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Computer-Aided Design and Applications

A MBSE-based Approach for Architecting Concepts for Business Model Innovation of Smart Product Systems

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Abstract. The ultimate success of smart product innovation lies in proposing appropriate business models that facilitate the marketing promotion of smart products and the smart product system. As a complex technological system built on interdisciplinary knowledge, the development of a smart product system requires a lengthy and labor-intensive process. Furthermore, the design of business models for smart products typically comes after the completion of their development, allowing very little room for innovation in this area. To pave the way for successful business models of smart products, this paper aims to propose a new approach to constructing conceptual solutions for business model innovation (BMI) of the smart product system. This approach leverages existing methods and tools from model-based systems engineering (MBSE) through a synergistic workflow. The proposed method integrates various MBSE methods and tools into the BMI process, encompassing different types of smart products. To illustrate the practical applicability of the proposed method, we use the construction of the BMI for a new rural household waste collection system as a case study. Lastly, we discuss the advantages and limitations of the proposed approach and propose several opportunities for future research.

Keywords: Smart product system; Business model innovation; Conceptual design; MBSE
DOI: https://doi.org/10.14733/cadaps.2024.155-170

1 INTRODUCTION

Nowadays, technological innovations often manifest in the form of smart products or smart product systems, encompassing various types of smart products. These innovations are made possible by advancements in Information and Communication Technologies (ICTs) and enabling technologies for the Internet of Things (IoT) [1-2]. Technological innovation is a widely recognized avenue for enterprises to gain and sharpen their competitive edge in the market. The success of technological innovations hinges on proposing appropriate business models that better cater to customers' requirements and realize value creation, which in turn fuels further innovations. Previous studies have highlighted that as much as 80% of the quality, cost, and performance of a product is determined during the conceptual design stage of new product development (NPD) [3]. In line with this perspective, it is crucial to propose a feasible method for architecting business models for complex products, particularly smart product systems, as early as the conceptual design stage. Failure to do so can result in significant losses in terms of time and resources.

Even though the marketing promotion stage closely follows the product development stage according to the theory of overall product lifecycle management (PLM) [4], there are few studies focusing on the construction of business model innovation through collaboration with engineering design [5]. One of the main reasons for this gap stems from the disciplinary divide between engineering design and product marketing promotions [6]. To bridge this interdisciplinary gap and propose BMI concepts from the perspective of engineering design, this study seeks to leverage approaches and tools from the domain of model-based systems engineering (MBSE), as they enable intelligent multidisciplinary knowledge management in complex engineering systems [7]. As an emerging approach, MBSE employs modeling to represent and analyze various requirements of complex systems, encompassing design, analysis, verification, and validation activities. MBSE methods vary in their specific forms but share a common challenge: modeling the intricate and ambiguous relationships between different levels of abstractions in engineering systems [8-11].

To address this gap, this study proposes a novel MBSE-based approach for the conceptual design of business model innovation for smart product systems, with the aim of analyzing and intelligently managing interdisciplinary knowledge in complex engineering systems. To accomplish this, the remainder of the paper is organized as follows: Firstly, a concise literature review elucidates the background and theoretical foundations of the proposed method. Secondly, the framework of the proposed method is comprehensively explained, highlighting how various existing MBSE methods and tools are integrated into the innovation process of business models that encompass diverse types of smart products through a synergistic workflow. Thirdly, an exemplar case of constructing a new rural household waste collection system is presented to demonstrate the practical feasibility of the proposed method. Lastly, the advantages and limitations of the proposed approach are discussed, along with suggestions for future research opportunities.

2 LITTERATURE REVIEWS

This paper builds upon existing studies in the fields of MBSE approaches for engineering system development, methods and tools that support business model innovation, particularly for smart products and smart product (service) systems, as well as theories and methods for conceptual design of complex engineering systems across multidisciplinary backgrounds. By doing so, it aims to address existing research gaps and highlight the potential theoretical and practical contributions of the proposed approach.

2.1 MBES Approaches for Engineering System Development

Engineering has transitioned from document-centric approaches to model-based engineering systems (MBSE) as a result of evolving standard practices for designing multidisciplinary complex systems. MBSE approaches, with their top-down models, enable comprehensive descriptions of engineering systems from various perspectives, typically encompassing structural and behavioral aspects [8]. Previous studies have proposed various forms of MBSE approaches, each with different phases guiding the modeling of engineering systems.

Among these MBSE modeling methods, several have gained widespread popularity while employing distinct workflows. IBM Harmony-SE, serving as a suitable modeling approach for initial system architecture design, utilizes a service request-driven framework that iterates through requirement analysis, system functional analysis, and design. It employs the System Modeling Language (SysML) blocks with streams to represent communication between blocks. Similarly, Object-Process Methodology (OPM) is another MBSE approach designed for modeling general engineering systems. OPM categorizes everything into three types: objects, processes, and states [9]. Within a single graphical model of OPM, engineering systems are represented through functions, structures, and behaviors across stages such as requirement specification, analysis and design, implementation, use, and maintenance.

Vitech MBSE, an ontology-based approach, defines systems using meaningful semantics and model structure syntax to capture necessary information across four domains: source requirements, behaviors (including specific input/output information, control, and sequence), architecture (including components, interfaces, and system architecture), and validation/verification. Originating from the field of software engineering, Object-Oriented Systems Engineering Method (OOSEM) has evolved into an extensible approach for modeling both software and hardware systems, particularly complex and multifunctional systems like aerospace engineering systems. The OOSEM process involves six steps: stakeholders' requirements analysis, defining system requirements (black-box analysis), defining logical structures (white box), synthesizing allocated architectures and physical alternatives, optimizing and evaluating alternatives, and validating and verifying with requirement traceability [10].

Meanwhile these MBSE approaches differ in their specific forms, they share common characteristics. They employ a graphical syntax to represent system components in terms of functionality, behavior, and structure, and they follow workflows adapted from Product Lifecycle Management (PLM). They formalize modeling applications to support system requirements, design, analysis, verification, and validation activities from the conceptual design phase through development and the entire life cycle [11]. Variations in MBSE approaches mainly revolve around changes and new proposals in the modeling architecture elements and the modeling process.

2.2 Business Model Innovation (BMI) of Smart Product System

Emerging in the 1970s, the concept of a business model (BM) was initially developed to support the modeling of information technology systems. Over the course of more than 30 years, the concept of BM has evolved into its modern interpretation, which refers to the design and architecture of the mechanisms that create, deliver, and capture value within a specific business context [12]. In essence, a BM outlines how a business operates to generate value for all stakeholders [13]. It encompasses the design and structure of the mechanisms involved in creating, delivering, and capturing value. The ultimate success of technological innovation is heavily influenced by the proposal of a suitable BM that facilitates the marketing promotion of these innovations [14]. Without well-developed BMs, innovators would struggle to effectively deliver or capture value from their innovations [15]. Essentially, a BM is a conceptual rather than financial model of a business, and it is crucial in formulating sustainable competitive advantage and achieving significant profitability [16].

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. The published studies on the BM come from interdisciplinary backgrounds mainly including the E-business and the use of information technology in organization, innovation and technology management, strategic issues about value creation and competitive advantages of firms [17]. 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 [18]. Triggered by changes in competitive environment or legislations, BM innovation (BMI) is defined by changes of BM as response to internal and external incentives, new BMs can themselves represent a form of innovations [19]. 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. [20-21]. Technological innovations in forms of smart products or products system play essential roles in the realization of sustainability-oriented and digitalization-oriented BMI since the smart products and products service systems are physical foundations to architecture BM. Tasks to configure the BMI mainly involve: confirm of available revenue streams, identify targeted market segments, determine benefit brought to the customers from consuming or using products or services, select enabling technologies or features to be embedded in the products or services and the design for mechanism to deliver and capture the value[22]. Therefore, BMI requires a comprehensive workflow supported by methods and tools from multiple disciplinary backgrounds, moreover, the ever-growing complex of technological systems require builders to manage wisely on the configuration of the more complex technological system. In line with those points, a MBES-based approach is of importance to facilitate the architecture and configuration of BMI for smart products and services system built on transdisciplinary backgrounds.

2.3 Ontology-based Function Models for Complex Engineering System

One of the most important facts for BMI is what customers really want are solutions to their perceived needs rather than certain kinds of products or services [23]. In practical product development, customers' requirement obtained from their words of mouth or comments are firstly collected and ranked based on their importance and then are transformed into the functional requirements to guide the whole product development process, which can be seen in most practices of quality function deployment (QFD) and systematic engineering design process [24-25].

Function plays an essential role in product development, especially at the conceptual design stage of product innovation [24, 26-27]. Functions can indicate customers' perceived needs through changes in material, energy, and information flows [27]. Ontology-based methods, as one of the most important branches of function modeling in engineering design, enable the interoperability of heterogeneous sources and support the establishment of shared and common agreement on meaning across diverse domains [28-29]. Consequently, various types of ontology-based function modeling frameworks are widely utilized in the architecture of complex engineering systems. For example, an engineering design ontology integrated with UML representation methods has been proposed within the aerospace industry [30], primarily due to the prioritization of ontology in formalizing design knowledge in an accessible, shareable, and reusable manner [31]. From this perspective, ontology-based function modeling serves as a promising starting point for configuring the business model innovation (BMI) of complex engineering systems, such as smart product and service systems.

2.4 Research Gap to be Filled

With the growing complexity of engineering systems, MBSE approaches are faced with increased demands to support the architecture and configuration tasks of multi-domain systems within the context of transdisciplinary knowledge convergence, particularly in realizing the business model innovation (BMI) of smart product systems. There is a practical need to bridge this research gap by developing new MBSE approaches that are specifically tailored to support transdisciplinary system engineering. Such approaches provide fresh perspectives for developing resilient engineering solutions to complex system problems by addressing these problems from multiple angles. This endeavor holds significant practical value and can contribute to advancements in the field.

3 THE FRAMEWORK OF THE PROPOSED METHODOLOGY

The framework proposed MBSE-based approach for BMI of smart product system mainly contains three subsections: At the first, a multiple-layers MBSE modeling structure is developed to represent all the necessary blocking elements for complex engineering system of BMI from multidisciplinary backgrounds; Secondly, strategies and rules are represented to enable transdisciplinary knowledge convergence in generation of conceptual solutions to BMI projects; Thirdly, the workflow in forms of step-by-step design algorithm to implement the proposed MBSE-approach is explained in detail for practical usage.

3.1 Structure of the Proposed MBSE Modeling Approach

The essence of BM depends on the value chain formulated by different stakeholders to fulfill their perceived needs. From this viewpoint, the BM is usually in forms of social networks connected by various stakeholders interacted in a series of activities. The ultimate goal of BM is to gain profit for investors while providing satisfied products or service for targeted customers. Value creation in the BM is facilitated by the series of activities in which two most fundamental elements: stakeholders and streams are interconnected. Therefore, there are three main kinds of building blocks: stakeholders, streams and activities are applied by the proposed method to architecture concepts of BMI.

Generally, the value creation chain forms the core of constructing the business model (BM) and consists of various activities that span different stages of Product Lifecycle Management (PLM). Throughout these activities, stakeholders assume different roles to facilitate the development of the value proposition and creation mechanism of the BM, which is illustrated in the Figure 1.

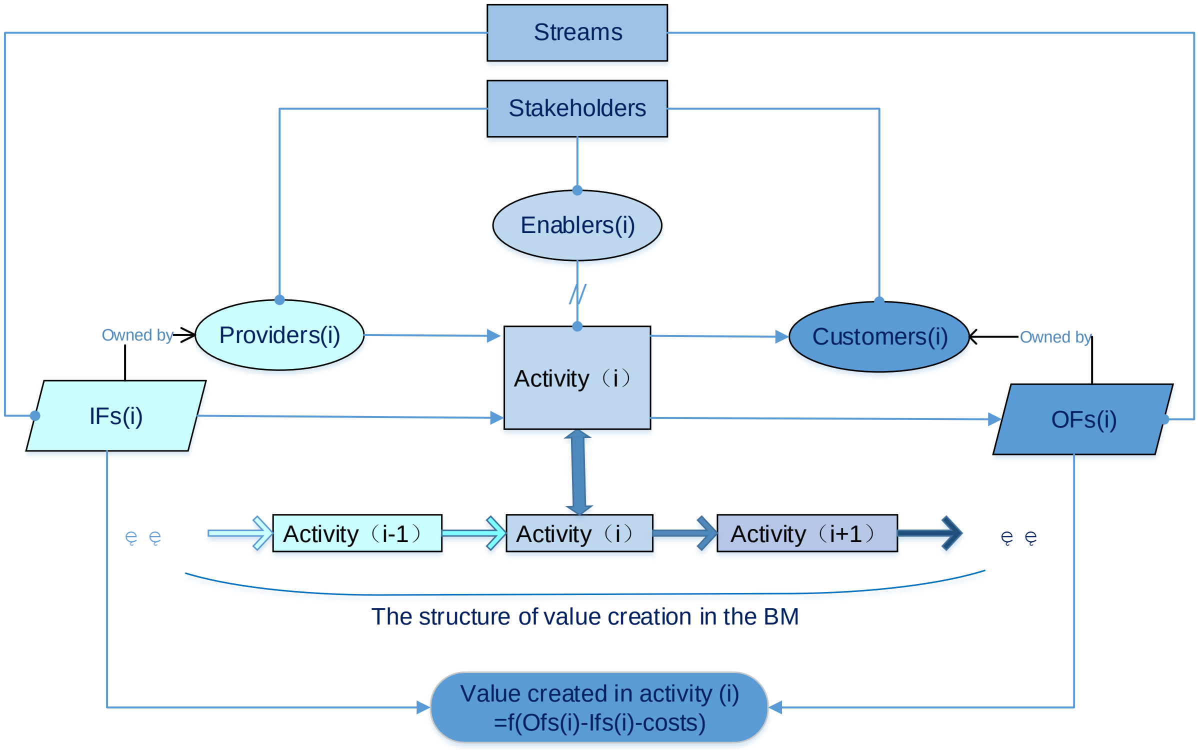

Figure 1: Fundamental building blocks in the configuration of BM.

Refers to Figure 1, there are mainly three roles played by stakeholders: provider, customer and enabler. To be specific, providers own all the input flows (IFs) of streams, customers hold all the output flows (OFs) of streams, enablers conditionally exist to activate or catalyze required activities. It should be noted that certain stakeholder plays the role of provider in one activity of the BM can play other roles such as the enabler or customer in the other activity. However, one stakeholder plays the definite role in the certain activity.

Various stakeholders are interconnected by streams that facilitates the value creation, delivery and capture mechanism of the BM, in other words, BM depends on transfers and transformations of those streams to realize its final goal i.e., fulfilling perceived needs of customers. There are mainly four kinds of streams that fabricate the structure of BM. They are the stream of information including data, information, knowledge about the BM; the stream of technology in both tangible and intangible forms including equipment, patents and design solutions; the stream of funds including money flows and government funds; streams of substances including core materials energies and other kinds of fundamental objects for propelling the value creation mechanism in the innovative concepts of BMs. In certain activity, the added value in each activity can be calculated by the total value of all the OFs of streams minus the total value of all the IFs of streams with the costs in the activity. The overall added value of the whole BM can be arrived at by calculating the sum of added values in all the activities in the BM.

3.2 Strategies of the Proposed MBSE Modeling Approach

Connections of stakeholders and streams of various types can be used to configurate the conceptual idea of BMI since they help to represent the novel proposal of value creation, deliver and capture mechanism. In most circumstances, value is created, delivered and captured throughout interactions of stakeholders, which can also be formatted as changes and transfers of streams.

Specifically, activities in the BM have the same ultimate aim to serve targeted customers and gain profits. Therefore, stakeholders interact with each other in those activities to support or provide products, services and other necessary resource to facilitate the value capture, creation and deliver. Those activities are organized in sequence by referring to basic ideas of product lifecycle management (PLM) with the purpose of supporting the whole engineering design process. Table 1 list those main activities and their correlations with the value creation chain in the BM. Figure2 indicates how different stakeholders and streams are interacted in activities belonging to certain steps in the overall PLM process to facilitate the BMI through a circulation of six steps to maintain the sustainable innovation of smart product system.

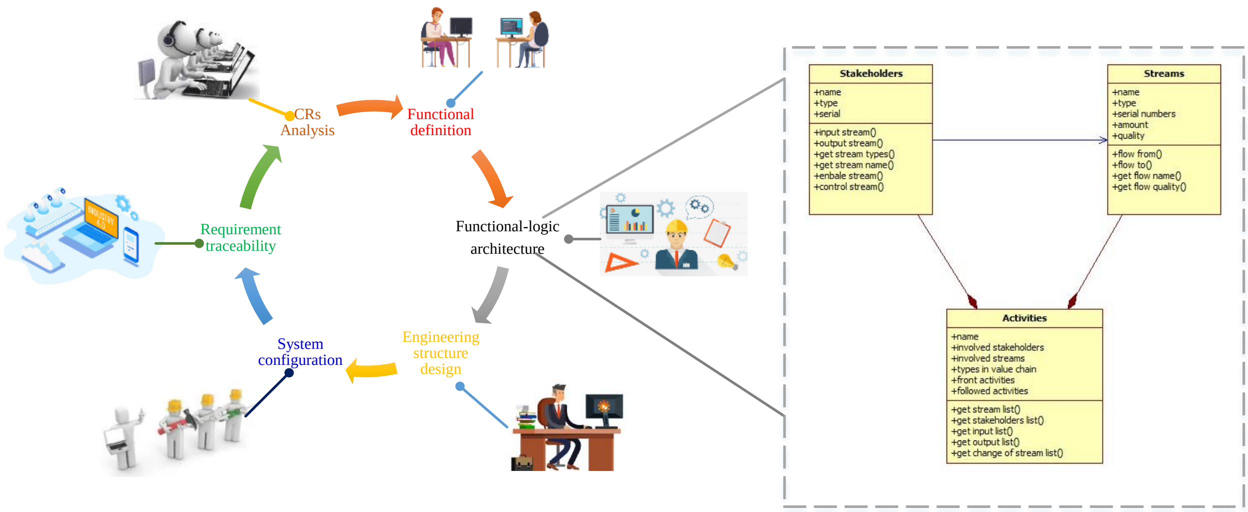

Figure 2: MBSE modeling structure for analyzing involved stakeholders and streams in BM

As the smart product system is a complex technological system, there are main activities involved in each of the six stages, as illustrated in Figure 2. According to Figure 2, the development process of a new smart product system typically begins with an analysis of customers' requirements, where all the customers' requirements (CRs) from various stakeholders are collected. These CRs are then transformed into functional requirements (FRs) through function definition. Next, function-logic analysis is employed to design the functional structure of the engineering system that will be developed. In the fourth step, the engineering structure required to fulfill each defined FR is designed, forming the overall technological structure of the engineering system. This is followed by the fifth step, which involves the configuration of the engineering system by arranging all the devices and departments within the proposed engineering system. Lastly, information, data, and knowledge are collected to facilitate requirements traceability within the proposed engineering system. As a result, these six stages form a continuous cycle that enables a sustainable Product Lifecycle Management (PLM) strategy for the smart product system.

3.3 Value Chain of the Proposed MBSE Modeling Approach

The value propositions of the business model (BM) to be designed are defined in the activities of CRs analysis and function definition. During these activities, new functional requirements are identified and defined to initiate the development of innovative products and services that meet the growing demands of customers, who are willing to pay for the provided products or services. The conceptual design and detailed engineering design steps play crucial roles in value creation within the configuration of the business model innovation (BMI), as they transform the design schema of products and services into tangible entities.

The value delivery of the entire BM is primarily achieved through the sale of products and services to targeted consumers, resulting in the flow of money from customers to dealers. Within the complete BM, value can be captured by analyzing data and information derived from customer feedback, thereby uncovering new opportunities for future innovations. Table 1 outlines the key stakeholders and streams involved in each main activity of the conceptual design for the BMI of smart product systems.

Main activities	***Positions in the value chain***	***Innovation opportunities***	***Involved stakeholders and streams***
Collection of CRs	Value proposition	Define CRs to capture new values	Manufacturers, dealers, customers; data, information
Function definitions	Value proposition	Transfer opportunities to design problems	Manufacturers, research centers, designers; data information
Function -logic architecture	Value creation	Formulate technological solutions	Designers in research centers and manufacturers; data information
Structure design	Value creation	Provide prototypes of products and service	Manufacturers, research centers; money, design knowledge, prototypes.
System configuration	Value delivery	Market promotion, sales, delivery of solutions	Manufacturers, transporters, dealers; products, service and money
Requirement traceability	Value capture	After sale operations and collect information	Data centers, dealers, customers; information

Table 1: Main activities involved of stakeholders and streams in BM.

Figure 3 indicate how the conceptual ideas of BMI for smart product system is formulated through six main activities. 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.

In Fig.3, 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.

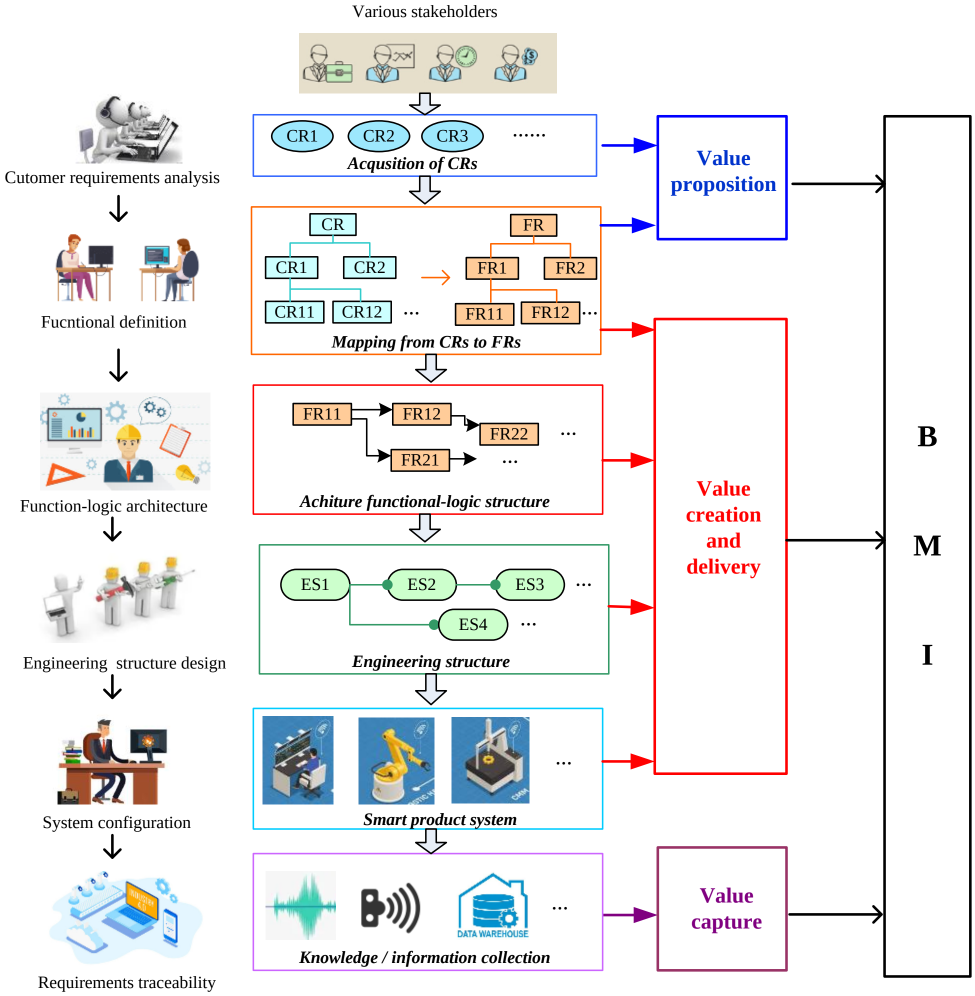

Figure 3: Value creation mechanism in the proposed MBSE modeling process.

3.4 Workflow of the Proposed MBSE Modeling Approach

The proposed MBSE modeling approach mainly includes five steps to construct the conceptual solutions to BMI of smart product systems, which is shown as the Figure 4.

Refers to Fig.4, there are mainly six steps to use the proposed MBSE modeling approach for constructing the conceptual design solution to the BMI of smart product system.

Step1: Stages analysis of BMI to be developed

The BM of typical smart product system contains six stages shown as the Fig.2, however, not all the BMs have six stages. Therefore, it is necessary to analyze included stages in the BMI to be developed.

Stage 2: Activities analysis in each stage

Analyze and summarize main activities involved in each defined stage of BMI to be developed.

Stage 3: Stakeholders and streams analysis

Analyze stakeholders and streams involved in each activity in all the defined activities.

Step 4: Flow logic analysis of streams transformation

Analyze the flow change and transformation logic of different types of streams and formulate flow chain belonging to certain type of stream, which helps build the collaborations of different stakeholders.

Step 5: System synergic to formulate the conceptual idea of BMI

The overall conceptual solution of BMI can be formulated by synergizing different streams flows to organize all the stakeholders, streams and activities in the whole BM.

Step 6: Validation of conceptual solutions to BMI in development

The conceptual solution of BMI to be designed is validate by its completeness and indicators about value creation for stakeholders involved in the proposed BM.

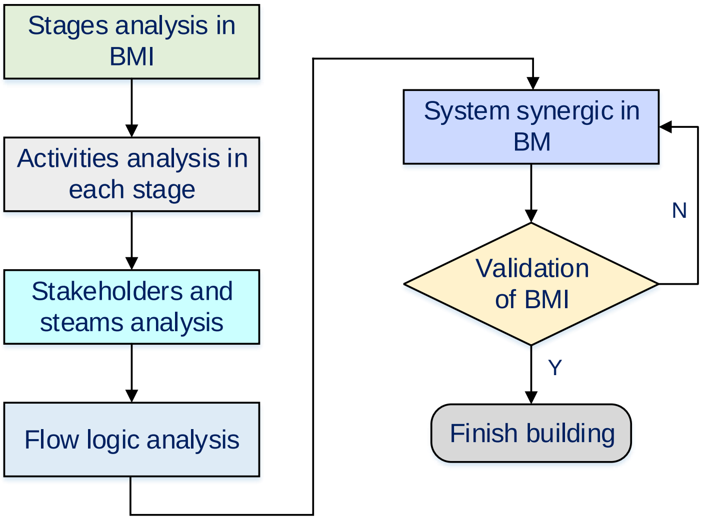

Figure 4: Workflow of the proposed MBSE modeling approach.

4 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 of smart products, which works as the exemplar study to address the feasibility of the proposed method. The current BM of the rural household waste collecting system is shown as the Figure 5. In general, both the government and farmers should pay the fee to recycling companies which take responsibility of cleaning the rural household waste. In the current BM, there is very limit value capture mechanism since the government and farmers simply buy the service from recycling companies. There is only one stage of PLM i.e., the service sales and delivery among three main stakeholders including the government, farmers and recyclers with two basic types of streams: money and the household waste. In the current BM of the Fig.5, working as the only provider of the service, recycling companies gain profit by filtering and selling recyclable materials from the household waste to refuse collection center. Meanwhile, recycling companies also bear the cost of landfilling of the non-recyclable parts of household waste and the logistics. Both the government and farmers are the customer of the service to clean the rural household waste.

The conceptual solution to the BMI of rural household waste collecting system can be obtained by using the proposed MBSE modeling method shown in the Fig.4. To be specific, it takes six major stages to generate the conceptual ideas of the BMI.

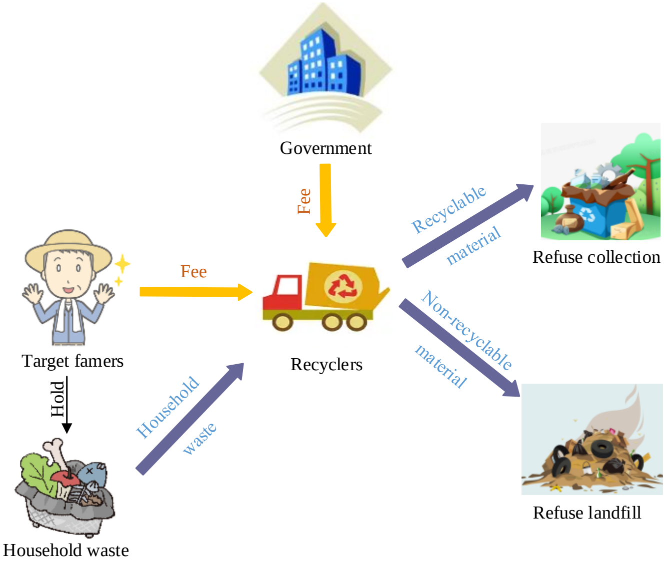

Figure 5: The current BM of rural household waste disposal.

4.1 Stages Analysis of the Proposed Conceptual Idea of BMI

Refers to Fig.5, the current BM of the rural household waste collecting and disposing system only contains the service sale and delivery that belongs to the system configuration stage by referring to the circular chain of stages in Fig.2. The proposed BMI for the rural household waste collecting system is built on the smart product system. Therefore, all the six stages are taken into consideration in the construction of the conceptual solution to the proposed BMI of smart product system with the purpose of building a novel and sustainable BM.

4.2 Activities Analysis of the Proposed Conceptual Solution of the BMI

Main activities in each stage of the proposed BMI are list in the Table 2, which cover tasks from as early as the CRs collecting to the copying and diffusion of the proposed BM.

Stages	***Main activities***	***Opportunities for creating new values***
CRs analysis	Customers' requirements collections;	Value capture for finding new CRs.
Functional definition	Data sharing, conceptual design for products and services	Value proposition in transferring CRs into design problems

Function-logic architecture	Generated innovative solutions to defined engineering design problems	Value created in using new principles or structures to improved solutions
Engineering structure design	Products and service prototyping and trail operation	Value created in providing feasible new solutions
System configuration	Products and service promotion, delivery and diffusion	Value created and delivered in marketing the products and service
Requirement traceability	Users support, education and comments collecting for the iteration	Value captured in finding and defining new design problems

Table 2: Main activities of each stage in the proposed BMI.

4.3 Stakeholders and Streams in the Proposed Conceptual Idea of BMI

There are various stakeholders are connected with diverse streams make up the structure of the BM of the rural household waste collecting system. Those stakeholders can be organized by according their roles played in the transfer and transformation of streams. To be specific, those stakeholders are divided into three types: providers, customers and enablers. Moreover, the proposed BM of the targeted engineering system is evidently different from the typical BM of products and services, therefore, farmers, original owners of rural waste play roles of both providers and consumers from different viewpoints. Specifically, main stakeholders and their roles played in the targeted BM is shown in the Table 3 by systematically analyzing the environmental conditions.

Stakeholders	***Roles played in the BM***	***Involved streams***
Famers	Providers & consumers	Waste (P); Knowledge (C); Equipment (C); feedback information (P).
Promoters	Providers, enablers, consumers	Knowledge (P); Equipment (E); Data/information(C); Local market information (P).
Manufacturers	Consumers & providers	Equipment, products (P); Technologies (C); F.
Data center	Providers & enablers	Information (P,E); Data knowledge (P,E)； market information (P,E)
Research center	Providers, enablers, consumers	Information(C); Funds/Invest (C); Technologies(P,E)
Social funders	Providers& consumers	Information(C); Funds/invest(P)
Recyclers	Providers & consumers	Waste (C); recyclable materials (P)
Energy generator	Providers & consumers	Waste (C); Green energy (P)
Energy market	Providers & consumers	Green energy (C); Carbon share (P); Funds (P)
Carbon market	Providers & consumers	Carbon (C); Funds(P)

Table 3: Main activities involved of stakeholders and streams in BM.

4.4 Main Activities in the Proposed Conceptual Idea of BMI

Value creation mechanism lies in the chain of activities to facilitate transformation of streams in different forms or types. There are mainly three activities chains in the conceptual structure of the targeted engineering system, which are illustrated separately as the Figure 6(a), (b) and (c).

To be specific, activities to facilitate the transfer and transformation of information stream is shown as the Fig.6(a), which indicates how data, information, knowledge gather, collect, transmit, diffuse and transform over different stakeholders. Similarly, activities to facilitate the transfer and transformation streams of enabling technologies such as key equipment, product and other engineering systems are shown as the Fig.6(b). Meanwhile, activities to transform rural household waste to money flows are illustrated as the Fig.6(c).

Those activities chains help to build the main structure and logic of value creation, delivery and capture mechanism. Built on activities chains, innovative conceptual solutions to the rural waste collecting smart products and service system.

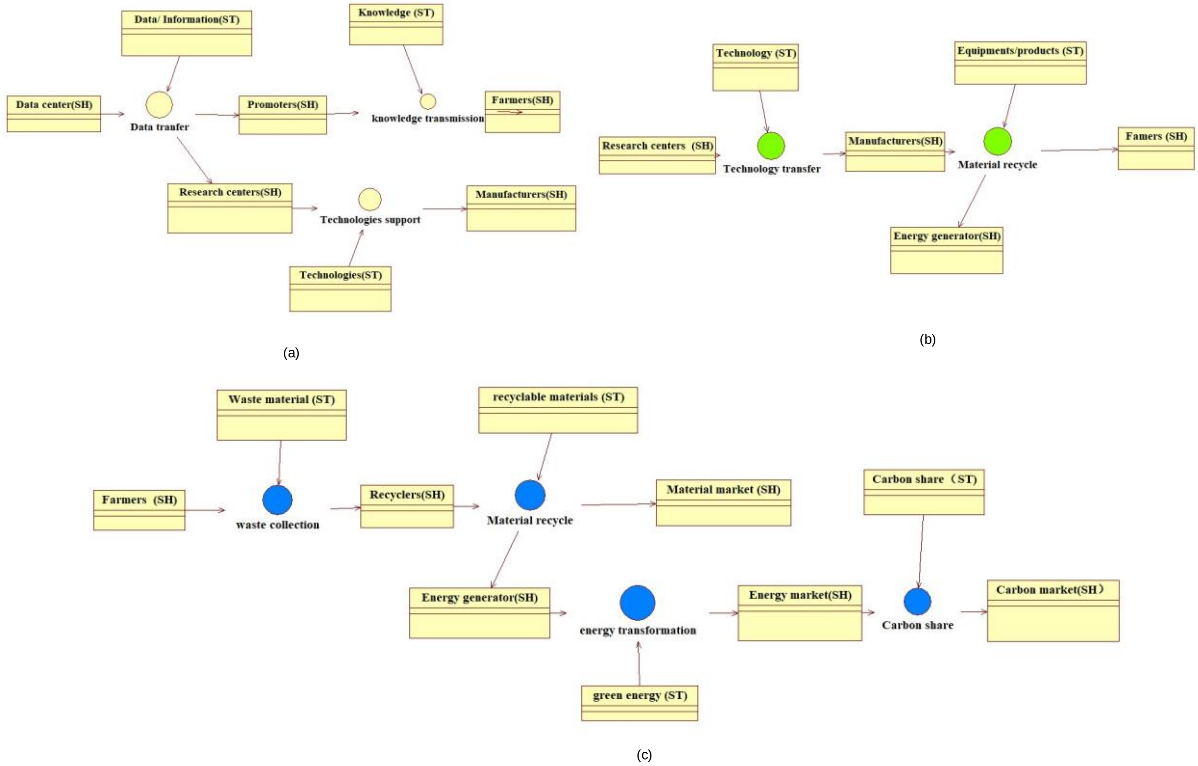

Figure 6: Illustrators about main activities chain in the proposed BMI concepts: (a) activities to transfer and transform streams of information;(b) activities to transfer and transform streams of technological systems; (c) activities to transfer and transform streams of waste materials.

4.5 Overall MBSE-based Model of the Proposed Conceptual Idea of BMI

The main activities chains among different stakeholders from multidisciplinary backgrounds in the exemplar case is illustrated as the Figure. 7. Refers to Fig.7, 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 targeted BM, those stakeholders are interacted with various streams of the information (data), materials (technological system, equipment, products), 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.

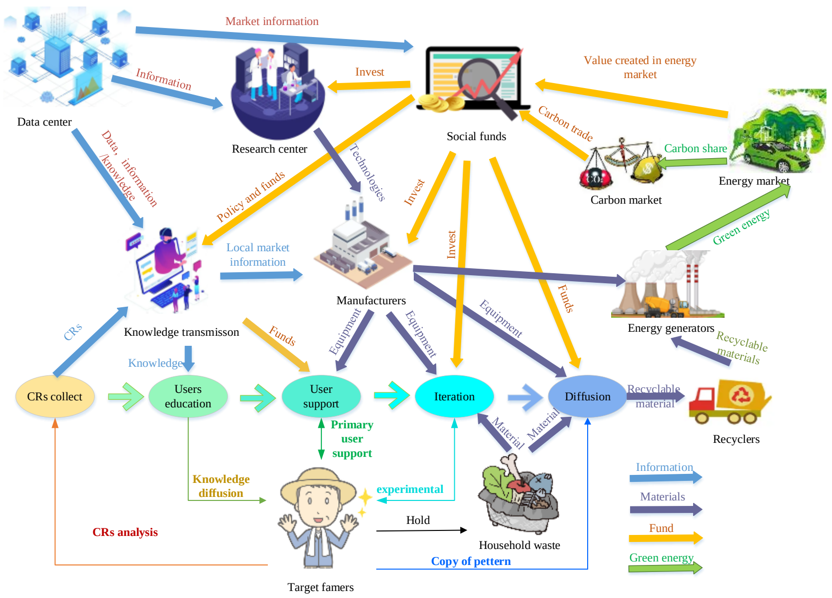

Figure 7: Main constitution of the conceptual solutions to the proposed BMI.

4.6 Validation of the Proposed BMI

The conceptual solution to the proposed BMI shown as the Fig.7 is validated by analyzing profits and costs of all the involved stakeholders by comparing with the current BM shown in Fig.5. The analysis result of the former BM is list in the Table 4(a), meanwhile the analysis result of the proposed BMI is shown in the Table 4(b). Refers to these results in table 4, the proposed BMI is clearly better than the current BM as it has better satisfied all the involved stakeholders.

Stakeholders	***Profits***	***Costs***	***Overall attitudes***
Famers	None	Fee for the service	☹
Government	None	Fee for the service	☹
Recyclers	Fees and sales of material	Cost for operation	😐

(a)

Stakeholders	***Profits***	***Costs***	***Overall attitudes***
Famers	Paid for waste	None	☺
Promoters	Funds	Operation costs	☺
Manufacturers	Sales of equipment	R&D costs	☺
Data center	Fees for service	Operation costs	😐
Research center	Funds and fees for service	R&D costs	😐
Social funders	Carbon trade and energy sale	Invests	☺
Recyclers	Fees and sales of material	Cost for operation	😐
Energy generator	Energy sale	Operation costs	😐
Energy market	Energy transition fee	Operation costs	😐
Carbon market	Carbon transition fee	Operation costs	😐

(b)

Table 4: Profits and costs of stakeholders involved in BM;(a) analysis results in the current BM, (b) analysis results in the proposed BMI.

5 DISCUSSIONS AND CONCLUSIONS

5.1 Main Contributions

This paper aims to present a new MBSE-based approach for constructing conceptual solutions to the business model innovation (BMI) of a smart product system designed for collecting rural household waste. The proposed approach makes significant contributions in the following three aspects:

At first, 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.

Secondly, the approach expands the domain of MBSE modeling by incorporating ideas, methods, and tools from software development. This allows for the configuration of more comprehensive engineering systems, encompassing not only hardware components such as equipment and smart devices but also software components including data cloud and data service applications.

Thirdly, the approach provides a feasible way to architect the conceptual solution for the BMI using the lens of MBSE. It enables the modeling, analysis, and refinement of relationships among multiple stakeholders, which are fundamental to the mechanisms of value creation, delivery, and capture within the business models.

Overall, the proposed approach bridges disciplinary gaps, enriches MBSE modeling capabilities, and offers a pathway for innovative business models that involve multiple stakeholders, ultimately supporting the development of effective conceptual solutions for the BMI.

5.2 Limitations and Opportunities for the Future Studies

The proposed approach is still in its early stages and, as such, it has certain limitations that require further investigation and research in the future.

One limitation is the manual analysis and modeling involved in the approach. Constructing the overall conceptual model of BMI, which involves complex relationships among various stakeholders, can be a labor-intensive task. To address this limitation, the use of computer-aided modeling approaches can greatly assist in systematically configuring the components of the BMI within a complex engineering system.

Another limitation is that the proposed approach primarily focuses on the conceptual design stage in the PLM process. While the application of MBSE methods in this stage is valuable, there is potential for further development. Future studies can explore the use of MBSE-based methods in other stages of the PLM to facilitate the BMI process for complex engineering systems. This would involve developing new enabling methods or tools that utilize MBSE approaches throughout the entire product lifecycle.

By addressing these limitations and conducting more in-depth studies, the proposed approach can be further enhanced and extended to better support the BMI process. This would involve leveraging computer-aided modeling techniques and expanding the application of MBSE-based methods in different stages of the PLM, resulting in a more comprehensive and efficient approach to BMI for complex engineering systems.

ACKNOWLEDGEMENT

The paper is sponsored by the National Key R&D Program of China (2022YFD1601102), the Humanities and Social Sciences Youth Foundation of Ministry of Education of China (19YJC630109); and the start-up research fund for new teachers of Tianjin University of Commerce.

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