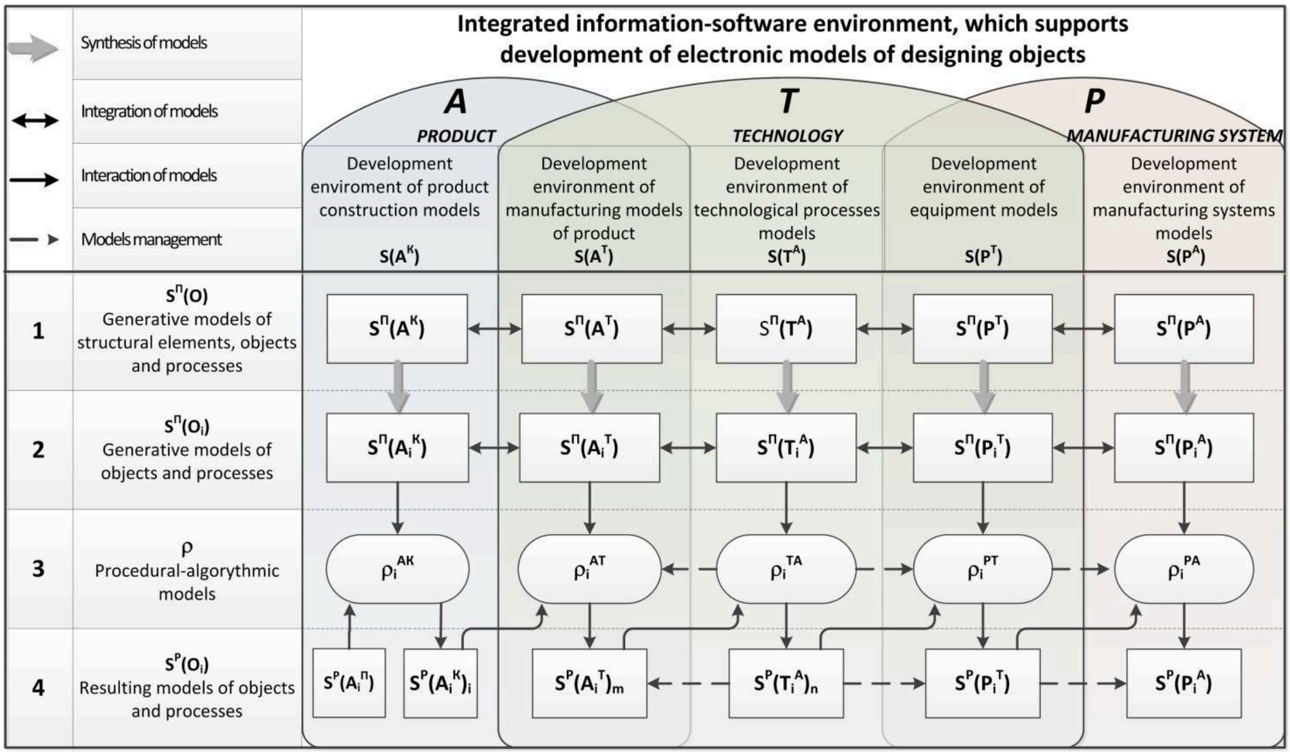

Fig. 2. Scheme of relations between parallel engineering models.

5. Models of production configuration management

To determine process of technical documentation management of baseline product and its modifications aircraft designers and manufacturers use a term "configuration". Normative documents consider configuration management as forming of current configuration from baseline configuration using configuration rules. Using mechanism of configuration management allows rational data storage of product elements replicable in different configurations. It also reduces labor cost of development of design documentation, allows doing and monitoring of construction changes in different modifications.

Normative documents declare four kinds of configuration: functional, design, manufacturing (production) and operational. Production configuration considered as a set of design and technological documents and data, which uses in manufacturing of particular product (i.e. clearly defines construction, technology and equipment, which uses in manufacturing of particular product in specified production period).

To provide configuration management configuration elements and their properties are being identified in an object structure. Combination of configuration properties of all elements defines configuration properties of whole object.

Hierarchical structure described as a graph tree G=(A,C), wherein A – a set of vertices – each is a detail or assembly. And the set of arc are:

$$C \ni c_{j(i)} = \begin{cases} 1 - if\ A_i^J \in A_j^{J+1} \\ 0 - else. \end{cases} \quad (3)$$

wherein J – number of level in hierarchical structure;

i, j – number of elements on the levels J and $J+1$ respectively.

For a set of products in different modifications, structure describes as a combined graph-tree, which elements have different designs and represented as "and/or" vertices. Existence of any vertex in a product modification is determined by a set of relations, which is associated with configuration rules.

Suppose that $A=\{A_I\}$ – a set of product elements (graph vertices), which describes a hierarchical structure of product, wherein I – an index – unique number, which determines existence of element in product structure. In accordance to accepted system of product designation, identifier of any structure element is combined, and includes a set of index, which determines product, its modification, number of element in assembly, and a design version.

Let's select a set of configuration elements in a product structure $A^{ЭК}$, and besides $A^{ЭК} \subseteq A$. For any element $A_i^{ЭК}$ we determine a set of configuration $F^{ЭК}{}_{Ai}$. A range of configuration properties of set of products A is formed by combining sets of properties of single elements: $F_{\rm A}^{\rm K} = \bigcup_{i=1}^{n} F_{{\rm A}i}^{\rm ЭК}$. Suppose that $K_A=\{K_t\}$ – is a set of possible (current) product configurations A. Relations between configurations and its configuration rules may be described as a Boolean matrix $||C_{t(j)}||_{K_A, F_{\rm A}^{\rm K}} = [\, K_A \times F_{\rm A}^{K}]$, wherein $C_{i(j)}$=1, if property F_j exist in configuration properties K_t, and $C_{i(j)}$=0 if else. Then any configuration K_t may be determined as Boolean row vector, which have 1 in those components (columns), which are the configuration properties.

In this way, model of configuration management $S^У(K)$ may be determined using (2) by following formula:

$$S^И(K_t)\ \rho^K\ S^П(K_t) \rightarrow S^P(K_t) \quad (4)$$

wherein

$S^И(K_t)$ – model of initial description of current configuration;

ρ^K – procedural-algorithmic configuration environment;

$S^П(K_t)$ – generative model of current configuration;

$S^P(K_t)$ – resulting model of current configuration.

Model $S^И(K_t)$, as it described above, determines as Boolean row vector in a space of configuration properties. Procedural-algorithmic configuration environment ρ^K includes a set of operators of product structure conversion $\rho^K=\{\rho^A,\rho^D,\rho^S\}$ («add», «delete», «substitute») and implemented by PDM-system basic functionality.

Generative model of current configuration $S^П(K_t)=(S^P(K_Б),\{\Delta K\}$ includes a model of baseline configuration $S^P(K_Б)$ and a set of changes ΔK, which necessary to do in baseline configuration to receive current. Any changeable structure element, a kind of conversion and a condition for implementation are determined in any change specification.

In a context of solving problem, objects of configuration are a product, technological processes and manufacturing system. In that way, we need to take into account relations between objects of different classes (construction ↔ technology ↔ manufacturing system) as well as relations between objects of one class (i.e. between elements of product structure in design configuration management). The technological effectiveness of production and manufacturing efficiency for individual serial product is being estimated during analysis of production configuration.

6. Simulation model of assembly production

Simulation model of assembly production should provide working out and optimization of production processes in conditions of multi-nomenclature manufacturing, variance of product design, variance of technology process and production resources. For this we need to realize procedures of forming electronic models conditions of product and equipment which occur in defined time period in simulation model. Then structure of assembly production simulation model $S_{ИМ}(A,T,P)$ may be determined as a set of following components:

$$S^{ИМ}(A,T,P)=(S^{У}(K),G^{Ц},N^{Э},t) \qquad (5)$$

wherein $S^{У}(K)$ – model of product configuration management;

$G^{Ц}$ – consolidated schedule of production program;

$N^{Э}$ – technical and economic parameters of production efficiency;

t – system time.

When system time t changes, i.e. marker moves on time scale, module $S^{У}(K)$ forming product configurations A, content of technological processes T and manufacturing system structure P. And a model of schedule $G^{Ц}$ – forming conditions of electronic models of product and manufacturing system. Discontinuity in the description of dynamic objects of simulation model (number of conditions in defined time period) and a detail of production processes simulation (levels: phases of work, operations, actions) depends on specific of solving problem and planning horizon. Herewith local and comprehensive working out of production process may be implemented.

Local assembly process working out (on one workstation) includes simulation of interaction of electronic models of product, performers and equipment during technology process, including additional and auxiliary operations (maintenance and setting of equipment, formation of assembly kits and etc.). Herewith following actions taking place: test on possibility to assembly, test on access to the work area, analysis of labor conditions in work area, test of movability of working parts of equipment and assembly jigs. This functionality implemented in system “ТеМП”.

Comprehensive working out of assembly process in production division (station, line, shop) performs optimization of assembly organization scheme. Herewith a “bottleneck” identification, valuation of transport and material flows efficiency, identification of free production capacity taking place.

Assembly production simulation modeling includes following procedures:

- Setting of timeslot, in which assembly simulation modeling planned to be;
- Identification of product nomenclature, which are in production at specified calendar period according to assembly program;
- Formation of electronic models of assemblies, technological processes and manufacturing systems according to production configuration;
- Formation of consolidated schedule of assembly production program, which includes products assembly schedules, including phases of transportation, storage and other auxiliary processes;
- Implementation of dynamic simulation and visualization of production processes as a set of conditions of product electronic models and models of elements of manufacturing systems, generated according to scale of timeline (Fig. 3);
- Calculation and analysis of production efficiency parameters for individual phases and time period at all. In case of identifying inefficient decisions forming a set of changes in model components and repeating simulation process.

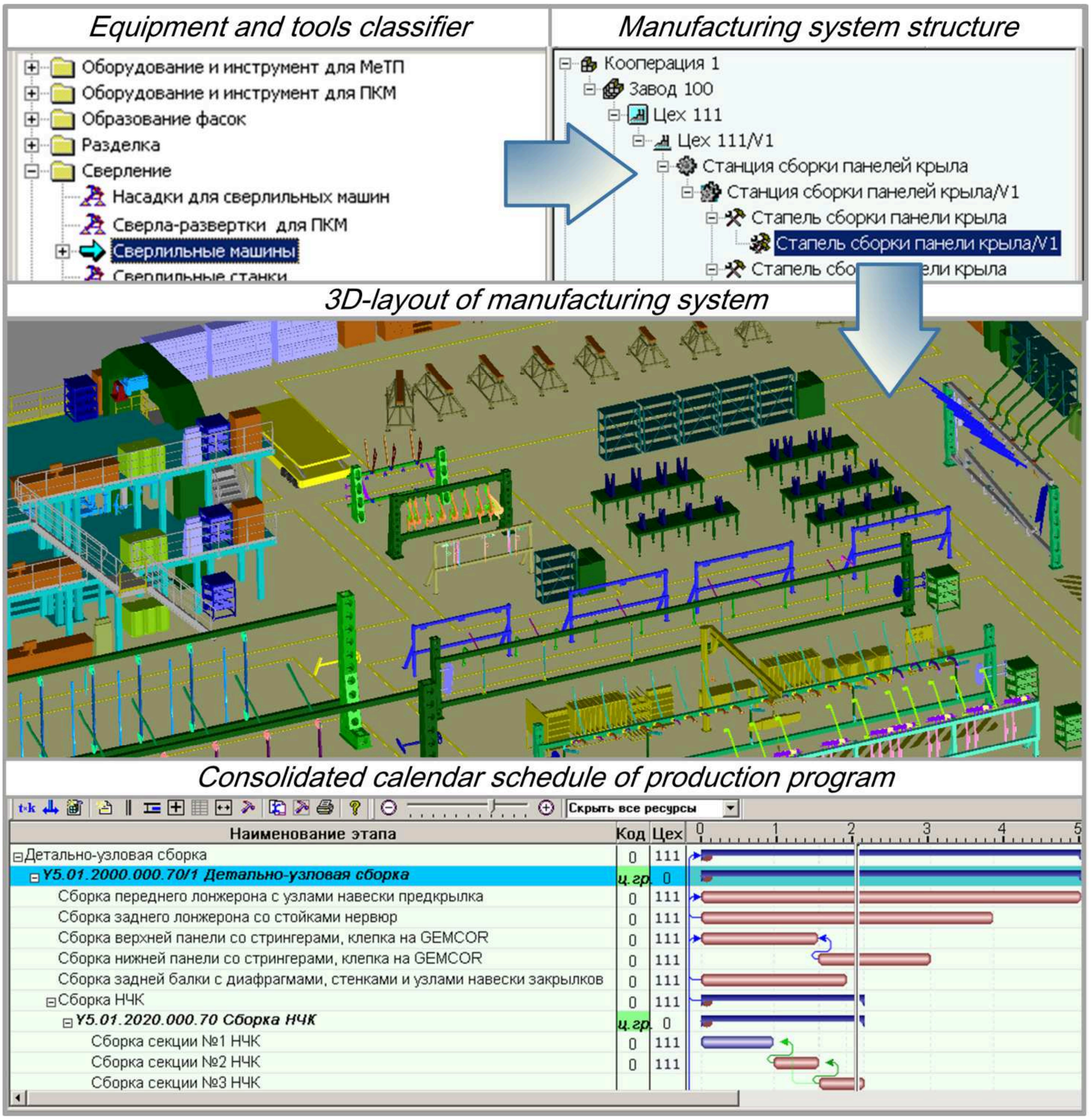

Fig.3. Assembly production simulation model.

Development and optimization of assembly implemented by integrated software-information complex of construction-technology development which includes:

- Software products of "Siemens PLM Software" to develop and manage different engineering bill of material (EBOM) and MBOM taking into account configuration rules; centralized storage of normative and reference data; storage of technology processes models, created by different CAM (CAPP)-systems; design of top level of technology process; design of detail manufacturing processes using a special "Teamcenter" applications;
- Software modules of Russian system "ТеМП" to develop technology processes and electronic assembly schedules using product electronic models and models of production environment created in NX-Teamcenter environment as initial data.

Integrated software and methodical complex is now using to develop a prescriptive technology of assembly of schort- and medium range aircraft MS-21, as well as to develop operating assembly technology on serial plants.

Copyright Statement

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