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INFORMATION TECHNOLOGY OF GENERALIZED MODEL CREATION OF COMPLEX TECHNICAL OBJECTS

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Abstract. The paper introduces a knowledge representation framework for design and geometrical modelling of complex technical objects such as ships, aircrafts, cars, etc. The design process cannot be fully automated yet because of a lot of technical and economical factors that influence the decisions during that process. In order to make the process more efficient, a knowledge modelling framework is suggested. The basic principles of conceptual knowledge modelling and data exchange framework are presented. A practical use case of aircraft ramp modelling is provided.

Keywords: Knowledge base, geometric model, managing parametric model

1 INTRODUCTION

Aircraft creation process is very complicated and important. Now the aircraft models are almost not linked and the geometric models connections between different design stages are also almost absent. Knowledge-based approach of aircraft geometrical modelling is trying to decide these problems. Tasks and features of the knowledge-based systems adoption in aircraft geometric models creation are described. In this article a knowledge-based approach of aircraft geometrical modelling is represented. Also the knowledge-based approach modification for parametric information control of aircraft geometrical modelling and the modification for data transferring of aircraft geometrical modelling are shown. Realization of the knowledge-based approach of aircraft geometrical modelling and its estimation are made. The task of any complex technical object creation (CTO), which is characterized by a large quantity of elements and different links, is the development of chart, structure and construction of the future CTO and constituents of its elements, which must provide at certain limitations the most effective performance of the put goals. Fully automated process of CTO creation is impossible, because of a lot of factors, as technical and economic, influence on decisions, which are adopted in this process. The main task of information technology adoption in the process of CTO creation is the best possible simplification of operations by automation of the most possible number of CTO creation tasks. This task is resolved by the development of generalized model of CTO and knowledge-based modelling approach of CTO.

1.1 The Main Problems of Modern Complex Technical Object Creation Process

Modern complex technical objects, which are characterized by a large quantity of elements and different links (ships, aircrafts, space techniques, cars, etc.), are created using such information technology (IT) as continuous acquisition and life cycle support (CALS), which includes the main information systems (IS): product lifecycle management (PLM) and computer-aided systems (CAx). Different models of CTO describe the relationships between CTO parameters and its characteristics [1]. Modern CTO creation includes following main stages: requirements specification (RS) and draft proposal (DP), master-geometry model (MGM, conceptual design), objects allocation model (OAM, preliminary design) and complete product definition model (CPDM, detail design) [2, 3]. Compliance of the classic CTO creation process and modern CTO modelling using IT are represented in Figure 1. Over

75 % of the basic technical and organizational solutions for the project are taken at the conceptual and preliminary design stages at costs up to 20 % of time and 10 % of the funds [1, 3, 4].

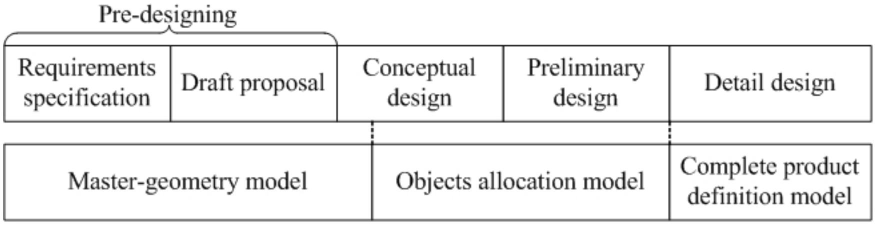


Figure 1. Compliance of the classic CTO creation and modern modelling

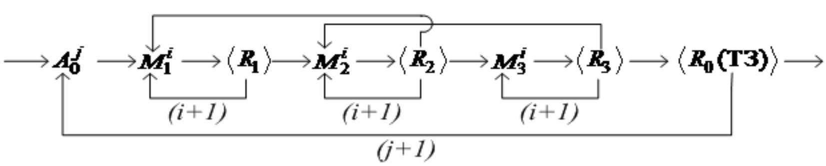
The level of structural synthesis problem complexity applied to CTO creation is very difficult. Effective solution of these problems is only possible when using CALS. However, CALS usage focuses on formalized statement of the structural synthesis problem. The basis of such formalized statement is the formulation of structural synthesis problem as a mathematical problem of design decisions making (DDM) as follows [5]:

$$DDM = \langle A, C, M, R \rangle$$

where

- A – alternatives set of design making;
- $C = (C1, C2, \dots, C)$ – criteria set (initial parameters), which evaluated alternative compliance goals;
- M – model, which allows for each alternative to calculate the criteria vector;
- R – decision rule for selecting a suitable alternative to multi situations.

The developed process of CTO creation can be represented as the following generalized iterative procedure:



where:

- A_0 – initial design data (pre-designing),
- M_i – models: MGM(M_1), OAM(M_2) and CPDM(M_3),
- $(i + 1)$ – new (changed) parameters, design updating, appearing on the results of the next design stages, can then be modified in the previous stages.

Any model on different stages is possible to present as:

$$M_i = \sum_{i=1}^{N} m_i$$

where:

- m_i are the components of the appropriate design stage,
- N are the models set.

The main problems of modern complex technical object creation process are:

1. CTO models include parts and assembly units created by CAx and PLM systems and often contain many expressions between components, references, restrictions, etc., and that requires a detailed description of the process of CTO creation.
2. CTO models at various stages of CTO creation are not linked. That is, if there are changes in the components of models at the early design stages, these changes do not appear in the detail design stage of CTO creation.
3. Described various CTO models are actually unrelated in the process of CTO creation with the use of CAx and PLM systems. Many data in general remain beyond a joint project of CTO development.
4. CTO creation involves many disciplines and communication between different units. As for design techniques and tools, it is desirable that the design takes place in parallel with further manufacturing and assembly, which is currently extremely difficult, exhausting and almost unrelated procedure due to weak production automation that prevents the use of the process of CTO models.
5. CTO models creation is also using different systems CAx and PLM, which creates a constant difficulty of data converting from one software to another and leads to a partial or complete loss of generalized model components, its history, topology and parameters. To reduce the time-to-market and to minimize errors when displaying CTO models, new approaches must be applied in data transferring between different systems CAx and PLM. Delays in setting up controversial issues when exchanging data will cause many recycles in CTO creation and thus causing a significant delay in the project schedule.

Considering these problems, the relevant scientific and practical task of work follows – to research and develop the generalized model of CTO, which is able to solve the task of different models links on different stages of CTO creation lifecycle, and to develop the knowledge-based modelling framework of CTO based on the developed generalized model.

2 TASKS AND FEATURES OF THE KNOWLEDGE BASED SYSTEMS ADOPTION IN AIRCRAFT GEOMETRIC MODELS CREATION

The generalized model of CTO contains the main CTO models from different IS of CALS at the different CTO creation lifecycle; this is researched, developed and presented as:

$$MGM = \{MG, MW, MA, MAA, MS, MPP, MT, ME\}$$

where the following models appear: geometrical; weight; aerodynamic; arranging and alignment; strength; power plant; manufacturability; economical, respectively. Any model contains the common information with other models and owner information. Any component of the models is described by owner set of parameters and can be represented as:

$$m_i = f(P_i)$$

where P_i – models parameters: $P_i = \sum_{i=1}^{N} p_i$.

The generalized model of CTO component can be represented as:

$$m_{GM} = f^i(p_i,\ i = 1, \dots n).$$

$m_{GM} = (m_1, \dots, m_n)$ – is a vector of parts of CTO generalized model of component creation, any of them contains the defined restrictions (geometrical; weight; manufacturability, etc.) depending on parameter type, $m_i \in M_i$.

The aim of work is formulated as the definition on the permissible set of decision variants, which are described by restrictions of such variants so that the optimality criterion (objective function or functional), which defines the decision quality, accepts the extreme value:

$$F^* = extr_{P_n \in E_k(m_{GM})} F(P_n)$$

where $E_k(m_{GM})$ – parameters efficiency criteria $m_{GM} \in M_{GM}$.

Systems of restrictions looks like:

$$\left\{ \begin{array}{l} E_1(m_{GM}) \geq 0 \\ E_2(m_{GM}) \geq 0 \\ \vdots \\ E_n(m_{GM}) \geq 0 \end{array} \right\}.$$

In particular, the inequality of the system $E_1(m_{GM})$ has a geometrical character; CTO creation specific puts also restrictions: $E_2(m_{GM})$ – alignment; $E_3(m_{GM})$ – CTO weight; $E_4(m_{GM})$ – by external influences on the development area (mechanical, climate, etc.), equipment compatibility; $E_5(m_{GM})$ – implementation of manufacturability requirements, which are the interlink between CTO design and manufacture, etc. Acceptable level of $E_k(m_{GM})$ makes mention of some normative document, CTO creation requirements, RS, etc. Knowledge-based modelling approach is a basis for IT development. Developed approach supplements and extends the current methods of CTO creation using IT and defines the main design stages of the knowledge-based system (KBS) adoption in CTO models building process. The development of engineering knowledge project management (Managing Engineering Knowledge, MOKA) had tremendous significance in the decision of knowledge representation problem in CTO creation [6]. In the project of MOKA, the unified modelling language was used for knowledge representation. The area of the knowledge using comes into question very often; some researchers assume that any object can be represented as area of knowledge. Other works conflict with this principle [7] and suggest to build small areas which are easier to support. But in any case, each researcher realizes the importance of the knowledge using in CTO creation.

Theory and practice of the creation and use of KBS is the most actual direction of computer sciences that has been intensively developing. Using the results promotes efficiency of creation of tools, application systems and computers application. At work KBS is included for combination of such main CTO creation processes (Figure 2).

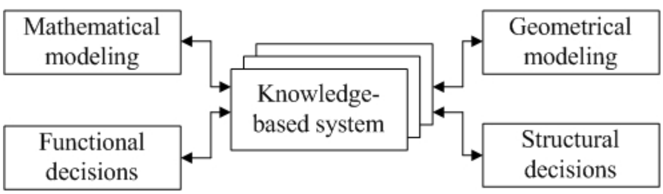


Figure 2. Place of the knowledge based system in CTO design

On the existing stage of development of CAx and PLM systems the main interest lies in the use of the knowledge in CTO creation, which would allow a subsequent perfection of the process of CTO creation, and this process can be named knowledge based modelling of CTO – it includes the use of suitable software for acquisition and reusing the knowledge in CTO creation by the most possible complex approach. The tasks which are executed by traditional methods, mainly, do not cause unexpected problems, but they are tiresome and by such approach labor intensive and expensive (from the economic point of view). According to Stokes [6], the percentage of time spent on the conservative jobs processing at CTO creation is approximately 80 %.

KBS adoption in the process of CTO GM creation is related to reusing the knowledge that comes from previous developments. Developing the approach of KBS adoption in CTO creation allows to solve the following tasks: to describe the process of CTO creation in details, to apply the modern KBS; to create the links of GM on the different stages of CTO creation; to link GM with other CTO models; to apply new approaches at data transferring between different CAx and PLM systems. For the effective solution of the listed tasks it is necessary to analyze the main features of subject domain of CTO creation and to develop a feasible approach and facilities for implementation of automation in this area [8]. Extended tasks of KBS adoption in the process of CTO creation are shown in Figure 3.

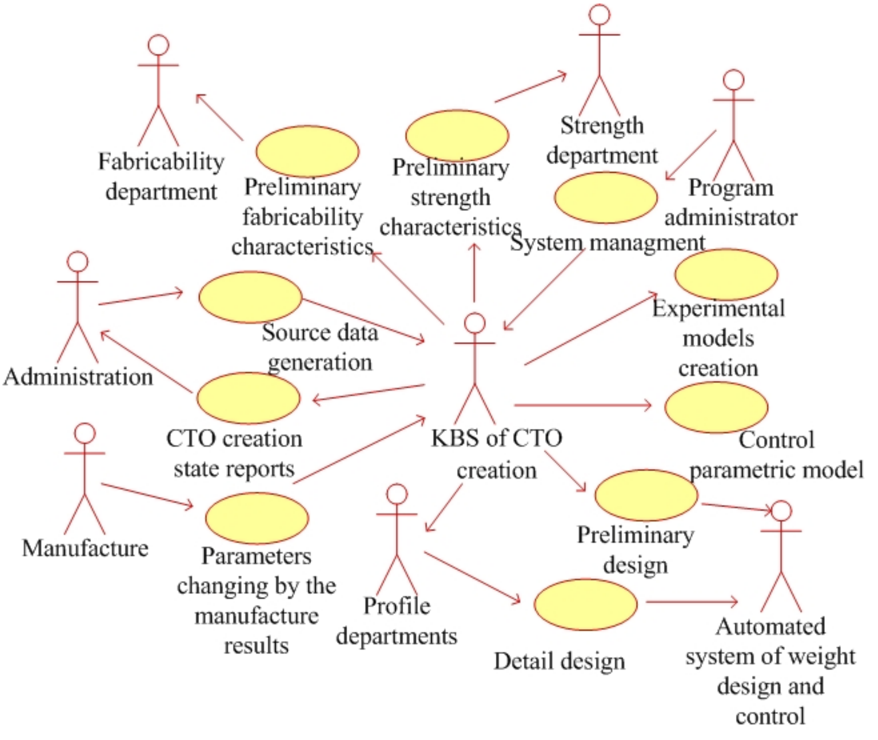


Figure 3. Tasks of KBS adoption in the process of CTO creation

The approach of KBS adoption in CTO creation and the subsequent modification of the approach are designed – to manage parametric information; to exchange the data. Let us analyse the use of knowledge in modern systems CALS order to ensure feasibility of KBS adoption in the process of CTO creation. Consider the examples of knowledge using in the most popular systems CAx at a high level. Pro/ENGINEER or PTC Creo system from PTC Company contains elements of knowledge to use standardized conceptual design and has the libraries: library of standard two-dimensional layouts; library of standard three-dimensional layouts; library of standard drafts, separate components, standard design solutions [9]. CATIA, ENOVIA and DELMIA systems from the Dassault Systèmes Company allow to maintain the enterprise rules-based design and knowledge reuse. Controlled methodology that uses skeletal geometry allows a quick changing of specifications and knowledge reuse [10]. The module "Knowledgeware" has the following most important sub-modules: knowledge adviser; knowledge expert; knowledge of product template; business process knowledge template. NX system from Siemens PLM Software Company is built on knowledge architecture that provides unlimited opportunities for the application in the knowledge process design and experience gained by company or industrial "know-how" [11]. The system raises the design process to another level with the DesignLogic technology, which manages the product using the embodied knowledge in the form of functions and formulas, associative dimensions and links. All the above listed elements of knowledge using contained in various CAx systems have significant disadvantages – for instance the knowledge used in the existing CAx attached directly to the system makes it impossible to use the universal knowledge base in different CAx.

3 KNOWLEDGE-BASED MODELLING FRAMEWORK

3.1 Conceptual Modelling

Considering tasks which stand before the developer of methods and facilities of KBS adoption in the process of CTO creation, it is possible to define the features of their structure and functioning. The analysis of subject domain is the special type of scientific activity. The result of analysis of a subject domain is built of interpretation model of the subject knowledge [13]. CTO creation efficiency is largely conditioned using system approach like its constituents, and as systems engineering and systems analysis (SA). Methods of SA are the basis of CASE-technology (Computer-Aided Software Engineering, automation of processes of planning and software development). Methods of SA are described by the series of IDEF standards of ICAM (Integrated Computer-Aided Manufacturing) DEFinition [IDEF], which are used for task decision making on the design of difficult systems. For example, IDEF5 is standard of KBS (ontological research of the difficult systems) [14]. By IDEF5 methodology, the ontology of the system can be described by the certain dictionary of terms and rules on the basis of which the reliable assertions about the state of this system can be formed in some moment of time. By the opinion of specialists of SA area [15, 16], for the decision of analysis tasks and planning of some object there are designed: functions of this object, for example, by the diagrams of data flows – Data Flow Diagram (DFD); relation between data which are used in object, for example, by diagrams "essence-connection" of Entity-Relations Diagram (ERD); behavior of the object (event), for example, using Activity diagrams. The functions (processes), depositories of data and streams which link them, are represented by DFD. Presentation of object functions, as a rule, occurs at a few levels of detailing, and the content of the processes shown at previous level is opened up at every next level. In Figure 4, the context DFD of KBS adoption in CTO creation is represented.

The built DFD allows defining the basic stages of work on KBS adoption in the process of CTO creation, and also basic types of data sets with which work

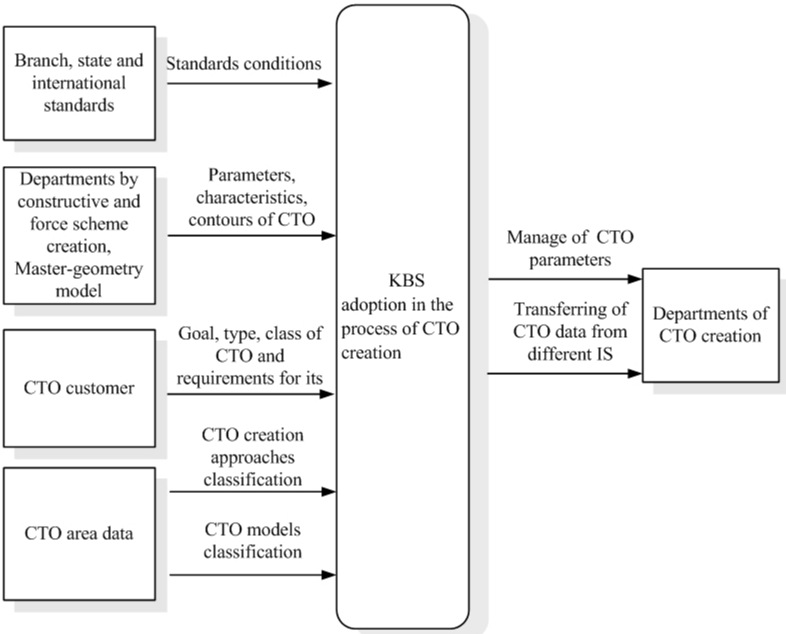


Figure 4. The context DFD of KBS adoption in the process of CTO creation

will be in the process of functioning of the system: parameters; output data and results of GM creation; terms of classifications, correlations, rules of interpretation, norms, and requirements of standards. Entity-Relationship Diagram is intended for development of data models and provides the standard approach of determination of relations between them. These KBS of CTO creation are organized in three structures: knowledge base (KB), that contains the terms from the CTO area, connections between them, rules which establish order of the terms interpretation, application of knowledge from a knowledge base, conditions of calculations, concordance with the requirements of standards; database (DB), that contains files of CTO creation, results of calculations, different service information located in PLM system [17]; file DB contains parameters for CTO creation determination. In Figure 5, ERD of the main data sets of KBS of CTO creation is represented.

Analyzing the main tasks, requirements, features of functioning and order of implementation of operations of CTO creation, it is possible to formulate the general features of KBS adoption of CTO creation: work with large data sets; iteration character of CTO creation on the different stages of GM creation; CTO modelling realization by different methods, the choice of which depends on a type, configuration and parameters of CTO; the necessity of selection and use of separate parameters and characteristics of CTO creation which will be used from previous stages of CTO

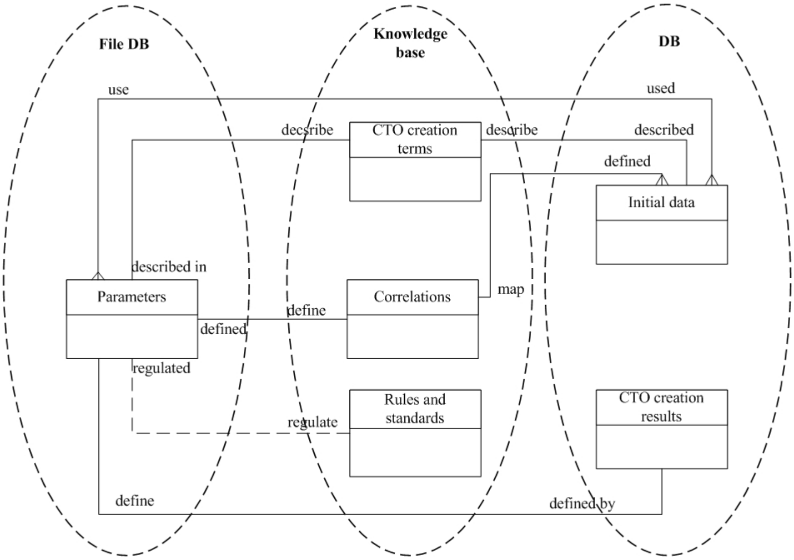


Figure 5. The context DFD of KBS adoption in the process of CTO creation

creation and finishing the CTO production; necessity of providing a connection between different CTO models.

3.2 Parametric Information Control

Control parametric model (CPM) is the aggregate of basic data which is the basis for CTO creation at any stage, and it is a hierarchical structure in CAx/PLM system. CPM is the base of technical information in an electronic view, on the basis of which development of CTO is conducted in accordance with thematic directions of the CTO project [18]. The geometry, which is passed from the previous stage of CTO creation – master-geometry model is used at CPM building. CPM is the aggregate of geometrical elements which are used in the process of GM creation. CPM differs from GM, which is the typical result of the CAx system, and the universal presentation of CTO. CPM is built by rules which determinate the project and are the basis for GM (Figure 6).

Approach modification for parametric information control (Figure 7 as the activity diagram) provides for creation of the interconnection of CTO models development stages.

3.3 Data Transferring

Disadvantages arise while creating CTO in different IS CAx. Most of them are connected with the exchange of data from different models. Further, it proposes

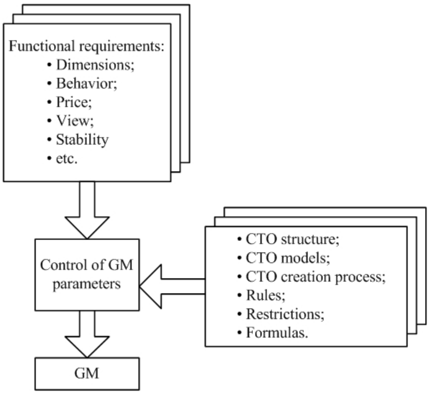


Figure 6. Control of generalized model parameters

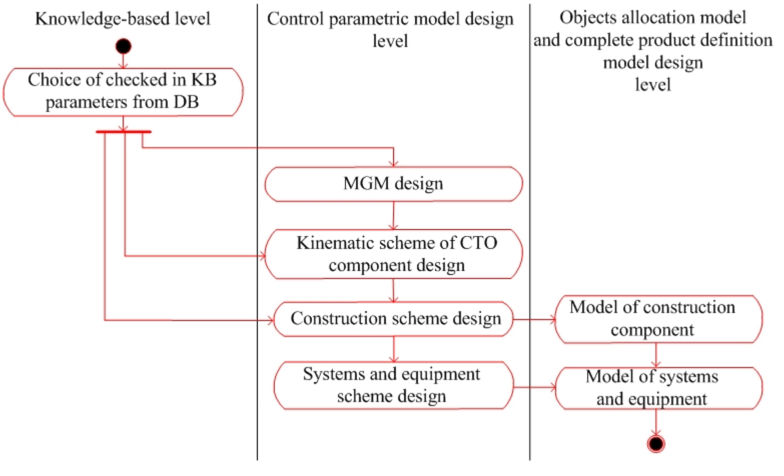


Figure 7. Approach modification for parametric information control

that a knowledge-based approach in communicating CTO models is created in different IS CAx by developing a modification of the knowledge-based modelling approach. Data exchange between CAx-systems is mainly using translators to facilitate the exchange between models from CAx-systems. Data loss during transmission leads to the fact that models transferred between different systems are incomplete. Available compilers developed for specific CAx-systems are expensive and not universal.

Neutral standards should provide a single interface to information applied software. The most used standards: Standard Generalized Markup Language; Computer Graphic Metafile; Initial Graphics Exchange Specification [19]; Standard for Exchange of Product model data [20]; STL format – Stereolithography. A software library for the programming language Javascript that allows to create Javascript interactive 3D-graphics, operating in a wide range of compatible web browsers (Mozilla Firefox, Google Chrome, Opera and Internet Explorer), supporting HTML, without the mediation of plug-ins, is distributed by the use of WebGL standard (based on OpenGL) [21]. And this standard has serious disadvantages: models are built using WebGL and are kept only in the format of STL, which is not supported by all CAx-systems; WebGL also contains many significant security problems, in particular, the arbitrary code execution and possible cross-domain attacks on models saved.

These data formats between different CAx-systems are capable of handling full set of information from different CAx-systems and transfer all the information about the models, including the history of building and constraints within it. A lot of different methods are described on how to implement data exchange between different CAx-systems, each of which has its advantages and disadvantages. General scheme of data exchange with models from different IS CAx using KBS is shown in Figure 8.

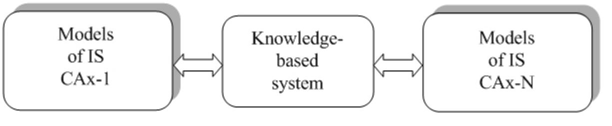


Figure 8. Data exchange with models from different IS CAx using KBS

Approach modification for data transferring from different IS CAx, using KBS is shown as the diagram of activity (Figure 9) [22].

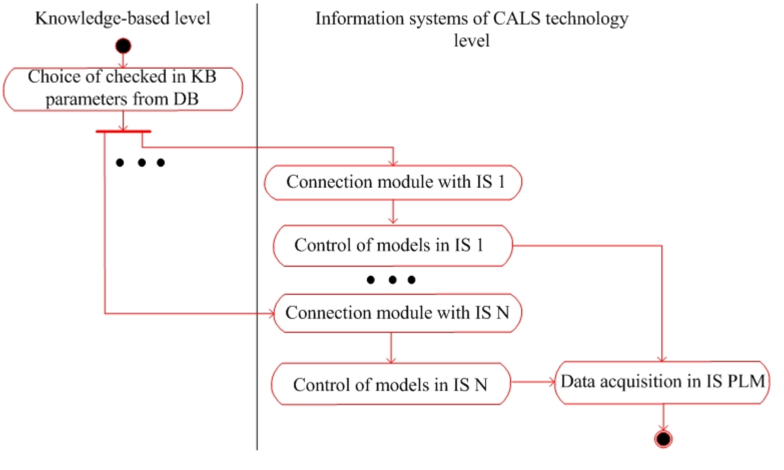


Figure 9. Approach modification for data transferring from IS CAx using KBS

4 USE CASE: KNOWLEDGE BASED ENGINEERING DESIGN

Based on the features development means of KBS, the CTO models creation is selected, with the main features of the development, and it identifies the main means of implementing the methods of implementation of KBS in CTO creation.

A variety of information which affects the decision to incorporate this information as well as to store data about the state of the system and to facilitate its management is processed. All this information should work together to create the knowledge base (KB), which includes a global information system as a whole and combines its separate parts.

The system must work with large amounts of data on GM parts and assembly units. A database should be developed for saving this information. From the set of data stored in the database, you can select entities, such as dimensions, limitations of CTO, etc. that have certain attributes and relationships with each other. Therefore, the development and implementation of the database (DB) can be made using the model "entity-relationship".

The multi-agent systems are used. Since the task and the process of CTO creation are closely linked, it is difficult to identify independently solvable subtasks that can be executed simultaneously regardless of the computer, so the use of intelligent agents in this case is not appropriate, however non-intelligent agents may be used.

Guided by the principles of client-server technology and structured approach, we logically choose the implementation of knowledge-based systems in the design of CTO structure of Web-based applications. There are distributed softwares that use the basic infrastructure of the Internet for communication between its components and standard tools navigation Web-browser – as the foundation for the user interface.

In work guided by the principles of visual programming, paradigms and tools are based on J2EE technologies.

The work shall be chosen by means of CALS technology adopted to implement the methods in the form of systems CAx and PLM.

Ontology of some industry knowledge, together with information about the properties of specific objects, can be called knowledge base (KB) [23]. The knowledge base chart of CTO creation process is shown in Figure 10.

CTO creation ontology is shown in Figure 11.

It describes the main connection and correlation between the main parts of the design process under development of CTO at the earliest design stages. DB chart "CTO models parameters" in the example of an aircraft is shown in Figure 12.

Ontology of CTO creation was built by the tools of Protègè 4.3 [28, 24], its connectivity and correctness was checked up by the instruments of this application. The functions of addition, change and verification of ontology are carried out by the application programs of this system, and also tools of the proper libraries of Java, Jena, Pellet. An ontological KB plays a key role in realization of the process of KBS

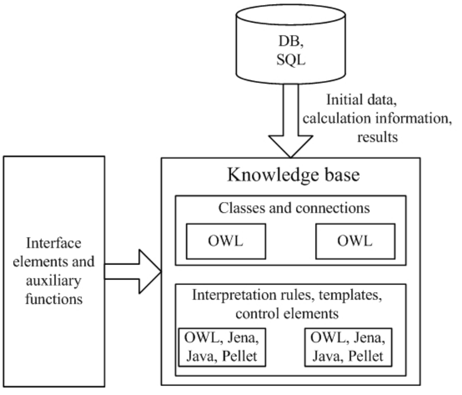


Figure 10. Knowledge base chart

adoption at CTO creation process. The KBS adoption in CTO components circuit is shown in Figure 13.

The components of KBS adoption in CTO creation are:

1. Module working with KB, DB and decision making: basic module system organizes the interaction of all its parts; it supplies the conduct of process designing, based on the data from KB and DB.
2. Module working with CAx systems: it organizes iteration plans and conducts designing steps by organization of connection with CAx systems, and subsequently, with PLM.
3. Information security module: it supplies the user identification and authentication; it organizes various types of access to KBS adoption in CTO creation process.

Figure 14 presents the data exchange from CPM to GM. In particular, something with the change of the aircraft ramp in DB makes automatically the changes coming from the kinematic scheme of CPM of the aircraft ramp.

Some authors [1, 25, 26] suggest that the average duration of the aircraft creation project cycle takes 6 years. It is important to bear in mind that this does not include the development, which is given for early configuration and market analysis. The duration of modelling is an important economic characteristic of CTO creation, because it often defines the general terms of product development, and that is, the speed of the project realization. Reduction of time determined by the entire lifecycle of CTO cannot be achieved by significantly increasing the productivity specialists – programmers, designers, production engineers, etc. Also, it is less dependent on the software being used. Adoption of new approaches of work organizing the CTO creation reduces significantly time for the CTO development, due to increase in the portion of transactions or components that are used repeatedly. According to [27], the impact of KBS on the main stages of CTO is very significant. Let us compare the

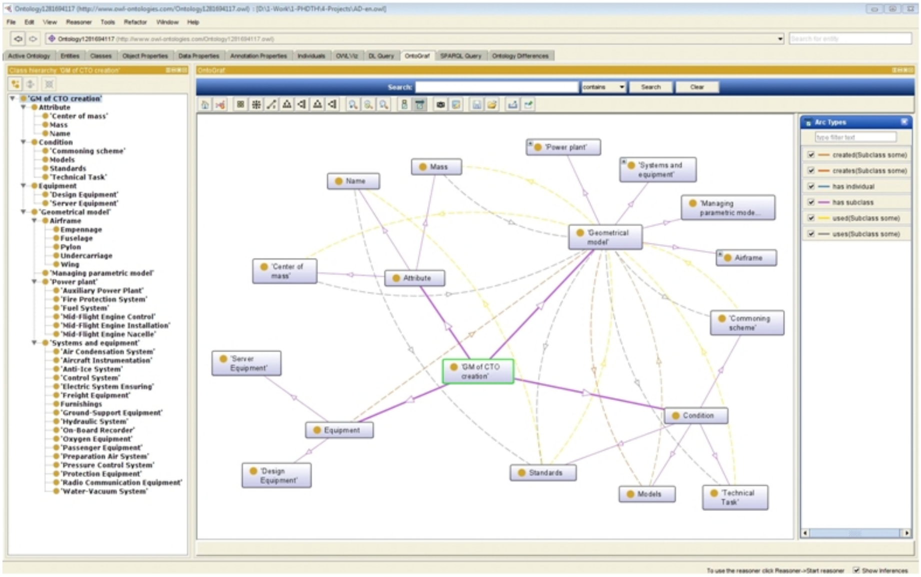


Figure 11. Ontology of CTO creation

average time of GM creation using CAx and PLM systems [1, 3] and the described KBS approach adoption of GM creation (Figure 15).

The time taken for CPM, DB and KB development, of course, is longer than the creation of MGM only, which CPM includes. Later, however, there is a significant time saving of CTO creation by reducing the duration of creating the next stages of CTO creation: SAM and CPDM. Knowledge-based modelling approach of CTO creation gives the freedom to design changes.

5 CONCLUSIONS

The tasks and features description of a complex technical object using knowledge based framework enables reliable and efficient linking of different models of CTO. The concept of CTO control parametric information was developed for the first time. Using this concept in the CTO design allows linking the various stages of design and linking together the design stage and the production of CTO by controlling the main parameters within a single CTO GM. Considering IT data exchange while creating GM in the different CAx-systems identified shortcomings of the existing methods and showed the approach of adoption of intellectualization of the exchange of data from different CAx-systems. An example of KBS adoption in CTO creation approach is presented in this paper.

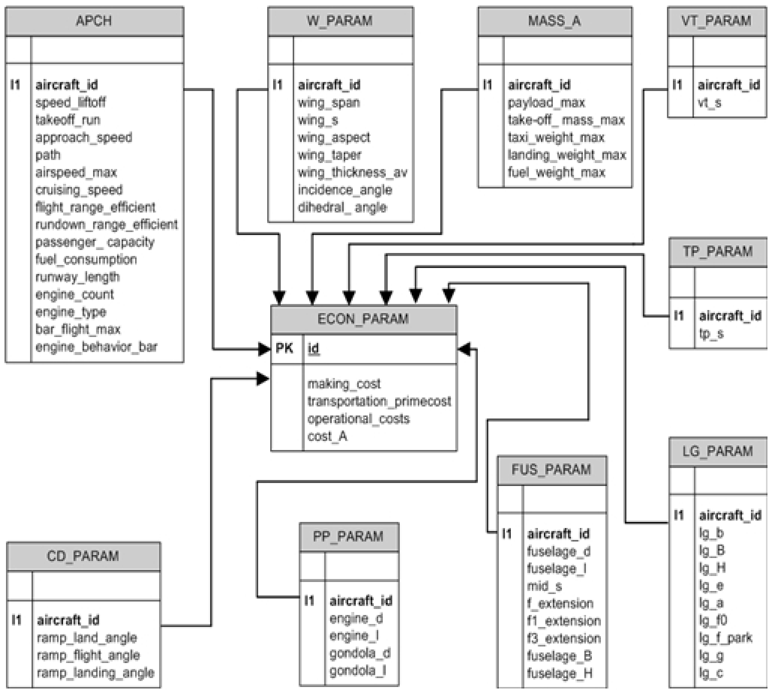


Figure 12. DB chart “CTO models parameters”

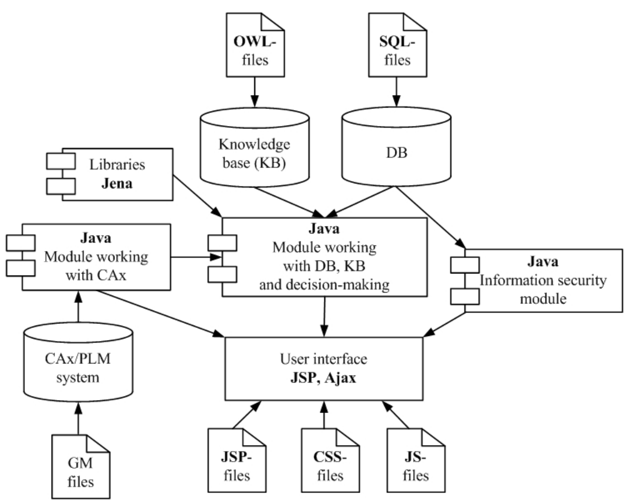


Figure 13. KBS adoption in CTO components circuit

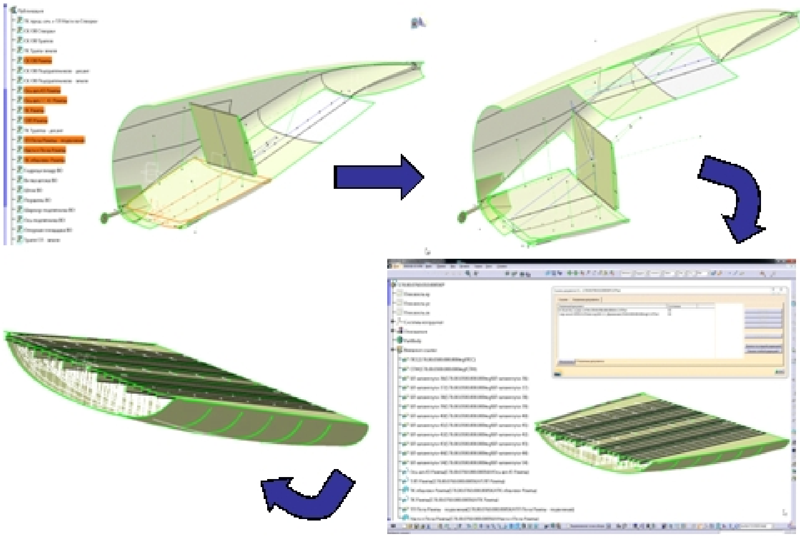


Figure 14. Data exchange from CPM to GM

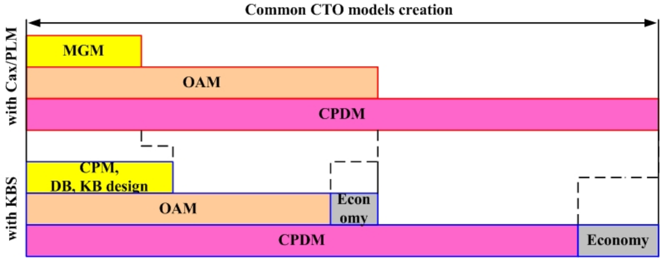


Figure 15. Comparing the average time of CTO creation using CAx, PLM systems and KBS

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