Title:

A MBSE based approach for architecting concepts for business model innovation of smart product systems

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Introduction:

Nowadays, with the advancing of Information and Communication Technologies (ICTs) and enabling technologies for the Internet of Things (IoTs), technological innovations usually take forms of smart products system including various types of smart products [1-2]. Success of technological innovations keenly lies in the proposal of appropriate novel business model to better serve customers' requirements. Previous studies ever pointed out that more than 80% quality, cost and performance of overall product has been determined as early as at the conceptual design stage of new product development (NPD) [3]. In line with this viewpoint, it plays a significant role to propose a feasible method for the business models innovation (BMI) of smart products system to be developed especially at the conceptual design stages.

Even though the marketing promotion stage usually follows the stage of product development according to the overall product lifecycle management (PLM), however, there is seldom studies focus on the construction of BMI based on the perspective of engineering design. One of main reasons lies in the disciplinary gap between the engineering design and product marketing promotions. In order to bridge the interdisciplinary gap in the proposal of BMI concepts from the viewpoint of engineering design, this study attempt to use the model-based system engineering (MBSE) approach to facilitate the multidisciplinary knowledge management in the development of complex engineering system. As an emerging approach, MBSE applies modelling methods to support complex system requirements, design, analysis, verification and validation activities. MBSE methods varies in their specific forms but share the common issue: modeling complex and unclear relations between different levels of abstractions in engineering system [4]. Moreover, there is very limit efforts to apply MBSE in architecting conceptual solutions to BMI. To fill this gap, this study attempts to propose a new MBSE-based approach for the BMI for smart product system at the conceptual design stage. To do so, the rest of paper is organized as follows: Firstly, a concise literature review to explain the backgrounds and theocratical foundations of the proposed study; Secondly, the framework of the proposed method is expounded in detailed to address how several exiting MBSE methods and tools are integrated into the process of innovation of business models that consists of various types of smart products throughout a synergic workflow; Thirdly, an exemplar case of the construction of a new rural household waste collecting system to address the practical feasibility of the proposed method; Lastly, discussion about both the advantages and limitations of the proposed approach are represented with proposal of several opportunities for the future studies.

<u>Main Sections:</u>

A brief literature reviews

This paper is built on existing studies in fields of MBSE approaches for engineering system development, methods and tools to support the BMI of smart product system.

- MBES approaches for engineering system development

Engineering has switched from documents-centric forms to the model-based engineering system (MBSE) forms for design of multidisciplinary complex systems. With top-down models, MBSE approaches are capable of describing the entire engineering system from different viewpoints that usually cover at least the structural and behavioral descriptions. There are many various forms of MBSE approaches have been proposed by previous studies [5-8], each of which involves different phases to guide the modeling of engineering system.

Among those MBSE modeling methods, there are several typical methods enjoy the wide popularity with different specific workflows. Applied as a suitable modeling approach for initial system architecture design, IBM Harmony-SE uses a service request-driven framework consisting of iterations from the steps of requirement analysis, system functional analysis and design synergic by using the System modeling language (SysML) blocks with streams to represent communications between blocks. Similar as the Harmony-SE, Object-process methodology (OPM) is another MBSE approach designed for modeling the general engineering system, which regards everything as one of three types: objects, process and states [5]. Within a single graphic model of OPM, engineering system are represented by using function, structure and behaviors through a series of stages including requirement specification, analysis and design, implementing, using and maintaining. As an ontology based MBSE approach, Vitech MBSE defines system by using meaningful semantics and model structure syntax to formulate necessary information of engineering system from four domains: Source requirements, behaviors such as the specific information about the inputs/outputs, control and sequence, architecture including information about components, interfaces and system architecture, validation and verification. Originated from the domain of software engineering, object-oriented system engineering method (OOSEM) has developed into an extensible approach for modeling both software and hardware systems and it is suitable for modeling complex and multiple-functional system such as the aerospace engineering system. Main activities to facilitate a complete cycle of the OOSEM process include six steps: stakeholders requirements analysis, define system requirement (black-box analysis), logical structure (white box) definition, synthesize allocated architectures and physical alternatives, optimization and evaluations for alternatives, validation and verification with requirement traceability [6]. Although those MBSE approaches vary in their specific forms, all of them share several common characteristics that involves a set of graphic syntax to represent system constitution components on functional, behavioral and structural aspects and workflows consisting of steps adapted from the PLM [7].

- Business model innovation (BMI) of smart product system

Emerged in 1970s, business model (BM) was originally developed to support information technological system modelling. After more than 30 years self-evolved, BM has developed into its modern interpretation that being understood as the design and architecture of the value creation, delivery, and capture mechanism within certain business [8]. In short, BM indicates how a business work to realize the value creations for all the stakeholders [9].

Generally speaking, the framework of BM covers the whole value creation logic process of enterprise, organizations in vain chain, and industrial sectors that can be represented by different types of elements. All the blocking elements that constitute BM are architected in four pillars: value (e.g., either in forms of products or services) propositions, financial aspects, customers interface and infrastructure management. In the further study, four pillars of BM have been refined as the three stages to manage the value creation process involving value proposition, value creation and delivery, and value capture [10]. With increasing attentions on the environmental crisis and advance of Industry 4.0, BMI is attracting increasing interest from different specific areas such as the sustainability, digitalization, etc. 11-12]. With the ever-growing complex of technological systems to realize the BMI, a

MBES-based approach is of importance to facilitate the architecture and configuration of BMI involves transdisciplinary backgrounds.

- Research gap to be filled

With the ever-increasing complex of engineering systems, MBSE approaches face higher requirements to support architecture and configuration tasks of muti-domains systems within the transdisciplinary knowledge convergence. It of practical value to fill the research gap by developing new MBSE approaches that are adapted to support transdisciplinary system engineering since it provides new ways of thinking for developing more resilient engineering solutions to complex systems problems by addressing the problem from multiple perspectives.

Framework of the proposed approach

The overall framework of the proposed approach at its preliminary stage is illustrated as the Fig.1. Refers to Fig.1, the workflow of the proposed approach mainly locates on the left side, which involves six specific steps the begin with the requirement analysis to collect all the customers requirements (CRs) from different stakeholders. Then, CRs are transformed into functional requirements (FRs) through the function definition. Subsequently, function-logic analysis is applied to architect the functional structure of engineering system to be developed. At the fourth step, engineering structure to realize each defined FR is designed to formulate the whole technological structure of the engineering system, which is followed by the fifth step to configurate the engineering system by arranging all devices and departments in the proposed engineering system. Lastly, information, data and knowledge are collected to facilitate the requirements traceability of the proposed engineering system.

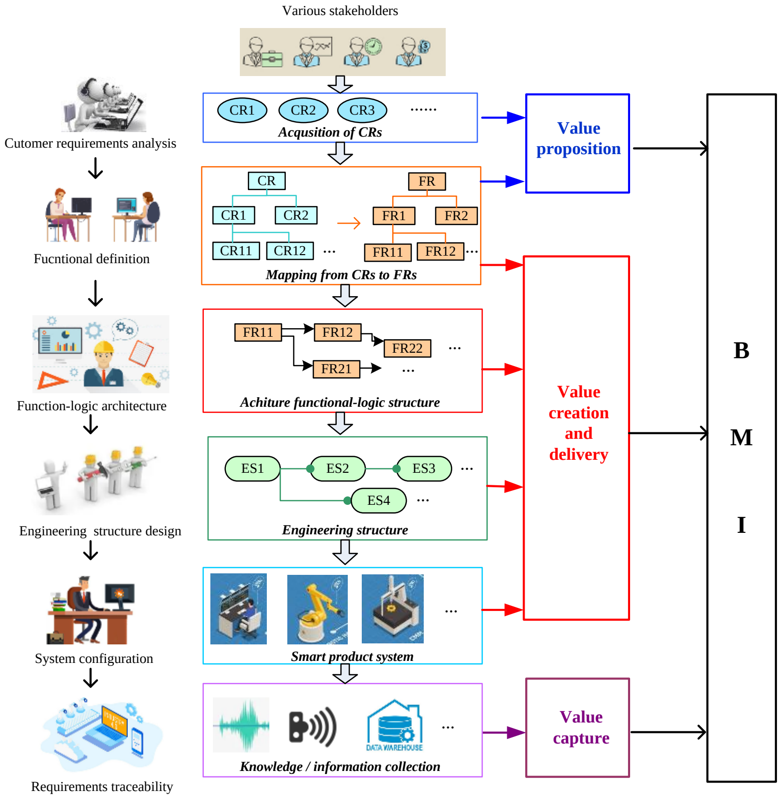

Fig. 1: The framework of the proposed MBSE-based approach.

The central part of the Fig.1 indicates the necessary components for formulating the modeling sections of the proposed MBSE approach. Generally speaking, the proposed MBSE approach at least contains elements to represent CRs from various stakeholders, defined FRs to realize CRs (e.g., black-box modules), logic function-behavior structure (e.g., the white box modules), technological structure to facilitate the function architecture, configuration of engineering subsystems and systems and strategies to collect knowledge and data to trace back and validate CRs for various stakeholders. It also indicated strategies to architect the conceptual design solutions to BMI of smart product system by transforming design information from CRs to engineering system configuration throughout the function -behavior-structure-physical state mapping process which can be seen as a variant of FBS ontology.

The right part of the Fig.1 explains the correlations between steps of the proposed MBES-based approach and the value-centric strategies for BMI. To be specific, both the acquisition of CRs and definition of FRs help to figure out main value propositions of the BMI since they clarify how the proposed BM to satisfy needs of various stakeholders. F-B-S-PS mapping strategy facilitates the transitions from the black box to the white box to realize the value creation and delivery in BMI. Lastly, thanks to the requirement traceability of smart products system by collecting necessary knowledge and information, new value can be captured by proposing add-value service as well as the opportunities for iteration of further improvement to increase the sustainability of the proposed BM.

Case study

This paper attempts to construct the conceptual solutions to BMI of rural household waste collecting system that will be formulated by various types pf smart products. The main behavior logic chain among different stakeholders from multidisciplinary backgrounds in the exemplar case is illustrated as the Fig.2.

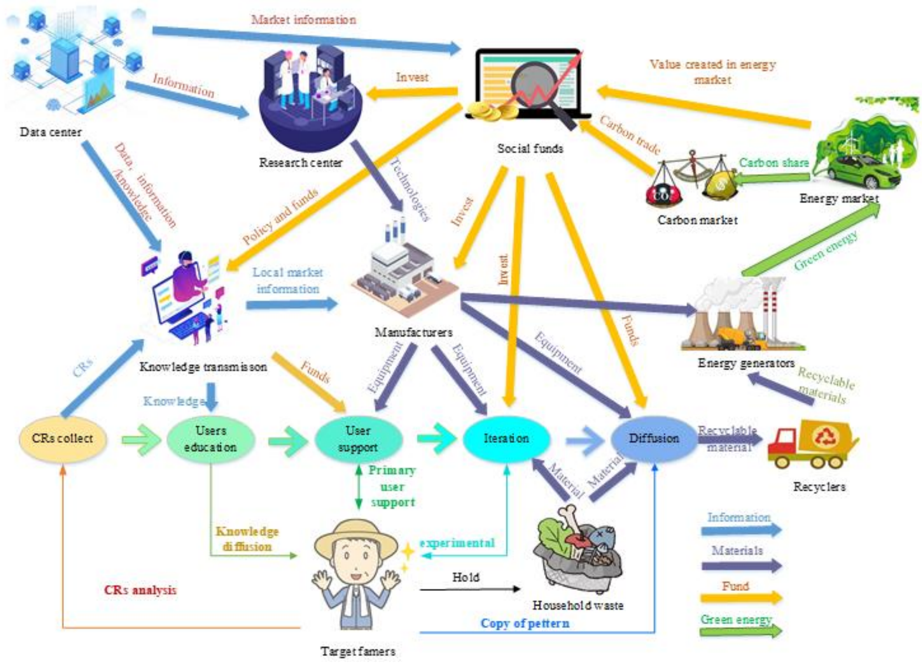

Fig. 2: Main constitution of the targeted business models.

Refers to Fig.2, main stakeholders in the targeted BM involves: target farmers who possess the household waste to be managed, data centers, knowledge transfers, manufacturers, social funds administration, material recovery, energy and carbon market. In the target BM, those stakeholders are interacted with various streams of the information (data), technology (system, equipment), funds (social invest, financial support, bonus), and the green energy (carbon equivalent). Based on aforementioned explanations, the BM to be developed involves multidisciplinary backgrounds. Therefore, innovations on the BM of this engineering system have to cope with the transdisciplinary complex engineering system tasks requiring a compatible and effective design and system configuration approach. The innovative conceptual solutions to the rural household waste collecting BM then can be achieved by using the proposed MBSE-based approach with the validation and verification of the generated solutions.

Conclusion:

This paper attempts to provide a new MBSE-based approach for constructing conceptual solutions to BMI of smart product system. The proposed approach attempts to bridge the interdisciplinary gap between the engineering design of complex technological systems and configuration of multiple stakeholders and other building elements to formulate the conceptual ideas to the BMI. Moreover, the proposed approach has enriched the domain of MBSE modeling by using basic ideas, methods and tools from the MBSE domains that are originally designed for the software development to configure more comprehensive engineering systems.

The proposed approach is only at its very preliminary stage. Therefore, it has several obvious limitations requiring more in-depth studies in the future. On one hand, the proposed approach is still requiring manually analysis and modeling, which makes it a very labor costing jobs to construct the overall conceptual model of BMI. On the other hand, the proposed approach mainly applied the MBSE ideas, methods and tools to focus on proposing conceptual design solution i.e., which focuses on the conceptual design stage in the PLM. Therefore, new studies can be conducted to develop new enabling methods or tools for BMI by using MBSE based methods in other stages of PLM to smooth the process of BMI especially for the complex engineering systems.

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