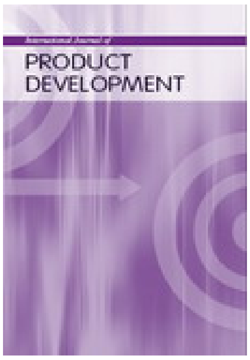

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Future innovation framework (FIF) for value co-creation of smart product-service system design in a global automotive manufacturing company

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Future innovation framework (FIF) for value co-creation of smart product-service system design in a global automotive manufacturing company

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Abstract: The Product-Service Systems (PSS) methodology faces new challenges as digital servitisation drives product-oriented companies to integrate digital services into their offerings. A value co-creation strategy and global collaborative innovation are now essential for these companies to develop smart PSS models. This study introduces the Future Innovation Framework (FIF) which is proposed as a mechanism to facilitate value co-creation in smart PSS design, specifically tailored for global manufacturing contexts. Through qualitative analysis and literature review, the research investigates collaboration among key stakeholders, defines a structured smart PSS design process, and demonstrates how value co-creation can enhance design outcomes. The proposed FIF framework, applied to a Smart Electric Vehicle (SEV) case with Volkswagen, supports early-stage collaborative innovation and informed decision-making. This paper discusses the practical implications, challenges, and future opportunities of implementing FIF in industrial smart PSS design. Finally, the potential for adapting FIF across various industry sectors is explored.

Keywords: smart product-service system; FIF; future innovation framework; PSS design process; value co-creation; automotive manufacturing company.

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1 Introduction

Product–Service Systems (PSS) has emerged as a response to the sustainability demands concerning both production and consumption (Tukker, 2004). PSS is also promoting a transfer in engineering design, away from manufacturing and selling products to the value co-creation, offered in providing function-oriented business models from a servitisation perspective (Mont et al., 2006). PSS are initially described as 'the result of an innovation strategy' (Manzini and Vezzoli, 2001).

PSS design methodologies and cases have already been researched and demonstrated for value transformation of manufacturing industries from sales of products to the provisioning of services (Goedkoop et al., 1999; Baines et al., 2007). Both industry and society as a whole are shifting toward digitised solutions (Bertoni and Bertoni, 2022), and urgently need to begin the practical innovation approach to designing and developing PSS, which are considered the primary means of changing the current economic systems toward a more circular system view (Kjaer et al., 2019; Pieroni et al., 2018). The concept of PSS is a way to design for today and for the future by identifying and addressing the gap between today and tomorrow (Gaiardelli et al., 2021).

The ongoing digital servitisation transformation is forcing solution providers to pursue innovative development approaches to manage the value co-creation process with customers (Struwe and Slepniov, 2023). The idea of implementing smart Product-Service Systems (PSS) is being increasingly recognised as a novel approach to add new value to businesses while addressing sustainability concerns (Machchhar et al., 2022). The academic discourse surrounding smart Product-Service Systems (sPSS), in particular, has recently explored the influence of advanced technologies on the design of innovative business propositions, hardware, and associated services (Cong et al., 2020). In addition, the collaboration and communications of various stakeholders is enhanced to value co-creation through embedded ICT and advanced technologies (Thoben et al., 2017; Lee and Lee, 2019; Pirola et al., 2020).

To support the development of smart PSS, various methodologies and methods have been proposed (Aurich et al., 2006). However, most of the methodologies for designing smart PSS are either product-oriented or service-oriented (Mendes et al., 2015), which leads to a lack of a holistic design approach. Hence, this study proposes a methodology to organise the design process of smart PSS using a range of design tools. It is that current PSS design approaches and tools do not meet the requirements of designing smart PSS and collaborative approaches for designing smart PSS are still scarce, with real applications still lacking (Pirola et al., 2020). Based on recent research by Reim et al. (2015), and the result of collaborative projects between global car manufacturing company, academia, a novel concept of smart PSS is emerging, that seeks to offer possible guidelines and roadmaps for these transforming and emerging industries (Sarancic et al., 2023). In this paper, the authors have explored how the value co-creation can contribute to development of a SEV in a global automotive OEM.

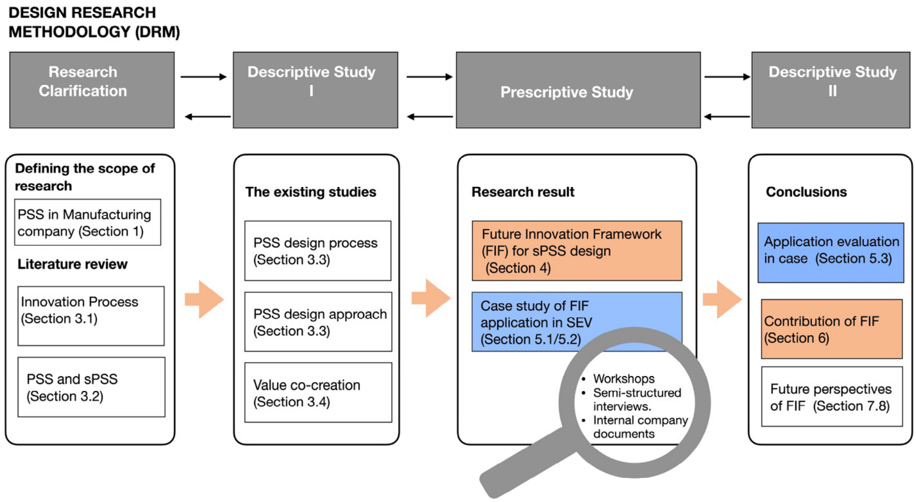
The paper is organised as follows. Section 3 provides an overview of current research in PSS design and smart PSS design processes. Section 4 presents the Future Innovation Framework (FIF) for smart PSS design. Section 5 exemplifies in a case study related to the application of the FIF with a global automotive OEM, Volkswagen and discusses the main findings from the process of implementing and evaluating of the FIF. The last section summarises the main content, contribution, limitations and future perspectives.

2 Research methodology

2.1 Design research in building up the framework

To improve the procedural rigor of the research – and to balance industrial relevance with scientific consistency – the work was conducted using the Design Research Methodology (DRM) framework (Blessing and Chakrabarti, 2009) as inspiration. The centrepiece of the DRM methodology is the four-step framework that features Research Clarification (RC), Descriptive Study 1 (DS-I), Prescriptive Study (PS) and Descriptive Study II (DS-II) in Figure 1. In this contribution, the authors close the loop between these stages: after defining the scope of their research, presenting both the findings of the empirical study and the prescriptive solution and evaluating the latter, they go back to stage one to reflect on the gaps and questions in future research.

Figure 1 Overview of the research methodology and data collection methods at the basis of the research (see online version for colours)



In addition to DRM, Case Study Research (Yin, 2014), has also influenced the research approach in this work. First, the research motivation was clarified by reviewing literature within the areas of innovation process, smart PSS, PSS design process and value co-creation, which provided a deeper understanding of the challenges and existing gaps in current research. In the prescriptive study, an initial model of the future innovation framework was created, integrating the tools and approaches of other references into an initial framework, which was then investigated with respect to the relevance of the framework in a real industry case based on the design of a SEV.

2.2 Case study research in refining and validating the framework

A comprehensive evaluation of the FIF was conducted in the descriptive study II, where innovation teams of a global automotive OEM, Volkswagen participated to evaluate the use of FIF at different stages, resulting in an improved innovation framework. Data collection, such as data generated from the PSS design process, was performed through interviews, notes, photos, videos and canvases emerging from four workshops. Also, an evaluation form was completed in different workshops by the participants from the case company. In the final evaluation session, participants must use the evaluation criteria to assess the value of applying FIF in the smart PSS design process. The results and notes from the interviews, workshops, concept design, and formal meetings to evaluate the PSS design result were used to assess the usability and feasibility of the FIF contribution. During the project, the data was organised by the author according to the different outcomes of each phase of the framework, including the influence and relevance of the data. However, the global automotive case company conserves a reasonable degree of credibility to ensure a realistic description of the results of applying the FIF.

3 Scientific background

3.1 Innovation process

The term 'innovation' refers to 'the introduction of something new' or 'a new idea, method, or device' from Latin. Schumpeter (1942) defined innovation as the outcome of an entrepreneur's work creating new combinations and changes in the economy's business environment, including new products or services, methods or processes, markets, sources of raw materials or organisations.

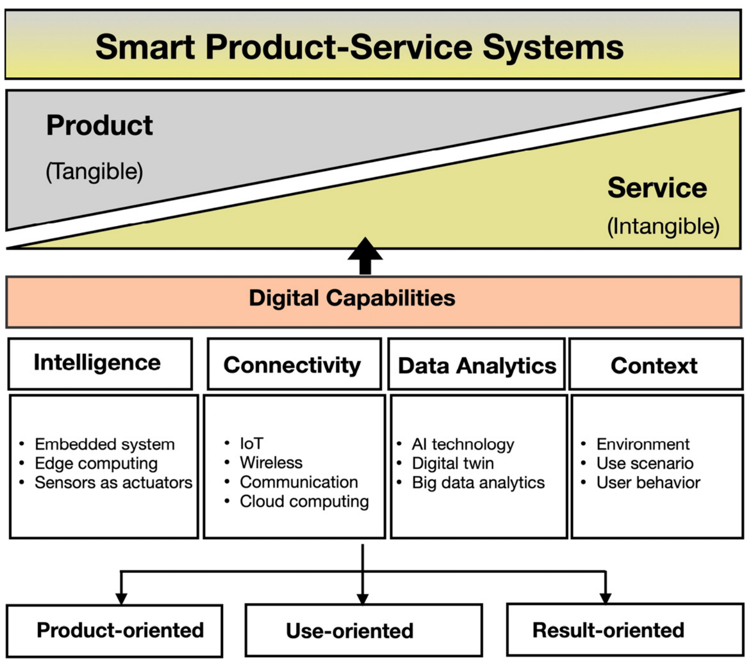
Innovation processes are usually described as a sequence of stages that are followed from the generation of an idea to the creation of value. Although the names and number of stages may vary, the process typically includes ideation, concept development, prototyping and implementation (Gericke and Blessing, 2012; Garud et al., 2013). Global innovative companies have a process for dealing with ideas (Nanda and Singh, 2009). There are several suggestions for how to define the different phases that compose innovation processes (Gericke and Blessing, 2012). Moreover, the research has shown that innovative companies are able to adjust their processes to promote learning, collaboration and reconfiguration of companies' resources (Teece, 2014); hence, they are able to adapt to changing environments, but are also able to shape them. In manufacturing companies, the product innovation process faces new challenges such as: global pollution (Griggs et al., 2013), digital transformation in Industry 4.0 (Loonam et al., 2018) and value co-creation between innovation teams (Alves, 2016). To address these challenges mentioned above, manufacturing companies are in need of an innovation framework that can guide the innovation process in practice (Zine et al., 2014).

3.2 From PSS to smart PSS

A Product Service System (PSS) is a marketable set of tangible products and intangible services that together can fulfil a customer's needs (Goedkoop et al., 1999; Mont, 2002). At a broad level, PSS can be divided into three categories depending on the orientation (Tukker et al., 2006), i.e., product-oriented, use-oriented and result-oriented PSS, and these systems can achieve an increased customer value with practical and effective use of resources, by their virtue of providing a 'function' (Isaksson et al., 2009) rather than a traditional product. PSS do not necessarily have to be provided by a single company but can also consist of an ecosystem that includes multiple actors (Bertoni et al., 2016).

Smart products are physical objects with embedded systems and connected capabilities that enable intelligent adaptation to customer needs and changes in usage scenarios (Serpanos and Wolf, 2018). Valencia and Mugge were the first to introduce the concept of smart PSS, which combines smart products and smart services into an integrated offering. They pointed out that the development of traditional PSS has two limitations: a strong focus on PSS per se and no ICT or IoT functionality. Smart PSS is characterised by utilising ICT that enable the machine to connect, collect and process information' (Valencia et al., 2015). IoT-enabled PSS have created new opportunities for designing of smart PSS with the goal of achieving even higher market capitalisation and customer satisfaction (Zheng et al., 2019). Digital capabilities as the one of the most noticeable distinctions between traditional PSS and smart PSS, as shown in Figure 2 (Carrera-Rivera et al., 2022). The first capability of sPSS is intelligence, the system can capture and sense information using embedded systems and sensors integrated into products to collect data and respond to their environment. The second capability of sPSS is connectivity, the collection and processing of data by service providers is improved through cloud computing, made possible by smart products enabled by IoT technology and wireless communications. Data analytic is the third capability of sPSS, it enabled by technologies such as Artificial Intelligence (AI), Digital Twins (DT) and Big Data analytics, enable the conversion of data from the connected products and launches intelligence for visualisation the insights of businesses (Lenka et al., 2017). Finally, the context is an entire background of usage environment, user scenario and user behaviours in the user task (Mont, 2002).

Figure 2 Smart product service system graphic description (see online version for colours)



Source: Adapted from Carrera-Rivera et al. (2022).

When designing smart PSS in industry, the innovation team consisting of designers, engineers and managers with different backgrounds should follow a framed design process that can successfully ensure the goal of value co-creation (Boukhris et al., 2017). The challenges of innovation collaboration include: the practical method should support the combination of different values, methods, processes of IoT-enabled physical products definition, customer experience and services offering (Pirola et al., 2020), such as the core value proposition of smart PSS and meeting customer needs through customer participation in the design process. This allows for the consideration of value co-creation throughout the entire design process.

3.3 PSS design process and approach

Designing a PSS means designing a system consisting of product, service and infrastructure components. It is important that all components are considered and that the accumulated value of these triumphs the value of each component produced separately (Kuijken et al., 2017). A new issue arises for PSS design, it is the product design and service design should be included in the same design process of PSS design. (Mendes et al., 2015). From the literature study of existing PSS design methodologies, several design methodologies targeting the PSS design have been conceptualised and developed throughout the research. Mendes et al. (2015) reviewed five acknowledged PSS design methods from the research (see Figure 2). The design process for the development of an integrated solution (Morelli, 2002, 2003, 2006); Service Model (Sakao and Shimomura, 2007; Shimomura and Arai, 2008, 2009; Sakao et al., 2009); Fast Track Total Care (Alonso-Rasgado et al., 2004; Alonso-Rasgado and Thompson, 2004); Integrated Product and Service Design Processes (Aurich et al., 2004, 2006) and Methodology for Product-Service System – MePSS (Van Halen et al., 2005). Over the last few years, the interest in these methodologies has increased, but these mentioned methodologies still need further empirical research and use case analysis of PSS design process in industry (Meier et al., 2010; Cavalieri and Pezzotta, 2012; Vasantha et al., 2012). Figure 3 summarises the main characteristics of the PSS methodologies discussed.

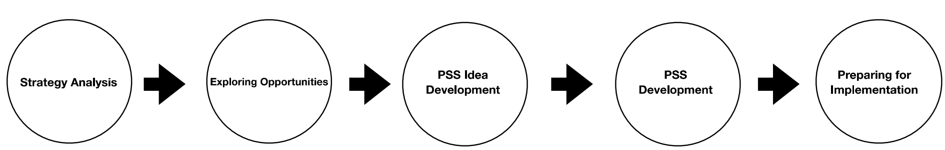
Among the five PSS design methodologies summarised, only the Methodology for Product-Service System (MePSS) by Van Halen et al. (2005) underlines the design process of PSS. The MePSS is organised in a modular approach, where each phase is divided into steps, and each of the step is defined by relative processes. The MePSS is organised into five main phases (seen in Figure 3).

Figure 3 PSS design process methodology characteristics

Methodology	Author(s)	Definition of PSS	Emphasis	Aim of design output	Tool Support
1.The Design Process for the Development of an Integrated Solution	Morelli (2002, 2003, 2006)	*A systemic solution including products and services*	**Service Design**	New combination of technological artefacts on the basis of functional parameters	Not mentioned
2.Service Model	Sakao and Shimomura (2007); Shimomura et al. (2008, 2009); Sakao et al. (2009)	*A discipline seeking to increase the value of artefacts by focusing on service*	**Service Design**	Service contents	Service CAD Service Explorer
3.Fast Track Total Care	Alonso-Rasgado et al. (2004); Alonso Rasgado and Thompson (2006)	*An integrated system comprising hardware and support services*	**PSS Business Proposal**	Functional products	Supported by computational tool
4.Integrated Product and Service Design Processes	Aurich et al. (2004, 2006)	*Technical PSSs are interrelations between physical products and non physical services*	**Service Design Systematization and Modularization**	Technical services	Not mentioned
5.Methodology for Product Service System – MePSS	Van Halen et al. (2005)	*An interconnected system of products and services*	**PSS Design Process**	New PSS offerings	Web tool

Source: Adapted from Mendes et al. (2015).

Figure 4 Methodology for product-service system design



Source: Adapted from Van Halen et al. (2005).

Design methods for PSS stress the early stages of the process and merge the service mindset in the development (Mendes et al. 2015). An important aspect for the PSS design team is to move from focusing on exploiting technologies implemented in the PSS to exploring and enabling the forms of value co-creation (West et al., 2018). Eventually, it has been agreed that PSS design is a process of value co-creation, but more attention should be paid to the involvement of company, customers and other stakeholders. Manufacturing companies today primarily rely on intuitive and ad hoc approaches in designing PSS. Innovation teams consisting of people with different backgrounds should follow a framed design process that can successfully ensure the goal of value co-creation when designing the PSS (Boukhris et al., 2017).

Achieving smart PSS design brings challenges to traditional design methodologies of PSS. Hence, developing practical approaches for designing smart PSS design considering their unique design feature has become a major topic has been widely discussed (Bertoni and Bertoni, 2022). Through literature study, this paper found that different existing design approaches have been applied to PSS design (seen in Figure 5).

Figure 5 Literature review of design approaches for product service system design

Approach	*Qualitative vs Quantitative*	*Aim of the approach*	*Emphasis phase of PSS design*	*Reference*
Collaborative workspaces	Qualitative	Interest in the development of customer interactive group workspaces, engagement between different participants.	Strategy analysis Explorating opportunities PSS idea development	(Larsson et al. 2005; Sarancic et al.2023)
Data-driven design	Quantative	Methods to design data-driven PSS based on data and criteria.	PSS development	(Bertoni et al. 2019)
Systematic decision support	Qualitative	Knowledge enabler for decision supporting in PSS planning.	PSS development Prepare for implementation	(Bertoni et al. 2019)
Scenario simulation	Semi-quantative	Provide clear data to base decision uon in PSS design. Simulation has been used to support the design of all the PSS components.	PSS idea development PSS development Prepare for implementation	(Peruzzini et al. 2016; Chowdhery and Bertoni 2018b; Bertoni et al. 2019; Bertoni 2023; Rondini et al. 2017a; Rondini et al. 2015)
Digital Twins	Quantative	Build data correlation and communication between physical and virtual for improving the product development.	PSS development Prepare for implementation	(Schroeder et al. 2016a; Loizou et al. 2019, Bertoni et al. 2022)
Artificial intelligence	Quantative	how Machine Learning and Artificial Intelligence can be effectively used to support PSS design.	PSS idea development PSS development	(Chowdhery, 2018a; Abramovici et al. 2018; Wang 2019)

3.4 Value co-creation

The ongoing digital servitisation transformation is forcing solution providers to adopt innovative development approaches to manage the value co-creation process with customers (Struwe and Slepniov, 2023). Compared to the traditional product sales model, engineers have raised their awareness of customer and stakeholder needs to participate in the process along the entire product and service development, in order to realise solutions that are value-adding for all the actors involved (Isaksson et al., 2009). Value co-creation in the industrial innovation environment relates to the collaboration of manufacturers, employees, service providers, suppliers and customers in business-to-business relationships (Chowdhury et al., 2016; Santos-Vijande et al., 2016; Franklin and Marshall, 2019) that contribute Win-win such as the improvement of service offerings and the creation of new value for solving the customer's problems (Skjølsvik, 2016; Dong and Sivakumar, 2017; Ribes Giner et al., 2017). As a key player in development of service offering, customers have taken a more active role in this collaboration, thereby creating value together with their service providers in the so-called value co creation process (Galvagno and Dalli, 2014; Wang et al., 2019).

Liu et al. (2018) provided an in-depth description of how value co-creation evolves across various domains of products and services, identifying the smart PSS value co-creation process as comprising four stages: co-existing stakeholders, co-designing service functions, co-implementing service systems and co-evaluating service systems. The need to integrate several knowledge domains means for industry to move 'downstream' knowledge into the early phases of the design process, which further raises the requirements for methods and guidelines that support team collaboration and cross-disciplinary teamwork in the process of design (Bertoni, 2019). Furthermore, the study reveals that Knowledge Management (KM) is essential for a successful value co-creation. According to the concept of 'resourceness', the potential of resources depends on the knowledge and skills from participants (e.g., customers) (Lusch and Vargo, 2014; Koskela-Huotari and Vargo Stephen, 2016). One strategy to address collaboration is to combine this knowledge in a framework that allows different stakeholders to participate in defining design concepts and finding the optimal combination of hardware and service within a structure (Isaksson et al., 2013). More recent research showed the need for the value co-creation to create a shared understanding among business stakeholders and technology-focused design teams (Panarotto et al., 2019), and methods have been proposed to trade off parameters such as flexibility and changeability against traditional engineering attributes (Machchhar and Bertoni, 2022).

Although the concept of value co-creation has been discussed for decades, but empirical examples of how companies use and practice value co-creation with stakeholders, such as customers, have only recently emerged (Breidbach and Maglio, 2016). Value co-creation has already been a well-established topic in manufacturing companies, but as research expands into the manufacturing of bundles of products and services, it can be argued that the PSS design methodology neglect to specify the roles and responsibilities of the actors who co-create PSS offerings and that there is a lack of understanding the entire process and how it is implemented in industrial practice (Vasantha et al., 2012; Liu et al., 2018). Moreover, one of the main differences of PSS from traditional products is the increasing involvement of customers in the early design phase (Tran and Park, 2015). Although there are several examples of PSS co-creation in the literature, they mainly focus on the production phase and neglect the design phase (Marilungo et al., 2015).

4 Future innovation framework for smart PSS design

4.1 Introduction of FIF in smart PSS design

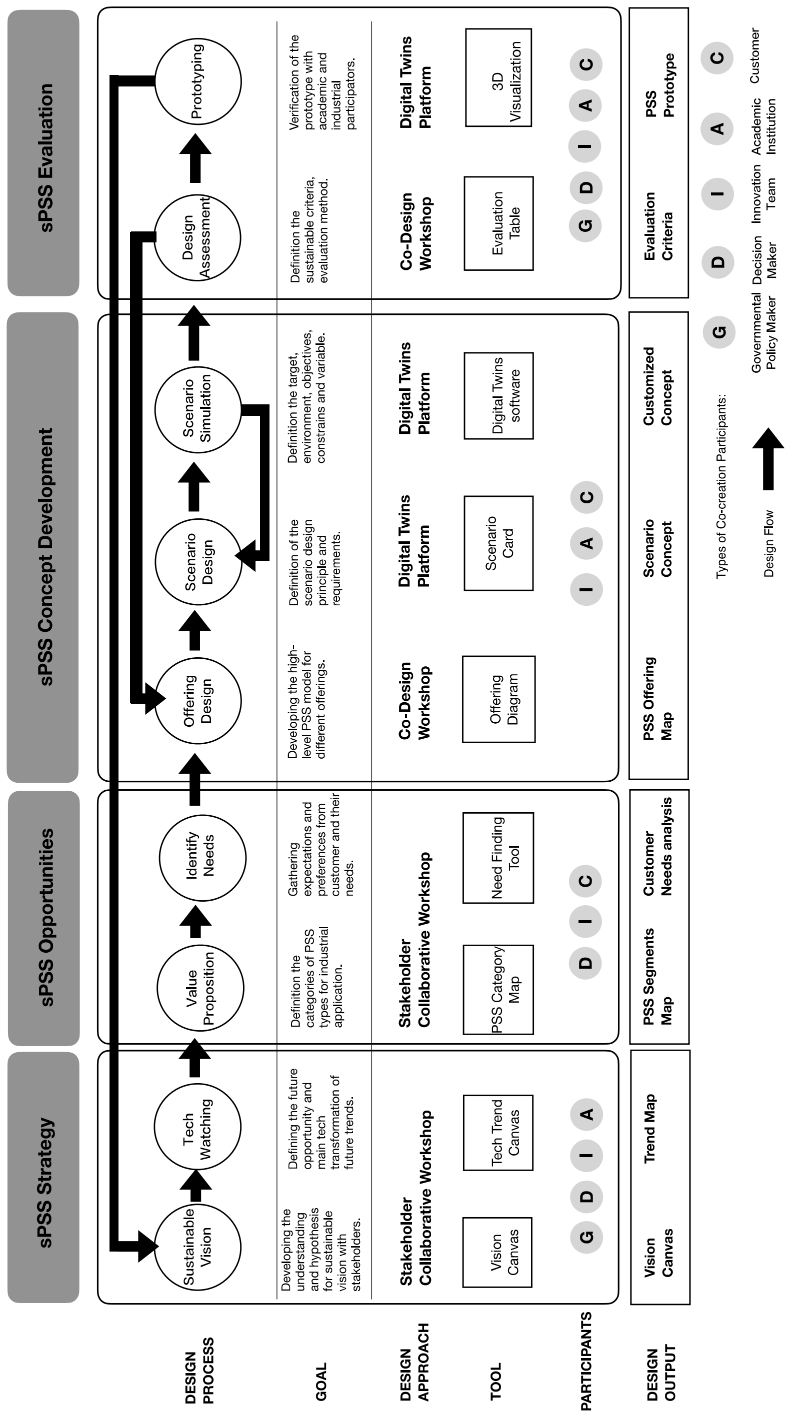
The Future Innovation Framework (FIF) for designing smart PSS was developed by the authors in previous research that built on a comprehensive systematic literature review of relevant PSS design methodology and approaches presented in Section 3. The FIF is structured in a tiered fashion based on the innovation process and methodology of PSS design to ensure broad adoption in manufacturing companies (see Figure 6). The FIF consists of:

- A temporal dimension of value co-creation split into four distinct stages (PSS strategy, PSS opportunities, PSS concept development and PSS evaluation).
- A content dimension divided into six clusters (design process, goal, design approach, design tools, participants and PSS design output.)

The structure of FIF, a comprehensive collection of entities, and a temporal perspective further enable the incorporation of value co-creation of PSS, increasing the chances of developing a smart PSS offering. Although the innovation stages are presented independently, they are in fact interconnected through the PSS design process, and iterations and feedback loops are to be expected when using FIF. However, the approach and tool were deliberately chosen for the benefit of industrial applicability and ease of managing the smart PSS design process with participants. The outputs, therefore, serve as stage reviews where the innovation team in the company reviews the quality of co-creation of the stage work and decides whether to proceed to the next stage.

To explain the FIF into more detail, the innovation stage level consists of four stages that organise the design phases and the flow of the entire smart PSS design process. The smart PSS design process level consists of nine design steps, so the participants must follow each step to complete the design work when using the FIF. These steps are the design flow created based on the PSS design methodology (Van Halen et al., 2005). The goal level provides guidance to designers for each design step. The approach level represents the application of different innovative approaches, such as workshops. The tool level consists of different smart PSS design tools, and each tool corresponds to each design step. When FIF is in use, the innovation team can choose to use the corresponding tools to work, and these tools consist of canvases, maps, diagrams, cards, software systems and tables, etc. The participator level is mainly composed of the different stakeholders involved throughout the innovation stage, such as: policy maker, innovation team, academic institute, lead user, customers, etc. In each stage, it will be suggested to select different stakeholders to participate. Below, the corresponding outcomes of each stage are also provided to help participants understand what can be achieved throughout the design process.

Figure 6 Future innovation framework (FIF) for smart PSS design



4.2 Smart PSS strategy

In this stage, the purpose is to determine the symbiotic stakeholders and to identify their requirements from a high-level strategic level to collect the future perspective of government policy makers, academia and internal innovation teams. At the same time, based on the Sustainable Development Goals (Manzini and Vezzoli, 2001), the sustainable orientation of the smart PSS is selected as an indicator for designing it. Future emerging technology trends are also to be discussed by stakeholders as competitive development digital capabilities of smart PSS.

Goal:

- *Developing the understanding and hypothesis for sustainable vision with stakeholders.*
- *Defining the future strategy and main tech transformation of future trends.*

Design process: Sustainable vision, Tech watching. A sustainable vision is usually developed by setting up a collaborative workshop with the different stakeholders, especially policymakers and academic institutes. This requires participants from different areas, such as strategic leadership, product planning, etc., to share their knowledge on the co-creation of a sustainable vision. The workshop develops the sustainable vision of smart PSS through qualitative group discussions and the use of a vision canvas throughout the co-creation workshop. At the same time, it is necessary to explore emerging technologies that have the potential to contribute to a sustainable vision in the early design of smart PSS. Therefore, a Tec watching map is also used to identify and select emerging technologies in the co-creation process among participants.

Design approach: Stakeholder collaborative workshops (Larsson et al., 2005), providing both a physical and virtual online co-creation environment including tools for developing a sustainable vision and technology roadmap during the workshops. The canvas deliverable enables capturing the results of the workshop and sharing this information with participants and other stakeholders.

4.3 Smart PSS opportunities

The smart PSS opportunities is the sum or classification of the overall value delivered by the types of smart PSS given the new value received from market customers and the industrial ecosystem. The smart PSS opportunities represents the value orientation of smart PSS in the early design phase.

Goal:

- *Defining the categories of PSS types for industrial application.*
- *Gathering expectations and preferences from customer and their needs.*

Design process: value proposition, identify needs. First, use the PSS segments tool to identify the PSS types and select the appropriate business model for the new design (Tukker, 2004). Another step is to identify the customer needs of the relevant customers, where the Need Finding tool (Patnaik and Becker, 1999) is used to support the collection of customer needs during the collaborative workshop by, i.e., creating scenarios as examples.

Design approach: The stakeholder collaborative workshops focus on information gathering and are characterised by rationality in process management and accuracy of information. The workshops provide tools such as the PSS segment map and the Need Finding tool to assist the innovation teams in generating the outputs. This workshop requires the participation of decision-makers, lead users and customers in activities that can take place in a physical workshop environment or distributed in an online virtual room (Torlind and Larssoon, 2002).

4.4 Smart PSS concept development

In this stage, the innovation team and the customer are asked to co-design the smart PSS system, starting from the full complete system offering to describe the integration of new products and services and the rational business model. This includes scenario design, starting from specific user scenarios to designing user journeys, user experience and functional performance of products and services. In addition, it includes scenario simulation (Rondini et al., 2017) of the concept of smart PSS solution and shows the concept in the user scenario, and the experience of the customer through visual simulation.

Goal:

- *Developing the high-level smart PSS model for different offerings.*
- *Definition of the scenario design principle and requirements.*
- *Definition the target, environment, objectives, constrains and variable.*

Design process: This stage of value co-design includes; offering design, scenario design and design simulation. According to the identified PSS types, the offering diagram tool is applied to design the complete system journey of the new smart PSS, which should include the user journey, user experience, and value flow between different stakeholders. To design the scenario, the participants use the scenario card which can integrate and represent the scenario definition, customer behaviour, functional description and concept story representation, etc. After the scenario design step, the computer simulation can support the development of the concept feasibility and develop the concept of smart PSS in different scenarios through Digital Twins (Bertoni and Bertoni, 2022). The Digital twin by the 3D engine is included as a way of prototyping support (Ruvald et al., 2021).

Design approach: Co-design workshops (Larsson et al., 2005) organises participants such as the innovation team, academic institution/ and the customer to co-create design concepts through Digital Twins platform support scenario design, group communication and virtual scenario simulation.

4.5 Smart PSS evaluation

In this stage, the activities of evaluating and prototyping the concept of smart PSS design can support decision makers, customers, and innovation teams in making the right decisions and customer experiences for smart PSS design based on the design evaluation and prototype.

Goal:

- *Defining the sustainable criteria, evaluation method.*
- *Verifying the prototype with academic and industrial participants.*

Design process: design assessment (Bertoni et al., 2013), prototyping support (Ruvald et al., 2021). Establishing interactive large-screen and virtual simulation methods that can convey and show smart PSS concept value, which can demonstrate the value of the smart PSS and allow stakeholders to receive an immersive experience of the outcome of smart PSS scenarios. The stage also establishes evaluation tools through indicators and value evaluation systems (Bertoni, 2019), including four evaluation directions: Market, Brand, Business and Digitisation to evaluate the PSS concept. Different stakeholders use the evaluation table to assess the quantitative value and select the PSS design concept. After finalising the prototype, the experience and testing of the prototype can be used to verify that the sustainable vision from the first stage can be realised by the outcome of smart PSS prototype.

Design approach: During the co-design workshop, the value evaluation form is jointly given to participants, such as policy makers, decision makers, academic researchers and innovation teams. Participants provide their individual ratings for the smart PSS concept according to the evaluation criteria table. After the scores are collected and summarised, the smart PSS concepts with the highest value score are selected. At the same time, prototypes will also be shown during the co-design workshop through Digital Twins platform support, so that participants can experience and feel the outcome of the smart PSS design.

5 Case studies

5.1 Introduction and data collection of FIF to the case company

The case study presented in this paper is based on a global large OEM in the automotive manufacturing industry, with its new SEV product development. To investigate the practical aspects of the proposed framework, a real case of smart PSS development was conducted in Volkswagen case company during 2021. During the study, Volkswagen, the case company under observation, was in the early stages of developing a smart Product Service System (sPSS). The purpose of this development was to contribute to a comprehensive product innovation process that focused on an electrification strategy and the enhancement of competitiveness in digital mobility services. The case company has recognised the lack of structured processes for development of new electric vehicles and digital services (seen in Figure 7). To solve the above challenges, the FIF was deployed in this case to support Volkswagen's its global innovation team in the product development process.

For data collection, four collaborative workshops were organised, adding different stakeholders to the smart PSS development process with case company. Among them, the workshops in stage 1 smart PSS strategy and stage 2 smart PSS opportunities were all in the form of stakeholder collaborative workshops, and the workshops in stage 3 smart PSS concept development and stage 4 smart PSS evaluation were in the form of co-design workshops. Each workshop usually took between 2 to 3 hours, and the four workshops a total of 10 hours. During the smart PSS design process, each workshop team selected corresponding tools based on the FIF framework and collected corresponding outputs as the results of PSS design. The participants involved in the entire smart PSS design stage were the marketing department, product planning department, design centre and R&D centre from the case company. External participants consist of recruited customers, academic institutions and consulting companies. An overview of the participants, the departments, and the job positions are compiled in Table 1.

Figure 7 Context of FIF applied in Volkswagen case (see online version for colours)

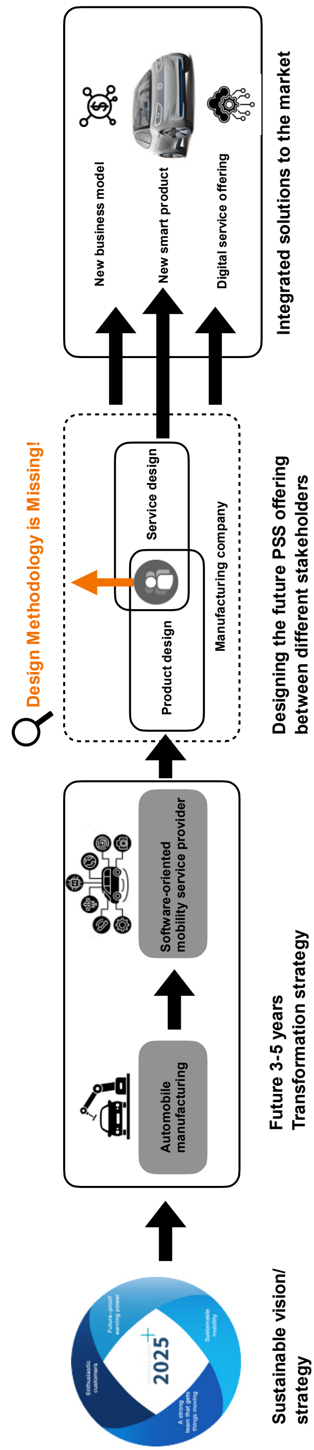


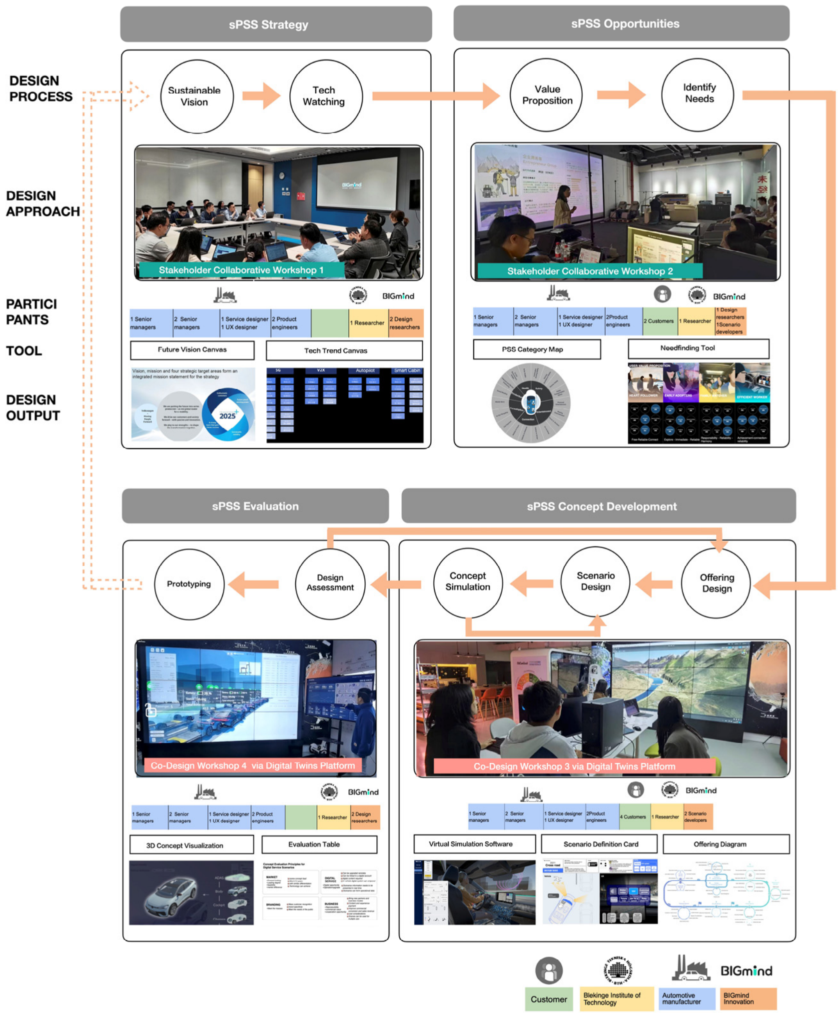
Table 1 Workshops and participants' statistics from case (see online version for colours)

Innovation stage of FIF	Type of FIF workshop	FIF tools use in workshop	Output from FIF workshop	Duration of worshop (hour)	Case company Marketing	Case company Product Planning	Case company Design Center	Case company R&D center	Customers	Academic Institution (BTH)	Consulting company (BIGmind)	Total number of participants
PSS Strategy	Stakeholdern Collaborative Workshop	Vision Canvas Tec Watching Canvas	Vision Canvas Tech watching	3hours	1 Senior managers	2 Senior managers	1 Service designer 1 UX designer	2 Product enginers		1 Researcher	2 Design researchers	**10**
PSS Opportunities	Stakeholder Collaborative Workshop	PSS Catgory Map Need Finding Tool	PSS segements Customer needs analysis	2hours	1 Senior managers	2 Senior managers	1 Service designer 1 UX designer	2Product enginers	2 Customers	1 Researcher	1 Design researchers 1Scenario developers	**12**
PSS Concept Development	Co-design Workshop	Offering Diagram Scenario Card Simulation Software	Offering Diagram Scenario concept card 3D simulation	3hours	1 Senior managers	2 Senior managers	1 Service designer 1 UX designer	2Product enginers	4 Customers	1 Researcher	2 Scenario developers	**14**
PSS Evaluation	Co-design Workshop	Crierial Evaluatio Table 3D Visualization	Design evaluation criteria 3D Prototype	2hours	1 Senior managers	2 Senior managers	1 Service designer 1 UX designer	2 Product enginers	2 Customers	1 Researcher	2 Scenario developers	**12**
Total number of participants	**4**	**9**	**9**	**10**	**4**	**8**	**8**	**8**	**8**	**4**	**8**	**48**

5.2 FIF application in the smart PSS design process

For the application of FIF in the Volkswagen case study, the four innovation stages of FIF were completed in four workshops (see Figure 8).

Figure 8 FIF applied into smart PSS design process in Volkswagen's SEV case (see online version for colours)



In stage 1 smart PSS strategy, the stakeholder collaborative workshop 1 was performed with 10 participants (no customer included) who were brought together to co-create in early-stage smart PSS design using two tools: the Vision canvas captured the strategic vision, and the Tech trend canvas captured the tech trends for the next three to five years. In stage 2 smart PSS opportunities, the stakeholder collaborative workshop 2 was performed with 12 participants with all stakeholders that were brought to explore the opportunity of PSS using two tools: PSS category map and Need Finding tool captured the design output of PSS segments and customer needs analysis. In stage 3 smart PSS concept development, the co-design workshop 3 was performed with 14 participants from all stakeholders that were brought together to co-develop the smart PSS offering and scenario design using three tools: the offering diagram designed the entire of PSS journey, and the scenario card captured created scenario information. The Digital Twins platform simulated the scenario on the computer by designers from design centre. In stage 4 smart PSS evaluation, the co-design workshop 4 was performed with 12 participants with all stakeholders that were brought together to co-evaluate the design concept of PSS using two tools: the evaluation table assessed the result of design concept, and the Digital Twins Platform shown the design prototype to the automotive company's decision makers and stakeholders to better understand the design outcome.

5.3 Validation of FIF in case study

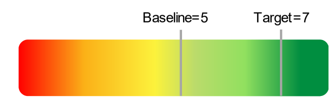
In order to give a full descriptive evaluation of the FIF for early-stage smart PSS design, a set of six defined criteria (clarity, completeness, collaborativeness, utility, simplicity and precision) for evaluation of FIF was designed by the authors. At same time, this set of criteria was used to evaluate the FIF by including case company. The descriptive criteria presented in Table 2 is a guideline of the authors' attempt to explain the criteria of FIF and is not to be understood as an actual final evaluation.

Table 2 Criteria for evaluation of FIF

Item	*Criteria for Evaluation*	*Questions for Evaluation*	*Evaluation Guidelines*
1	Clarity	How difficult is the FIF to understand?	FIF is easy to understand with its stage and process. Whether the FIF is quite challenging and a lot of accompanying explanations.
2	Completeness	Does the FIF miss any process or activities in for PSS design?	FIF covers the necessary work stages in the PSS design process, tools and guideline for output. Is there something missing that is not included in the FIF?
3	Collaborativeness	Can FIF applicable to different sectors/ stakeholders in company?	FIF allow participants from different backgrounds and across functions to co-create, effectively promote co-design, and it helps communicate and understand design work at each stage. FIF helps customer co-creation in the product development and design process of PSS.
4	Utility	FIF is usefulness in supporting the creation of design process?	The design steps, sequences, instructions and tools are feasible when FIF used in company practice. Available tools and order of design guidance are provided. Can be used in workshops and co-creation activities in company
5	Simplicity	Could the FIF represented more simply?	Can the FIF be using by manufacturing companies within the context of the complete design of PSS? The early-stage of PSS design in all its complexity could be so succinctly depicted more simply. The FIF resort to simpler representations.
6	Precision	Are the tools of the FIF produced precisely enough?	The accuracy of FIF at different stages in using, collaboration, design output and evaluation. The difference between academic terminology and industry terminology ultimately makes the output results of higher quality and higher precision.

Table 3 Value assessment of FIF application (see online version for colours)

Item	FIF Stage for PSS design	FIF Process for PSS design	Clarity - how difficult is the FIF to understand?	Completeness - does the FIF miss any process or activitiesin PSS design?	Collaborativeness - FIF applicable to different sectors/ stakeholders?	Utility - usefulness in supporting the creation of design process	Simplicity - could the FIF represented more simply?	Precision - are the tools of the FIF produced precisely enough?	Total Value of FIF Process	Tatal Value of FIF
1	PSS Strategy	Sustainable vision	6.10	6.13	7.80	4.70	4.50	5.20	**5.74**	**5.92**
2		Trendwatching	7.25	5.30	7.50	6.70	4.80	5.10	**6.11**	
3	PSS Opportunities	Value position	6.70	6.50	8.10	7.20	6.10	5.50	**6.68**	**6.91**
4		Identify needs	7.20	7.30	6.70	7.10	7.25	7.30	**7.14**	
5	PSS Concept Development	Offering design	6.50	7.50	7.20	7.30	7.50	6.50	**7.08**	**7.03**
6		Scenario design	7.20	7.30	7.70	8.20	5.70	7.20	**7.22**	
7		Simulation	7.25	6.50	5.30	7.35	6.30	8.00	**6.78**	
8	PSS Evaluation	Design evaluation	5.60	7.20	7.60	8.30	5.30	7.80	**6.97**	**6.40**
9		Prototype	4.25	6.40	6.70	6.30	5.10	6.30	**5.84**	
Total value of FIF evaluation			**6.45**	**6.68**	**7.18**	**7.02**	**5.84**	**6.54**		

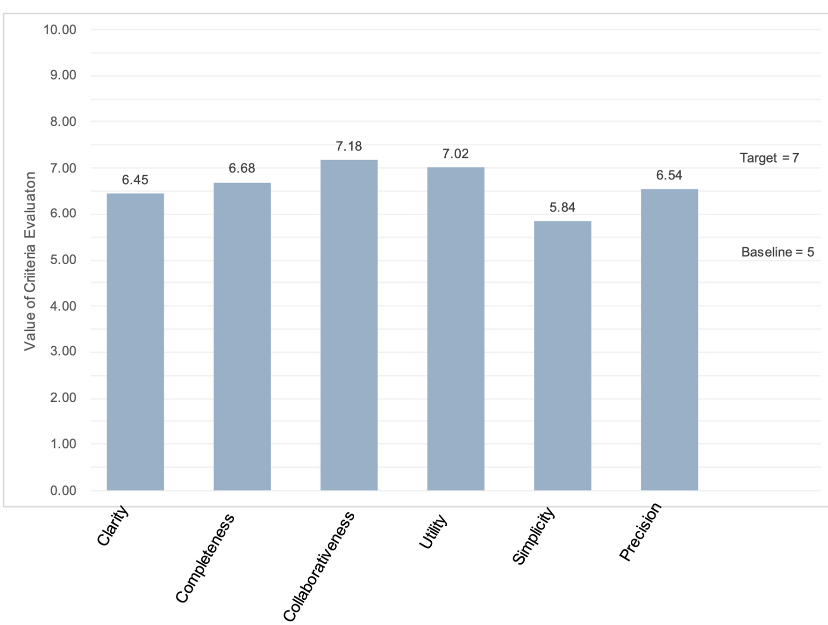


0-2 Unusable
3-5 Not Good
5-6 Good
6-7 Very good
7-9 Excellent
10 Perfect

To evaluate and verify the described six criteria of FIF for the industrial case after the co-design workshop, the author invited decision makers and members of the automotive company's innovation team to provide an evaluation of the use of FIF throughout the smart PSS design workshops. To obtain an assessment of FIF, an evaluation session was conducted using the value assessment form in Table 3 below. Participants completed the evaluation table for the use of FIF in the different smart PSS design processes. The assessment includes four innovation stages, and nine design steps based on FIF. The evaluation criteria and value score were set according to the value assessment method supporting PSS concept design (Bertoni, 2018), and each project member was asked to fill in the score based on the six evaluation criteria from Table 2. The scoring result uses the colour-coded assessment method to visually distinguish the results (Bertoni et al., 2013), by using the colours from red, yellow and green to distinguish the importance of FIF for smart PSS design in the specific case. The overall value contribution is evaluated on a scale from 1 to 10, where 5 represents the baseline and 7 is the target for each value dimension. The assessment scores range from a minimum of 0–2 for unusable, 3–5 for not good, 5–6 for good, 6–7 for very good, 7–9 for excellent and a maximum of 10 for perfect. Based on the result, we can conclude that the overall result of assessment for FIF is good and the total value of the FIF stages are ranging from good (PSS strategy=5.92) to very good (PSS opportunities=6.91, PSS concept development=7.03 and PSS evaluation=6.40).

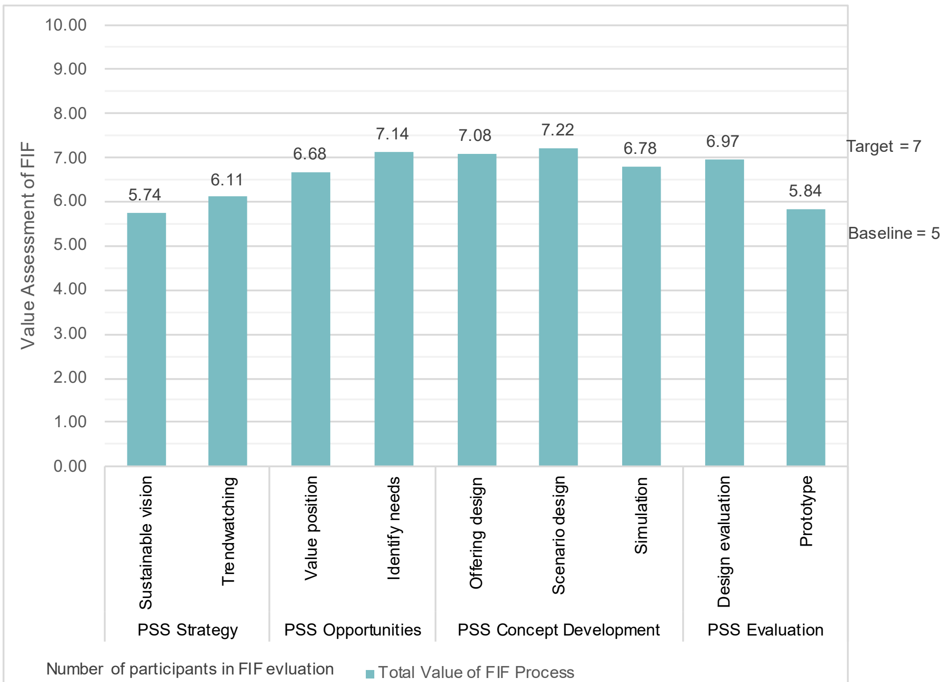
Further analysing the result of the value assessment exercise, the result shows (seen in Figure 9 below) that the total value of evaluation criteria all exceed the baseline 5, with the highest evaluation value scores (collaborativeness and utility) reaching target 7. The results indicate that participants recognised that FIF can support the value co-creation and utility of PSS design in manufacturing companies. The criteria with the lowest score is Simplicity, which is 5.84, which shows that there is still room for improvement in the simplicity of the FIF.

Figure 9 Value assessment of FIF evaluation criteria



From result analysis of the design process perspective (seen in Figure 10 below), we can see that identify needs, offering design, scenario design and design evaluation are the four design processes with the highest values reach target 7. The rest of the design processes are all above the baseline 5.

Figure 10 Value assessment of FIF design process



Comparing the total value of the FIF stages and process, the value of PSS concept development is the highest. This is because the scores of the two included processes are all the highest score for the design process. The highest score for the design process is scenario design. It indicates that scenario design has the potential to assist innovation teams in creating the scenario concept. The second highest process is identity needs. The motivation to understand and translate customer needs are the most needed and recognised design processes in industrial PSS design. Another high value is scenario simulation. The use of the 3D virtual simulation platform has significantly promoted the virtual demonstration and scenario concept of smart PSS result, enabling innovation teams to improve the concept of the offering through simulation. In conclusion, the result of value assessment shown that participants recognised the need to connect the smart PSS design process through a framework of FIF to facilitate value co-creation with different stakeholders inside and outside the organisation. Recognition the professionalism of the tools completed in FIF.

6 Discussion

Smart PSS development is introduced as a process of value co-creation and way of scenario-based development. FIF offers a comprehensive framework and practical guidance for manufacturing companies to use the traditional PSS design method while maintaining the design process flow. It also ensures that the goals of each stage align with the overall goals of designing a smart Product Service System. In manufacturing companies, value co-creation involves collaboration between the company's internal innovation team, decision-makers and external customers, suppliers and technology providers. This collaboration requires the knowledge of innovation management and knowledge management to ensure that values of different dimensions can be created separately by participants (Martin-Rios and Erhardt, 2017; Wang et al., 2018). Additionally, the FIF presents unique challenges when it comes to collaborative activities at each stage of the process. Stage 1 – smart PSS strategy and Stage 2 – smart PSS opportunities involve external stakeholders with qualitative data collection to co-creation strategies. These stages require the analysis of predictable data such as trend data, market data and customer needs. Stakeholders should be clear about their expectations and strategic requirements for the smart Product Service System, which can be achieved through the approach of collaborative workshops. However, developing a smart PSS strategy remains a challenging task due to differing future visions and goals among stakeholders and decision-makers from manufacturing companies and other organisations.

The evaluation results reveal a positive interest within the automotive OEM manufacturer in incorporating the FIF approach into its new generation of SEV development with ongoing digitalisation transformation, indicating openness toward integrating FIF into future smart PSS design processes. In Stage 3 – smart PSS concept development, the emerging technologies such as virtual scenario simulation provide a way of generating and optimising the smart PSS concepts more effectively to help the innovation team in manufacturing. It can also improve the efficiency and accuracy of scenario design to a large extent. The digital design tools in FIF have enhanced collaboration capabilities among customers, manufacturing companies and stakeholders. The use of digital design tools provided by FIF can reduce the obstacles caused by 'expert knowledge' and solve the problem of limited design knowledge among various participants (Chih et al., 2019). FIF offers virtual prototyping tools to facilitate collaboration between decision-makers and the innovation team during Stage 4 – smart PSS evaluation (Loizou et al., 2019). The Digital Twins enhances decision-makers' understanding of smart PSS concepts, improves decision-making efficiency and enables them to utilise evaluation indicators. Participants can interact with the design concept and evaluate the feasibility of smart PSS (Bertoni, 2023). This helps to identify potential problems and obstacles that may arise during the implementation phase. Feedback from Volkswagen, the global automotive OEM underscores the significance of value assessment between the cross-disciplinary team collaboration in the large organisation context. The implementation of the FIF for scenario-driven SEV design has effectively supported decision-makers in selecting design concepts within numerous dynamic scenarios. Another notable insight from the industrial implementation is that the Digital Twins platform proves beneficial in supporting collaboration across diverse teams within the automotive company. It was shown to provide visual support for innovation teams with diverse backgrounds, facilitating collaborative efforts in value creation (Bertoni, 2023).

Uncertainty about the future is a common problem and challenge for global industry and its activities to develop smart PSS. The smart PSS evolved based on the development of emerging technologies and requires a practical design process in line with value co-creation to support their use by industry players. It also finds that there are some areas that need to be improved and optimised, such as from qualitative analysis of the sustainable vision, trends to the quantitative simulation and evaluation, this process still suffers from the subjectivity of many conclusions and the uncertainty of the results. The process of designing smart PSS is systematic and interdisciplinary value co-creation that needs to be solved by different innovation participants in the face of future uncertainties under a unified framework.

6.1 Limitation and uncertainty

The smart PSS has only been promoted in the industry for a few years, and there is a lack of successful cases that have come about through effective smart PSS design to prove the sustainable value and system changes brought by the design of smart PSS. Most of the smart PSS cases on the market are based on the improvement of subsequent operational data rather than the future trends that come from early design from the beginning. When FIF is currently made available for use by industry, it still depends on guidance and explanation by professional personnel before it can be used by companies. There is still room for improvement in the way of value co-creation in smart PSS design. The capabilities offered by the smart PSS tool are still individual rather than universal. To achieve wide application in industries, it is necessary to collect more design requirements from different types of industries, business models and evaluation criteria to improve the versatility of the innovation framework. The FIF was developed by the author's academic institution and an industrial company and has not yet been commercialised on a large scale. Future research and evaluation are needed to ensure its applicability to a wide range of industrial applications. In the case study, it was found that the global automotive company is open to the use of FIF. A smart PSS design process, tailored methods and the digital toolkits are also needed and are not yet well developed.

7 Conclusions

This paper addresses the introduction of the Future Innovation Framework for value co-creation of smart PSS design in global manufacturing companies. The paper introduces PSS as a systematic innovation strategy and methodology to promote the sustainable development of the manufacturing industry. The innovation process is important for product development in manufacturing companies. The industry needs a methodology that can integrate the whole product development process to apply to the innovation process. The paper also introduces the transformation from PSS to smart PSS in the digital era, introduces the system characteristics of smart PSS and explains the difference and correlation with PSS. It also introduces the PSS design process and PSS design approach based on literature review and describes the methodology of PSS design. At the same time, this paper introduces the design approach for smart PSS mentioned in the current research, it is found that the existing PSS design methodology and approach are insufficient for the complete design practice of smart PSS. Through the study of value co-creation, this paper discussed the challenges and existing gaps in stakeholder collaboration in value co-creation of smart PSS, and the lack of innovation frameworks, design guidelines and approaches for applying value co-creation in industrial practice.

By introducing the FIF, this paper describes in detail the structure of FIF, its contents, application guidelines and design-flow relationship. It explains how stakeholders need to be involved in value co-creation based on the FIF. The full FIF provides a complete framework description and specific working methods for industrial practice. The industrial case section presents how a global automotive OEM, Volkswagen used FIF in the early design phase of SEV to address sustainability and digital transformation challenges. The case shows how FIF was conducted with various stakeholders in smart PSS design according to value co-creation. The case particularly highlights the application result of the design process and the design evaluation process in the case. To review the FIF results in the case, this paper introduces the value evaluation method to evaluate the usability of FIF with different stakeholders.

In summary, FIF can comprehensively support the value co-creation of smart PSS design. FIF can meet the requirements of manufacturing industry in the entire process of smart PSS design. FIF can also solve the problem through a framework design process with various stakeholders and deliver the product concept result through Digital Twins and virtual prototype. One limitation is that more research and cross-industry practice are needed to investigate the use of FIF in different industries and to analyse the results comparatively. As a framework to support smart PSS design for global manufacturing industry, FIF needs to be introduced in more cross-industry cases and gain wider application through future research.

8 Future work

Further research will extend the application of FIF by using Digital Twins approach in current and future case companies. Such Digital Twins should be conducted to ensure broad applicability of the FIF. Use emerging technology such as data-driven, virtual technologies and DT to further develop FIF. At the same time, research should be conducted on the evaluation of the value assessment of smart PSS in different industries, and evaluation indicators and systems for industry should be established in the Digital Twins.

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