Methods Used to Support a Life Cycle of Complex Engineering Products

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Abstract. Management of companies involved in the design, development and operation of complex engineering products recognize the relevance of creating systems for product lifecycle management. A system of methods is proposed to support life cycles of complex engineering products, based on fuzzy set theory and hierarchical analysis. The system of methods serves to demonstrate the grounds for making strategic decisions in an environment of uncertainty, allows the use of expert knowledge, and provides interconnection of decisions at all phases of strategic management and all stages of a complex engineering product lifecycle.

1. Introduction

The process of product lifecycle management in complex engineering systems, associated with most challenging multistage production environments, is a prerequisite for good governance.

During each stage of the complex engineering product (CEP) life cycle (LC), a number of project-related conflicts occur, since project participants interact in an environment of incomplete information about the current and projected state of the related products. For solving this problem and eliminating contradictions between all project participants in the development of complex engineering products, Product Lifecycle Management systems are provided (PLMS) [1], [2].

Complex engineering products are developed in a variety of industries. For example, it is a nuclear power station in the electric power generating industry and the geohod [3] and other machinery in the mechanical engineering industry. Today in Russia, the issue relating to lifecycle management of complex engineering products becomes important and this importance is comprehensible. But experts have not arrived at consensus on means and tools for solving the problem. It is worth noting that not all Russian companies employ PLM systems in projecting and managing complex engineering products. Or they use similar tools only during certain stages of CEP LC. Thus, according to the research made by the Foundation Center for Strategic Research "North-West", less than 40% of the companies-respondents use software for product lifecycle management. The results, obtained during the market research among the companies that use specialized lifecycle management software [4], allow us to judge on a level of Product Lifecycle Management in Russian companies. Elements of the planning and developing processes are mostly often used (86%), as well as production or services (82%). Least of all companies are involved in implementing management tools for products' after-sales activities and products recycling (50% and 30% respectively). And only 18% of companies are associated with PLM fully involved [4].

Lifecycle management of complex engineering products is associated with certain difficulties. As a rule, any complex technical systems are characterized by long cycles in development, issues related to adaptability to manufacture, cost efficiency and technical risks [5]. When managing complex engineering products, it is necessary to solve a lot of ill-defined problems at different stages of the life cycle. Solving those problems requires the use of tools to support decision-making under conditions of high uncertainty, intelligent methods for information processing, and experts' involvement [6], [7]. There is a need for a set of tools to ensure the relationship of strategic decisions through all stages of CEP life cycles.

It should be noted that today the issues relating to LC strategic management is given insufficient attention, and existing PLM systems do not have the necessary set of tools to support the strategic level of complex engineering product lifecycle management.

There is no single platform developed with Russian specialists' involvement to address the issue of efficient systems to manage CEP LC. Commercial unavailability of specialized software designed to support the strategic level of complex engineering product lifecycle management may lead to the increased dependence of Russian software designers on solutions offered by foreign companies and producers of tools used to support individual LC processes while implementing complex systems.

Thus, an urgent need appears as to design and develop a system intended to support lifecycle management of complex engineering products in uncertain environments.

2. Survey of the existing PLM systems for complex engineering products

The results of researches show that Product Lifecycle Management (PLM) systems are most commonly used when dealing with related issues. For example, according to the market researches delivered by the Foundation Center for Strategic Research "North-West", the usage measured with regard to specialized software packages have been obtained as follows: PLM-systems - 40%; CAD / CAM / CAE systems - 17%, ERP-systems - 21%; 1S: Production management - 12%; in-house developments - 17% [2].

Today, there is a wide variety of PLM solutions in the IT market of the systems for lifecycle management of end products, ranging from simple tools that can aid you in product lifecycle managing within a small company to powerful systems used to effectively process amounts of engineering information to help manage complex technical products [8], [9].

Analysis of the researches delivered by TAdviser, a Russian analytical agency in the field of Product Lifecycle Management, shows that for last 3 years the leaders in terms of software used were the following PLM packages: 1S: Enterprise 8. PDM engineering data management, Teamcenter, Siemens NX, Windchill, Lotsman (Loodsman): PLM [10].

1S: Enterprise 8. PDM engineering data management is software that allows a company to reduce the production time by automating the process of selecting ready components and their adopting to designed products and providing tools to control the works flow on projects in design and technological preparation of manufacture.

Siemens NX is a PLM solution offering the broadest package of integrated, fully associative CAD/CAM/CAE applications in product design, manufacturing and simulation.

Teamcenter is an integrated PLM package that provides manufacturers with help in delivery complex products to market and streamlining global operations.

Windchill is PLM software that offers comprehensive capabilities to provide function ability required for effective global management of team works.

Lotsman: PLM is an effective solution for product lifecycle management, enabling centralized and structured storage of technical documentation on products.

All of above mentioned systems are the advanced solutions for product lifecycle management, and designed for a range of companies different in their size and tasks to be performed. The existing PLM systems offer the main processes automated with the purpose of full-scale professional management of the main stages of product life cycles: management of product structures, the processes of product developing, and the production process.

Despite the variety of tools for product lifecycle management, the ill-defined problems are not enough supported by available software relative to PLM in the environment of incomplete information about complex engineering products at different phases of their production.

Therefore, development of a system offering the methods for supporting lifecycle management of complex engineering products under conditions of uncertainty is relevant.

3. The conceptual approach to the development of a system of methods for supporting LC strategic management

The main stages of the process are distinguished in LC strategic management by a difference in a combination of methods applied, demands submitted to decision-makers (experts, analysts), types and sources of information, etc. (in total, it is a strategic analysis, choice, and control).

In strategic PLM, the typical stages of a life cycle are defined (marketing, concept, development, production, operation, maintenance, removal from operation).

It is proposed to develop two types of strategic decision-making support tools: universal and specialized.

The universal tools can be used in systems to support a life cycle of any complex engineering product, while the specialized tools are designed for accommodating peculiarities of each CEP in terms of different criteria to classify them (e.g., industry, type, level, etc.).

The software package for supporting CEP LC must meet the following functional requirements:
–   to provide interconnection of decisions through all major phases of strategic management;
–   to provide tools and interconnection of decisions made within typical stages of CEP life cycle;
–   to facilitate the use of qualitative expert information along with quantitative information in evaluating alternatives and making a decision; to provide information on the relations between factors in the form of verbal expert statements, rank them and, on the basis of this information, determine the order of certain policies and measures to be implemented;
–   to establish the relationship between the results of operating elements in the environment of the complex engineering product and the overall development of the organization;
–   to enable the combination of management systems used to support CEP life cycles from libraries of universal and specialized tools.

The developed system of methods for supporting complex engineering product life cycles is intended for use in DSS-class systems at the strategic level [11], [12].

4. The concept of universal methods for supporting strategic management of CEP life cycles

Analysis of the main problems in strategic management relating to complex product life cycles allows us to point out the following typical decision-making problems, which are in the focus of universal models, methods and algorithms developed to support decisions based on experts' knowledge:
–   evaluation of strategic factors with reference to the CEP life cycle driven by experts knowledge;
–   formalization of expert knowledge on the relationship of strategic factors, internal and external environments;
–   calculation of the importance of strategic factors and their combinations;
–   assessment of strategic development projects for CEP according to objectives and effects due to acting external and internal forces in the environment;
–   formalization of targets to be achieved while implementing the strategy for the CEP development and the results evaluation after implementing the strategy for CEP lifecycle management;
–   effect assessment of strategic decisions made at various stages of CEP life cycle, and interrelation between decisions;
–   organization and processing of the results of expert surveys.

The following approaches are proposed to solving these problems:

1. A SWOT-analysis on the basis of fuzzy sets. For this purpose, the following models and methods are used: the methods for constructing membership functions of linguistic variables; the systems of fuzzy production rules; models based on fuzzy logic. This approach allows us to calculate quantitative estimations according to the importance of opportunities, threats, strengths and weaknesses, as well as combinations thereof, on the ground of qualitative expert information.

2. A hierarchical model for evaluating development projects by analyzing alternatives (projects, programs) available for the CEP development, based on the influence exerted by the acting forces (the parties concerned).

3. A fuzzy integrated model for evaluating the CEP development strategy. It allows us to monitor the achievement of targets set in the strategy individually and to assess the overall success of implementing the selected strategy for CEP development.

4. A full cycle of evaluation made by experts, including the following: forming a group of experts, assessment of experts' competence, conducting expert surveys, consolidating evaluations made by a group of experts, assessing the degree of coordination among experts. The main feature of the proposed methods is the compiling of tables indicating the level of competences of experts that take into account the knowledge and experience of experts in different functional activities of socioeconomic systems.

The scheme in Figure shows how the decision-making models are applied and interact as to support strategic decisions on the basis of experts' knowledge, as well as the results of their application.
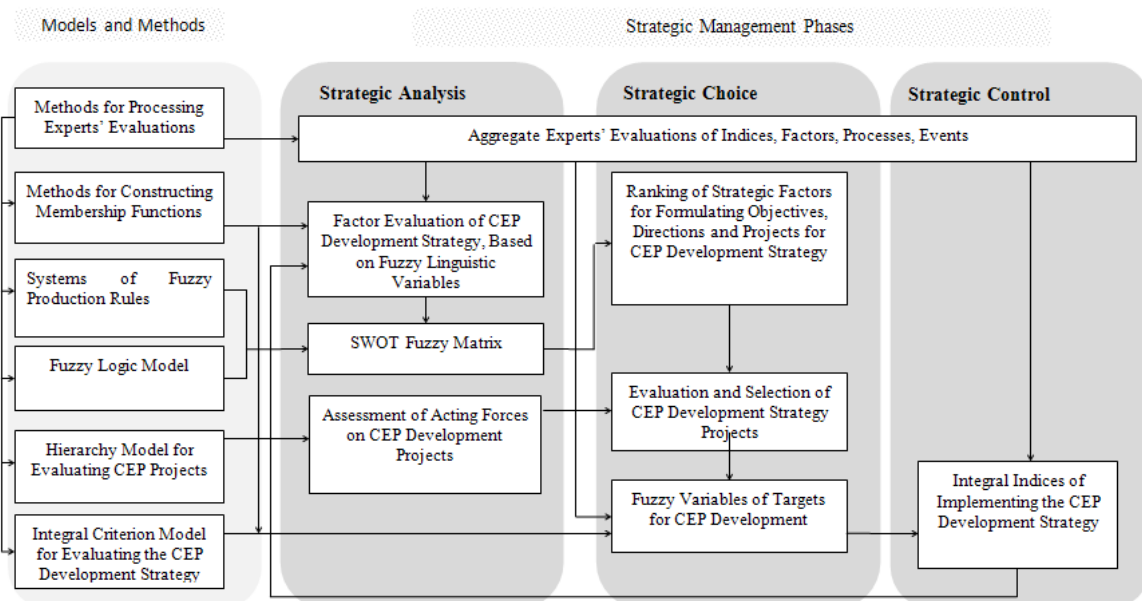

Figure 1. System of Universal Methods for Supporting Complex Engineering Product Life Cycle under Uncertainty

5. The main directions for the development of specialized methods for supporting strategic decision-making in lifecycle management of complex engineering products

According to the works, carried out earlier to develop the strategic Decision Support System, the following objectives were identified for strategic decisions based on experts' knowledge, requiring the development of specialized tools:

–   Factors evaluating for strategic development of CEP (actual, planned, projected, etc.);
–   Relations establishing between CEP elements and their external environment;
–   Relations establishing between functional factors of SES elements and their environment;

  –   Influence evaluating of CEP elements on each other and on the whole development strategy for CEP;

  –   Forming a feedback loop in strategic management of CEP life cycle;

  –   Databases creating within the context of a particular CEP domain, etc.

The above list may be supplemented by the results of further research. For this purpose, the most frequently occurring problems will be analyzed, synthesized and formulated in relation with strategic decision-making that require the development of special tools to support decision-making on the basis of expert knowledge.

Conclusion:

This paper describes the significance of tools for use in supporting lifecycle management of complex engineering products in an environment of uncertainty at all stages of their lifecycle. The concept necessary to create the system of methods used to support life cycles of complex engineering products under uncertain conditions is proposed. The problems associated with the development of universal models for decision-making were analyzed and formulated. A system of methods is proposed for use in supporting life cycles of complex engineering products, based on fuzzy set theory and hierarchical analysis. The main directions were identified for the development of special methods for strategic decision-making in lifecycle management of complex engineering products, with specifying the scope of further research.

The main advantage of software is its capability to implement the principle of integrity and continuity in the process of strategic managing the CEP life cycle, which is achieved by:

  –   providing decisions interconnected through all major stages of strategic PLM;

  –   ensuring the relationship of strategic decisions over all stages of CEP LC;

  –   establishing relations between the results of CEP elements functioning to comply with the overall company strategy.

Implementing this principle allows us to expand the limits for possible decisions made by management while specifying the strategy of CEP lifecycle management, and thus to improve quality and validity of strategic decisions in PLM with regard to complex engineering products.

The proposed system of methods intended for the life cycle support of complex engineering products under the conditions of uncertainty is a basic part of the software package designed to support strategic lifecycle management of complex engineering products. Software for the system to support strategic lifecycle management of complex engineering products is an add-in component for PLM, PDM, CAD / CAM, PM, ERP packages.

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