Implementation of Model-driven Complex System Engineering Development System

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Abstract. This paper summarizes the related technologies of model-driven complex system engineering development system and establishes a framework for the development system. Then, expounds the implementation process of the development system in detail and emphasizes the key path points of how to achieve the model-driven system research and development capability. Finally, the author puts forward two suggestions for the application and promotion of the development system.

Introduction

Since the 1960s, system engineering has become the main method to guarantee system development of national defense field such as aviation and space [1], while, as the complexity and the cross-domain coupling of systems increasing, rapid changes in external demand and situation have higher requirements in efficiency, quality and innovation capabilities of systems development. Disadvantages of traditional systems engineering method which using text as the main information carrier become more and more obvious in system development:

1) Capturing requirements inaccurately;
2) Changing and tracing the source of Information is difficult;
3) Controlling progress, costs and risks of system development is difficult.

To solve the problem of complex system development, the European industry proposed the concept of model-based system development and advocated that the text should be replaced by the models as the main information carrier and driving the whole process of complex system development.

As the new round of industrial revolution sweeping the whole world, China is promoting the deep integration of information technology and industrial technology [2]. These theories and techniques, such as Industrial Internet, Model Based Definition, Model Based Systems Engineering, Cyber-Physical Systems, CAD/CAE, Digital Thread, Digital Twin have created a powerful external environment for the “model-driven” development of complex systems engineering.

In this context, this paper have studied the implementation process of the model-driven complex system engineering system systematically and put forward two suggestions for the application and promotion of the development system.

Overview of Relevant Technologies

Model Based Definition

The core idea of Model Based Definition [3] (MBD) is to express the product structure, shape, size, process and manufacturing information through 3D model. After the emergence of CAD technology, 2D drawings have become the main basis for product designing and manufacturing, while 3D model is an auxiliary reference. The emergence of MBD technology integrates the design information and product manufacturing information into a three-dimensional digital model perfectly, which help to
realize the deepening integration from CAD to CAM, and make models becoming the main information carrier gradually.

**Digital Thread**

Digital Thread\[^{4}\] establishes a configurable and extensible enterprise level analytical framework for model information representation and transmission. Digital Thread can be interpreted as almighty DMU, which describing and reflecting the multi-physical characteristics of complex systems. Digital Thread can solve two problems: first, ensuring the models, data and information are unified, continuous and traceable, enhancing the interaction and control capability of data, information and knowledge in the whole life cycle of the system development; secondly, realizing the information interaction between physical space and digital space, the information in physical space can be fed back to the digital products development synchronously and trace back to the designing changes, which help to reduce the technical risk.

**Digital Twin**

The concept of Digital Twin \[^{5}\] is presented by Professor Michael Grieves in 2003 at the University of Michigan's Product Life Cycle Management course. With the development of digital modeling technique and modern communication technology, NASA translated the concept of Digital Twin into practice in the Apollo Project \[^{6}\]. Digital Twin is the process and method of simulating or mirroring the system operation process in physical world by DMU or digital model, and the corresponding DMU or digital model is called digital twins. The conceptual model of Digital Twin includes three parts: physical product in physical space, digital product in virtual space, information exchanges and interface between physical space and virtual space.

The supporting role of Digital Twin technology in the development of complex systems is mainly reflected in two aspects. On the one hand, Digital Twin technology realizes the fault diagnosis, risk prediction and remote control of physical products in digital space through simulating and monitoring the formation of complex systems. On the other hand, Digital Twin technology provides support for the synergy and innovation of the whole value chain for complex systems or products, based on the traceability of data and model.

**Model Based Systems Engineering**

In the late 1980s, the concept of MBSE was put forward abroad \[^{7}\], with the constant evolution, in 2007, the international council of systems engineering (INCOSE) defined the concept of MBSE as \[^{8}\]: a formal application of modeling method, which supporting system activities, such as requirements, design, analysis, validation and validation, in the whole life cycle of system design and development.

MBSE is a method that focusing on supporting the system development in system engineering design stage, emphasizing the integration of design, simulation and verification, and having stronger dependence on modeling Languages and modeling tools. And the outputs of model based system engineering activities are mainly requirements diagrams, use-case diagrams, use case diagrams, activity diagrams and state charts, etc.

In order to promote the application of MBSE, several professional research institutes and large software vendors have launched the relevant technology research and application exploration. NASA's Jet Propulsion Laboratory has put forward the state analysis method innovatively \[^{9}\], combining with its own exploration in MBSE; in order to eliminate the differences in expression and terminology between different languages and unify symbols and semantics, INCOSE and OMG have created the standard system modeling language based on extending UML2.0 \[^{10}\]; IBM, No Magic, LMS and other large software vendors have played an important role in the engineering application of MBSE technology by developing support tools; Airbus has enhanced its analysis and development capability by applying MBSE to the entire process of developing A350 series aircraft. Following the pace of foreign research, other domestic fields, such as aerospace, are exploring the Application of
MBSE in China actively. Due to the limitation of domestic industrial foundation, the research development of MBSE is still at the initial stage.

**Implementation Process and Data Structures**

Illustrated in Figure 1, the full life-cycle stages of complex system engineering development can be summarized as: design phase, manufacturing and assembly process, maintenance and service, retirement and recovery.

**Design Phase**

Processes of system requirements analysis, functional analysis, architecture design, multi-physical system modeling and joint simulation in the design phase are all based on models.

**Requirement Analysis.** Establishing a system requirement analysis model which running through the whole life cycle of the system development at stages and levels, transforming stakeholder needs into system requirements which defining what the system must do and how well it must perform by requirement interfaces, use case scenarios, requirement traceability matrixes, requirement baselines, etc.

**Functional Analysis.** The main goal is to transform demand into continuous system business/business operations, define system functional structure and interface, distribute functions to subsystems, establish mapping relations between functions and requirements and logical relationship between functions, combining with the business scenarios. The system function model provides input for system logic architecture design and comprehensive analysis.

**Architecture Design and Comprehensive Analysis.** The goal is to form an optimal system architecture that meets system functions and performance requirements. Defining system architecture elements and interfaces and distributing functions to system architecture elements; identifying key functions and building a variety of feasible system architecture solutions; establishing a reasonable evaluation system and evaluating the best scheme as the output of the logical architecture model of the system.

**Multi Physics System Modeling.** Modeling according to architecture design, function and performance index, and the models carry all the information that the system needing to express. Co-simulation: identifying interdisciplinary coupling and functional performance conflict, during the design phase, verifying design ideas and updating dynamically. The output model data of this stage include multi-professional design model, design BOM, simulation and verification model, which are the main basis of the manufacturing and assembly stage.

**Manufacturing and Assembly Stage**

Model-based product digital manufacturing and assembly is an extremely complex process, which main tasks including process modeling and simulation, simulation and verification of manufacturing process, digital detection, large-scale space measurement, path planning, automatic programming, quality control, accuracy analysis and optimization, manufacturing resource management, planning and scheduling, manufacturing data acquisition and reconstruction, etc. As the original input data, the design model provides the foundation constraints and basis for the design, modeling, simulation and planning of the manufacturing and assembly process. The model data output in this stage mainly include the medium difference models, PBOM, process simulation animation, standard library, tooling model, detection model, measurement model, technical state data, quality data, etc.

**Maintenance and Service**

The main task of this stage is to realize the maintenance, upgrading and transformation, during the process of system application. Specifically, combining with the environmental monitoring data, sensing data, alert data and product models that accumulated in the previous stages, the system fault can be identified and located quickly; simulating and checking system functions and performance
characteristics based on models, analyzing and predicting the potential risks, can provide data support for system upgrade and transformation; based on models, combining with VR and AR technologies, the efficiency and quality of maintenance can be significantly improved. The model data output in this stage mainly include the system application process data, environmental perception data, simulation test model, fault diagnosis and maintenance process data.

**Retirement and Recovery**

Model data are mainly system decommissioning process data, such as decommissioning reasons, service life, effective working time, decommissioning process analysis, etc. After system decommissioning, all the models and data accumulated or collected during the system development process form a complete model library, which can provide closed-loop data link to support the development of the same series of products, and enhance the efficiency, quality and innovation ability of the system development.

![Figure 1. Model data structure of model-driven complex system engineering development system.](image)

**Key Path Points for the Implementation of the Model-driven Development System**

The construction of "model-driven" R&D system is not a simply matter of building several information systems or several supporting platforms. We must pay attention to the following three key path points.

**Model Definition**

The accurate and comprehensive definition of the models is the basis for developing the capability of "model-driven" development system. High-speed development of MBSE, MBD, CAX and other technologies and the corresponding tool software, such as DOORS, Rhapsody, Mworks, LMS, Dymola, etc, which can be able to support the model definition in the full life cycle of complex system development. While, in addition to technologies and tools, enterprises should integrate their business practices, focus on the practical issues, in the process of pushing "model definition". For example, in the process of promoting MBD, it is necessary to solve these problems, such as standardization of
PMI, transformation between design models and medium difference models, and the implementation capability of manufacturing enterprises.

**Transmission and Application of Models**

In order to realize the effective transmission and application of models, first, we must get through the data path among tools software and application systems; then, establishing the relationship among models. To solve the above application requirements, industry has proposed an analytical solution framework called "Digital Thread", which provides capability of model access, integration and transformation for "model-driven" development system across the life cycle. When building the model-driven development system, enterprises can refer to the content of the framework and adjust it according to the characteristics of the industry and business requirements.

![Figure 2. The framework of the model-driven complex system engineering development system.](image)

**Evolution of Models**

In the process of "model-driven" complex system development, the model data in different stages have been changing. There are two main models of evolution: one mode is the interactive evolution of models among different stages; another mode is the interactive evolution in physical space and digital models. With the development of MBSE technology, industry has been able to support the interaction and evolution of models in requirements analysis, functional analysis and logical architecture design phase. However, due to the limited support of tools and software for continuous system modeling, discrete system simulation, continuous system simulation and multi-physical domain simulation, the interactive evolution of models involving cross domain modeling and joint simulation require designer analysis. The process of interactive evolution in physical space and digital model is similar to the concept of “Digital Twin", a hot topic discussed by industry recently. When building “model-driven” R&D capability, enterprises can consider "Digital Twin" as one of the main supporting technologies.

**Proposals of Application Development**

Based on the current industrialization in China, this paper puts forward two suggestions:

**Perfect Model Library and Build Core Competitiveness**

Many units in China tend to focus on "buying a good model libraries" when promoting the process of informationization. In fact, this method can help enterprises to improve efficiency, but cannot improve product quality or enterprise innovation ability. The real valuable model library is the
combination of model data accumulated in the process of products and projects development, which
accompanied by many tests, application practices, fault maintenance, upgrade and update. It has
strong local characteristics and cannot be purchased. Building a competitive model library,
enterprises must spend a lot of time and energy, relying on a large number of real data feedbacks, to
accumulate and inherit continuously.

**Improve Information Integration Level and Build High Quality Data Link**

Many units in China do not pay enough attention to basic data. Lacking of their own data management
standards, data reduction is difficult, the ability of data interaction and correlation analysis is weak,
these cases lead to a large amount of garbage data generated in the design and manufacturing process
dispersing in various information systems, while, the ability of data interaction and recognition
between information systems is limited, and even many information systems are in the "island" state.
The whole data link is very weak, which has a great impact on data processing, and even cannot get
real and effective data at all. So, in the process of advancing model-driven complex system
engineering development system, enterprises must attach importance to improving the ability of
information integration. On the one hand, breaking down barriers between information systems and
realizing seamless connection in the entire data link. On the other hand, enhancing data management
capability, formulating feasible information exchange standards, model encapsulation specifications
and interface protocols to ensure the effective reuse and controllable quality of data produced in
different fields and different stages. At the same time, we should focus on business difficulties,
improving the ability of information processing, forming effective data association analysis ability,
and promoting the quality of the whole data link, to realize the efficient application and Value Mining
of data.

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