Multi-architecture unified modeling for manufacturing service value net system design*

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Abstract

The synergistic development of product after-market is an effective way for manufacturing enterprises to extend their value chains. As a system architecture design formalism method, model-based systems engineering (MBSE) provides capable support in the design process of complex systems. In this paper, a cloud-based manufacturing service value net system is proposed to help manufacturing enterprises coordinate with partners. However, in this cross-organization collaborative activities, experts with different domain backgrounds are familiar with various system specifications and modeling languages, which makes it extremely hard for related stakeholders to collaborate and conduct information interaction. Therefore, this article presents a semantic modeling method of GOPPRR and unified ontology modeling karma language to support different MBSE standards. The specific domain meta-models of manufacturing service value net system are developed throughout the whole lifecycle process. MetaGraph tool is applied to build meta-models and models. Karma codes with consistent semantics can be generated automatically in real time no matter what modeling language is taken. Concretely, an instantiated modeling case was created in the basic of developed meta-model library. This paper conducts ongoing research for system design in the manufacturing service field, and the proposed modeling method also implies reference significance for designing of similar systems.

Keywords

MBSE, value chain theory, semantic modeling, collaborative design, forward design

1. Introduction

The development trend of manufacturing industry has changed from the traditional mass produce to the downstream maintenance service business process [1]. Manufacturing enterprises create value by concentrating in post-market service of products [2], leading the equipment production industry in the stage of "service-orient manufacturing". Value chain focus on the profit sources of production and operation in a company from the value flow perspective, including a series of value-related activities [3]. The manufacturing industry based on value chain theory commonly has the status of "value siloes". It is difficult for a single enterprise to provide optimal services in multiple specific areas of expertise. Therefore, it is urgent to establish a cooperative platform to help manufacturing industry transform from single chain

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mode to collaborative mode [4]. The aim is to coordinate multiple entities to create and distribute benefits, and support closed-loop feedback of information [5]. In this paper, a manufacturing service value net system is proposed to provide personalized service solution schemes for customers. This system integrates services of multiple subjects, including core enterprises, parts suppliers, maintenance providers and logistics providers, adopting cloud platform as the operation carrier which is described as manufacturing service cloud platform.

Business processes of manufacturing service cloud platform are extremely complex. It is It is hard to implement system function definition. To this end, model-based systems engineering (MBSE) has been proposed to tackle system complexity [6, 7]. MBSE technology can enhance the integrity of system design by establishing system models to describe complex product systems. It has already been studied and practiced in the field of aerospace [8, 9] and military [10]. Therefore, a semantic modeling method of GOPPRR (Graph, Object, Point, Property, Role, and Relationship) approach and multi-architecture unified modeling language karma is proposed. GOPPRR basic elements are used as the foundation of modeling while karma language is adopted to normalize the semantic description of the system.

In addition to the complexity of the system itself, the coordination of the system design process is also difficult. On account of the different knowledge backgrounds of experts, supportive technique tool is needed. MetaGraph, a multi-architecture unified modeling software, is applied in this paper to meet the requirements of multi-team collaborative system design.

On the whole, in order to establish the proposed manufacturing service value net system, a semantic modeling method is adopted. Based on GOPPRR theory and RFLP (Requirements engineering, Functional design, Logical design, Physical design) forward design principle, it provides distinct creation procedure of manufacturing service system. Moreover, the unified formalism description of models is beneficial to semantic integration purpose, which improves coherence and interoperability of different designer and developers. Additionally, the established meta model library made direct contributions to instantiated system modeling.

The rest of the paper is organized as follows. Section 2 presents the literature review. In Section 3, the manufacturing service value net system design problem is described and the modeling methodology is illustrated. A case study conducted in Section 4 validates the proposed method. Section 5 concludes the article.

2. Literature review

The design and development of complex systems has long been the focus of systems engineering. Oriented by the classic V-model, its life cycle includes a top-down design process and a bottom-up validation process [11]. User requirements are regarded as the core of forward design in project management, promoting the availability after project implementation. Compared to document-based systems engineering (DBSE) approaches, model-based systems engineering (MBSE) can significantly improve coordination throughout design phases. The traditional mode, in which each stage is carried out independently, involves a large amount of data and files and has low tolerance for operational errors. Not only is the communication consuming high, but also the reuse of experience and knowledge is inconvenient once design changes or system upgrade iterations occur. However, although model-based systems engineering methods can ease these problems, engineers still face barriers from modeling languages in building models.

In order to meet miscellaneous scenarios, there are several specifications and general modeling languages of model-based systems engineering in academia and industry, such as BPMN [12], UML [13] SysML [14], EAST-ADL [15], etc. However, most of the existing studies still cannot meet the requirements of collaborative design across multiple groups. As an expression form of the design content of the system, models contain the underlying abstract elements and the detailed domain-specific information describing actual physical world. As the most powerful graphical representation method, GOPPRR approach supports meta-model definitions in the basis of abstract elements of meta-meta-models [16]. Therefore, this paper uses a semantic modeling method based on GOPPRR to remove the ambiguity of the graphical descriptions, which is helpful for designers familiar with different design specifications to understand each in formal definition of meta models.

3. Modeling approach of manufacturing service system

As mentioned in Section 1, the current stage of service-oriented manufacturing means manufacturing enterprises need to extend their value chains, and promote value synergy among enterprises to create value innovatively. So as to offer customers more sophisticated service solutions. This section introduces manufacturing service value net system in detail. We proposed a karma-based semantic modeling method to construct concept model libraries for manufacturing service value net system.

3.1. Problem statement

As mentioned above, it is urgent for manufacturing enterprises to upgrade from single product-centered value chain mode to integrated customer-centered value net mode. The most important thing is to improve the after-sales service of products. It comes the circumstance that one equipment manufacturer (referred to as a core enterprise in this paper) cannot provide complete post-sales service. This paper carried out inter-enterprise business coordination on a centered platform by virtue of the integration of value chains.

Requirements of customers' needs can be described in two different after-sales service scenarios: 1) equipment products are still in the warranty period; 2) or beyond the warranty period. In former scenario, core enterprises always provide full warranty service. The department responsible for after-sale service immediately respond to the customer's request for repair and provide corresponding maintenance service or material allocation. As for the other situation, the enterprise is not solely responsible for the operation failure, but the participation of core enterprise can bring considerable benefits to itself and customers. Enterprises can collect more operational quality information and operational status data. Customers can also get more professional service solutions schemes. In the meantime, material suppliers and maintenance service providers join to stimulate the diversity and competitiveness of the post-product market. Thus, it is up to the user to choose different system functions, such as fault diagnosis only or several of system function. In addition, users can also freely choose partners with different roles, for example, with maintenance service providers, or just coordinate with material suppliers to deliver parts.

Based on the above scenarios, the manufacturing service value net system proposed in this paper includes three main functions: fault diagnosis and residual life prediction, after-sales market service and material allocation. The stakeholders involved include customers, core enterprises, maintenance service providers, material suppliers, logistics providers and cloud service providers. Detailed system business process design is introduced in Section 4.

3.2. Overview of semantic modeling method

Based on two above mentioned scenarios, main functions and business processes can be defined for manufacturing service value net system designed for a specific platform named manufacturing cloud platform. According to the principles of forward design methods, RFLP theory is adopted and a semantic modeling method is proposed. Aiming at the features of domain-specific modeling for complex system design, the graphical system models are constructed through GOPPRR approach combined with a third-order framework which is comprised of meta-meta-models, meta-models, models and instantiated conceptual models. Moreover, in order to support co-design across multiple groups, karma, taken as a unified modeling language, can describe conceptual models of the system under the same semantic and syntactic structure. The overview of the research methodology is shown as Figure 1.

Before developing conceptual models for project design, requirements model, functional model, logical model, and physical model, take RFLP theory as the system architecture design principle. As shown in Fig. 1(a), requirement analysis is carried out against the background of actual service scenarios to analyze and capture the needs of stakeholders. Functional framework is defined oriented from requirements, and system functions (overall systematic functions and subsystem business processes) are planned based on technical support (e.g., cloud platform infrastructure). In addition to the business logic of the key functional subsystems, the logical interactions between blocks, or between a block and a stakeholder are also considered to describe system behavior in the logical design. Finally, the physical architecture of the system can be determined, including physical configuration, subsystem structure, as well as detailed description of components.

Karma language is a semantic language with consistent textual semantics and syntax across different modeling languages. In other words, whatever modeling language used by system engineers in any field can be formalized into consistent descriptions under this uniform specification. For cross-team system design barriers, a multi-architecture modeling tool, MetaGraph, is applied to construct system models. It supports meta-model definition based on meta-meta-models, and all stakeholders can edit the meta-model in the tool according to their domain expertise, which provides good scalability for the method proposed in this paper. Furthermore, code generation function of MetaGraph supports the karma ontology transformation of system models, solving the problem of heterogeneity in the process of cross-organization system design.

4. Case study

It is particularly beneficial to adopt MBSE method for modeling analysis when designing complex systems. This section verifies the feasibility and necessity of proposed semantic modeling method during system operation and development. Fig. 2 shows a comprehensive

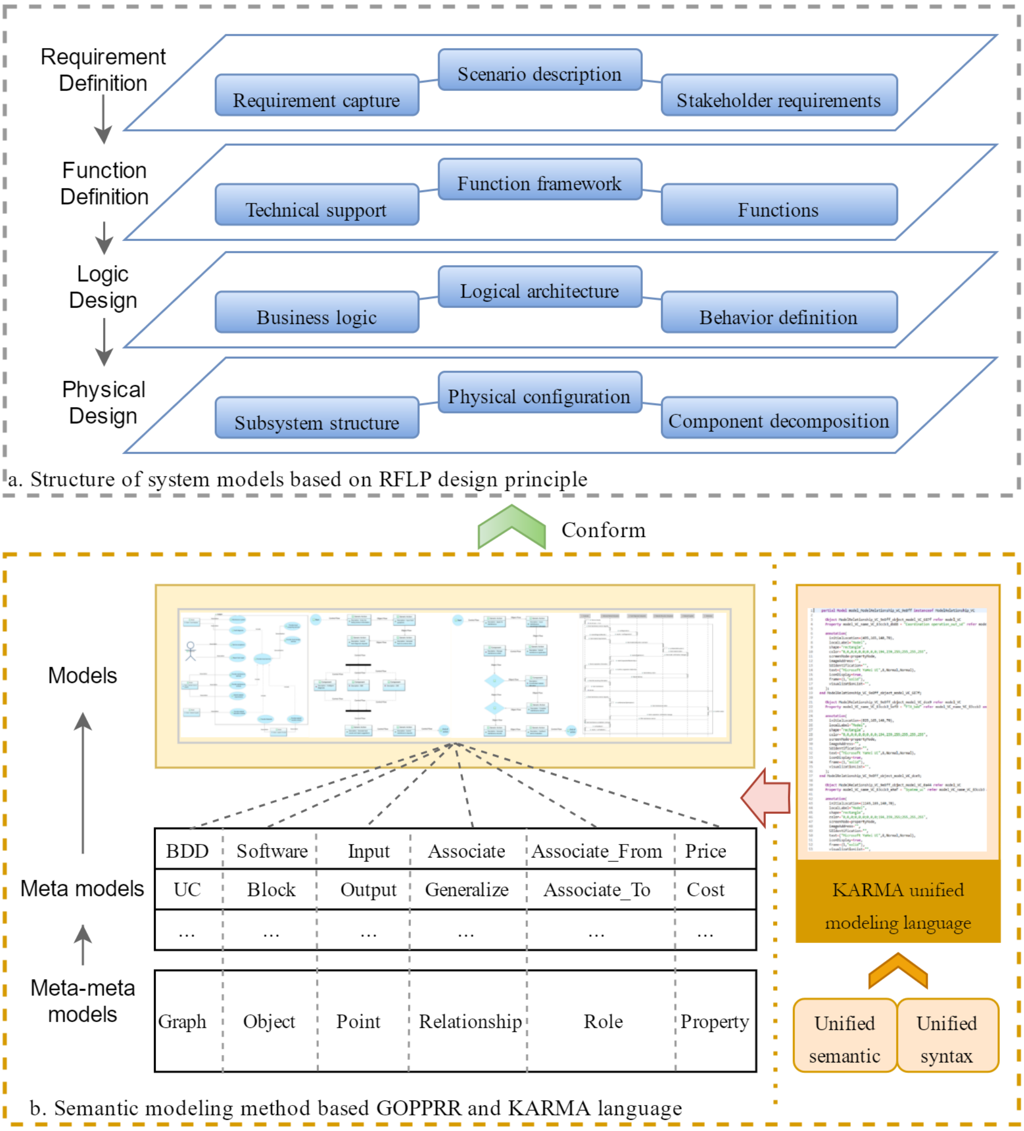

Figure 1: Semantic modeling method under RFLP principle

overview of this case study. Aiming at realizing the value extension of post-market service for large manufacturing enterprises, the business collaboration process workflow of relevant stakeholders under industrial scenario is presented. For the purpose of scientifically expressing this system, the manufacturing service value net system instance models are developed using meta-model library based on RFLP process. Meanwhile, the unified karma language formalism is given for all kinds of concept model files. All models are defined and constructed in the MetaGraph.

4.1. Business process workflow of manufacturing service value net system

As described in Section 3, the system consists of three key functional subsystems (shown in Fig. 2(a)). The first is represented as Faulty Diagnosis and Residual Life Prediction Subsystem, including faulty diagnosis component and residual life prediction component. The fault diagnosis component executes online diagnosis to get fault modes and maintenance suggestions according to customers' requests. Only fault symptom information is needed by users while using. The residual life prediction component generates product lifecycle curves according to the state detection data to estimate whether the product is in a safe operating period. In this way, when operation failure is about to occur, early warnings are attainable, so that materials can be scheduled in advance in coordination with the material allocation function to speed up the response. The Aftersales Market Service Subsystem defines the after-sales service delivery modes for different contexts. If the fault occurs while the product is still under warranty, all maintenance services are provided by core enterprises. According to the warranty policy, if the core enterprise does not assume the maintenance responsibility when the fault occurs, customers only need to publish the repair information on the platform. Moreover, the After-sales Market Service subsystem supports different users to call platform functions on demand, recommends the optimal maintainers and coordinates with material configuration. The Material Allocation Subsystem handles orders based on material requirement forecasting function component. In addition to this basic function, it should also support warehouse inventory optimization through the material configuration situation, thus to generate the optimal material scheduling scheme. This design of function can effectively alleviate the problem of material idleness and reduce the cost under the premise of ensuring the timely supply of materials.

In the maintenance service scenario described in this paper, the customer first releases the service requests and interacts with partners in the order processing interface through the After-sales Market Service subsystem. According to the reported fault phenomenon, the Fault Diagnosis subsystem is designed to obtain diagnosis results, which is used as the basis to issue material requirement orders. Then, the After-sale Market Service subsystem triggers the Material Allocation subsystem to generate configuration schemes. Through the abovementioned business processes on the manufacturing service value net system, maintainers can directly provide maintenance services on site and obtain feedback from customers.

4.2. Semantic modeling process of proposed system

In this case study, the semantic modeling process is presented in Fig. 2(b). The first step of the system design is the requirement definition based on the requirement scenario. Oriented toward customer demands of actual manufacturing practice is a vital principle. Items in ReqIF (Requirements Interchange Format) and requirement diagram are used to systematically illustrate requirement analysis, and the stakeholders are defined using the scenario use case diagram. Functional analysis includes a comprehensive activity diagram of the manufacturing service value net system, as well as functional descriptions and functional use cases for each key functional subsystem. Logical analysis regulates the interaction process among stakeholders and system components. The following four interaction processes are represented by sequence diagrams: purchasing interaction process; interaction process between residual life prediction

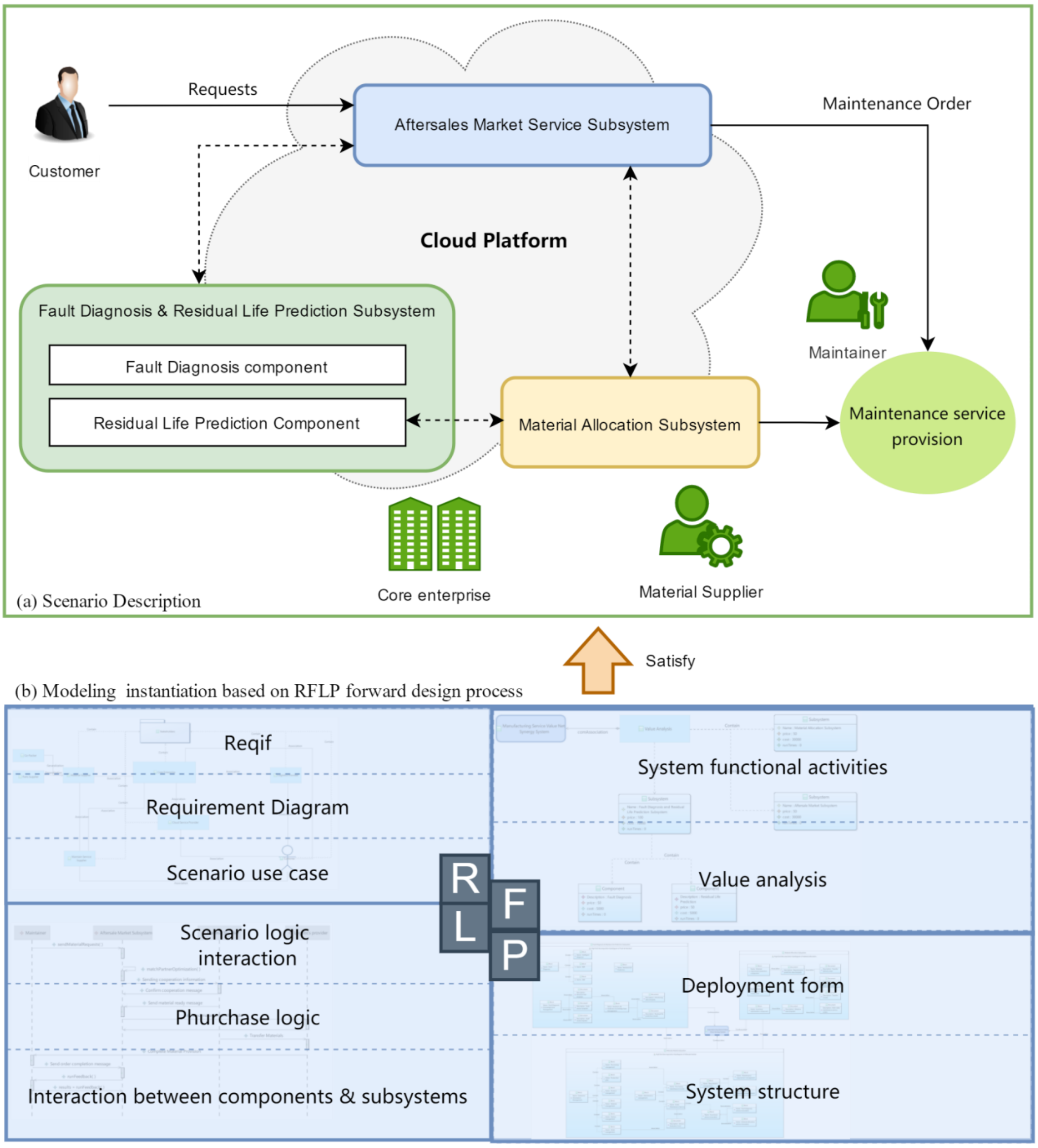

Figure 2: Instance modeling through proposed semantic method under system scenario

component and Material Allocation subsystem; information interaction of lifeline objects in the maintenance service provision within warranty; and information interaction of each object in maintenance service provision out of warranty. Thus, the physical structure of the system can be constructed. In this case, block definition diagram is used to express the composition relationship of subsystem modules and component modules. Combined with the advanced decomposition display of technical tools, the physical decomposition diagram of components can be shown simultaneously in the same page as a sub-diagram of the whole system structure. System structure design process also defines the Docker form of deployment mode on the proposed manufacturing service cloud platform.

5. Conclusion

In this paper, a manufacturing service value net system is proposed to raise the benefits from aftersales market of manufacturing companies, and a GOPPRR approach is adopted under RFLP design principle to construct a theoretical framework through a proposed semantic modeling method for collaborative designing. A multi-architecture modeling language named karma is used to formalize models built by manufacturing service value net model library. In order to demonstrate the practical operability of the method, instantiated models are conducted in an MBSE tool. In the meantime, feasibility is also verified by the case study. The contributions provided in this article support a strong foundation for the design process in this specific domain, and offer inspiration for development stages of other similar complex systems.

References

[1] L. Sun, G. Li, Z. Jiang, L. Zheng, and Z. He, "Service-Embedded Manufacturing: Advanced Manufacturing Paradigm in 21st Century," China Mechanical Engineering, vol. 18, no. 19, p. 2307, 2007.

[2] S. Vandermerwe and J. Rada, "Servitization of business: adding value by adding services," European management journal, vol. 6, no. 4, pp. 314-324, 1988.

[3] X. Chi and G. Xuan, "Summarization on the research of value chain," Foreign Econ Manage, vol. 22, no. 1, pp. 25-31, 2000.

[4] R. Normann and R. Ramirez, "From value chain to value constellation: Designing interactive strategy," Harvard business review, vol. 71, no. 4, pp. 65-77, 1993.

[5] P. Kothandaraman and D. T. Wilson, "The future of competition: value-creating networks," Industrial marketing management, vol. 30, no. 4, pp. 379-389, 2001.

[6] J. A. Estefan, "Survey of model-based systems engineering methodologies (MBSE) rev B," International Council on Systems Engineering. INCOSE, Seattle, 2008.

[7] P. D. Ciampa, G. La Rocca, and B. Nagel, "A mbse approach to mdao systems for the development of complex products," in AIAA Aviation 2020 Forum, 2020, p. 3150.

[8] J. Ma, G. Wang, J. Lu, S. Zhu, J. Chen, and Y. Yan, "Semantic Modeling Approach Supporting Process Modeling and Analysis in Aircraft Development," Applied Sciences, vol. 12, no. 6, p. 3067, 2022.

[9] X. Zheng et al., "Development of an application ontology for knowledge management to support aircraft assembly system design," Proceedings http://ceur-ws. org ISSN, vol. 1613, p. 0073, 2020.

[10] S. Yu, Z. Ruping, and W. Jun, "On the Practice of Model-based System Engineering in Missile Development," Acta Armamentarii, vol. 43, no. S1, p. 97, 2022.

[11] H. Cotterman, K. Forsberg, and H. Mooz, Visualizing project management: models and frameworks for mastering complex systems. John Wiley & Sons, 2005.

[12] M. Chinosi and A. Trombetta, "BPMN: An introduction to the standard," Computer Standards & Interfaces, vol. 34, no. 1, pp. 124-134, 2012.
[13] D. Torre, Y. Labiche, M. Genero, and M. Elaasar, "A systematic identification of consistency rules for UML diagrams," Journal of Systems and Software, vol. 144, pp. 121-142, 2018.
[14] S. Friedenthal, A. Moore, and R. Steiner, A practical guide to SysML: the systems modeling language. Morgan Kaufmann, 2014.
[15] P. Cuenot et al., "Managing complexity of automotive electronics using the East-ADL," in 12th IEEE International Conference on Engineering Complex Computer Systems (ICECCS 2007), 2007, pp. 353-358: IEEE.
[16] C.-J. Sjöstedt et al., "Developing Dependable Automotive Embedded Systems using the EAST-ADL; representing continuous time systems in SysML," in Proceedings of the 1st International Workshop on Equation-Based Object-Oriented Languages and Tools: Berlin; Germany; July 30; 2007; conjunction with ECOOP, 2007, no. 024: Linköping University Electronic Press.