System for managing common information space of a machinery production enterprise

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Abstract. A structure of management system for a Common Information Space of engineering manufacturer is proposed. The system features adaptive tuning capabilities.

Keywords — management system, common information space, design and production model, controller, algorithm

I. Introduction

The present-day machinery production is characterized by high complexity and research intensity of the products produced in small lots. Furthermore, the duration of production cycle shall be minimal, and the quality of the products shall be high in order to preserve a competitive edge of the manufacturer. These requirements drive the need to use the well-known systems of the CAD/CAM/CAE, PDM/PLM, ERP, MES class and other CALS technologies, that have a fairly efficient and proven functionality in automating the products life cycle. The standards for integrating information resources and establishing open systems make it possible to form a Common Information Space (CIS) of an enterprise, providing powerful capabilities for accumulating and exchanging information between participants in the design and manufacturing processes. The use of open systems technologies makes it possible to expand the scope of management, to make provisions in the information space not only for the operational and tactical management of the enterprise, but to reach the strategic level as well.

In view of the fact that it is the CIS that contains the knowledge required for making the management decisions, and it reflects product life cycle events, the development of a CIS managing system, which enables enterprise management via managing its CIS evolution, seems to be fairly promising.

At present, various CIS management models are being proposed:

- Networking model based on systems approach, which makes it possible to set up an efficient structure for organization and interfaces between subsystems and network elements;
- IRP (Informational Resources Planning) – information portal of the enterprise, the main function of which is to manage information resources of the enterprise;
- Involving the use of artificial intelligence, making it possible to take into account various factors;
- Establishment of multi-agent architecture, enabling development of protocols for data exchange between its components in order to construct proper mechanisms for information management;
- and others. [1-5]
Present-day technologies of integrating automated systems for machinery production enterprise management are implemented in many systems for engineering data management (PDM-systems) and resource planning systems (ERP-systems), and are also described in the current international and Russian standards.

These approaches, as a rule, are designed to form either technical or structural (modeling) components of the CIS. The lack of a systems analysis of this subject causes difficulties in introducing the CIS to the enterprise, in its adaptation and integration of all applied programs constituting this space.

To address these problems, ref. [6-7] provides design and production systems model of CIS for product life cycle support based on its self-organization taking into account the specifics of machinery production.

This work is the continuation of studies into CIS and is dedicated to the development of the CIS management algorithm using design and production systems model of management based on the CIS restructuring and intended for making managerial decisions. Also proposed is a structure for a management system implementing the operation of the algorithm.

II. Design and production model of the CIS

The project development process at machinery production enterprises is characterized by the fact that the earlier phases of the project, as opposed to the later phases, are characterized by a higher degree of uncertainty, diversity of implementation options, the number of possible alternatives, higher entropy (randomness, disorder, large number of errors and changes). [8] As the phases of building a physical prototype and starting the product production approach, the uncertainty, the number of options and alternatives, and, along with them, the number of errors and changes must be minimized.

Despite all known achievements in math simulation, development of a complex engineering project occurs in the form of consecutive iterations, which involve repeated backtracking and partial repeat of earlier stages. Most of the changes affecting the quality of design work have to do with human factor (errors by developers and project customers, changes in the design inputs, appearance of new technologies, etc.). In the course of its development the project has to pass through some ‘quality gates’, the passage through which involves some checks to make sure it meets certain criteria. Failure to meet these criteria results in the project being returned to an earlier phase.

Conceptually, the ‘quality gates’ are established when:

- the project concept is being established and evaluated,
- feasibility is being assessed from the standpoint of achieving the required efficiency targets,
- conformity to the requirements of the project feasibility study is being evaluated,
- the project is feasible from the standpoint of manufacturability, production capacity, serialization. [5, 9-10]

According to the new technologies, all the information (models, drawings, documentation, etc.) generated during various design phases is to be sent, stored and processed in the enterprise CIS, within the framework of which the work is parallelized. The iterative process of project development is reflected in the changes in the amounts of information that is being stored and processed. Flows of transactions, updating and supplementing the project (design and technology knowledge network), make it possible to generate a large number of executions, dynamics of which could be described in the form of a decaying oscillation:

$$I_i(t) = A_{0i} \cdot e^{-\lambda t} \cdot \sin(\omega t + \varphi_0) + F_i,$$  \hspace{1cm} (1)

where:

- $I_i$ is the i-th of the overall number $N$ design and manufacturing documentation package, sent to the shop floor (equivalent execution);
- $A_{0i}$ is the maximum number of equivalent executions obtained during the project development;
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\( k_i \) is the design process inertness factor which characterizes the CIS response to changes in the amount of the design and manufacturing documentation, as well as to the innovative solutions (appearance of new knowledge or discovery of relationships);

\( \omega_{0i} \) is the solution provenness factor, which characterizes the number of iterations during design product development;

\( F_i \) are the results of the design manufacturing preparation activities (documents, models, drawings, etc.)

The process of changes in the numbers of executions looks as follows (Fig. 1).

Figure 1  Reduction in the project uncertainty by the start of production

This model is based on network representation of results of the design and manufacturing preparations for production, the evolution of which is shown as oscillating response (1) to new design data. [5]

Since the key parameters characterizing CIS oscillations are \( \omega_{0i} \) and \( k_i \), their adaptive correction will provide the required CIS organization, in which new information coming from the designer and the production engineer results in the CIS restructuring, under which is meant a reduction in the amount of information through creation of modules. Changes in the inputs to business processes \( F_i(t) \) using feedback will enable the CIS management. [11-13]

Such management of the design and production model needs to be based on the data about the current oscillations \( I_\Sigma \), reflecting changes in the business processes of the enterprise, manufacturing processes and document flow.

III.  CIS management algorithm

We will build CIS management of the machinery production enterprise on the basis of the identification adaptive synthesis method for the management systems. In so doing, the controller tunings are adapted after identification of parameters of the design and production integrated system model of CIS and based on their assessment. In order to satisfy the quasi-stationary principle for the time spent for identification of the integrated CIS system model and correction of the controller parameters should be significantly less as opposed to the time of the project implementation.

The beginning of the algorithm performance (Fig. 2) is a design process (development of design and process documentation), which final results (equivalent executions) are put into CIS (an increase in the number of equivalent executions appears). A part of the intermediate information generated and used in the design process is converted into the final one, the other part is transferred to the archive or deleted, i.e. the information content in CIS is reduced to a certain insufficient level. Therefore, some oscillations in CIS appear.[14]

Oscillations \( I_\Sigma \) in the algorithm are analyzed on the basis of solution of the equation (1). A high amplitude of oscillations \( I_\Sigma \) not leading to swinging makes it possible to explore the market, attract new customers, start production of completely new products. [15] A low amplitude of oscillations \( I_\Sigma \) describes the production configuration for manufacturing customized products. In this case, level \( I_i \)
does not change drastically, oscillations in CIS are insignificant, and there is no need to reconfigure the production.

The adaptive system tuning is implemented by correcting parameters $k_i$ and $\omega_0$ through balancing the archive and changing the CIS structure (restructuring). To restructure CIS the author-developed configuration subsystem for production process (PP) representation structure is used.[16]

The CIS management is performed through a change of input actions $F_i$, i.e., modification of business processes based on their analysis.

**Figure 2** CIS management analysis based on the design-production system model

**IV. Synthesis of CIS management system**

For synthesizing the CIS management system structure, it is necessary to define the production meaning of the system components: define the system inputs and outputs, establish control actions, feedback, etc.

CIS contains information which is generated and then used in various phases of the product life cycle (PLC). Let us consider a phase of design and engineering preparation of the production, in which the CIS information platform is generated (based on the PDM-system). In this phase a large number of design and engineering documentation is developed, one part of which is used in this phase (within CD and CIE departments), and another part being a result of designers and product engineers activities is transferred to the production. [17-18]

Disturbance effects $F(t)$ are input to CIS, which are associated with initial information (events and data) external to CIS received from other departments, as well as any other results of the design and engineering preparation of production in the form of:

- Internal application for execution of works;
- Preliminary design;
- Technical design and detailed design which include technical datasheet, drawings of parts, basic assembly drawings, specifications;
- Support equipment certificate;
- List of materials;
- Process flow charts for products;
- Business plan for introduction of new technologies;
- Pre-production schedules;
- Application for manufacture of equipment;
- Enterprise standards (EST) and regulations;
- Structure assembly and welding documentation;
- Documentation for provision of metallic structures;
- Tasks of CDD for designing support equipment;
- Software for numerically controlled machinery;
- Documentation on development of generic PP;
- Documentation on development machining and assembly PP;
- Task for designing non-standard equipment;
- PP expert report;
- Other documents.

The CIS output is an indicator of volume of design and process documentation expressed as a number of equivalent executions \( I \), which is taken to mean a working design and process documentation, i.e. the information which is forwarded directly to the production, for example

- Working design: drawings of parts and assembly units, technical datasheet, specifications;
- Materials lists;
- Flow process chart;
- Equipment certificate;
- Other working documents.

Based on this documentation CIS forms a set of documents, which title contains the name of a product to be manufactured and a code of the current project. This set has a tree-type structure, in which the structure objects are allocated to appropriate classes. In other words, CIS stores a certain amount of elements of sets making up the content of parameter \( I \).

Let us consider the structure of management system for CIS with regard to its adaptive unit (Fig. 3). It contains a controller element \( W_{PEF} \) and a delay element \( W_3 = e^{-s \tau} \), reflecting a period of time required for making decisions about CIS management.

The transfer function of CIS according to equation (1) is as follows:

\[
W_{LML}(s) = \frac{I_i(s)}{F_i(s)} = \frac{k_w}{T_i^2 s^2 + 2sT_i + 1}
\]  

(2)

where \( T_i = \frac{k_0}{\omega_0} \); \( k_w = \frac{1}{\omega_0} \); \( \tau = \frac{2k}{\omega_0} \).

To satisfy the specified criteria of management quality, let us select a controller. The analysis showed that the most common type of controller is a PID controller, which transfer function is given by:

\[
W_{PEF}(s) = k_p (1 + T_d s + \frac{1}{T_i s})
\]  

(3)

By means of the conjugate gradient method the controller tuning parameters were calculated. The PID-controller function is performed by the system administrator responsible for CIS operation; a
product engineer keeping track of the information integrity makes a decision about archiving the information; a business process control manager makes a decision about changing a specific job or a business process as a whole. [19-20] A proportional controller element makes it possible to send a part of information directly into CIS, and then to the production. An integral element of the controller is responsible for accumulation of information (control of transactions in the database log), which is later can be restructured. A differential element makes it possible to pre-define the configuration and structure of CIS (semantic network). Parameter \( k_p \) of PID-controller defines a part of the total amount of information equal to 2.3% which is to be integrated into CIS as soon as available, thereby to ensure its stable performance. Parameter \( T_i \) shows the time during which the information shall be supplied in advance in order to set the basic structure of CIS. Parameter \( T_i \) determines an information delay (accumulation) time in order to avoid the system overload and failure.

Each new project entering CIS requires the controller retuning, so that oscillation parameters in CIS do not exceed the prescribed requirements, and the management system meets the specified quality criteria. This is due to the different labor content in different projects, and therefore different \( A_{0i}, k_i, \omega_{0i}, \varphi_{0i} \) in the solution (1).

The adaptation unit is implemented by two algorithms:
1. Approximation and identification algorithm for parameters \( k_o, T_i, \xi, \tau \) (Fig. 3);
2. Adaptive tuning algorithm for controller parameters \( k_p, T_p, T_i \) (Fig. 3).

The first algorithm is implemented by the method of coordinate descent with minimization of parameters using method of parabolas. The second algorithm assumes the use of the conjugate gradient method for adaptive tuning of the controller parameters.

The adaptive tuning of the controller starts with the development of a new project characterized by its values of parameters \( k_o, \omega_{0i}, A_0, \varphi_i \).

The time of adaptive tuning is subject to the execution time of a new project. Specialists using a software package developed in the thesis research and implemented in the early phases of CIS generation are considered as a controller. However, the adaptation time depends on: the length, complexity and labor intensity of the project, volume of existing designs, degree of formalization of the order, nature of the order and work with the customer, degree of order configurability, degree of CIS modularity. [21-22] Therefore, the overall time of adaptive tuning consists of time to retune the controller and time to change each specified indicator if it shall and can be changed. According to the requirements of the enterprise the time of adaptive tuning shall not exceed 20% of the total project execution time.

V. Conclusions

Therefore, the paper presents CIS evolution control algorithms based on the implementation of the design and production system model of the research and production enterprise by means of present-day management systems for engineering data and product life cycle. The results of work can be used to solve the following problems: organization of enterprise CIS, implementation of the management system for engineering data and product life cycle (PLC), integration of CAD (computer aided design, automated design preparation of production)/CAM (computer aided manufacturing, automated manufacturing preparation) system and PDM-system.

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