UNIVERSITY
OF TECHNOLOGY
SYDNEY

Towards Cyber-Physical Product-Service Systems Design

by Mohd Ahsan Kabir Rizvi

Thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

under the supervision of Prof. Eng K. Chew, Dr. Phillippa K. Carnemolla, Prof. Shankar Sankaran and Dr. Man Hang Yip

University of Technology Sydney
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December 2020

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Certificate of Original Authorship

I, Mohd Ahsan Kabir Rizvi, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy in the School of Built Environment, Faculty of Design, Architecture and Building at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

I certify that the work in this thesis has not previously been submitted for a degree, nor has it been submitted as part of the requirements for a degree at any other academic institution except as fully acknowledged within the text.

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Acknowledgements

Finally, after losing a few important people in my life, four years and some weight while gaining some wisdom, white hair, and the doctoral experience, I have come to the end of this journey. I would like to start the acknowledgement with my thankfulness and humbleness to God (ﷲ), the almighty who says, *"(He) Taught man that which he knew not"*[1]. Although this thesis bears my name as the author, it does no justice to all the people whose contributions made this possible. As Prophet Muhammad ﷺ (peace be upon him) said, *"He who does not thank the people, does not thank Allah"*[2]. So, since this could be the biggest research document ever authored by me, I would like to take the opportunity express my gratitude to the long list of people that contributed towards me reaching this stage.

I would like to start chronologically, with my mother, Mrs Asma, who is the biggest influence in my life. Since the time I can remember, she sacrificed everything in her life to teach me how be a good person and to keep me motivated. So, undeniably my greatest gratitude goes to her for her unconditional love, care, guidance, prayers and blessings. My father, Mr Humayun Kabir, thanks for all the life lessons that you taught me. Thanks to my siblings Afsana, Marwa and Ahmed for always being there to encourage me and taking care of mom and dad in my absence. Thanks to my grandmothers, Mrs Aktararnessa and Mrs Nazeeba, and my aunties, Mrs Salma, Mrs Jasma and the late Mrs Nazma, for their unconditional love and continuous prayers for my success. Special mention to aunt Ferdous, my first best friend. I thank all my cousins, especially Mamun, Tuni and Mr Didar, for their unconditional support and good wishes. Special thanks to Rifat for always sharing her doctoral experience and providing me with her guidance. Thanks to my uncles, notably, Mr Ferdoush Khaled, Mr Munsur Khaled,

[1] Al Quran (96:5)
[2] Sunan Abu Dawud: 4811

Mr Zaheer Khaled, Mr Yasin Khaled, Mr Kamal Pasha, Mr Azam Khan and the late Mr Alamgir Khaled, and their respective spouses, for relieving me of so many personal, family, and financial stress throughout this journey.

I would also like to thank my primary school teachers, Mrs Victoria, Mrs Naseema, Mrs Suman, Mrs Gomes, Mrs Kavita, Mrs Rochelle, Mrs Judith, Mrs Radhalakhmi, Mr Kalyana, Mr Sanjay, Mr Gopal, Mr Isaac and others for introducing me to the English language and helping me excel in science and mathematics. I thank my high school teachers, Mr Jose, Mrs Seema, Mr Shiva, Mr Anthony and others for expanding my knowledge in science and helping me choose engineering for further study. Along that way, I thank my school friends, Akkas, Jahar, Jude, Waseem, Shehla, Amalesh, Kalhan and others for making the journey so educational and fun.

I thank Mr Mohammed Mohatram, Mr Vikas Sharma, Mrs Anusya Patil, Mr Shyam Sunder Purohit and many others who during my undergraduate education not only made me an engineer but motivated me to study further. I also thank my friends Yahya, Ahswin, Neeraja, Aditya, Shrey, Advaita, Hridya, Divya, Greeshma, Zikra, Safi, Avishek, Akash, Vaibhav and others for always being there for me and working together towards numerous accomplishments that set the stepping stones towards pursuing my postgraduate studies. Especial mention to Avishek, who helped me find the right postgraduate program. I thank the excellent professors and researchers like Professor Afaq Ahmad, Dr Tariq Jamil, Dr Saqib Ali, Dr Zia Nadir, Dr Miftaur Rahman Khan Khadem, Dr Zakir Hossain, Dr Taiseera Al-Balushi, Dr Khaldoon Nusair, Dr Hamed Al-Azri and others I met during my postgraduate days for turning me into a researcher and building in me the enthusiasm to pursue a PhD. Special thanks to Professor Afaq Ahmad, who was my first mentor in research, Dr Saqib Ali, who introduced me to and taught me about cyber-physical systems, and Dr Zakir Hossain, on whose advice I chose Australia as my PhD destination. I was also encouraged by Ms Shaima Ahmed, Mr Farhan Muhammad, Mr Rana Jose, Ms Hadeel Al-Rawahi, Ms Bashayer Al-Ajmi and Dr Osama Rehman and their research collaboration.

At UTS, I start by thanking the university for giving me the opportunity and offering me the scholarship to pursue my doctoral ambitions. I would like to thank immensely my principal supervisor the late Professor Eng K Chew who responded to my enthusiasm and accepted to supervise me. He introduced me to product-service systems and taught me numerous concepts of marketing, business, and management of which I was completely unaware of due to my engineering background. Unfortunately, he left us all mid-way through my thesis, but he had laid all the groundwork for me to accomplish my goals. No amount of gratitude will be enough for my supervisor and design expert Dr Phillippa Carnemolla, who not only made the supervisory transition smooth but also took motherly care of me throughout the program. Whether it was the death of my principle supervisor, the pandemic issues, or the scholarship timeline, she was always there to relieve my stress and motivate me. I thank my co-supervisor, Dr Man Hang Yip, for accepting to supervise me after Professor Chew passed away. Her sharp eyes and deep expertise in my field of research helped me in improving my thesis by leaps and bounds. Last, but not the least, I thank Professor Shankar Sankaran for volunteering to supervise me and guide me. His years of research and supervisory experience helped me in choosing the right research techniques and in constructing the thesis in the best possible way. I also thank Professor Catherine Killen and Dr Charles Crick for their deep insight, appreciation, and constructive comments on this thesis. The work of any researcher is communicated through organised language and writing. I am immensely grateful to Ms Hazel Baker for taking care of this vital aspect by painstakingly going through this whole thesis and perfecting its language.

My colleagues Selina, Shiva, Glenn, Mervyn, Mick, Mbui, Nathan, Ory, Scott, Arun, Mark, Sarpreet, Rana, Gil, Alwin and others deserve special thanks for making my doctoral journey stress-free. They not only gave me flexibility and comfort at work but also enriched me with numerous life lessons, wisdoms and skills.

Finally, and very importantly, I thank my newly-wedded wife, Samanta Zahir, for helping me survive the final and most dreadful year of the candidature. Although we have been living thousands of miles apart, so far, she has never failed to demonstrate her support and encouragement. With an architectural background, her contributions to my presentations and slides were invaluable. Through Samanta I also found new relatives and in-laws, Mrs Nigar, Mr Yeahia, Mr Ali, Elma, Abrar and Enaya, who always keep me upbeat with their admiration and blessings.

There is a good chance that I may have missed a few contributors to my life. I thank you all for your contribution, no matter how big or small.

List of Publications

1. Rizvi, M. A. K., Chew, E. K. (2018, June 10-13). *Designing Service-Centric Product-Service Systems* [Paper presentation]. 25th Innovation and Product Development Management Conference (IPDMC), Porto, Portugal.

2. Rizvi, M. A. K., Chew, E. K. (2018, May 21-24). *Towards Systematic Design of Cyber-Physical Product-Service Systems* [Paper presentation]. 15th International Design Conference, Dubrovnik, Croatia. https://doi.org/10.21278/idc.2018.0248

3. Yip, M. H., Rizvi, M. A. K., Chew, E. K. (2019, August 25-29). *Managing value co-creation an integrated design framework for service-centric product-service systems* [Paper presentation]. Proceedings of PICMET '19 Conference: Technology Management in the World of Intelligent Systems, Portland International Center for Management of Engineering and Technology, Portland, USA. https://doi.org/10.23919/PICMET.2019.8893876

4. Rizvi, M. A. K., Yip, M. H.; Chew, E. K. (2019, June 10-11). *Designing for Changing Societal Requirements - An Integrated Design Framework for Product-Service Systems* [Paper presentation]. 26th Innovation and Product Development Management Conference (IPDMC), Leicester, UK.

5. Rizvi, M. A. K., Yip, M. H.; Chew, E. K., Carnemolla, P. K. (2019, December 15-18). *Designing Through Value Co-creation: A Study of Actors, Practices and Possibilities* [Paper presentation]. 2019 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Macao, China. https://doi.org/10.1109/IEEM44572.2019.8978902

6. Rizvi, M. A. K.; Yip, M. H.; Sankaran, S., Carnemolla, P. K. (2021, June 16-18). *Value co-creation in developing sustainable cyber-physical product service systems: Applying design science research method* [Paper presentation]. EURAM 2021 Online Conference: Reshaping capitalism for a sustainable world, Montreal, Quebec, Canada.

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List of Abbreviations

ANT	Actor-Network Theory
BOL	Beginning of Life
CPPSS	Cyber-Physical Product-Service System
CPPSSDM	Cyber-Physical Product-Service System Design Method
CPS	Cyber-Physical System
DSRM	Design Science Research Method
EOL	End of Life
MOL	Middle of Life
PSS	Product-Service System
SDL	Service-Dominant Logic
SLR	Systematic Literature Review
VCC	Value Co-creation

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Abstract

As markets evolve, businesses recognise that customers perceive value in the utility of a product rather than in the product itself. Consequently, business strategies are being reconfigured from selling products to providing solutions. These solutions combine products and services to form systems which, with the advancement of technology, have developed into "smart" or "cyber-physical" product-service systems that provide numerous benefits to stakeholders through mutual collaboration. This research aimed to develop a service-oriented cyber-physical product-service system (CPPSS) design method that, through customer value co-creation, was adaptable to customers' dynamic needs.

The six-step design science research method used in this study helped to identify research opportunities and to develop and test the cyber-physical product-service system design method (CPPSSDM) reference model. Where earlier design methods have contributed to either actor-dynamics or service science, this study integrates the concepts of actor-network theory and service-dominant logic into a single methodological approach. This CPPSSDM consists of four stages which address how providers, managers, designers, and end-users (1) identify problems, (2) negotiate relationships, (3) integrate resources and (4) communicate solutions. At the same time, it contributes a new theory to PSS/CPPSS design literature with new research directions.

The case studies here and the practitioner feedback derived suggest that CPPSSDM facilitates continuous value co-creation for dynamic adaptation to customer needs. Further knowledge translation and improvement are suggested for the CPPSSDM through application in industry.

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Chapter 1 – Why Design Cyber-Physical Product-Service Systems?

1.0 Introduction

The purpose of this thesis was to develop a design method for cyber-physical product-service systems (CPPSS) to be used in generic industrial sector value co-creation. A six-step design science research method (DSRM) shown in Figure 1 (Peffers et al., 2007) was used to develop the cyber-physical product-service system design method (CPPSSDM), which was followed by case studies and a practitioner survey to evaluate the model. This chapter gives an overview of the thesis, including the research motivation, methodology, outcomes, and contributions from the research. There are numerous important concepts and terminologies that are discussed throughout this thesis. To ensure the reader clearly understands these terminologies, their definitions and explanations are provided in Appendix I.

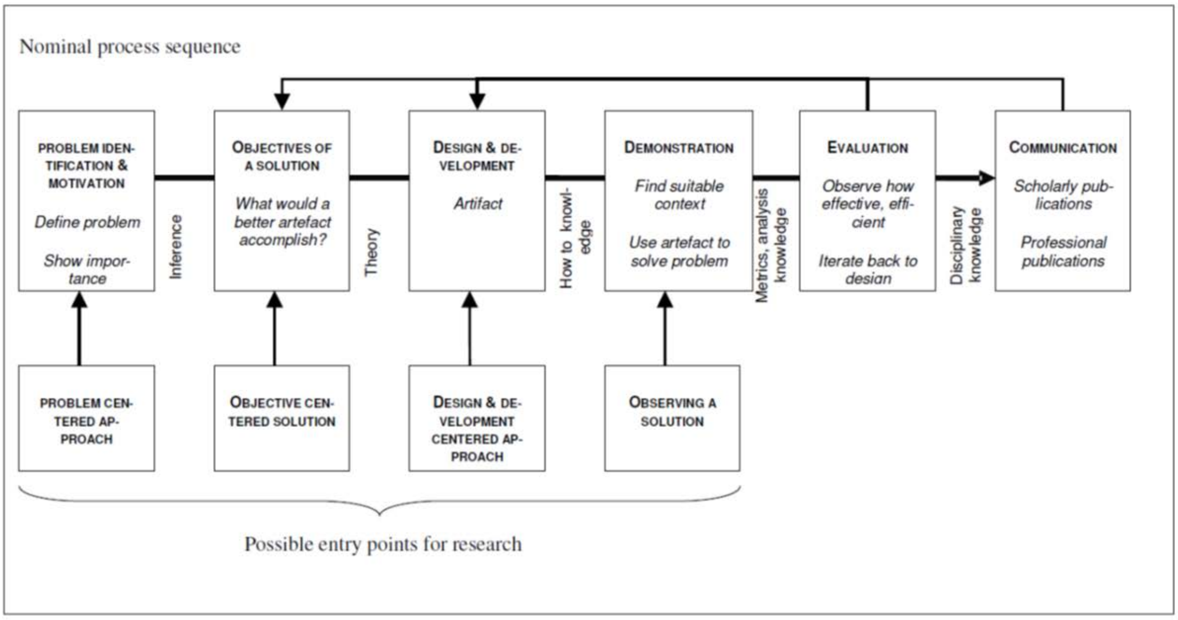

Figure 1: Design Science Research Method (obtained Peffers et al., 2007)

This chapter is structured into six sections, as shown in Figure 2. Section 1.1 introduces the concepts related to CPPSSs and their importance; Section 1.2 highlights the purpose and aims of this research; Section 1.3 discusses the research approach and Section 1.4 sheds light on the contributions; Section 1.5 summarises the chapters to describe the thesis structure.

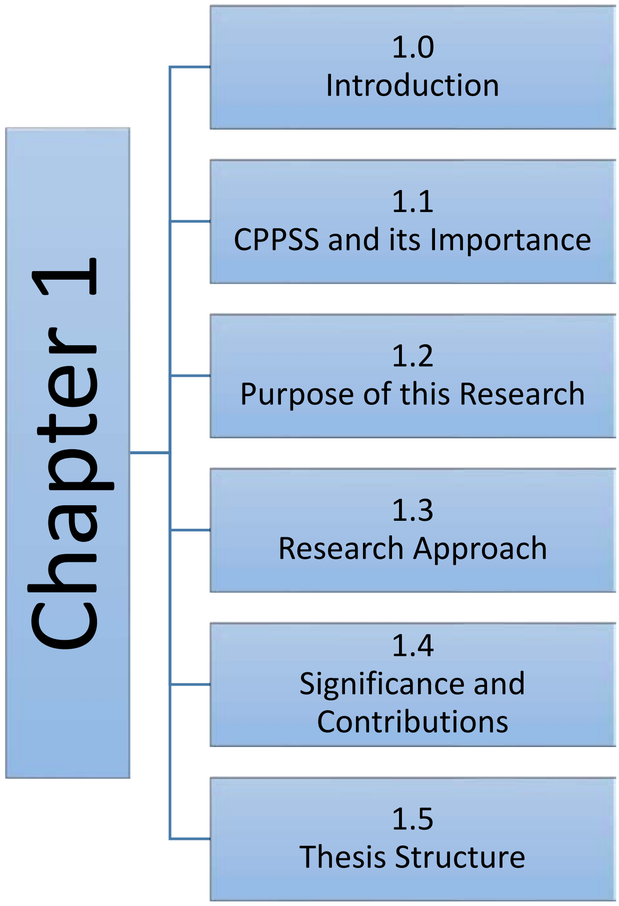

Figure 2: Structure of Chapter 1

1.1 What is CPPSS and Why is it Important?

There is an increasing trend to design, and use connected or networked solutions within our built environment, making life easier for large populations. A few examples of such solutions are listed below.

- Smart systems to control devices from anywhere in the world (e.g., Honeywell Home[3], Vivint Smart Home[4] and Control4[5])

  Smart homes are improving human lives with better connectivity, home control, a cleaner environment, safety and security through home automation and energy awareness. Smart home consists of smart cameras and motion detectors, alarms, doorbells, and other devices to detect, deter and alert suspicious behaviours by intruders. Smart monitors also help care for babies (e.g., Nanit[6]) and pets at home by monitoring their movements and vital signs. Smart thermostats, air cleaners, humidifiers, lights and other devices create a comfortable home environment. These smart devices also help residents save on energy consumption and energy source selection (Stojkoska & Trivodaliev, 2017).

- Virtual personal assistant and home control through voice commands (e.g., Google Home, Amazon Alexa, Apple Siri and Microsoft Cortana)

  Artificial intelligence and dialogue systems can conduct a natural conversation between humans and machines (Kepuska & Bohouta, 2018). This advancement has led to the development of virtual personal assistants that interpret human speech and respond accordingly. The users of such personal assistants can use voice commands to ask questions, control home automation systems, create reminders, respond to emails, make bookings, listen to music and much more (Hoy, 2018).

- Wearable devices to track daily movements and exercise (e.g., Fitbit and Garmin)

  Wearable activity trackers have been shown to help users adopt a healthier lifestyle through improved physical activity and real-time feedback (Maher et al., 2017). These devices help track heart rate, step counts, calorie burn, workouts, distance and sleep to

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[3] https://www.honeywellhome.com/us/en/ [Last accessed: 27/07/2021]
[4] https://www.vivint.com/ [Last accessed: 27/07/2021]
[5] https://www.control4.com/ [Last accessed: 27/07/2021]
[6] https://www.nanit.com/global/ [Last accessed: 27/07/2021]

improve quality of life (Seneviratne et al., 2017). In addition, these data also have the potential to be implemented in other applications like medical sciences and forensics (Massoomi & Handberg, 2019; MacDermott et al., 2019).

These developments suggest that the penetration of such systems into our daily lives is inevitable (Abramovici et al., 2015; Bohn et al., 2005). As customers are increasingly using these technologies to connect to anything from anywhere, businesses are trying to tap the capabilities of technology to interact with these customers in new ways and to enter new markets. Businesses are co-creating *value* with their customers to design smart solutions that enable higher customer involvement and potentially higher satisfaction. These businesses are mainly the manufacturing industries, which create products and services that cater to customers' needs. Here, the customer (or beneficiary) is defined as the recipient of the benefits of the service in response to their demands or problems. The benefits are a result of the activity executed by a combination of product and service functionalities. Value denotes the gains or benefits received by an entity in exchange for specific cost in each context.

These sophisticated systems are equipped with *smart* or *cyber-physical* technologies that help deliver to customers improved customised solutions using a combination of *products* and *services*. These systems, which are also called *cyber-physical product-service systems* (CPPSS), are integrated smart products and services that are being presented to the customers as a single solution to satisfy their needs. Although such solutions are currently available to customers, there is significant potential for enhanced offerings through the co-creation of better customised solutions.

Manufacturing and industrial design is a significant part of the Built Environment. However, a literature review shows that the design methods for CPPSS are still in their infancy (see Chapter 2). There is a need for a holistic design method to develop CPPSS for the generic industrial sector and implement value co-creation throughout its lifecycle. So, this thesis aims to address this lack of maturity and develop a CPPSSDM reference model that adopts a value co-creation and lifecycle approach, using theory (see Chapter 4) and practice (see Chapter 5). The research question (see Section 1.1.5), research focus (see Section 1.2), research method (see Section 1.3) and research plan (see Chapter 2.8) were chosen appropriately to address this aim. The design science research method was implemented using service-dominant logic (see Section 4.1.1) and actor-network theory (see Section 4.1.2) to develop the abovementioned CPPSSDM reference model. This research relates to, but is distinguished from, other concepts within the field such as new product development process, service development process and service design by developing a solution consisting of product and service combination enhanced with cyber-physical capabilities.

1.1.1 Importance of Service

For centuries, skilled artisans collaborated with their customers in designing their desired products and services. Be it an artefact as small as a shoe or as majestic as a monument, customers could contribute to their design and production. Over the centuries, the advancement in technology triggered the Industrial Revolution, which enabled producers to design and mass produce products. Although the Industrial Revolution enabled an extended reach and cheaper commodities, it also resulted in the lowering of customer involvement and customisation, which in turn impacted on the satisfaction levels of customers, providers and employees (Kanji, 1990; Obschonka, 2018). In more recent times, manufacturers have started adding services to their products using a phenomenon referred to as *servitisation* (Vandermerwe & Rada, 1988). Consequently, the service component has evolved from being a cost attached to the provisioning of the product to being a strategic tool for differentiation from competitors (Pawar et al., 2009). Businesses now realise that customers are concerned about the solutions, experiential outcomes and utility of the product rather than just the product itself (X. Yang et al., 2009). As a result, businesses around the globe are now shifting from a *product-oriented model of product delivery* to a *service-oriented model of solution delivery* (Annarelli et al., 2016).

Since the service component has been proven to provide businesses with a competitive edge by keeping customers satisfied and loyal, it has become their principal focus (Tan et al., 2010). This fact is emphasised further by the emergence of service-dominant logic, which states that *service* is a process by which all economic exchange takes place (Vargo & Lusch, 2008a, 2016). In other words, service is exchanged for service, and all products are enablers of service (Vargo, 2009).

The surge in bundling a service with products in business offerings has created the phenomenon of servitisation. This bundling helps managers to create a holistic solution to customer problems and gain a competitive edge (Vandermerwe & Rada, 1988). In addition, it creates value to customers and providers alike (Baines et al., 2009). Service-dominant logic (SDL) is an effort towards understanding the phenomenon of servitisation.

1.1.2 Importance of Value Co-creation

Service literature has evolved to cover the concept of *co-creation*, where *customers* and *providers* collaborate in creating the solution (explained further in Chapter 2). These entities, i.e., customers, providers and other stakeholders, are known as *actors* as they are directly or indirectly involved in the exchange relationship and influence one another. The actor consists of humans, machines and technologies. The co-creation process may involve joint problem definition, problem-solving, offering, construction of services, creation of experiences and benefits. In the co-creation process, the provider is not developing the solution independently but engaging the customer and its perspective in the design and implementation to ensure higher customer satisfaction. The literature sometimes uses the term *co-creation* and *value co-*

creation (VCC) interchangeably (Grönroos & Voima, 2013). However, to avoid any confusion, this thesis differentiates the latter (VCC) as the creation of value *through* co-creation.

Taking this discussion of value co-creation to a greater level of detail, SDL suggests that value is always determined by the beneficiary and is co-created by multiple *actors* that include the beneficiary (Vargo & Lusch, 2008b, 2017; Wiesner et al., 2016). This value is co-created through interactions, integration of resources and the application of competencies among providers and beneficiaries. With VCC, the question asked by manufacturers is not “What we can do for you?” but “What can you do with us?” (Wind & Rangaswamy, 2001, p. 21). Congruently, the importance of VCC in SDL is discussed in numerous articles (Lusch & Vargo, 2006a; Vargo & Lusch, 2008b, 2016). In addition to SDL, the importance of VCC is discussed in service science (Maglio & Spohrer, 2008; Spohrer et al., 2007), service logic (Grönroos, 2008) and critical service logic (Grönroos & Voima, 2013).

VCC is developing into a concept that is considered as one of the most provocative, paradigm-shifting and practical ideas in marketing (Fisher & Smith, 2011). Businesses realise the advantages of VCC by encouraging consumer engagement to enhance business performance and consumer value (Chan et al., 2010; Prahalad & Ramaswamy, 2004a, 2004b). VCC is extensively applied using SDL to form the customer solution known as product-service systems (PSS) (Kowalkowski, 2010; Neely, 2008; Ng et al., 2010; Smith et al., 2014).

1.1.3 Importance of Product-Service Systems

This trend of servitisation and VCC has given rise to the creation of *product-service systems* (PSS). The PSS value proposition is formed by the integration of product and service in such a way that it gives the customer the most sustainable, economic, social, practical and efficient outcome (Baines et al., 2007; Goedkoop et al., 1999; Mont, 2002; Rizvi & Chew, 2018a). It is a system that combines tangible products with intangible services, the collaboration of manufacturers and customers with support from infrastructure and network, to create a superior solution.

PSS offers value in a different way to all its participants. Providers appreciate the new revenue streams and differentiation from their competitors while customers enjoy a higher level of flexibility, customisation, personalisation and solution alternatives (Armstrong et al., 2015; Baines et al., 2007; Mont, 2002; Mario Rese et al., 2009; Richter et al., 2010). Waste and the environment are major actors in any business system and, in most cases, the optimum use of resources in PSS provides additional benefits like waste reduction and environmental sustainability (Minguez et al., 2012).

The research by Thomas et al. (2008) finds that PSS design results from customer-defined requirements. However, service innovation literature shows that the customer's demands are always evolving. Therefore, firms need to adapt their offerings to these changes dynamically to meet these evolving demands (Kindström et al., 2013). The current literature on PSS, however, seems not to address this dynamic nature of demand adequately.

1.1.4 Importance of 'Cyber-Physical' in PSS

Cyber-physical systems (CPS) are systems that aim to provide solutions to customer problems (Wiesner et al., 2017), using a combination of hardware components, software services and networking techniques. CPS does this by combining the computational, networking and physical processes to obtain the desired functionalities (Khaitan & McCalley, 2015). It has been argued that CPS has the potential to overshadow the IT revolution, which dwarfed the Industrial Revolution (Lee, 2008). Its importance can be realised by the fact that most developed nations are investing heavily in CPS research and development while their governments are treating them as a national priority (Wang et al., 2012). Applications of CPS have already emerged in objects as small as a pacemaker to as large as a power grid (Khaitan

& McCalley, 2015; Rajkumar et al., 2010). In the manufacturing and industrial context, advances in CPS have enabled the fourth industrial revolution, Industry 4.0, that enhances performance with smart decision making, higher automation and greater connectivity (Pivoto et al., 2021).

Although the aim of CPS is similar to that of PSS, the two concepts have different foci. While PSS focuses on the business side, CPS focuses on the technical side. The literature reviewed for this thesis revealed that extant PSS lack technological capabilities such as real-time sensing, monitoring and decision-making (Evans et al., 2007; Flores-Vaquero et al., 2016; Isaksson et al., 2009; X. Yang et al., 2009). To address this limitation, researchers have recently started to equip PSS with cyber-physical capabilities, thereby creating the CPPSS. This combination enhances PSS to be more intelligent and robust, resulting in a new system that is superior in terms of both the business model and technological capabilities (Scholze et al., 2016). CPPSS is expected to serve customers with the combination of technological and business competencies that provide real-time demand analysis and solution delivery, attributes that were not achievable by PSS. Consequently, industries have started integrating products, services, sensors, actuators and the internet (M. Zheng et al., 2016). This integration enables the monitoring and decision-making capabilities that give rise to '*smart*' PSS (Marilungo et al., 2017). CPPSS enable customers to enjoy the advantages of continuous improvement in service by using customer-specific data sensing and analysis (Wiesner et al., 2017), accelerated processing (M. Zheng et al., 2016) and improved human-machine interactions (Wiesner et al., 2016).

Furthermore, since CPPSS provides data analysis and decision-making functionalities, it can support manufacturing industries with better time to market their offerings, cost of production and quality constraints to achieve higher customer satisfaction (Marilungo et al., 2017; Wiesner et al., 2017). Overall, combining PSS with CPS to form the CPPSS could provide an innovative solution towards the advancement of Industry 4.0. Modern industries can benefit from the smart technological capabilities that deliver better value through customer-oriented solutions.

1.1.5 What's Missing?

A review of the literature on PSS and its design reveals that although PSS has been researched for two decades, most PSS design methods so far have not supported the customer VCC process in the PSS lifecycle (see Sections 2.2, 2.3 and 2.4 for further details). One challenging aspect for PSS is that customers' needs are always evolving and companies have to continuously adapt their resources and offerings (Kindström et al., 2013). Consequently, there is an urgent need for a service-centric PSS design method that focuses on customer value co-creation through resources integration, as defined by SDL (Tan et al., 2010; Vargo & Lusch, 2008b). Value co-creation also requires an understanding of the actor dynamics in the solution network (Pinho et al., 2014; Storbacka et al., 2016). These requirements had led to the creation of a smart version of PSS in the form of CPPSS. However, despite its potential, CPPSS is a relatively new concept, and consequently, there is still no recognised definition, model or design method for it (M. Zheng et al., 2016). This research, therefore, intends to address this gap by proposing a new reference model for a method to design CPPSS through the exploration of service-dominant logic, actor-network theory, value co-creation and a lifecycle approach. Based on the reviewed literature (see Chapter 2) and the current state of the art in the field of CPPSS, this thesis plans to answer the following question:

How could service-oriented CPPSS be designed through value co-creation to make it adaptable to customers' dynamic needs?

As will be exhibited throughout this thesis, SDL provides the principles of service-centricity in the CPPSS design method (see Sections 4.1.1, 4.2.3 and 4.3.3). ANT helps characterize the actor dynamics and relationships to form the CPPSS solution network (see Sections 4.1.2, 4.2.3 and 4.3.3). The combination of ANT and SDL defines the actor-to-actor orientation in a co-creation network (see Sections 4.1.3, 4.2.3 and 4.3.3 and 6.4). Value co-creation concepts are systemised using SDL to integrate actor resources in designing the CPPSS. All these concepts combine to form the design method congruent with the lifecycle approach (see Section 4.2.4). The lifecycle approach specifies the stages of CPPSS's life, which is co-decided by the actors through value co-creation. The ANT helps strategise this approach using the four-stage design method. The connection between the above theoretical lenses is shown in Figure 3.

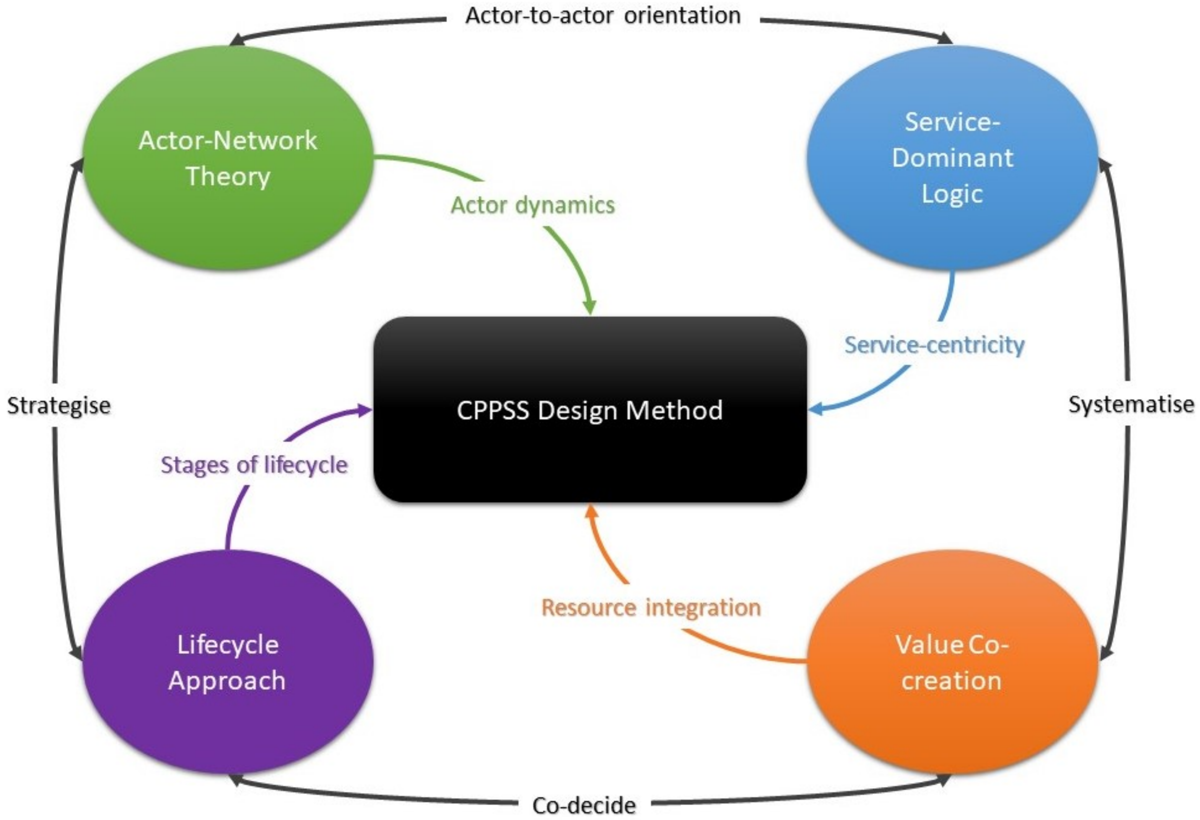

Figure 3: Theoretical lenses used in this thesis.

1.2 Purpose of this Research

Product-service systems, although highly useful to numerous applications, are inherently limited in the smartness and intelligence that could enable real-time sensing and actuation. CPPSSs are a type of PSS that are now becoming prevalent in addressing this limitation. CPPSS combines the smart or cyber-physical capabilities of CPS with the business strategy of PSS to serve customers with better customised and more intelligent solutions.

This research assists providers, customers, designers and end-users with a design method to develop PSSs and CPPSSs. The thesis investigates the development of a service-oriented CPPSSDM capable of catering to changing customer demands through value co-creation, its objective being to develop a reference model for CPPSS design that addresses value co-creation.

The literature shows that service is prevalent in business-to-business (B2B) markets, and most manufacturing industries are highly involved in B2B relationships (Hakanen et al., 2017; Lay et al., 2009; Raddats & Kowalkowski, 2014). B2B systems also attract the application of value co-creation (Kohtamäki & Rajala, 2016; Marcos-Cuevas et al., 2016). Similarly, the B2B context is of great interest in the PSS design and implementation research (Guzzo et al., 2019; Hakanen et al., 2017; Schenkl et al., 2014). So, the focus of this research is on the business-to-business value co-creation in CPPSS. Appropriately, the unit of analysis is chosen as the value co-creating processes and activities for CPPSS design. This unit is studied by observing the co-creating interactions between customers, providers and other actors. Further details of the research plan can be found in Section 2.8.

This thesis first develops a reference model (see Glossary and Appendix I). In the context of this thesis, the reference model is a CPPSSDM for the generic manufacturing industry. The research then takes an interpretivist case study approach towards understanding practitioners' realities to evaluate the CPPSSDM in the B2B manufacturing industry context. This approach is best suited to this research because it is concerned with the design processes implemented by practitioners towards co-creating value. As a result, a significant behavioural dimension influences the relationships between the actors involved in value co-creation. The interpretive paradigm forms a response to this research requirement.

The research needed to be designed as a comprehensive strategy to operationalise a study (Creswell & Creswell, 2017; Crotty, 1998). Since this research is concerned with developing a CPPSSDM reference model artefact[7], the DSRM was chosen. During this process, case study and survey methods were employed to evaluate the CPPSSDM reference model. The following steps were taken to develop a CPPSSDM in a B2B context:

1. Explore the design methods used to develop PSS and CPPSS respectively
2. Explicate the knowledge gaps in the definitions and design methods of PSS and CPPSS
3. Develop the research questions and determine the most appropriate research method
4. Discover the artefacts that represent and comprise PSS and CPPSS
5. Synthesise new, integrated and theoretically endorsed definitions for PSS and CPPSS
6. Theoretically develop the novel design methods for PSS and CPPSS
7. Evaluate and refine the developed design methods through appropriate procedures
8. Develop a theory- and practice-induced CPPSSDM reference model.

[7] See Appendix I

1.3 Research Approach

As stated above, this thesis used the design science research method (DSRM) to address the research questions posed. A coded diagram is provided in each of the chapters of this thesis, indicating how they correspond to the DSRM steps. As shown in Figure 1, DSRM provides a six-step procedure to develop artefacts in the form of construct, model, method and instantiation in order to serve humans. Implementation of the six steps is listed below. Further details of this research method and its steps are provided in Chapter 3.

- Step 1 – Identification: Accomplished through the SLR, to find the problems, gaps and motivation for the research (see Chapter 2).
- Step 2 – Objectives: Determined the objective for a solution in the form of the research question (see Chapter 2), resulting in the plan to develop a service-oriented CPPSSDM.
- Step 3 – Development: Developed a holistic method to design PSS and CPPSS using the reviewed literature and foundational theories (see Chapter 4).
- Step 4 – Demonstration: Implemented the case study method to demonstrate the feasibility of the proposed design method in four industry cases (see Chapter 5).
- Step 5 – Evaluation: The proposed design method was refined and evaluated using the inferences from individual and cross-case analysis (see Chapter 6). It was also presented to CPPSS practitioners to obtain their feedback and for further evaluation and refinement (see Chapter 6).
- Step 6 – Communication: Six conference papers were published and presented to communicate knowledge and information. This thesis is also a part of the communication.

1.4 Significance and Contribution

1.4.1 Theory

This research employed design science, case study and survey research methods to contribute to the literature of PSS, CPPSS, design science, and the application of ANT in supporting the premises of SDL. The reviewed literature, discussed in Chapter 2, has shown a link between SDL and actor-network theory (ANT), as projected by various researchers, such as Vargo and Lusch (2016) and Storbacka et al. (2016). Accordingly, this thesis developed a novel integrated reference model for CPPSSDM that adopted a lifecycle approach based on the concepts inspired by SDL and ANT (see Chapter 4). The proposed design method was used to consider the interactions between the networks of actors in the value co-creation process of adapting the CPPSS value proposition to provide optimal value-in-use. The reviewed literature has also shown that PSS is an innovative system for sustainability. The CPPSS proposed in this research can implement smart technologies to attain more sustainable solutions to customer problems (Rizvi et al., 2021).

The proposed definitions, models, and design methods for PSS and CPPSS are the new knowledge created in the topic of interest to close the identified gaps from the reviewed literature. Some of the knowledge generated from the research was communicated through the six papers presented at prominent conferences in Europe, Canada, the USA and China. More journal and conference publications are planned for the future. This research is also expected to provide a pathway for future developments in the research on combining ANT, SDL and CPPSS concepts, creating a new research perspective. New studies on sustainable CPPSS solutions implementing smart technologies are also expected to be a research direction branching out of this thesis.

1.4.2 Practice

The proposed design method was evaluated using four case studies: a dairy manufacturing facility, a pool management business, a health informatics company, and an information technology start-up (see Chapter 5). The information obtained from the case studies showed that the proposed design method could explain and systemise the design and implementation processes performed by the designers, managers, and operators of CPPSS solution both as customers and providers. Actors in the solution network can extract value through co-creation in a systematic fashion. Actors can make better decisions by collaborating and integrating their resources more sustainably.

The evaluation of this design method using the survey technique also showed that it could provide a holistic design solution to these CPPSS practitioners (see Chapter 6). This CPPSSDM reference model was identified as practical, functional, straightforward and easy to implement. Segregation of each actor's roles, responsibilities, and tasks provides a transparent and sustainable approach towards solving customers and co-creating value.

1.5 Outline and Organisation of the Thesis

This thesis consists of seven chapters, as listed below:

Chapter 2 – Literature review of the concerned topics

This chapter reports on the systematic literature review (SLR) of PSS, CPS and CPPSS. The chapter starts by introducing the review methodology of systematic literature review. The chapter continues into the literature search and selection strategy and draws a trend graph using the results. The chapter then presents an organised understanding of the available definitions and design methods of PSS, CPS and CPPSS by analysing selected articles. The chapter then presents a summary of the findings and the gaps identified in the literature and proposes the research questions to address those gaps.

Chapter 3 – Research methodology for the research

This chapter explains the research methodology of the DSRM that helped develop the design method for CPPSS. The chapter then justifies the selection of the case study method and implementation of semi-structured interviews to obtain the required data. The chapter goes on to discuss the data collection and analysis strategy and explains the survey method used to evaluate the design method.

Chapter 4 – Theoretical development of the design method

This chapter develops the theoretical design method for PSS and CPPSS, using available knowledge. The foundational theories of ANT and SDL helped develop a new theory, which enabled the defining and designing of PSS and CPPSS using a four-step design method. The chapter then demonstrates that this design method is in congruence with the lifecycle of CPPSS and concludes by listing the limitations of the proposed design method.

Chapter 5 – Demonstration of the design method using cases

This chapter demonstrates the usability and acceptance of the design method by seeking expert information from designers, managers, users, and providers of CPPSSs in practice. The information was gathered from four case study organisations involved respectively in manufacturing, water management, healthcare and virtual reality. The chapter compares each case study with the proposed design method and finds it to be compatible with real-world practice. These cases also helped identify the roles and tasks of designers, managers, users, and providers in each of the four steps of the design method.

Chapter 6 – Evaluation of the design method

This chapter discusses the method implemented to evaluate the design method. The chapter initially described a cross-case analysis to refine the CPPSSDM to an iterative process. It then explains the survey conducted to obtain practitioners' feedback on the design method. It lists the resulting ratings of and reactions to the utility and clarity of each stage of the design method. The chapter then describes how these reactions were used to enhance the design method into its final form.

Chapter 7 – Conclusion

This chapter brings about the concluding notes to the thesis. The outcomes of the research are compared against the research questions and the axioms of the service-dominant logic. The chapter also lists the achievements, implications, and limitations of the thesis. The chapter concludes by suggesting some future research directions.

Chapter 2 – Literature Review

2.0 Introduction

Chapter 1 oriented the reader to the importance and purpose of this research, combined with a brief understanding of the terminologies and approach. The purpose of this chapter is to explore the concepts of PSSs, CPSs, CPPSSs and value co-creation in the literature. These concepts are presented in this chapter in relation to the aim of this thesis.

As shown in Figure 4, this chapter covers the first and the second steps of the DSRM. The first step, *problem identification and motivation*, is presented by introducing the reader to the current research knowledge, trends and gaps (Peffers et al., 2007). The second step, *define the objectives of the solution*, is discussed using the research questions and objectives.

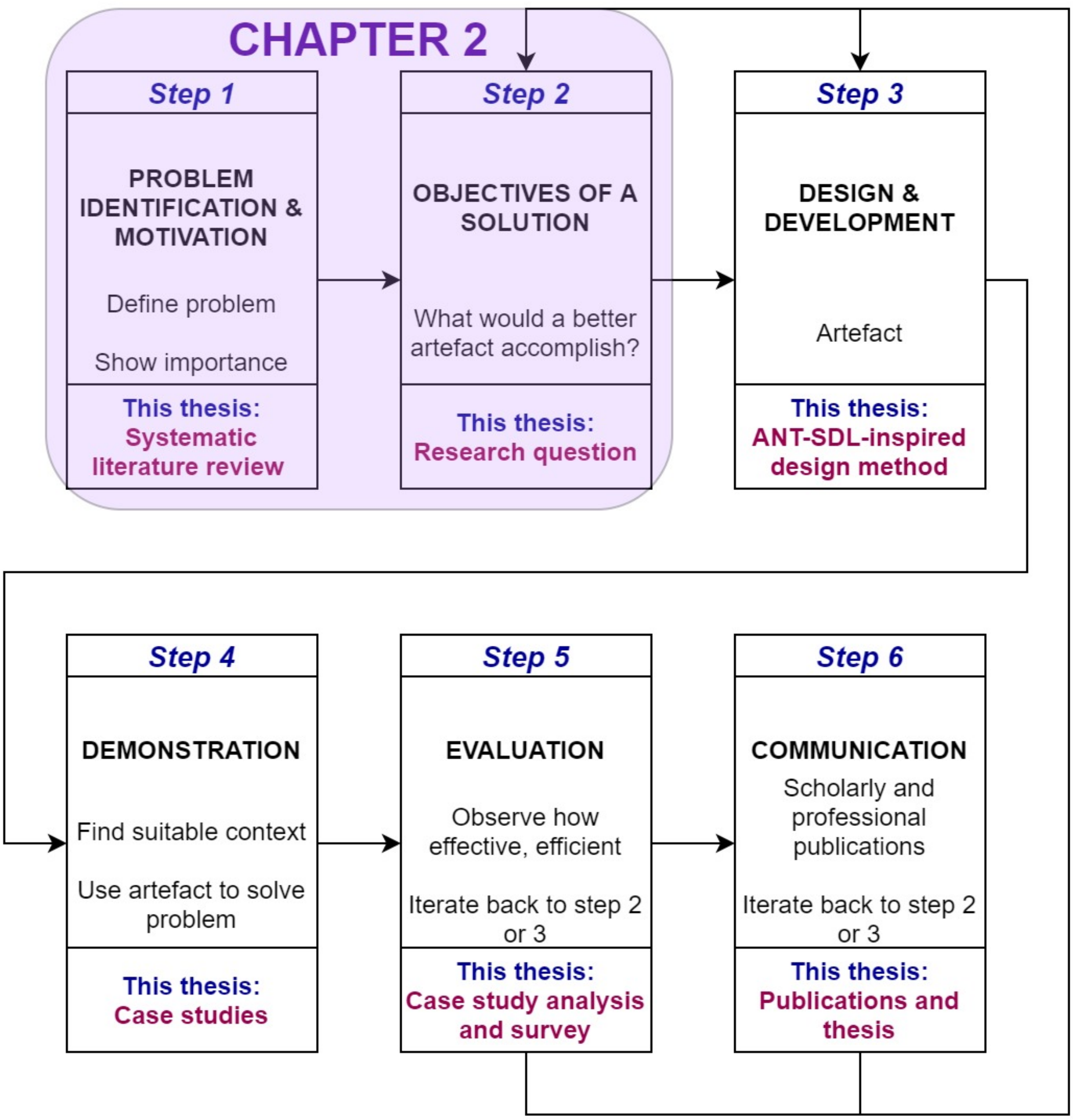

Figure 4: Steps 1 and 2 of the DSRM (adapted from Peffers et al., 2006; Peffers et al., 2007)

An SLR was performed to obtain an understanding of the theories relevant to developing the CPPSSDM. The structure of this chapter is provided in Figure 5. Section 2.1 elaborates on the review methodology by explaining the strategy used to search, select and filter the sources. The definition and design methods of PSS, CPS and CPPSS are discussed in Sections 2.2, 2.5 and 2.6, respectively. The concepts of lifecycle and value co-creation, which are vital for the design method, are described in Sections 2.4 and 2.5, respectively. The findings are presented in

Section 2.7, based on which the research plan to develop the CPPSSDM is proposed in Section 2.8. Lastly, Section 2.9 concludes the chapter.

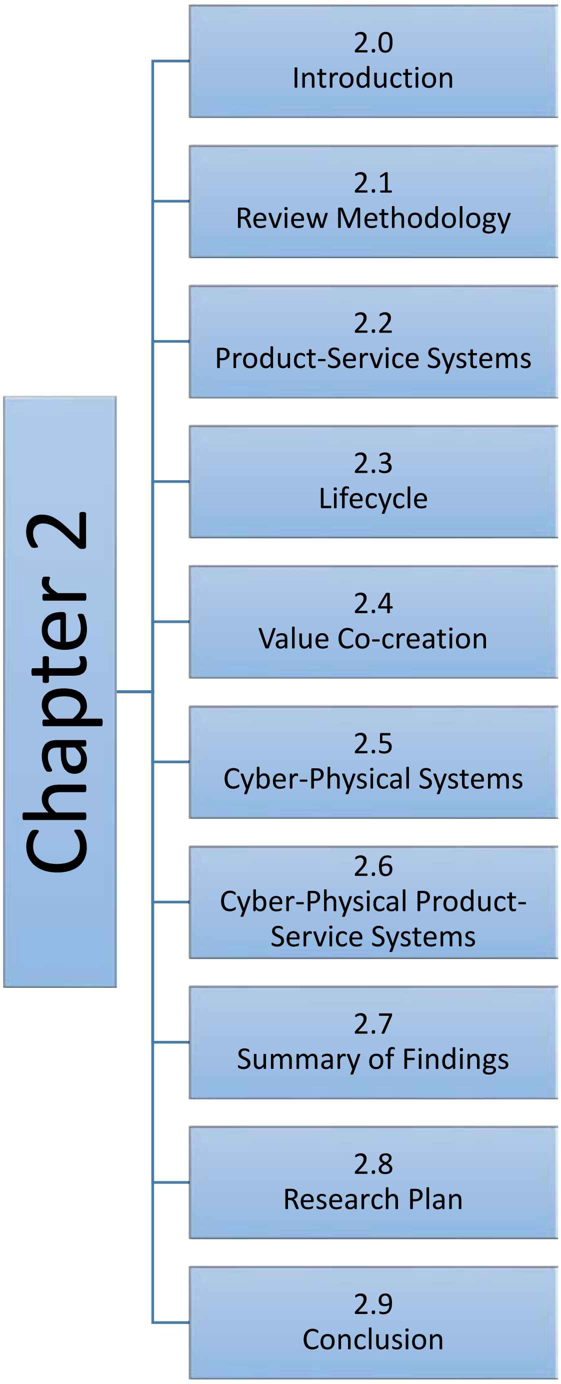

Figure 5: Structure of Chapter 2

2.1 Review Methodology

Literature reviews are conducted for several reasons, including helping the researcher understand the existing body of knowledge, providing a solid theoretical foundation, verifying the presence of research gaps, justifying the purpose of the research and framing a valid research approach (Levy & Ellis, 2006). A researcher summarises and integrates the existing knowledge about a topic using a literature review (Rowley and Slack 2004).

When choosing the literature review method, systematic literature review (SLR) has several advantages over traditional review due to its numerous unique procedures, reproducibility, and transparency (Kraus et al., 2020; Mohamed Shaffril et al., 2021). So, an SLR also requires comparatively more effort than a traditional review as it has more stringent methods and procedures. Researchers using SLR implement extensive searching methods, predefined search strings, and standard inclusion and exclusion criteria (Robinson and Lowe 2015). Some Definitions of SLR are:

- “An SLR is a review of an existing body of literature that follows a transparent and reproducible methodology in searching, assessing its quality and synthesizing it, with a high level of objectivity.” (Kraus et al., 2020).
- “A systematic literature review is a means of evaluating and interpreting all available research relevant to a particular research question, topic area, or phenomenon of interest. Systematic reviews aim to present a fair evaluation of a research topic by using a trustworthy, rigorous, and auditable methodology.” (Kitchenham & Charters, 2007).

One of the differentiating factors of SLR is the focus on a research question for performing the review and conducting the study (Kraus et al., 2020). Comparatively, this research also aims at addressing the research questions posed in Section 1.1.5. So, reviewing all the benefits of SLR applicable to this research, the SLR was implemented to study the state of the art and research gaps in the concerned fields.

2.1.1 Systematic Literature Review (SLR)

An SLR helps summarise existing knowledge about a specific topic, identify gaps in current research and provide a framework for new research activities (Kitchenham, 2004). Following Kitchenham (2004), this SLR was divided into the stages of planning, conducting and reporting explained in Table 1.

Table 1: The three steps of the SLR in this research

Step No.	**Name**	**Action**
1	Planning	Develop the review protocol and frame the questions corresponding to the relevant topics of interest.
2	Conducting	Identify the research papers through appropriate search strategy, selection criteria and data synthesis.
3	Reporting	Publish in journals, present at conferences or include in a thesis.

Guidance for undertaking the SLR was also taken from Okoli & Schabram (2010) and Okoli (2015). This guidance helped clarify the purpose of the review, set the protocol and training, search the literature, conduct practical screening, quality appraisal and data extraction, synthesise the studies and write the review. In line with the recommendation of Webster and Watson (2002), the most appropriate common keywords were chosen for the literature about PSS, CPS and CPPSS. These keywords are chosen by identifying them in topic-relevant research articles and through consultation with field experts. Table 52 in Appendix II lists the keywords used in the search process. Only papers from journals published in English language and with at least three relevant citations were chosen. The extracted data were analysed and synthesised using the processing guidelines provided by Levy and Ellis (2006); these involve the six sub-steps of knowing, comprehending, applying, analysing, synthesising and evaluating the literature.

2.1.2 Literature Search Strategy

The first step was to understand the purpose of this SLR and develop the required protocol. This SLR was conducted to identify the definitions and design methods for PSS, CPS and CPPSS from the perspective of value co-creation. The aim mainly was to study these three systems implemented in the B2B context to deliver value in the manufacturing industry. The approach was to find a commonality among the three systems to combine PSS and CPS to form the CPPSS. This commonality would enable a generalisable design method to be implementable to the generic industrial sector. So, the factors like business model, research perspective, design methodology, application, contribution and lifecycle stage were analysed (see Appendix III, IV, V and VI).

The papers collected for this review were sourced mainly from the Scopus database. The Scopus database was chosen because it is the database of choice for such researchers as Qu et al. (2016), Tukker (2015) and Annarelli et al. (2016), all of whom had conducted literature reviews previously in this domain. Only publications since the year 2000 were considered for this review. This selection was because most of the advances in this area took placed post-2000, as shown later in the literature study presented in Sections 2.3 to 2.6. As discussed in sections 1.1.4, 4.3 and throughout this thesis, CPPSS is considered a combination of PSS and CPS. So, all papers that contained an overlap between any of these three topics were considered a paper on CPPSS.

A search for the relevant keywords of the product-service system (see Appendix II) on Scopus since the year 2000 produced a list of 1,536 research papers. The graph in Figure 6 illustrates the publications per year since 2000, clearly showing the increasing interest in PSS. Publication numbers surged from just 8 in 2000 to 215 in 2019, with an average increase of 33.6 % every year. The gain in interest was also strengthened by the steady growth of citations, with papers published after 2000 gaining more citations over time. The citation recorded in the year 2000 was just 1, a number that soared to 8472 in 2019, rising by an average of 92% every year. These numbers added up to a total of 39864 citations for all the papers combined between 2000 and 2019.

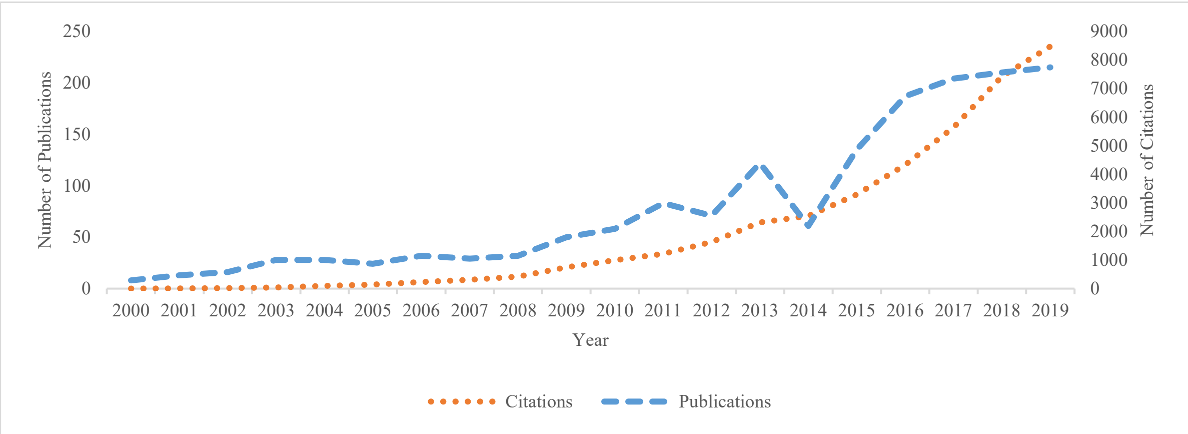

Figure 6: Publications and Citations graph for PSS

Limiting the 1,536 papers to those published in English language journals reduced the number to 558 papers. Further selecting those papers with at least three citations relevant to PSS and design reduced their number to 389. When these were manually checked using their titles and abstracts, the list reduced further to 115 articles. Additional analysis of complete papers relevant to the PSS design method reduced the list even further to 72 articles. Citation analysis of these 72 papers added five more articles that had been missed in the search process but were cited by many of the selected papers. Thus, as shown in Figure 7, a total of 77 articles were selected for analysis during the SLR (see Appendix III – Table 53).

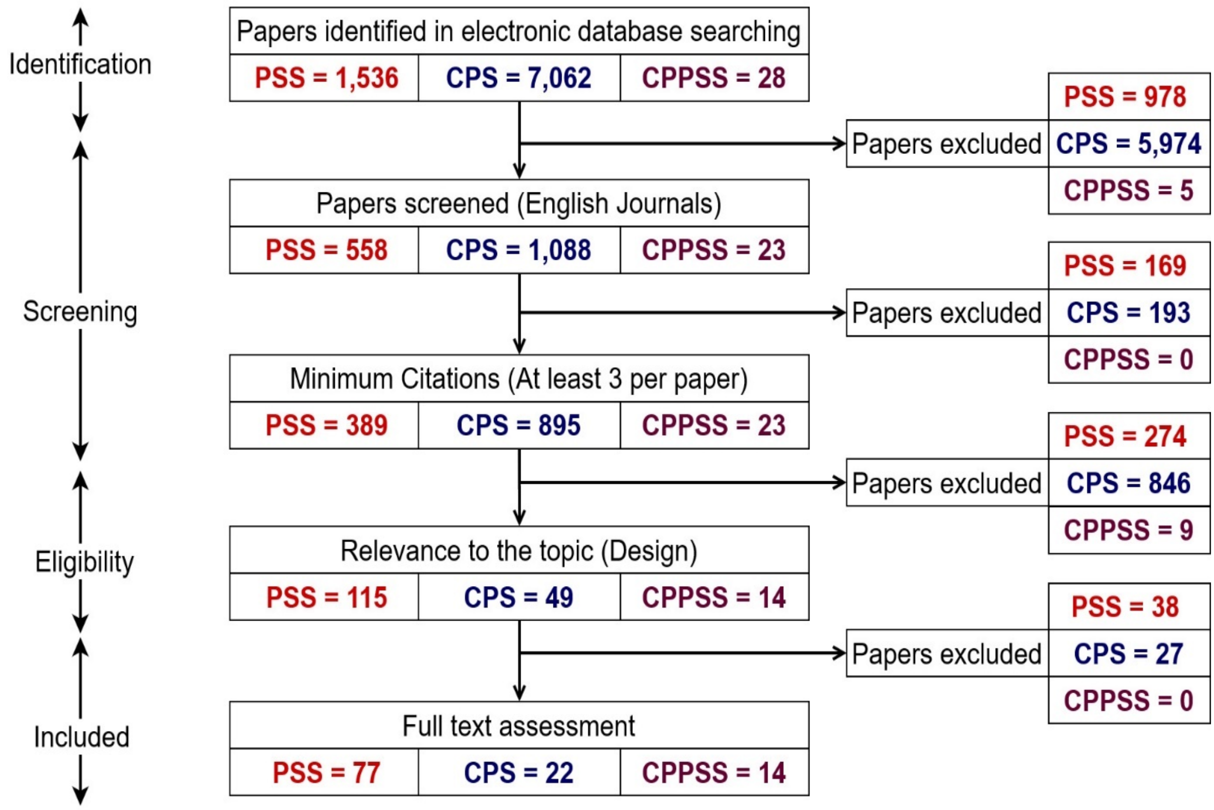

Figure 7: The SLR Method Implemented

A similar search for the relevant keywords of cyber-physical systems (see Appendix II) on Scopus yielded 7,062 papers. This number was reduced to 1,088 papers by selecting the journals published only in English. These papers were then filtered according to topic, abstract and keywords by looking for terms such as “design”, “framework”, “architecture” and “model” to reduce the list to 49 articles. A comprehensive study of these 49 papers to identify those with at least three citations reduced this list to a final total of 22 relevant papers (see Appendix IV – Table 54). The flowchart for this search process is shown in Figure 7.

Since the topic of CPPSS was relatively new, only a few publications that featured this term came up on Scopus. To obtain more papers on this topic, the selection criteria were relaxed to include conference papers, and the search source was expanded to include the UTS Library and Google Scholar. Figure 8 shows the gain in popularity of CPPSS in terms of the publications and citations over the years.

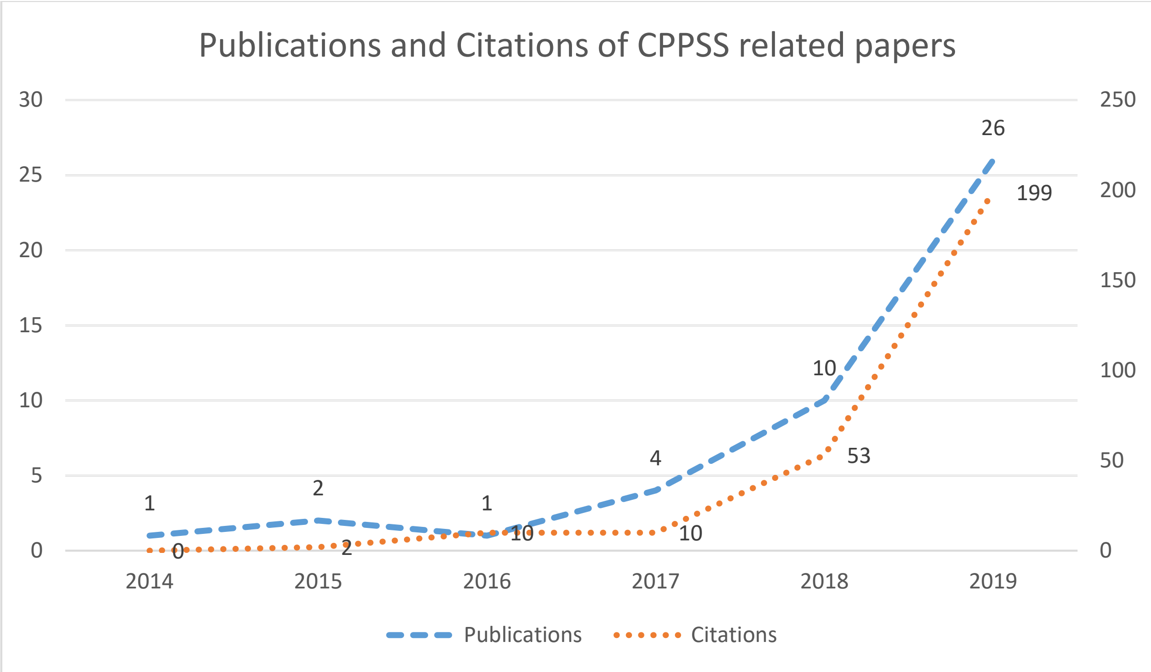

Figure 8: Publications and Citations graph for CPPSS

A search using the keywords for cyber-physical product-service system (see Appendix II) yielded 28 papers, which was reduced to 23 papers when papers published only in English language were selected. The condition of at least three citations was relaxed for CPPSS, to obtain a more inclusive list of papers. A comprehensive reading of these reduced the list to 14 papers (see Appendix V – Table 55). Figure 7 shows the selection criteria used for the Conducting step with the number of papers included or excluded.

2.2 Product-Service Systems

The concept of a product-service system (PSS) was introduced in the late 1990s, and research into the subject became prominent in the early 2000s (Baines et al., 2007). Some of the earliest works were by Mont (2002), Manzini and Vezzoli (2003) and Tukker (2004). A literature review was first presented by Baines et al. (2007), which motivated other researchers to explore this concept further (Martinez et al., 2010; Meier et al., 2010; Park et al., 2012). There have been some systematic literature reviews in more recent times (Annarelli et al., 2016; Beuren et al., 2013; Reim et al., 2015). The primary characteristic of the PSS is to incorporate customer-specific products and services that satisfy customers' needs better than the product or the service on their own could do. One of the early definitions proposed for PSS was, "a marketable set of products and services capable of jointly fulfilling a user's need" (Goedkoop et al., 1999, p. 18). The definition of PSS evolved over the years to numerous, diverse and at times conflicting descriptions (Rizvi & Chew, 2018a).

Some literature has demonstrated the importance of value co-creation in designing PSS (Yip et al., 2013; Zine et al., 2014). Value co-creation enables different actors to work together to co-create or co-produce value (Saarijärvi et al., 2013). These actors consist of the human entities of suppliers, partners and customers and the non-human entities such as hardware, software and performance (Mont, 2000; Saarijärvi et al., 2013). ANT is an approach that has been used extensively to study the socio-technical[8] world of human and non-human interactions (Tatnall, 2005). Additionally, the founders of SDL acknowledge the congruence of the ANT and SDL frameworks (Vargo & Lusch, 2016). Drawing from the reviewed literature and as specified by numerous researchers, PSS appears to fit the description of a socio-technical system (Annarelli et al., 2016; Joore & Brezet, 2015; Rizvi & Chew, 2018a; Rizvi & Chew, 2018b; Roy, 2000). The PSS involves the social, technological and cultural positions and knowledge of the actors in designing the solution (Morelli, 2006). Thus, the principles of ANT were adopted here to study and explain the value co-creation activities in PSSs. The applicable principles of ANT and its combination with SDL is discussed in detail in this thesis. Section 1.1.5 and Figure 3 describes the role of ANT on the design method. ANT and its four translational stages are explained in Section 4.1.2. The ANT-SDL model for value

[8] a system that comprises the interactions and communications between human and non-human technical actors in an environment

co-creation is developed in Section 4.1.3. This hybrid model was then used to develop the design method for PSS (see Section 4.2.3) and CPPSS (see Section 4.3.3).

2.2.1 Definition of PSS

The definition of PSS is a debated concept due to a variety of perspectives that use different terms to define it. As PSS research was initially started to achieve more sustainable and environmentally friendly operations, the definition of PSS at the time was aimed at extending product life cycles by adding services to improve availability, efficiency and performance (Baines et al., 2007). Some early examples of a PSS were the Xerox paper management system and Rolls-Royce's Power by the Hour business system (Baines et al., 2007; Mont, 2000). Over the years, the range of applications and market reach of PSS has expanded through the use of various terms, such as product service, full service, service package, integrated solution and functional sales (Park et al., 2012). PSS has also been described as an offering (Baines et al., 2007; Park et al., 2012), a value proposition (Tukker & Tischner, 2006), a business model (Annarelli et al., 2016), an approach (Tan et al., 2010) and a strategy (Manzini & Vezzoli, 2003). However, the most popular explanation is that PSS is a 'system' (Goedkoop et al., 1999; McKay & Kundu, 2014; Tukker, 2004). As explained by Baines et al. (2007), treating PSS as a system comprehensively covers all its elements and their relationships. Table 56 in Appendix VI runs through the various definitions used for a PSS. In summary, a PSS can be defined based on three factors:

- its constituent parts, products and services
- the value generated during its operation
- a business model based on the ownership and offering of the constituents of the solution (such as hardware, software and services).

The extant literature on PSS yielded 21 different terms used in 35 different definitions for PSS (see Appendix VI – Table 56). For this research, every paper's Google Scholar citation was plotted on a graph so that the impact of these terms in the literature could be understood (see Figure 9). The graph shows that the '*integration*' (or combination of product and service), the fulfilment of customer needs and the impact on the environment were the most published and cited terms. One can notice that most of the definitions emphasise the integration of product and services. Some authors also expanded on this by highlighting the tangible and intangible nature of the two elements, that is, the tangible product provides functionality in the form of an intangible service in exchange for an economic value (Goedkoop et al., 1999).

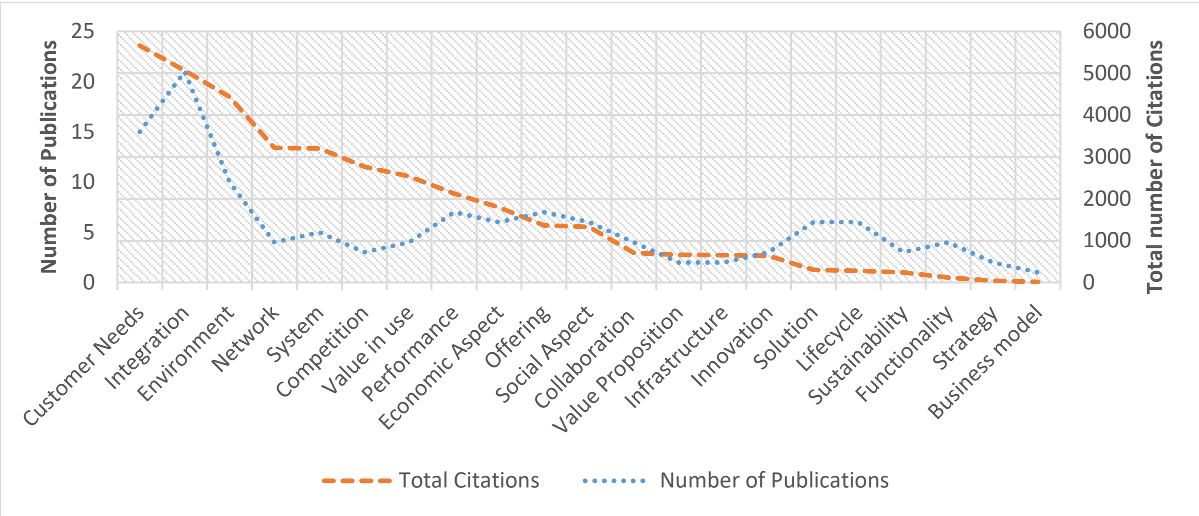

Figure 9: Terminologies used to define PSS

2.2.1.1 Types of PSS

The PSS business model is classified according to three types: product-oriented, use-oriented and result-oriented (Reim et al., 2015). These three kinds of PSS are discussed below and tabulated in Table 2.

The product-oriented PSS comprises commitment from the provider to deliver product-related services after selling the product to the customer (Tukker, 2004). Some examples of such PSSs are businesses where services like warranties, regular vehicle/machine maintenance, equipment repairs, software updates, training, consulting and system upgrades are provided after a product has been sold.

In the case of a use-oriented PSS, the provider makes the product available under rental or leasing arrangements rather than selling it (Tukker, 2004). Some examples of this PSS are vehicle/aeroplane leasing, car sharing and pay-per-use photocopying. These businesses do not sell the product but charge the users per use of the service; the ownership and maintenance responsibilities are held by the service provider rather than the customers.

A result-oriented PSS is the most sophisticated type, and it includes providing the customers with specific outcomes or results rather a particular product or a service (Tukker, 2004). Examples of such PSSs outcomes are providing lighting solutions for a specific space rather than just selling lights, offering a total air-conditioning solution for a building rather than just selling electricity or air-conditioners, implementing harvest loss control rather than just selling pesticides and selling engine power output rather than just selling the engine.

Table 2: Three types of PSS (adapted from Reim et al., 2015; Tran & Park, 2014; Tukker, 2004)

	Product-oriented PSS	**Use-oriented PSS**	**Result-oriented PSS**
Agreement focuses	Tasks, payment and information	Level of availability and monitoring	Characteristics of the results
Customer insight	Usage information	Customer habit	Comprehensive data collection
Customisation, risk and complexity	Low	Medium	High
Interaction	On-demand	Frequent	Frequent
Offering	Provision of agreed additional service(s)	Availability of a product as a service	Result or capability as a service
Ownership	Customer	Provider	Provider
Value	Functionality and durability	Ownerless consumption	Reduced customer responsibility

Examples	• Product maintenance, repair, recycle and upgrade • Advice and consultancy	• Product lease, share and rent • Product pooling	• Outsourcing • Pay-per-service • Functional result

2.2.1.2 Research status

Although the three types of PSS business model shown in Table 2 are well known, the design articles reviewed in the literature did not address the problem of how to design a PSS for a specific kind of business model. Several articles were implicitly concerned with a product-oriented PSS, while some were concerned with user orientation (see Appendix III – Table 53). However, no result-oriented PSS was discussed adequately. Instead, most of the articles discussed PSS design by focusing on a range of factors, which could be divided into activities/processes, actors, contexts and objectives. These factors are listed below.

- Activities/Processes: The activities/processes were decision making, rating, value contribution, co-development, co-production, information flow, feedback and knowledge management.
- Actors: Among the actors were the customers, manufacturers, suppliers, providers and other stakeholders.
- Contexts: At the same time, the contexts were needs, requirements, conflicts, contradictions, interference, constraints, relationships, scenarios, culture, emotions and capability.
- Objectives: The objectives included sustainability, innovation, productisation, servitisation, supportability, modularisation, competitiveness, satisfaction, optimisation and performance.

All these factors are listed in Table 3 with their appropriate references.

Table 3: PSS design focus factors

	Sub-factors	Description	References
Activities/Processes	Co-development	Developing sustainable PSS through multi-stakeholder design participation	Evans et al., 2007; Morelli, 2009
	Co-production		
	Decision making	Making PSS design decisions through methods like value assessment, fuzzy logic and requirements tree	Bertoni et al., 2016; Xiuli Geng et al., 2011; Pezzotta et al., 2016
	Feedback	Connecting feedback loops between the inputs and outputs of different phases to create a cyclic PSS design process	Clayton et al., 2012; Hussain et al., 2012; Igba et al., 2015; Schweitzer & Aurich, 2010; Vijaykumar et al., 2013
	Information flow	Describing PSS functions by determining its data consumption and information usage at its inputs and outputs	Durugbo et al., 2011; Igba et al., 2015
	Knowledge management	Capturing and reusing knowledge of the process, product and service to design PSS	Baxter et al., 2009; Igba et al., 2015; Zhang et al., 2012; Zhu et al., 2015
	Rating	Rating customer requirements to identify the engineering characteristics and design of the required PSS	Geng et al., 2010; Sutanto et al., 2015; Tran & Park, 2016
	Value contribution	Selecting design method based on their value assessment	Bertoni et al., 2013
Actors	Customers	Supporting PSS design by customer attributes like experience, satisfaction, value, needs, preference, requirements, activity and interaction	Carreira et al., 2013; Geng & Chu, 2012; Hara et al., 2009; Kimita et al., 2009a, 2009b; Peruzzini et al., 2015; Pezzotta et al., 2015; Rese et al., 2009; Sakao & Lindahl, 2012; Sutanto et al., 2015; Tan et al., 2010; Thomas et al., 2008; Wallin et al., 2015
	Manufacturers	Designing PSS based on manufacturers' requirements	Geng et al., 2010
	Providers	Governing PSS design by providers' perspectives	Yoon et al., 2012
	Stakeholders	Designing PSS through stakeholder collaboration and individual requirements	Berkovich et al., 2014; Hara et al., 2009
	Suppliers	Directing PSS design process through customer-supplier relationship	Alonso-Rasgado et al., 2004; Alonso-Rasgado & Thompson, 2006
Contexts	Capability	Customising PSS designs that align with the integrated stakeholders' capabilities of continuously generating the desired value	Hussain et al., 2012; Vijaykumar et al., 2013

	Conflict	Identifying and resolving PSS design conflicts in technical attributes	Song & Sakao, 2016
	Contradictions Interference	Resolving the contradictions and interference between product and service components in PSS design	Kim & Yoon, 2012
	Culture	Designing PSS based on the consumer culture covering contextual, symbolic, and experiential aspects of consumption.	Catulli et al., 2017; Vezzoli et al., 2017
	Emotions	Designing PSS to create positive emotional chain reactions	Stacey & Tether, 2015
	Needs	Focussing on customer needs while developing the PSS	Peruzzini et al., 2015
	Relationships	Directing PSS design process based on customer-supplier, people, stakeholders, resources, value, quality and environment relationships	Alonso-Rasgado et al., 2004; Dewberry et al., 2013; Liu et al., 2014; Macdonald et al., 2016; Sakao et al., 2009
	Requirements	Using requirements data model of customers and other stakeholders at various design levels to develop the PSS	Berkovich et al., 2014
	Scenarios	Mapping service scenarios of customer expectations and needs to develop PSS	Alix & Zacharewicz, 2012; Morelli, 2006; Morelli, 2009
Objectives	Competitiveness	Implementing a framework to design PSS with a competitive advantage in customer affordability, value, performance and opportunity	Roy & Cheruvu, 2009; Shikata et al., 2013
	Innovation	Innovating PSS design with structured routines and processes for continuous improvement.	Joore & Brezet, 2015; Wallin et al., 2015; Yoon et al., 2012
	Modularisation	Dividing the PSS into smaller reusable modules to enable greater flexibility and applications.	Garetti et al., 2012; Li et al., 2012; Shikata et al., 2013; Song & Sakao, 2017; P. Wang et al., 2011
	Optimisation	Optimising resources through distribution of processes, enhancement of lifecycle and customer satisfaction to design sustainable PSS	Manzini & Vezzoli, 2003
	Performance	Conducting performance analysis of technical, operational, economic, architecture and lifecycle factors to evaluate customer satisfaction and identify improvement strategies	Geng & Chu, 2012; Pezzotta et al., 2015; Schweitzer & Aurich, 2010; Shikata et al., 2013

	Productisation	Developing PSS based on the required service and delivering it as a product	S. Kim et al., 2015
	Satisfaction	Evaluating customer satisfaction to compare solutions and support PSS design	Geng & Chu, 2012; Kimita et al., 2009b
	Supportability	Designing PSS that assures repair, maintenance, reliability, availability, serviceability, usability and installability.	Tan et al., 2010
	Servitisation	Adding service to providers' products to design the PSS	Sun et al., 2009
	Sustainability	Balancing economic, environmental and social systems in designing PSS that facilitate sustainable production and consumption	Chen et al., 2015; Chen, 2018; Chou et al., 2015; Evans et al., 2007; Joore & Brezet, 2015; Liedtke et al., 2015; Liu et al., 2014; Peruzzini & Germani, 2014; Santamaria et al., 2016; Song & Sakao, 2017

The literature indicated that PSS applications were predominantly found in business-business (B2B) and business-consumer (B2C) contexts. The B2B contexts included manufacturers and customers of aircraft engines, power transformers, construction equipment, metering pumps, drilling machines, elevator services, air conditioning, logistics, railway, energy and heavy vehicles. B2C covered bus services, food services, education services, car/bike sharing, toys, mobile phones, healthcare and household appliances. The papers in the above business context are organised in Table 4. Table 4 also lists the various kinds of research methods implemented to study PSS. Qualitative methods include case studies (e.g., Song & Sakao, 2017), interviews (e.g., Stacey & Tether, 2015), action research (e.g., Yip et al., 2015) and grounded theory (e.g., Pawar et al., 2009), while quantitative methods include questionnaire surveys (e.g., Chou et al., 2015) and usage data (e.g., Roy & Cheruvu, 2009). This thesis adopted a combination of quantitative and qualitative research methods in the form of case studies and a survey questionnaire to address the research objectives.

Table 4: PSS business context and research methods

	Category		References
Business Context	Business-business		Durugbo et al., 2011; Roy & Cheruvu, 2009
	Business-customer		Rexfelt & Hiort af Ornäs, 2009
Research Method	Conceptual		Alonso-Rasgado & Thompson, 2006; Alonso-Rasgado et al., 2004; Garetti et al., 2012; Hara et al., 2009; Komoto & Tomiyama, 2008; Rese et al., 2009; Sakao et al., 2009; Santamaria et al., 2016
	Qualitative	Case Study	Akmal et al., 2014; Alix & Zacharewicz, 2012; Baxter et al., 2009; Bertoni et al., 2016; Chen et al., 2015; Durugbo et al., 2011; Geng & Chu, 2012; Kim & Yoon, 2012; Krucken & Meroni, 2006; Li et al., 2012; Maussang et al., 2009; Morelli, 2009; Peruzzini & Germani, 2014; Peruzzini et al., 2015; Pezzotta et al., 2016; Sakao & Lindahl, 2012; Song & Sakao, 2016, 2017; Tan et al., 2010; Thomas et al., 2008; Trevisan & Brissaud, 2016; P. Wang et al., 2011; Zhang & Chu, 2010; Zhu et al., 2015
		Interview	Becker et al., 2010; Berkovich et al., 2014; Clayton et al., 2012; Durugbo, 2014; Hussain et al., 2012; S. Kim et al., 2015; Macdonald et al., 2016; Rexfelt & Hiort af Ornäs, 2009; Stacey & Tether, 2015; Vijaykumar et al., 2013; Wallin et al., 2015; Zhang et al., 2012
		Action Research	Carreira et al., 2013; Evans et al., 2007; Igba et al., 2015; Liedtke et al., 2015; Pezzotta et al., 2015; Yip et al., 2015
		Grounded Theory	Pawar et al., 2009
	Quantitative	Questionnaire survey	Bertoni et al., 2013; Chou et al., 2015; Kimita et al., 2009b; Yoon et al., 2012
		Usage Data	Roy & Cheruvu, 2009; X. Yang et al., 2009
	Combined		Geng et al., 2010; Xiuli Geng et al., 2011; Shikata et al., 2013; Sundin et al., 2009; Sutanto et al., 2015

2.2.2 Design of PSS

The PSS literature reviewed showed that the terms “design method” and “design tool” are used interchangeably. However, this thesis proposes to differentiate these by considering PSS design tools as instruments that help implement PSS design methods. Dealing with design methods, first, the extant reviewed literature provided several variations of PSS design methods, with most papers showing that the researchers used case studies. However, no paper describes a holistic approach from PSS ideation to PSS implementation and termination. A relationships model among the actors of an operational PSS during its design and deployment was similarly unexplored. It is therefore essential to note that in this research, an actor was treated as the entity that was directly or indirectly involved in the exchange relationships and influenced other entities towards value co-creation.

Some of the design methods described in the literature investigated and incorporated customer needs at the start of the design process to co-create with the customers, a process that some researchers accomplished through market research or lead-user involvement (Cooper, 1994; Von Hippel, 1976). Others considered the employee-user interactions in service transactions during the design process (Sakao & Shimomura, 2007; Shostack, 1984).

A PSS may be designed by implementing such concepts like methodology development and evaluation of PSS (MEPSS) and service engineering (Qu et al., 2016; Tran & Park, 2014). Service engineering systematically develops and designs PSS using suitable models, methods and tools (Pezzotta et al., 2015), and it focuses on designing products with a higher added value derived from enhanced services (Vasantha et al., 2012). MEPSS is a method that systematically analyses a company's resources to eliminate waste and identify the opportunities for optimisation (Van Halen et al., 2005). Service engineering and MEPSS are overarching design methodologies that use a variety of design method to solve the design issues. The following sub-sections examine the methods and tools used in PSS design.

2.2.2.1 Design methods

According to design science, a method is a set of steps, practices, processes, guidelines or instructions that are used to perform a task based on the underlying constructs and their relationships (Hevner et al., 2004; March & Smith, 1995; Offermann et al., 2010; Peffers et al., 2012). Methods are also described as ways of performing goal-directed activities. Consequently, the design method is defined as a description of the procedure(s) for artefact construction (Walls et al., 1992). In the PSS literature, numerous researchers have proposed design methods that are capable of developing PSSs based on the requirements set by the problem, the context and the application.

Among the design methods used to develop a PSS, some researchers have used a sequential or waterfall procedure (Hussain et al., 2012; Maussang et al., 2009; Sutanto et al., 2015). Other researchers have proposed the simultaneous development of products and services (Sakao & Shimomura, 2007; Tomiyama, 2001). More recently, an integrated PSS design method was proposed that used the concept of the functional block diagram to design the product and service of PSS holistically (Maussang et al., 2009; Trevisan & Brissaud, 2016). In this system, the blocks are developed further into the modularisation method, which divides the system into smaller reusable and replaceable sub-systems (or modules) to allow flexibility and customisation (P. P. Wang et al., 2011). This method effectively improves the reusability of a product or service, thereby reducing the internal diversification of the product and service, resulting in reduced production cost (Li et al., 2012).

Some researchers also used a lifecycle method to design a PSS, that is, in terms of its beginning, middle and end of life. This method is derived mainly by combining the lifecycle management concepts of products and services (Wiesner et al., 2015). Service modelling is another method that specifies the inputs, outputs and controllers of every element, including their interrelationships (Phumbua & Tjahjono, 2012). It assigns details of the functions and actions of the system and keeps the link between each element in the system (Morelli, 2006). Visualisation is yet another design method where the PSS is visualised using diagrams and colour codes to help designers understand and analyse complex systems (Lim et al., 2012).

Although the design methods discussed so far have resulted in numerous innovations, they do not provide a holistic PSS solution. Holistic PSS design is likely to be achieved only through the implementation of a PSS lifecycle. As discussed above, the lifecycle method is one that encompasses the entire timeline of the PSS's life and is therefore, an holistic approach to designing PSS. However, the literature showed that very few of the PSS design methods used adopted a lifecycle approach that considered actors' needs throughout the life of the PSS (Aurich et al., 2008; Bertoni et al., 2016; Collopy & Hollingsworth, 2011; Komoto & Tomiyama, 2008).

One of the most obvious gaps identified in the reviewed literature was the limited application of value co-creation in PSS design. As explained in Section 2.4, value co-creation is a joint creation of value through the collaboration of the system stakeholders. The value co-creation concept could enable a PSS to address customer problems better through co-created solutions. This gap in the literature forms one of the motivations behind this research. The research questions have therefore been formulated to discover the perception of value and the implementation of value co-creation in design processes. A summary of the features and limitations of the reviewed design methods are presented in Table 5.

Table 5: PSS design methods in the reviewed literature

Design Method	**Feature**	**Limitation**	**Example**
Lifecycle	Designs PSS in three stages: beginning, middle and end of life	Does not provide an approach to catering for dynamic customer needs	Wiesner et al., 2015
MEPSS	Consists of a toolkit to guide companies to PSS design innovation	Focuses only on the beginning of the life of the PSS	Van Halen et al., 2005
Modularisation	PSS is divided into smaller reusable and replaceable modules	Difficult to apply the lifecycle information in the design	Li et al., 2012; P. P. Wang et al., 2011

Service Engineering	Designs new PSS from an existing PSS using suitable models, tools and simulations	Requires modelling of human behaviour, which is difficult to accomplish	Pezzotta et al., 2015; Sakao & Shimomura, 2007
Service Modelling	Models the service in terms of inputs, outputs and controls	Customer-manufacturer interactions and value co-creation are not employed	Morelli, 2006; Phumbua & Tjahjono, 2012; Sakao et al., 2009
Visualisation	Defines the scenarios, situations and relationships using visual techniques	Technical details on the steps to design the PSS are ad-hoc and with no generalisation	Bertoni et al., 2013; Lim et al., 2012

2.2.2.2 Design tools

Two kinds of design tools emerged from the reviewed literature. One was used in the initial stage to prioritise the design tasks and the other was used to support the design process. This thesis recognises that these tools are not exclusive to PSS design. The tools identified to be used in PSS design are briefly discussed next.

The design tools that support the conversion and prioritisation of stakeholders' needs include the theory of inventive problem-solving (TRIZ), quality function deployment (QFD), analytical hierarchy/network process (AHP/ANP), Kansei engineering and the Kano model.

The TRIZ tool uses 40 inventive principles to define problems and solve them by generating service-supporting product concepts (Kim & Park, 2012). Kansei engineering (KE) is a tool that focuses on converting stakeholders' needs and customers' feelings into product and service features (Carreira et al., 2013; Nagamachi, 1995). QFD translates customers' requirements into technical requirements using matrices and numerical data to help decision-makers in the PSS design method (Akao, 1990; Peruzzini et al., 2015). Analytical hierarchy process (AHP) and the analytical network process (ANP) prioritise customer requirements towards decision making (Geng et al., 2010; Saaty, 2008; X. Yang et al., 2009). The Kano model prioritises customer requirements into three categories based on the degree to which those categories may satisfy customers (Sauerwein et al., 1996). A summary of these design tools in terms of their features and applications are provided in Table 6.

Table 6: Design tools that enable understanding and prioritisation of needs

Design Tool	Feature	Application	Example
AHP/ANP	Generate ratio scale priorities through pairwise comparison between dependent (in AHP) and independent (in ANP) elements for more transparent decision making	Service modelling	Dewberry et al., 2013; Zhu et al., 2015
Kano model	Provides the relationship between performance and customer satisfaction to classify customer preferences	Service modelling, modularisation	Geng & Chu, 2012; Mourtzis et al., 2018
Kansei engineering	Develops PSS features using an in-depth study of customer feelings/needs and providers' experience	Service modelling	Carreira et al., 2013
QFD	Uses matrices to translate customer demands to quality charts for designers	Service modelling, service engineering	Peruzzini et al., 2015; Shimomura et al., 2009
TRIZ	Follows 40 inventive principles to define and solve problems	Service engineering	Kim & Yoon, 2012; Lee et al., 2019; Regazzoni et al., 2013

Once the customer needs and demands have been prioritised, using the tools listed in Table 6, a new set of design tools that support the design process are brought into play, including a service CAD, a lifecycle simulator, an interaction map, a service blueprint, a PSS board and PSS characterisation.

Service CAD enables the design of business models from a systemic perspective (Vasantha et al., 2012), providing computerised tools that assist engineers and designers in designing PSSs (Akasaka et al., 2012). The lifecycle simulator is an approach that supports the design of PSS through simulation of the lifecycle (Garetti et al., 2012). The service CAD and lifecycle simulator tools facilitate the generation and evaluation of design alternatives (Komoto & Tomiyama, 2008). The interaction map demonstrates the interactions and scenarios between actors and social groups to define the PSS blueprint (Morelli, 2006), using visual techniques to provide a clearer understanding of the situations and relationships (Morelli, 2009). The service blueprint is used to describe service activities and interactions among providers and customers visually, sequentially and dynamically to explain who does what, to whom, how often and under what conditions (Shimomura et al., 2009; Shostack, 1982). The PSS board visualises the PSS process using a matrix board that shows how the PSS provider and its partners aid customers' job execution processes (Lim et al., 2012). Lastly, the PSS characterisation approach (PSSCA) is a tool that enables the visualisation of interactions and dependencies between and among product elements, service elements and stakeholders (Yip et al., 2015). A summary of the features and applications of these design tools is shown in Table 7.

Table 7: The design tools that assist the design process

Design Tool	**Feature**	**Used in**	**Example**
Interaction map	Helps define a map of the actors, requirements and structure to provide the PSS blueprint	Visualisation	(Morelli, 2006; Morelli, 2009)
Lifecycle simulator	A computer-aided technique to simulate the lifecycle of the PSS	Lifecycle	(Fargnoli et al., 2012; Kawaguchi et al., 2019; Komoto & Tomiyama, 2008)
PSS board	A matrix board that shows a simple representation of the PSS components involved in solving the customer problem	Visualisation, lifecycle	(Kim et al., 2016; Lim et al., 2012)
PSSCA	A five-step approach to systematically characterise PSS specifications according to four parameters	Visualisation	(Yip et al., 2015)
Service blueprint	Develops a picture or map of the PSS that helps every actor understand and act upon it	Service engineering	(Geum & Park, 2011; Shimomura et al., 2009)
Service CAD	A computer-aided design system that enables the designing of PSS	Service engineering, modelling	(Akasaka et al., 2012; Komoto & Tomiyama, 2008)

While the tools discussed above consider a comprehensive range of actors in the design process that goes beyond the human, only the PSSCA is built upon the integrated theoretical basis of ANT and SDL (Yip et al., 2015; Yip et al., 2019).

2.3 Lifecycle

Lifecycle management is a business management approach that can be implemented by organisations to improve their performance (Power, 2009). Initially, it was used to target, analyse and manage product-related information and activities (Remmen et al., 2007). Later, this concept was extended and applied by various industries to improve the sustainability performance of both their products and services throughout their value chains (Sonnemann et al., 2015). This section discusses lifecycle management in PSS.

Early works on PSS shows that lifecycle management was separated into product lifecycle management (PLM) and service lifecycle management (SLM). Various industries used PLM to manage products in three lifecycle phases, namely, the beginning of life (BOL), middle of life (MOL) and end of life (EOL) (Terzi et al., 2010). SLM was applied similarly to manage the life of services (Freitag, 2014). Combining these two models, researchers developed PSS lifecycle management (Wiesner et al., 2015). A review of the PSS design literature and analysis of the various articles revealed several design methods, tools and tasks that can be implemented in the BOL, MOL or EOL of the PSS lifecycle (Cavalieri & Pezzotta, 2012; Tran & Park, 2014). In other words, as shown by Cavalieri and Pezzotta (2012), most design methods can be projected (or mapped) to one or more of the lifecycle stages. Thus, the lifecycle design method seems to be the most holistic PSS design method. Figure 10 shows the lifecycle management proposed by Wiesner et al. (2015).

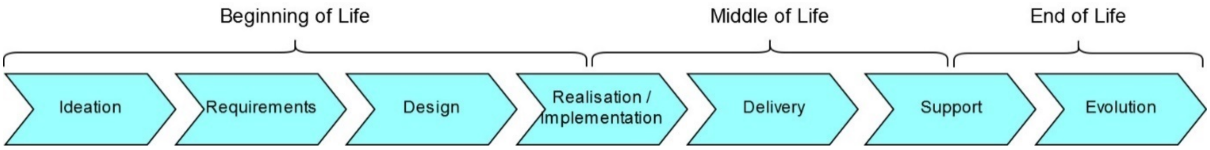

Figure 10: PSS Lifecycle Management (Wiesner et al., 2015)

2.3.1 Beginning of Life (BOL)

The BOL stage of lifecycle management comprises the ideation of the problem, the defining of the requirements for the PSS solution and then designing that solution. The Ideation step includes generating ideas, an assessment of such factors as value, risk and design and a value proposition. The Requirements step helps elicit and identify the design requirements while the Design step involves service design, product design and integration that may involve co-design. Between the BOL and MOL is a Realisation step that involves prototyping and implementing the PSS solution.

User-centred design is a useful technique here as it considers the customer's level of acceptance based on reducing uncertainty, reinforcing benefits and freedom of choice (Rexfelt & Hiort af Ornäs, 2009). The customer will accept a PSS solution that they find beneficial, easy to grasp with confidence and that gives them the flexibility of choice without any pressure to choose or act a certain way. Such aspects as cultural values (Santamaria et al., 2016), contradictions (Kim & Yoon, 2012), engineering characteristics (Geng et al., 2010) and functionalities (Peruzzini et al., 2014) are also studied in this step. Some of the techniques used are a requirements data model (Berkovich et al., 2014), a requirements-driven PSS (RdPSS) (Zhu et al., 2015), customer rating systems (Sutanto et al., 2015) and conflict resolution strategies (Song & Sakao, 2016).

Some steps involved in developing the customer solution are idea generation (Nemoto et al., 2015), co-development of PSS (Evans et al., 2007), co-creation/co-design of new services (Durugbo, 2014), service design (Alonso-Rasgado et al., 2004; Aurich et al., 2006; Stacey &

Tether, 2015), product design (Sundin et al., 2009), integration of products and services (Pigosso & McAloone, 2016; Trevisan & Brissaud, 2016; Zhang & Chu, 2010), module partition (Li et al., 2012), simulation (Garetti et al., 2012) and previous expertise (Baxter et al., 2009; Shimomura et al., 2015).

2.3.2 Middle of Life (MOL)

The MOL stage of lifecycle management consists of the implementation, delivery and support of the PSS by creating a service experience. The Delivery step involves the co-creation of value by delivering and using the PSS solution. The Support step involves physical support, such as maintenance, and remote support such as troubleshooting and diagnosis.

When customers use a PSS, they cognitively evaluate the service experience and their experience is a crucial part of value co-creation. In other words, customers' perceptions, emotions and behaviours need to be understood and this understanding is best gained through reaction-seeking activities such as collecting feedback, observing performance and interacting with customers. This, in turn, may trigger further innovation and therefore add value to the PSS (Schweitzer & Aurich, 2010).

2.3.3 End of Life (EOL)

The end of life (EOL) stage sees support for the PSS solution maintained, not least because the PSS may continue to evolve. This support can lead to a greater understanding of performance and relationships and hence to improvements and reconfigurations. The support is maintained because the EOL stage takes in the PSS development feedback and experience to iterate the design process and co-create new PSS solutions to new problems as they arise. The development and BOL of new PSS solutions thus depends on the EOL status of the current

PSS. Based on the evolution of the technology and the requirements of the customers, the EOL involves the reuse, remanufacture, recycle and retirement of the PSS solution.

2.3.4 PSS Design Methods and PSS Lifecycle

Among the PSS design articles reviewed, only those that discussed the service modelling method and service CAD tools addressed each of the three lifecycle stages. These papers discuss design in the BOL (Akasaka et al., 2012; Bertoni et al., 2016; Nemoto et al., 2015) and MOL stages (Hara et al., 2009; Pezzotta et al., 2016) of the PSS and sometimes even in the EOL stage (Komoto & Tomiyama, 2008; Sundin et al., 2009). However, each of these papers addresses only one or two stages of the lifecycle; not one provides a holistic design solution.

Most of the remaining articles reviewed for PSS design focus on the BOL stage while very few discuss MOL. Visualisation methods were found to be useful for both the BOL and MOL stages of the PSS lifecycle. QFD is useful in the BOL stage of the PSS design as it statistically and mathematically evaluates the variables related to the requirements. TRIZ helps resolve contradictions and conflicts in the design goals (Kim & Yoon, 2012; Song & Sakao, 2016) while modularisation helps segment the product and service components to enable higher customisation and flexibility (Li et al., 2012; P. Wang et al., 2011). Both TRIZ and modularisation are useful in the BOL stage of the PSS.

Table 8 shows the various design methods and tools used in PSS design categorised in terms of BOL, MOL and EOL. The table clearly shows that there is no design method available yet that holistically provides a solution to PSS design for all lifecycle stages.

Table 8: Mapping PSS design methods to the PSS lifecycle

	BOL Examples	MOL Examples	EOL Examples
AHP	✓ S. Kim et al., 2015	✗	✗
Kansei Engineering	✓ Carreira et al., 2013	✗	✗
MePSS	✓ Van Halen et al., 2005	✗	✗
Modularisation	✓ P. P. Wang et al., 2011	✓ Shikata et al., 2013	✗
QFD	✓ Geng et al., 2010 ✓ Sakao & Lindahl, 2012 ✓ Peruzzini et al., 2015	✗	✗
Service Blueprint	✓ Geum & Park, 2011	✗	✗
Service CAD	✓ Nemoto et al., 2015	✓ Hara et al., 2009 ✓ Pezzotta et al., 2015	✓ Komoto & Tomiyama, 2008
Service Engineering	✓ Pezzotta et al., 2016 ✓ Bertoni et al., 2016	✓ Pezzotta et al., 2015	✗
Service Modelling	✓ Nemoto et al., 2015 ✓ Rexfelt & Hiort af Ornäs, 2009	✓ Hussain et al., 2012	✓ Sundin et al., 2009
TRIZ	✓ Song & Sakao, 2016 ✓ Kim & Yoon, 2012	✗	✗
Visualisation	✓ Yip et al., 2015 ✓ Wallin et al., 2015	✓ Morelli, 2009 ✓ Joore & Brezet, 2015	✗

2.4 Value Co-creation

2.4.1 Value

The notion of '*value*' has different meanings and perspectives. Various authors have tried to define it over the years (Holbrook, 1999; Khalifa, 2004; Sánchez-Fernández & Iniesta-Bonillo, 2007). Value can be the trade-off between benefits and sacrifices in the interaction between a customer and a product or service (Payne & Holt, 2001). Value can also be the utility of a product or service (Tellis & Gaeth, 1990). Overall, value is a criterion that is employed by an individual to make a preference judgement (Sánchez-Fernández & Iniesta-Bonillo, 2007).

Different stakeholders perceive value in various ways. The provider perceives value as economic gains (profit) and the success of the business (Tukker, 2004). On the other hand, a customer perceives value as an affordable and reliable solution that improves her/his well-being (Dodds, 1999; Frow et al., 2014; Mario Rese et al., 2009). On a larger scale, sustainable consumption and production are valuable for the environment, society and government (Durugbo, 2014).

A customer's adoption intention (or decision to buy a service) is the result of customer benefits of enjoyment and usefulness of the service on one side and customer sacrifice of technicality and fees to redeem the service on the other (Kim et al., 2007). The customer initially anticipates this result through the perceived value of the offering. Perceived value is classified as monetary value, functional value, emotional value and social value (Grace & Iacono, 2015; Sweeney & Soutar, 2001). As shown by Petrick (2002), the value perceived by customers depends on the experience of the service. Appropriately, monetary and non-monetary prices are determined based on this service. These prices, combined with the customer's emotional response and the provider's reputation, form the cumulative value that determines the repurchase intentions (Petrick, 2002).

Among the four types of value, only monetary value can be measured using quantitative methods; the social, functional and emotional values generally require qualitative measures. Similar to customers, the provider conducts a business only when it perceives value in offering a product or service. In the PSS context, the provider gives importance to environmental value (sustainability), customer relations, information value, infrastructure value and time to market (besides monetary value) (Matschewsky et al., 2015). Thus, in this research, it is vital to understand what the customer and the provider perceive the value to be and pose the research question accordingly.

The ability to generate customer value is an essential factor in achieving a competitive advantage for providers (Woodruff, 1997; Zhang & Chen, 2008). To acquire this ability, modern businesses are trending to customer-centric value co-creation, that is, creating the need for a service-oriented design using the participatory mindset of providers and customers. The customer requesting the solution may participate in the development of ideas, knowledge and design by sharing his or her experience in a joint sphere (Grönroos & Voima, 2013; Sanders & Stappers, 2008). The customer experience is defined by sensory, emotional, cognitive, pragmatic, lifestyle and relational components (Gentile et al., 2007). Thus, it is understood that customer involvement or value co-creation is a vital part of modern businesses.

The customers, providers and other stakeholders of the value co-creation form a network of actors known as the *value-network*. A value-network is described as a structure of actors involved in the system of co-production and exchange of services to co-create value (Hammervoll et al., 2014; Lusch et al., 2010). This network is comparable to the actor network defined in ANT. In PSS and CPPSS, it is vital to know how the actors in the value-network perceive the benefits of the value co-creation process. Recognising these benefits will help the CPPSS actors understand why practising value co-creation could help design CPPSS solutions. In addition to the above, knowing the roles of the customers, providers and other actors in the value co-creation process of CPPSS would enable the development of the design method.

2.4.2 Co-creation

Co-creation is the activity of joint creation of an entity by the customer, the provider and other stakeholders (Prahalad & Ramaswamy, 2004a, 2004b). Co-creation can also be defined as a set of activities that fulfil customer needs based on the joint agreement and constraints of the customer, provider, supplier and other actors (Durugbo & Pawar, 2014). In co-creation, firms engage their customer-specific perspectives throughout the solution design and implementation rather than imposing a generalised solution on them. The co-creation process has been shown to reduce errors, engender happier employees, produce more satisfied customers and lower costs, all of which result in higher production, greater competitive advantage, better product/service quality and enhanced revenue (Kennedy & Guzmán, 2016; Lee & Kim, 2018; Ranjan & Read, 2016; Verleye, 2013).

2.4.3 Value Co-creation

The joint creation of value is termed as *value co-creation*. Value co-creation is dynamic, as value is generated through the configuration of resources, including people, organisations, languages, laws, technologies and other service systems (Spohrer et al., 2008). Value co-creation activity is essential in PSS design, as it will help satisfy stakeholder needs more effectively (Müller & Stark, 2010). The need for value co-creation is also supported by researchers who argue that value co-creation develops customised and personalised solution (Zine et al., 2014). Among other benefits, value co-creation also helps ensure sustainability (Li & Found, 2017), achieve competitive advantage (Barquet et al., 2013) and enables testing of prototypes (Tran & Park, 2015).

The value co-creation phenomenon is predominantly studied or analysed by service science, service logic and service-dominant logic approaches (Saarijärvi et al., 2013). Insights from Saarijärvi et al. (2013) suggest that:

- ‘*value*’ clarifies what kind of benefit and for whom the benefit is generated
- ‘*co-*’ clarifies the stakeholders involved in the process, and
- ‘*creation*’ clarifies the mechanism used for achieving goals.

The concept of value co-creation has evolved from its original focus on companies and customers to take into account the role of multiple actors that always include the beneficiary (Vargo & Lusch, 2004, 2008b, 2016). As a result, value co-creation is a multi-stakeholder activity; it requires trust, inclusiveness and openness among them all (Pera et al., 2016).

This thesis generalises these stakeholders as actors. These actors co-create value when they have a shared purpose, infrastructure design and have identified the gatekeeper (or decision-maker) for their numerous prepositions (Pera et al., 2016). The value co-creation concept shifts the focus from the provider being the centre of value creation (Xu et al., 2014) and centres it on the customer. Each actor in the system identifies their own value proposition which enables them to connect with suitable partners in the PSS. This process is demonstrated by Numata et al. (2015) by using six steps to identify the providers, customers and users of an offering. The six steps are: (1) define the position of the target PSS in the environment, (2) identify target customer segments and users, (3) establish a relationship between provider and customer, (4) determine a service value-chain, (5) maintain constraints in a value-chain and (6) maintain the PSS network. Each of these steps has further sub-steps to achieve the goals. The actors in the PSS share the value, benefits and risk of the offering (Xu et al., 2014). As discussed by Chew (2016), the value is co-created when the provider's and customer's competencies, resources and experiences are combined to provide mutual benefits.

SDL is the value co-creation logic used by most researchers. This is highlighted by the fact that four (FP6, 7, 8 and 9) of the ten foundational premises of SDL focus on value co-creation (Vargo & Lusch, 2008b). According to SDL, service is the appropriate logic for marketing (Ballantyne & Varey, 2008). It argues that service is the process of resource integration and goods are an indirect form of delivering service (Kowalkowski, 2010). SDL differentiates the definition of service (singular) as a process as opposed to services (plural) being a unit of output in goods-dominant logic (Vargo & Lusch, 2010). Thus, service is an application of one actor's resources, such as knowledge and skills, for the benefit of another actor in exchange for another service. In service logic, monetary value is treated as an indirect service which helps assure future service.

Value co-creation conceptually consists of two dimensions; co-production and value-in-use (Ranjan & Read, 2016). These two aspects were studied in this research to investigate the value perceived by various actors, including the customer in the system. In addition, its concepts are often investigated together with PSS (Neely, 2008; Ng et al., 2012; Ng et al., 2010).

Co-production covers the activities carried out by actors within the network to design the value proposition (Vargo & Lusch, 2008b). The firm directly or indirectly works with the customers to co-create value during interactions and exchange. Co-production involves the creation of potential value-in-exchange, which itself is comprised of co-design, co-development, co-manufacture and co-delivery (Grönroos & Voima, 2013). The value-in-exchange is the utility that is exchanged by the actors involved at a given point of time. This exchange is followed by the usage of the product and services, which creates value-in-use. Knowledge (idea and creativity), equity (information access, transparency and power-sharing) and interaction (communication and dialogue) are the non-human actors of the co-production dimension (Ranjan & Read, 2016). It is important to note that dialogue in co-production involves interactions and engagement among actors who are treated equally (Prahalad and Ramaswamy 2004b). It is a vital part of value co-creation, which enables the exchange of ideas about the problem to find a common solution rather than a debate to find a winning actor.

Value-in-use is the value generated during the consumption and experience of the service offering, depending on the time, location and other variables that help customers assess the value of a proposition (Vargo & Lusch, 2004). Thus, value-in-use is the strength or extent of the customer's feeling about the solution. Value-in-use provides the customers' experiential appraisal of the PSS based on their individual motivation, skills, actions and preferences (Edvardsson et al., 2011). As a result, with usage, value accumulates over time (Grönroos & Voima 2013). The experience (empathy, benefits, value extraction), personalisation (uniqueness, customer orientation) and relationship (involvement, interdependence, collaboration, network) among the actors form the value-in-use dimension (Ranjan & Read, 2016).

In the model developed by Durugbo and Pawar (2014), the co-creation process consists of participation, technique, customer needs and agreement within organisational and interactional constraints. Customer participation behaviour is, in turn, dependent on the degree of the customer's information-seeking nature, information-sharing inclination, responsible actions, personal interaction, feedback, advocacy, helping and tolerance (Yi & Gong, 2013). The co-creation of value also requires trust between the actors in the system to make a strong relationship (Chew & Gottschalk, 2013).

2.5 Cyber-Physical Systems

The CPS concept is a more recent research development than the PSS. However, the Scopus search showed that CPS is a vast field of research and application. CPS has been used in areas like engineering, business, economics, finance, management, computer science, information systems, environmental science and social sciences. However, the broader applications of CPS research falls outside the scope of this thesis as the research question being addressed is limited to cyber-physical systems per se. In the next section, the definition and design of CPS are discussed according to the reviewed literature and research focus of this thesis.

2.5.1 How is CPS Defined?

The term "cyber-physical systems" was coined by Helen Gill of the National Science Foundation in 2006 (Gunes et al., 2014; Lee & Seshia, 2014). CPS is defined as "an integration of computation with physical processes whose behaviour is defined by both cyber and physical parts of the system" (Lee & Seshia, 2017, p. 1). In the manufacturing industry context, CPS is a technology for managing the interconnected systems of physical assets and computational capabilities (Lee et al., 2015). CPS actualises a ubiquitous system that adapts to the context by learning, reconfiguring and co-operating (Broy et al., 2012). It is similar to other terms used recently, such as the internet of things (IoT) (Gunes et al., 2014). Some researchers consider CPS as part of IoT (Hehenberger et al., 2016), while others hold the opposite view (Wang et al., 2015). CPS is a term more prevalent in the US, while IoT is used more in Europe (Horvath & Gerritsen, 2012). IoT is based on the concept that objects around us can be connected using unique addressing and work towards a common goal (Atzori et al., 2010). However, CPS has a broader meaning and covers sensors and actuators that are also deployed to control a desired environment.

The generic CPS meta-model shown in Figure 10 is based on the CPS structure explained by Lee (2015) and De et al., (2017). The components of the CPS meta-model are cyber system, physical system and the communication network.

2.5.2 How is CPS Designed?

The 22 CPS design-related papers identified in the literature search (section 2.1.2) were divided into implementation (I) and design (D) phases. The implementation phase consists of CPS architecture covering its processes or layers. The papers on the design phase discuss the processes from ideation to deployment. These papers are summarised in Table 9 and further details can be found in Appendix IV (Table 54).

In the implementation phase, the CPS is perceived as a system that uses real-time communication and computation among the value-chain participants with socialisation, personalisation, servitisation and mass collaboration to satisfy customer needs (Colombo et al., 2017; Jiang et al., 2016). The implementation phase uses a multilayered architecture to functionalise the CPS. A few authors have discussed the implementation of CPS without dividing it into any architecture layers (Wan et al., 2014). Another group of authors divided the CPS into two layers. The architecture platform discussed by Hu et al. (2013) consists of the mobile and cloud knowledge base layers while that of Wan et al. (2013) consists of the IoT and decision/control layers to manage the CPS. Other authors, such as Jin et al. (2014), Lai et al. (2011); Liu et al. (2017) and Wang et al. (2011), have proposed a three-layer architecture based on their requirements and understanding of CPS. These architectures consist of the physical environment, an interface and a virtual environment. The rest of the authors, Bagheri et al. (2015); Hu et al. (2016) and Lee et al.(2015), have proposed architectures with more than three layers or cores in implementing their CPS. By analysing all these papers, it is concluded that in line with the popular view, a CPS consists of three main layers in its architecture, cyber, physical and interface layers, and they define the implementation of the CPS, as shown in Figure 11. Apart from the internet and intranet, the other communication networks are wireless sensor network (WSN), body-area network (BAN) and wide-area network (WAN) etc.

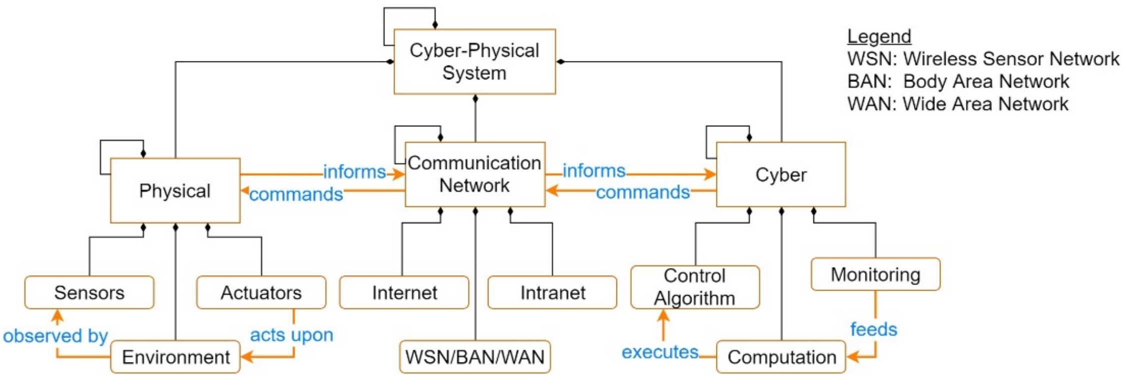

Figure 11: CPS Meta-model adapted from Lee (2015) and De et al. (2017)

The CPS implementation literature emphasises that the purpose of CPS is to deliver intelligence and autonomy in the devices that directly or indirectly serve customers (Sanislav & Miclea, 2012). For the purpose of serving customers, a service tier (La & Kim, 2010) or service layer (Wang et al., 2012) was introduced into CPSs using service-oriented architecture (SOA). SOA defines service as a self-contained, reusable software component that is provided by the provider and consumed by the customer (Zhang et al., 2007). Consumption occurs when the usage of the service component creates value for the customer and the provider captures value in return. In addition to the software components, a CPS consists of physical devices, which are abstracted as services using substitution and application rebuilding techniques (Yu et al., 2012). Thus, the cyber and physical components are represented as interoperable services that realise business functionalities (Wang et al., 2012). Service requirements are used to describe, manage and compose the physical devices that serve the customers (Yu et al., 2012). The customer requests a service through the network and the CPS then uses the data (or knowledge base) to take necessary actions (Hu et al., 2013; Jin et al., 2014; Zhang et al., 2007).

The design and implementation of a CPS depend on the context (Wan et al., 2014), application domain (Wang et al., 2012) and available information (Hehenberger et al., 2016). The manufacturer designs a CPS platform consisting of reusable components and service modules that are variably integrated to form customer-specific solutions by combining the resources of the collaborating providers (Broy et al., 2012; Eyisi et al., 2013; Sztipanovits et al., 2012). The combination depends on the factors including why (motivation), who (customer/user), where (location/environment), how (solution process), what (information/knowledge) and when (service delivery time) (Shafighi & Shirazi, 2017). The constraints depend on the cost and guarantees that define the contract/pricing among the actors in the form of a business model (Liu et al., 2016; Sangiovanni-Vincentelli et al., 2012).

The design phase of a CPS starts when the need for implementation is discovered. Customer interaction and adaptation to co-create value influence the CPS design (Broy et al., 2012; C. Zheng et al., 2016). As a result, and in line with SDL, this phase changes the role of customers from buyers to co-designers (Tseng & Hu, 2014) or *prosumers* [9] (Jiang et al., 2016) by their collaboration in the lifecycle, development, production and usage of the CPS (Jiang et al., 2016). Customers either interact with the provider regarding their requirements or directly design the solution using the provider's tools (Tseng & Hu, 2014). The process also addresses the variability of stakeholders and their conflicting goals (Penzenstadler & Eckhardt, 2012).

Several authors have described different steps that can be taken to understand customer demands, compute/communicate the system requirements, model the solution, integrate the components and deploy the solution (Banerjee et al., 2012; Eyisi et al., 2013; Hehenberger et al., 2016; Kumar et al., 2015; Sztipanovits et al., 2012; Zeng et al., 2016). Table 9 lists the reviewed literature in terms of the design and implementation phases. As can be seen, most of the CPS applications have been in the manufacturing industries that use smart technologies. Most of the papers focus mainly on CPS implementation, which may suggest the drive for practice-based research in the CPS field. These characteristics of CPS research were taken as guidelines in this research.

[9] a customer who helps a company design and produce its products. The word is formed from the words "producer" and "consumer" – Cambridge Dictionary

Table 9: Selected articles on CPS design

Phase	Article	Application
Implementation	Dillon et al., 2011	Web of things
	Lai et al., 2011	Digital home
	J. Wang et al., 2011	Healthcare
	Cao et al., 2013	The high-voltage air-conditioning system
	Hu et al., 2013	Crowdsensing
	Sampigethaya & Poovendran, 2013	Aviation
	Wan et al., 2013	Unmanned vehicles platform
	Jin et al., 2014	Smart city
	Wan et al., 2014	Park vehicles
	Bagheri et al., 2015	Industry 4.0
	Lee et al., 2015	Industry 4.0
	Xiong et al., 2015	Social systems (Transport)
	Hu et al., 2016	Healthcare
	Leitão et al., 2016	Manufacturing industry
	Liu et al., 2017	Review
Design	Banerjee et al., 2012	Body-Area Network
	Sangiovanni-Vincentelli et al., 2012	Aeroplane braking
	Sztipanovits et al., 2012	Unmanned vehicles
	Eyisi et al., 2013	Control
	Kumar et al., 2015	Unmanned vehicles
	Hehenberger et al., 2016	Production systems
	Zeng et al., 2016	Cyber-physical social systems

2.6 Cyber-Physical Product-Service Systems

The concept of integrating a CPS into a PSS is a new trend observed among researchers and industries alike (Wiesner et al., 2017). This concept initially was called Smart PSS, as in papers by Valencia et al. (2014) and Lee and Kao (2014b), to acknowledge the addition of information technology in PSS. Authors such as Wiesner et al. (2017b), Mikusz (2014) and Rizvi and Chew (2018b) included the more powerful cyber-physical capabilities into PSS and called it cyber-physical PSS (CPPSS). In either case, the popularity of this concept is increasing with time, as shown in Figure 8. The number of publications increased from just one in 2014 to 26 in 2019, while the number of citations increased from two in 2015 to 199 in 2019. This research adopts the term CPPSS since it signifies the presence of cyber-physical components in the PSS, in contrast to other terms such as “smart PSS”, “smart production systems” and “smart service systems”.

CPPSS offers enhanced equipment engineering, optimised operations, remote control, remote diagnosis, information-driven service and optimised service (Herterich et al., 2015). It also forms the human-product collaborative network that brings about higher automation and data interchange in the industry (Scholze et al., 2016). This capability enables idea competition, customer immersion, product platforming, collaborative design and innovation networking in an open environment (Marilungo et al., 2016). Although the possibilities of CPPSS are immense, gaps exist in its definition and design method. The industry needs a design method that describes the procedures, starting with customer requirements and leading to solution delivery (Dutra & Silva, 2016; Zheng et al., 2016). The current literature shows that a CPPSS must be equipped with such characteristics as consumer empowerment, individualisation of services, community feeling, service involvement, product ownership, shared individual experience and continuous growth (Valencia et al., 2015).

The literature on CPPSS design emphasises value creation, feedback, customer integration, innovation, context sensitivity and requirement analysis. However, descriptions of the interaction and interconnection between the PSS and CPS components are either missing or only partially addressed. Some researchers have treated the CPS solely as a software component of CPPSS (Mikusz, 2014) while some treated the PSS only as a product-service bundle (Wiesner et al., 2017). Others have tried to use the CPS approach to form the PSS

(Marilungo et al., 2017), while still others have tried to design a PSS with CP features (Scholze et al., 2016). This inconsistency has led to a design method that can be considered confusing. This confusion, however, does provide motivation to develop an holistic and organised design method for CPPSS.

The list of papers selected for this literature review is provided in Table 10. Most of them focus on the manufacturing industry. Only two papers discuss the lifecycle aspect of CPPSSs. Among the remaining papers, the research focus for some was on BOL, with activities like requirements engineering and innovation, while for others, the focus was on MOL with activities like feedback and context sensitivity.

Table 10: Articles on CPPSS

	Article	**Perspective**	**Application**
1	Lee & Kao, 2014	Innovation	Manufacturing industry
2	Mehrsai et al., 2014	Lifecycle, cloud, flexibility.	
3	Mikusz, 2014	Business-oriented CPS	
4	Herterich et al., 2015	Service innovation	
5	Valencia et al., 2015	Value of smart PSS & design	General
6	Scholze, Correia, & Stokic, 2016	Context/scenario sensitivity	Automation equipment
7	Scholze, Correia, Stokic et al., 2016	Feedback for new PSS	Machine industry
8	Wiesner et al., 2016	Requirements engineering	Video Surveillance
9	Zheng et al., 2016	Intellectualisation of industrial PSS	Manufacturing industry
10	Kuhlenkötter, Wilkens, et al., 2017	Value creation Lifecycle	Creation of research centre named ZESS
11	Kuhlenkötter, Bender et al., 2017	Customer integration	
12	Marilungo et al., 2017	CPS design for PSS	Plastic extrusion pipes
13	Uhlmann et al., 2017	Value creation	Manufacturing industry
14	Wiesner et al., 2017	Requirements engineering	Whitegoods, plastic extrusion

2.6.1 How is CPPSS Defined?

The concept of CPPSS is a relatively new domain of research and development. Thus, a formal definition of CPPSS is not readily available and needs to be established. The literature shows that the other terms for CPPSS are CPS4PSS (Toro et al., 2015), smart products-service systems (Kuhlenkötter et al., 2017; Lee & Kao, 2014; Valencia et al., 2015), industrial software PSSs (Mikusz, 2014), intelligent PSSs (Scholze, Correia, Stokic, et al., 2016) and CPPSSs (Wiesner et al., 2017). The term CPPSS is in itself somewhat self-explanatory as it helps clarify the use of cyber-physical technologies in PSS. This thesis adopts the term CPPSS and establishes a definition based on reviewing the following critical descriptions found in CPPSS literature:

- A special kind of smart industrial PSS (IPSS) fuelled by digital parts (Herterich et al., 2015)
- Smart PSSs that integrates a smart product with an e-service to connect, collect and process information that jointly addresses the needs of consumers (Valencia et al., 2015)
- Cyber-physical features that allow the building of intelligent PSSs, in which the products and services are integrated and built with a higher level of intelligence by communicating and providing information within collaborative networks (Scholze, Correia, Stokic, et al., 2016)
- A cyber-physical system-based PSS (Wiesner et al., 2016)
- The PSS has prospered by the diffusion of pervasive information and communication technologies that enable data monitoring, storage and post-elaboration to deliver smart systems with enhanced capabilities (Marilungo et al., 2017)
- Smart PSSs […] are integrated socio-technical product-service systems based on networked smart product and smart service systems to provide new functionalities (Kuhlenkötter, Bender, et al., 2017)
- Offer added values to customers as well as to providers that cannot be estimated entirely in early lifecycle phases (Kuhlenkötter, Bender, et al., 2017)

- Smart PSS that results from the digitalisation of products and services as the digital connectivity between components allow their autonomous interaction and further development (Kuhlenkötter, Wilkens, et al., 2017)
- An integration of PSS and CPS concepts that lead to product-service bundles provided on a cyber-physical basis, creating CPPSSs (Wiesner et al., 2017).

Based on an analysis of the descriptions listed above, this thesis defines CPPSS as

"A product-service system equipped with cyber-physical capabilities to enable value co-creation using its technology and intelligence delivering higher efficiency, usability and appeal"

2.6.2 How is CPPSS Designed?

As the field of CPPSS is relatively very new, research into its design method is limited and varied. Some of the design approaches found in the literature are engineering methodologies, service-oriented architecture, gamification, software-techniques, dominant innovation and the CPS design approach. Although these design approaches were applied in various fields, most applications are found in the manufacturing industry.

In a summary of recent papers on CPPSS design, Zheng et al. (2020) categorise the papers according to five different design topics. On studying the papers selected in this SLR, it was found that most of them fit within these categories of design topics. In addition to these topics, this research also found the topic of dynamic requirements and solutions to be an essential aspect of CPPSS design. The combination of the papers discussed in Zheng et al. (2020) and the papers selected in this SLR are listed in Table 11 below.

The papers listed in Table 11 and discussed in this section demonstrate that the available papers in CPPSS design are generally based on the engineering and technical aspect of the design process. Although these aspects are vital for the advancement of CPPSS design, they do not address the management and operational aspect of the design process. The papers hardly discuss the roles and tasks of the designers, manager and users in the collaborative design and implementation process. Furthermore, the research into understanding the user experience, stakeholder collaboration and dynamic human/market environment is less than that into engineering and IT-enabled design topics, even though these aspects form a vital part of CPPSS design. This research, therefore, is an advancement in finding the suitable methods of collaboration between the customer and provider to co-create value in a dynamic environment.

Table 11: CPPSS design topics covered by available articles (partly adapted from Zheng et al. (2020))

	Research Topic	**Articles**	**Design Technique**
1	Data-driven engineering solution design	Wang et al., 2019	Requirement elicitation
		Zhang et al., 2020	Bio-inspired approach
		Wang et al., 2020	Convolutional neural networks
		Zhang et al., 2019	Smart resource hierarchy
		Shao et al., 2019	Vehicle route optimisation system
		C. Lee et al., 2019	Greedy first-best-search
		Liu & Ming, 2019	Co-implementation framework
		F. Chang et al., 2019	Service-oriented maintenance grouping
		Scholze, Correia, & Stokic, 2016	Industrial application scenarios
		M. Zheng et al., 2016	Intellectualisation process architecture
2	Dynamic requirements in smart PSS	Wiesner et al., 2019	Agile software methods
		Wiesner et al., 2016	Gamification
3	Knowledge acquisition, representation and reasoning in Smart PSS	Wang et al., 2019	Requirement elicitation
		Mikusz, 2014	Software-enabled hybrid solution
		Scholze, Correia, Stokic, et al., 2016	Collaborative networks
4	IT-enabled smart system design innovation	Liu et al., 2019	Service encapsulation architecture
		Pan et al., 2019	Intelligent interoperable logistics paradigm
		Wang et al., 2020	Convolutional neural networks
		Zhang et al., 2019	Smart resource hierarchy
		Shao et al., 2019	Vehicle route optimisation system
		C. Lee et al., 2019	Greedy first-best-search
		Li et al., 2020	System engineering
		Lee & Kao, 2014	Innovation-tool set
		Marilungo et al., 2017	CPS adoption in PSS
5		D. Chang et al., 2019	User-centric smartness

	User experience modelling and analysis in smart PSS	Scholze, Correia, Stokic, et al., 2016	Collaborative networks
		Wiesner et al., 2016	Gamification
6	Value co-creation and co-implementation process of smart PSS	Li et al., 2020	System engineering
		Liu et al., 2019	Manufacturing service encapsulation architecture
		Liu & Ming, 2019	Co-implementation framework
		Mikusz, 2014	Software-enabled hybrid solution

2.7 Summary of Literature Review

This literature review has provided a deeper understanding of the range of published evidence relevant to this thesis. It has not only revealed the gaps in the evidence but also provided the foundational knowledge required to carry out the research. This section summarises the scope of the literature review findings to set up the research plan (outlined in Section 2.8). The critical information identified in the reviewed literature is listed in Table 12.

Table 12: Summary of findings from the literature

	Topic	Findings
1	Systematic literature review	• Literature on PSS, CPS and CPPSS designs were studied with a focus on value co-creation and lifecycle • Value co-creation and PSS can provide innovative customer solutions • The combination of PSS and CPS to form CPPSS has a great potential
2	Product-service system	• 77 papers were selected for the literature review • PSS definitions are numerous and diverse • service-centric design and customer value co-creation are underexplored • the lifecycle approach could form the most holistic PSS design method
3	Value co-creation	• Each actor in any given network perceive value differently • Value is co-created by integration actor resources through collaboration • Service-dominant logic helps implement value co-creation
4	Cyber-physical system	• 22 papers were selected for the literature review • CPS designs consist of design and implementation phases
5	Cyber-physical product-service system	• 28 papers were selected for the literature review • It is a novel research topic • Its definitions and design methods are diverse • It requires a design method with dynamic capabilities

2.7.1 Summary of Systematic Literature Review (SLR)

The SLR was conducted to obtain a deeper understanding of PSSs, CPSs and CPPSSs. The strict selection criteria helped identify the articles most relevant to setting up this research. The SLR also showed that the concepts of PSS, value co-creation, CPS and CPPSS had gained popularity over time. It revealed design method definitions and the gaps in PSS and CPPSS research and literature. The literature also highlighted the emergence of PSS and CPS and the importance of combining them to form CPPSS.

2.7.2 Summary of Product-Service Systems

The literature review of PSS focused on 77 selected papers that provided information on the definitions, types, business models, design methods, co-creation and lifecycle of PSS. The research also brought out four significant gaps in PSS (Rizvi & Chew, 2018a). These gaps are:

1. PSS definitions are numerous, diverse and at times conflicting, with at least 36 different keywords used to define it
2. The concept of the service-centric design method is nascent
3. The process of customer value co-creation in PSS is underexplored
4. Among the available design methods, the lifecycle approach is the most holistic. Other design methods tend to fit any of the three stages (BOL, MOL, EOL) of the lifecycle method but not all of them.

2.7.3 Summary of Value Co-creation

The concept of value co-creation is a combination of the terms *value*, *co-* and *creation*. Value is the utility of a solution to its customer and providers. Value is perceived differently by different actors in the CPPSS network, and each perception affects each actor's interest in and the decision to participate in the design process. Value co-creation is achieved by jointly creating value through mutual collaboration and resource integration. Service-dominant logic is one of the concepts that helps in the understanding and implementation of value co-creation. SDL is thus one of the foundational theories behind the development of the design method in this thesis.

2.7.4 Summary of Cyber-Physical Systems

The search for articles specifically on CPS design yielded 22 papers, which were divided into the implementation phase and design phase. Those focused on the implementation phase showed the functioning of CPS in real-time and the implantation of the service layer to better serve the customers. In this phase, customers changed their roles from buyers to prosumers and co-designers. The papers that focused on the design phase revealed the various steps that help resolve the requirements, constraints and context issues to design the CPS. The knowledge obtained from these two phases helped shape the design method developed in this research.

2.7.5 Summary of Cyber-Physical Product-Service Systems

The literature review of CPPSS initially consisted of 14 papers which was then extended to a further 14 more recent papers. The literature showed that PSSs are evolving to incorporate cyber-physical capabilities to form a CPPSS (Rizvi & Chew, 2018b). Since CPPSS is a relatively new research topic, the definitions and proposed design methods were wide-ranging. However, the review showed a gap in the dynamic capabilities of the design methods and the management aspect of co-designing the CPPSS, where “dynamic capability” is defined as an actor’s ability to address changes in the environment by building, integrating or reconfiguring the offering (Teece et al., 1997).

2.8 Research Plan

2.8.1 Research Questions

The motivation and aim of this research were confirmed by identifying the available knowledge and gaps in the literature reviewed. As elaborated in the previous sections, the significant gap identified in the reviewed literature was the lack of a holistic design method that could implement value co-creation in its design process. Thus, this research strives to develop a reference model for a CPPSS design method by answering the following research question:

How could a service-oriented CPPSS be designed through value co-creation to make it adaptable to customers' dynamic needs?

The value perception of CPPSS must be understood for it to address this research question. The design method involved in creating the CPPSS must be developed, and this design method must be justified. Based on these requirements, the following sub-questions are posed in this thesis.

RQ1: What are the perceived values of a CPPSS?

RQ2: How could value be co-created in the CPPSS environment?

2.8.2 Research Execution

The following tasks were executed to tackle the above research questions and they led to the development of a holistic design method for CPPSS:

1. Propose new integrated PSS and CPPSS definitions accentuating the customer value co-creation requirement.

2. Build the models of PSS and CPPSS according to this definition explicating the service-centred activities performed by them.
3. Develop a CPPSSDM capable of adapting to evolving customer needs, incorporating lifecycle and customer value co-creation.
4. Evaluate and improve the CPPSSDM using stakeholders' insights on how value could be dynamically co-created.

2.8.3 Unit of Analysis

The unit of analysis chosen for this research was *the value co-creation processes and activities* that contribute to CPPSS design. The unit of observation for this research was the interaction between the customer, the provider and other actors in the value co-creation process that would enable the adaptations that catered for a customer's changing needs. The interaction involves the dialogue (between actors to find a common solution), access (to required information and tools), identification of the risk-benefits (of the collaboration) and transparency (of information) (Prahalad & Ramaswamy, 2004b). The interaction could then determine the satisfaction, involvement and the intentions of the actors (Lai & Chen, 2011).

2.9 Conclusion of Chapter 2

The literature review revealed that very few PSS design methods adopt a lifecycle approach that consider value co-creation in meeting actors' needs and dynamic environmental concerns. However, lifecycle approaches are the most holistic PSS design methods, as other design methods can be mapped to one, two or all of its stages (i.e., BOL, MOL and EOL). Therefore, the research aim of this thesis is to develop a CPPSSDM reference model based on the lifecycle and value co-creation concepts.

CPSs are an intelligent combination of physical objects such as sensors, embedded systems and actuators with cyberspace, including the internet, data processing, software and networking (Shi et al., 2011). CPPSSs combine the business offering of PSS with the smart technology of CPS. CPPSS being a new concept, its discussion in various pieces of literature and sources are limited to a few lines of description with no further details about its inception, design or implementation (Mikusz, 2014; Wiesner et al., 2015; Wiesner et al., 2016). The next chapter, Chapter 3, discusses the research methodology.

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Chapter 3 – Research Methodology

3.0 Introduction

As the purpose of this research was to develop a holistic design method reference model for CPPSS, an SLR was conducted to explore the knowledge gaps and research trends in PSSDMs and CPPSSDMs. The SLR was chosen because much research has shown that SLR ensures reduced bias and enhanced data analysis (Reim et al., 2015). The outcomes of the SLR set the scene for the research, and the research questions were posed accordingly. This chapter continues the journey by clarifying the various research methods used in this thesis to address the research questions raised in Chapter 2. It also is intended to help the reader understand the procedures employed in this research towards achieving its goals.

This chapter is divided into seven sections, as illustrated in Figure 12. The primary research method implemented in this research is introduced in Section 3.1. This research method consists of six steps, which are elaborated on in Sections 3.2 to 3.6. Section 3.2 discusses Step 1, where the problem was identified through the SLR. The objectives of the solution, Step 2, are laid out in Section 3.3. Section 3.4 explains Steps 3 and 4, which form the heart of this chapter. This section describes the research methods used to collect the data, the data organisation technique and the analysis strategy used to answer the research questions and develop the CPPSS design method. Step 5 is the evaluation and further refinement of the CPPSS design method, which is discussed in Section 3.5. The last step, Step 6, is described in Section 3.6, which is followed by the conclusion in Section 3.7.

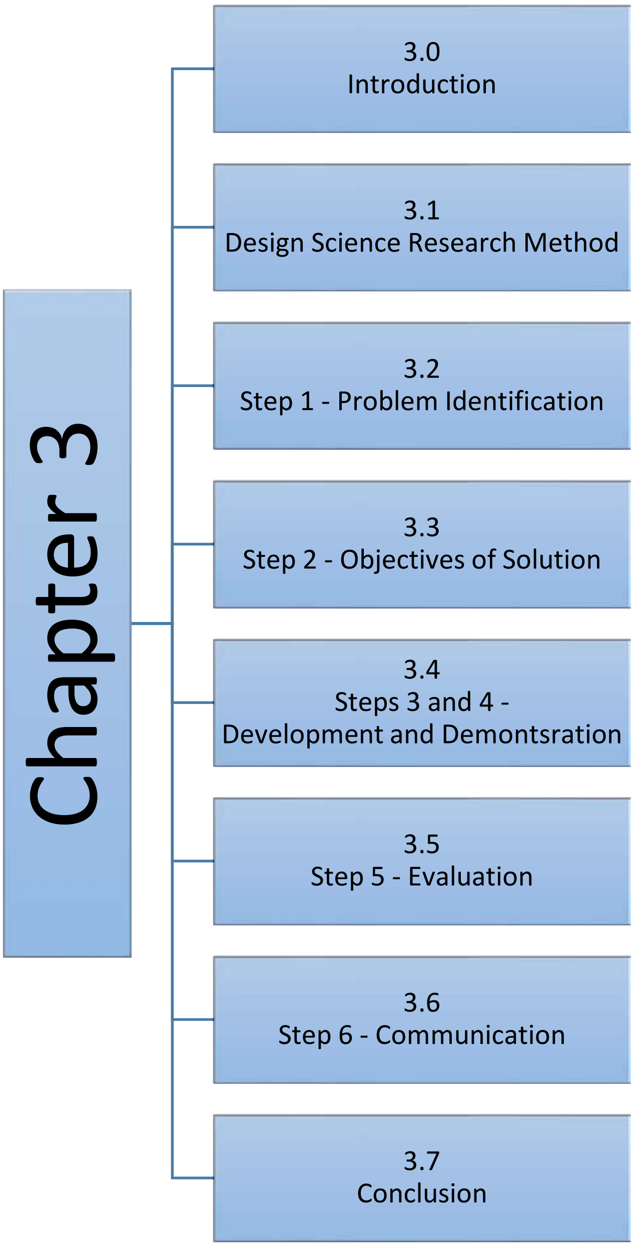

Figure 12: Structure of Chapter 3

3.0.1 Philosophical Positioning

This thesis implemented the six steps of the DSRM, illustrated in Figure 13, to conduct the research. The reasoning for implementing DSRM is explained throughout this chapter. While the DSRM advocates the use of either a quantitative or qualitative method to address a problem (Peffers et al., 2007), this research used a combination of the two, using case study and survey research methods. Most of the data was qualitative with some quantitative data that enhanced the findings.

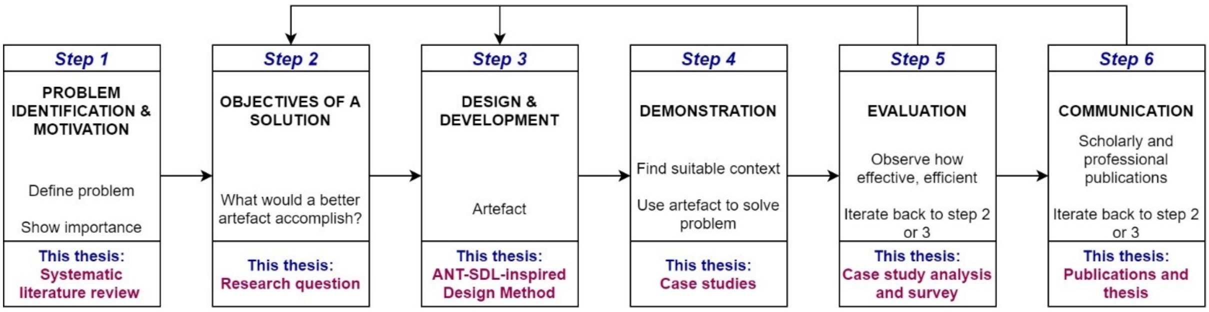

Figure 13: The six steps of the design science research method (adapted from Peffers et al., 2006; Peffers et al., 2007)

The philosophical positioning design science research methodology is different from the positivist and interpretivist approaches (Vaishnavi, 2007; Charinsarn, 2009). Accordingly, this thesis is mainly ontologically positioned to develop a design artefact that is socio-technically enabled with a dynamic reality. Multiple views from literature (chapter 4) and practice (Chapter 5 and 6) are used to develop the reference model. The epistemology was developed by iteratively constructing insights and interpretations from the data generated from the defined context of the research. Thus, in addition to the design science positioning, has also employed an interpretivist or constructivist approach from the case studies and qualitative methods to develop meaning and refine the artefact (Kuechler & Vaishnavi, 2008). Appropriately, the service-dominant logic (Section 4.1.1) and actor-network theory (Section 4.1.2) were utilized to develop the conceptual reference model while case study (Chapter 5) was used to refine the same.

3.1 Design Science Research Method (DSRM)

The DSRM provides a framework of procedures to define a problem, solve the problem and assess the solution. DSRM helps to create artefacts in the form of construct, model, method and instantiation (Hevner & Chatterjee, 2010; Hevner et al., 2004; Peffers et al., 2006). This research aimed to develop a CPPSSDM reference model that delivers beneficial value, which is aligned to the primary goal of DSRM, namely, to create things that will serve human purposes (March & Smith, 1995).

The DSRM process model described by Peffers et al. (2006; 2007) is shown in Figure 14. DSRM includes six activities that were adopted in this research to develop the CPPSSDM. The six steps of DSRM in relation to this thesis is discussed in the following sections.

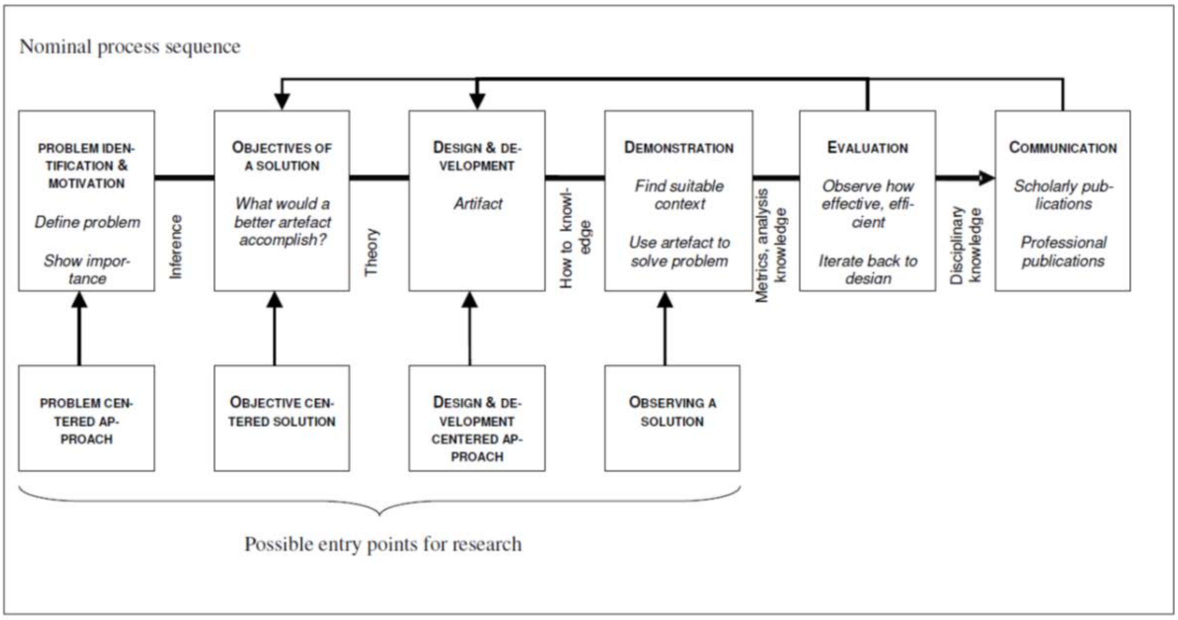

Figure 14: Design science research method (obtained from Peffers et al., 2007)

3.2 Step 1 – Problem Identification

The first step in this research method was problem identification and motivation to find a solution. As the world is rapidly progressing towards a smarter society, the demand for smart systems in all walks of life is ever increasing. Combining PSS and CPS to form a smart (or cyber-physical) PSS has the potential to be an innovative solution in this path. So, a holistic smart (or cyber-physical) PSS design method has become eminent. Due to these systems' connected and networked nature, the design method needs to implement value co-creation while developing the solution. So, developing such a design method was identified as the problem of this research. Further details about the importance and motivation of this research were discussed in Chapter 1.

To explore further into the motivation, the literature in this field was reviewed using the SLR. The literature study showed that the field of PSS, CPS and CPPSS are innovative solutions that can address the problems of the evolving smart societies. So, there is a demand for holistic PSS and CPPSS design methods and multi-stakeholder co-creative design processes. The design method also needs to cater to the changing needs of the customers. Congruence with the lifecycle approach could make the design method holistic. Further details of the reviewed topics were provided in Sections 2.1 to 2.7 of Chapter 2.

3.3 Step 2 – Objectives of the Solution

The second step was to determine the objectives of the solution that could address the problems identified in Step 1. The direction from research motivation and the insights from the literature review were combined to develop a holistic design method reference model for CPPSS as the objective of this thesis. This design method would support value co-creation and enable a dynamic response to cater to dynamic/changing customer needs. The congruence with the lifecycle approach would make the design method holistic. According to these objectives, the concepts of ANT and SDL would be used to develop the conceptual design method. ANT provides the principles of actor dynamics to make the design method adaptable to evolving customer needs. SDL provides the principles of value co-creation that enables service-centric solution design by collaboration between multiple actors. The conceptual design method would then be refined and demonstrated using the qualitative data derived from the case studies. The refined practice- and theory-based design method would then be evaluated by CPPSS practitioner survey. Further details of the objectives were discussed in Section 2.8.

3.4 Steps 3 and 4 – Development and Demonstration

The third step of a DSRM is the design and development of the artefact. In the case of this thesis, the artefact to be developed was the CPPSSDM reference model. As discussed earlier, the term *method* is used in this research to describe the set of steps that are used to perform a task based on the underlying constructs/entities and their models/relationships (Hevner et al., 2004; March & Smith, 1995; Offermann et al., 2010; Peffers et al., 2012). The Development step involved understanding various theories related to PSS and CPPSS to develop the design method best suited to them. Here, the design method is defined as a description of the procedure(s) for artefact construction (Walls et al., 1992). The Development step is explained in detail in Chapter 4.

As described by Chew (2016), the sense-making of an artefact is vital for proving its utility for businesses. In this research, this task was achieved through the fourth and fifth steps of the DSRM. A Demonstration step can be carried out through experimentation, simulation, case study, proof and other appropriate activities (Peffers et al., 2006). As suggested by the examples given by Peffers et al. (2006; 2007), case studies are one of the best methods to demonstrate the use of an artefact to solve a problem and the majority (~64%) of research on PSS design has used the case study research method (See Appendix III– Table 53). Following this trend, this thesis demonstrates the developed design method reference model (see Chapter 4) using case studies (see Chapter 5). The following sub-sections explain the case studies that were implemented.

3.4.1 Case Study: What and Why?

A case study is suitable for answering the '*how*' and '*why*' questions (such as those proposed in this thesis) (Yin, 2014). A case study is defined as an empirical inquiry that investigates a contemporary phenomenon in-depth within its real-world context, especially when the boundaries between the phenomenon and the context are not evident (Yin, 2014, p. 16). Case studies are also selected when the behaviour of the subjects cannot be manipulated but can only be observed or captured in interviews. Appropriately for this research, a case study enables researchers to obtain opinions from people involved in the design and development of solutions. Seeking the views concurrently of practitioners and end-users was therefore a suitable approach to demonstrating and evaluating the artefact in this thesis, namely the CPPSSDM reference model (Chew, 2016; Fernández & Wieringa, 2013). The case study approach uses one or more cases for investigation within a bounded system (Creswell et al., 2007). Using one or more cases helps to create constructs, propositions and relationships from the empirical evidence (Eisenhardt & Graebner, 2007).

3.4.2 Case Selection Strategy

A case selection strategy is essential to ensure the most effective evaluation or test of the proposed artefact (Mason, 2017). As suggested by Yin (2015), the goal of selecting a case is to yield the most relevant and plentiful study-specific data. The process of selection is called sampling, of which there are various types, depending on the research requirements. Purposive, or criterion-based, sampling was one such process implemented in this thesis as it allowed selection of cases that met predetermined criteria set by the research (Patton, 2014; Yin, 2015, 2017). Purposive sampling was preferred over other kinds of sampling, like convenience, snowball and random, because of its ability to provide data from the required field (Denzin & Lincoln, 2011; Yin, 2015). As can be noticed throughout this thesis, especially in Sections 1.2 and 2.1.2, this study is focused on a specific research question and research gap. A convenience, snowball or random sampling is unsuitable for finding the appropriate B2B organisation involved in designing and implementing CPPSS solutions. So purposive sample was found to be the most well-suited method for case selection.

In addition to purposive sampling, the other technique used in this thesis to select cases was theoretical sampling, which involves selecting cases based on their potential to expand knowledge, present conflicting ideas and eliminate alternatives (Eisenhardt & Graebner, 2007). So, the case organisations were chosen in such that each case had some differences that helped expand the knowledge while they also had some similarities that helped reinforce the understanding. The similarities and differences can be observed further in the discussions in Sections 5.1, 5.6 and 6.1.

The case study organisations were carefully selected to include a variety of applications. The goal of the case study selection was to ensure that the cases were adequately identified before data collection began (Yin, 2014). The purposive and theoretical sampling methods enabled the researcher to select the case study organisations to leverage participants' knowledge, experience and understanding of CPPSS design and implementation. The selection criteria were developed using the insights generated from the SLR and the consultation with academic and industry experts. The local geographical position of the case organisations was also considered to ensure that the local knowledge and needs were given importance. The cases were thus chosen from a large pool of potential cases by using the following selection criteria:

- The case (or organisation) had to be involved in implementing CPPSS either as a customer, provider or both. This criterion ensured that the data being collected is relevant to one of the core motivations of this research (i.e., CPPSS).
- The case had to be involved in interacting with other stakeholders/actors to change their value prepositions based on context of the customers' needs. This criterion ensured that continuous improvements are being implemented to cater to dynamic customer needs.

- The case study participants had to be ready to share knowledge, experience and opinion on the design and development of their CPPSS. This criterion ensured that the data vital to this research is easily and readily available for analysis.
- The case had to be operating its business in local markets in collaboration with local and international actors. This condition would enable easy access to the case without any major requirements for travel and accommodation. It would also facilitate understanding of the practice of value co-creation in the local context.
- The case had to be implementing a CPPSS in a business-to-business relationship to solve customer problems. This criterion ensured that the B2B value co-creation is being studied with the case organisation working either as a customer, provider, or other businesses.

Case study research provides two alternatives in practice, namely, single case and multiple case analysis. Although single case studies can provide a rich description of a hypothesis, multiple case studies provide a more substantial base for explanation and evaluation (Eisenhardt & Graebner, 2007). Multiple case studies allow a better delineation of concepts and relationships and provide higher analytic power as compared to a single case study (Yin, 2009). The research question in this thesis aimed to explore how CPPSSDM practised in industry aligned with the proposed reference model. This research aimed to evaluate the developed design method reference model across multiple cases. This method of case study selection helped strengthen the findings to support the proposed design method reference model.

Yin (2009) explains that two types of replications are possible from the case study analysis. The first is a literal replication, where cases are selected to predict similar results, while the second is theoretical replication, where cases are selected to predict contrasting results for theoretical reasons (Ridder, 2017). As seen in the case selection criteria, this thesis chose cases that were involved in designing and implementing a CPPSS. Consequently, literal replication was used to conduct the research and evaluate and refine the design method. A list of potential cases was created through convenience sampling and consultation with academic and industry advisers. The list was then shortened by studying the organisations' local presence, websites, business model, value preposition, size, technological maturity, the potentiality of knowledge expansion. Purposive sampling was then implemented by formally communicating with each short-listed organisation (see Appendix VII (ii)). Emails, posts, and phone calls were used to establish the communication and enable confirmation of organisations' case suitability and creation of awareness about this research. Interested and most suitable organisations based on the selection criteria were then chosen for case studies. The fit of these individual cases against the selection criteria are discussed in Section 5.2.1, 5.3.1, 5.4.1 and 5.5.1. It is recommended that three to four cases are sufficient for literal replication (Shakir, 2002; Yin, 2017). Based on that recommendation, case studies were conducted in four Australian organisations operating in four different industry sectors locally and abroad. The comparison of these cases with the type of CPPSS, complexity, value offering, business model and role are provided in Table 34. The cases are individually discussed further in Chapter 5 and cross analysed in Section 6.2.

The participants for the interviews were chosen to align with the focus of this research, i.e., unit of analysis and observation (Miles et al., 2018) and thus help the researcher understand a value co-creation actor-network in practice. A value co-creation actor network is a network that included the actors (who), resources (what), practices (how) and the reasons behind each of them (why). These participants were then involved in the ideation, design, installation, usage and continuous improvement of the CPPSS. The participant description of each of the cases is respectively provided in Sections 5.2.2, 5.3.2, 5.4.2 and 5.5.2.

3.4.3 Data Collection Strategy

3.4.3.1 Data collection technique

Following the DSRM guidelines, the case studies were aimed at evaluating and refining the proposed conceptual design method reference model. The research targeted four different organisations, involved respectively in manufacturing, management, healthcare and information technology because each business fitted the definition of PSS and CPPSS used in this research.

Interviewing is a suitable method for seeking information based on personal knowledge and experiences from people involved in a context (Hennink et al., 2010). Interviews are conversations between the subject and the researcher, where the researcher seeks responses from the subject in a particular area of interest (Gillham, 2000). Interviews can generally be categorised into three types; structured, semi-structured or unstructured (Morris, 2015). Semi-structured interviews lie between the structured and unstructured approaches by having a list of questions to discuss but with scope for digression. This technique does not confine the responses, as the participants are also given the freedom to vary the order and direction that the interview takes based on the responses (Gray, 2013). In other words, a semi-structured interview technique keeps a tight focus on the research questions while also giving the researchers and the informants the flexibility to allow for differences among the cases. As pointed out by Eisenhardt (1989), this arrangement is essential because the investigator is trying to understand each case in as much depth as is feasible. At the same time, semi-structured interviews do not result in information that is difficult to compare or off-topic. Thus, this research implemented the semi-structured interview technique to ensure both ease of comparison and data collection that would meet the aims of this research.

Semi-structured interviews were conducted with practitioners who possessed the skills, experience and knowledge in designing, developing, and implementing PSS and CPPSS solutions and who could explicate their practical design experiences in co-production and the value-in-use aspects of value co-creation. The practitioners in the four case organisations combined included a design engineer, a managing director, a general manager, a marketing manager, team leaders and operators. The diversity in personnel selection ensured that the design method could be studied from different perspectives, thereby enabling a holistic design method to be investigated.

3.4.3.2 Interviews

To obtain the consent of each target organisation, a letter of invitation letter was developed and ethics clearance for it was sought from the UTS Human Research Ethics Committee (HREC). These ethics clearances are Ref. No. ETH18-2445 and ETH19-4287 (see Appendix VI(i) and Appendix VII(i)). Participation in this research was voluntary, and each participant had the right to decline to answer any of the interview questions. The participants could also decide to withdraw from this research at any time. The interviews with the selected participants lasted approximately one hour each at a mutually-agreed location. They were asked about 18 to 20 questions related to their practical design-related experiences and, with their permission, the interviews were tape-recorded and later transcribed for analysis. Shortly after the interview, a copy of the transcript was sent to the participants to confirm its accuracy and allow them to clarify any points if they wished. Before the data analysis, the names and identifying information of the organisations and interviewees (or practitioners) were changed to preserve anonymity.

Each case study involved close examination of the value co-creation process and the interactions among the actors. The four types of value relevant to this research are listed in

Table 13. These values, combined with the two value co-creation processes (co-production/design and value-in-use), helped evaluate the proposed CPPSSDM reference model against case-specific real-world design processes.

Table 13: Types of value (partly adapted from Sweeney and Soutar (2001))

Value	**Customer**	**Provider**	**Measure**
Functional	Utility consumed	Utility generated	Quantitative
Monetary	Monetary cost **vs** monetary gain from users	Monetary cost **vs** monetary gain from customer	Quantitative
Social	Reputation observed	Reputation created	Qualitative
Emotional	Quality perceived	Quality emanated	Qualitative

The questions asked in the interviews followed the five levels of questioning suggested by Yin (2014). The context, domain, size and field of the organisation and the position of the interviewee determined the questions being asked. Since this research involved multiple cases, questions designed to find patterns across these cases were also asked.

The development of the interview questions' template was governed by the insights obtained from the reviewed literature, the aims of the research question and the consultation of appropriate industry and academic experts. The questions were revised and refined multiple times using recommendations from the case study and industry practitioners. The finalised interview template broke the interview into three parts, as discussed below and listed in Table 14. More details are provided in Appendix VII and Table 57.

1 - First, the interviewer and the topic part were introduced to the participant.

 This part facilitated a comfortable atmosphere for the participant and the interviewer by discussing the research. This part also helped set the scene for collecting the data vital to the research topic.

2 - Second, general and introductory questions were asked

This part helped the participant to open up about his/her position, experience and insights about general aspects of CPPSS. The information supported the interviewer to gauge the participant's perspective, the probes to implement and the data to be collected.

3 - Third, domain-based questions relating to the topic of interest were asked.

These questions provided the data vital to answering the research questions of this thesis. The questions also contributed to each of the four stages of the proposed design method.

Table 14: Interview sections and questions

Section	Possible Questions/Notes/Probes
Introduction	The interviewer: 1. Introduces himself 2. Introduces interest in studying the design method, smart solutions and product and service systems 3. Explains the aim of studying customer involvement in the design and development 4. Explains the sections of the interview and the semi-structured format
General Questions	1. What is your position and what are your duties in this organisation? Probes: Design engineer? Customer relation? Operator? Manage a team? Propose design, obtain customer inputs, cover reliability, feasibility analysis? 2. You have been involved in designing CPPSS, how has it been? Probes: Challenges, accomplishments, innovation. 3. What do you like about your work? Probes: Challenging? Meet people? Solve problems? 4. What have been the main challenges for you and the company? How have you coped with those challenges? Probes: Understand customer demands and needs? Achieve targets?
Domain-based Questions	**Perceived Value** 1. How did you manage to connect with your customers and understand their demands? 2. What does the term 'value' mean to you, your company and your customers? **3.** What do you think is missing in the value perception among stakeholders?
	Actors Involved in Design 1. How do you interact with other actors in the network? 2. What factors govern the process? 3. What are the shortcomings in this process that you wish to eliminate?
	Value Co-creation (Co-design) 1. What procedures do you follow in the design and development of the smart system? 2. How do you integrate customers into the design and development process? 3. What are your views on the level of customer involvement in such processes?

	Value Co-creation (Value-in-Use (ViU)) 1. How do you extract value during the use of your offering? 2. How do you bring in changes to the existing product and service system delivery? 3. How do you cater to the changing needs of the customers? 4. How do you think the ViU process can be improved?

The above interview questions and probes were framed in conjunction with the research questions proposed in the previous chapters (see Sections 1.3 and 2.8). Table 15 shows the connection between the research questions, the four steps of the design method (explained in Chapter 4) and the interview questions.

Table 15: Relationship between the research question, the interviews and the design method

Research Question	**Interview Question Domain**	**Design Method Stage**
What are the perceived values of a CPPSS?	Perceived Value	*Problematisation*
	Actors Involved in Design	*Interessement*
How could value be co-created in the CPPSS environment?	Co-design	*Enrolment*
	Value-in-Use	*Mobilisation*

3.4.3.3 Data organisation

The interview data and notes were coded into descriptive, topic and analytic themes and subthemes, as suggested by Richards and Morse (2012). The data was analysed and re-analysed using the suggestion by Miles et al. (2018) to obtain an understanding of the terminologies, patterns, information, practices, constraints and challenges concerning CPPSS design that were encountered by the organisations taking part in this research. These observations helped modify and improve the conceptual CPPSSDM reference model. The responses from the participants presented in this thesis were coded following the convention presented in Table 16.

The information was analysed using the thematic content analysis to ensure that the proposed design method made sense and had potential utility to the CPPSS businesses. The generalised design method developed from theory was evaluated by verifying if it applied to the specific cases, which in turn helped refine and build confidence in the design method using confirmation and non-confirmation of the propositions made (Yin, 2017).

Table 16: Participant quote codes

Organisation	Participant Group	Participant Code
DairyCo	Management	DM
	Engineering	DE
	Operator	DO
PoolCo	Management	PM
	Engineering	PE
	Operator	PO
HealthCo	Management	HM
	Engineering	HE
	Operator	HO
VRCo	Management	VM
	Engineering	VE
	Operator	VO

3.4.4 Data Analysis Strategy

The empirical evidence gathered from the cases was used to formulate various constructs and propositions (Eisenhardt & Graebner, 2007) and these constructs and propositions led to the evaluation of the conceptual design method reference model for the CPPSS. The case studies also helped identify emergent relationships between the constructs (Eisenhardt, 1989). These observations helped reveal the strengths and gaps in the proposed design method, which was then refined by the constructs developed from the evidence arising out of each case study organisation (Eisenhardt, 1989).

3.4.4.1 Data analysis

There are four general data analysis strategies discussed by Yin (2014), as follows:

1. Relying on theoretical propositions: In this strategy, the analysis follows the theoretical basis on which the objectives, research question and the case study design were built.
2. Working the data from bottom-up: This strategy contrasts with the first strategy by identifying relationships and building theories using the patterns observed in the data.

3. Developing a case description: Here, the researcher analyses a large amount of data without having any initial set of research questions or propositions to develop the theory or explanation.
4. Examining plausible rival explanations: This strategy is used in combination with any of the previous three strategies to find rival explanations for specific observations.

This thesis developed the design method reference model from the theoretical understanding obtained from the reviewed literature. Since the case study approach was used to evaluate and refine this design method, the primary strategy used to analyse the gathered data was (1) *relying on theoretical propositions*.

3.4.4.2 Analytic technique

There are five analytic data analysis techniques listed by Yin (2003, 2014). These techniques are:

1. Pattern matching: This technique is used to find patterns in the data and compare them with the patterns predicted before the data collection.
2. Explanation building: This is a type of pattern matching that is used to find links in the evidence in a case to explain what happened and why.
3. Time-series analysis: This technique is used mainly in experiments to study cases in a time series of events.
4. Logic models: This technique is used to explain a complex chain of cause-effect-cause-effect patterns over a period.
5. Cross-case synthesis: This is a technique applied especially in multi-case scenarios to compare the similarities and differences.

The main techniques implemented in this thesis were pattern matching, explanation building, logic model and cross-case synthesis. As can be observed in Table 14, several interview questions were intended to identify the patterns in the participants' responses. The patterns studied were value co-creation, interactions and the outcomes of the CPPSS design practices in the case-study organisations. These patterns enabled the cross-case synthesis to compare the likenesses and differences among intra and inter-organisation design practices. The explanation building technique was implemented to explain the successes and failures of the participants' design methods and practices and involved iterative tabulation of the pieces of evidence for each construct and replication of the logic across the cases. Some of the methods implemented are detailed below (Eisenhardt, 1989).

1. Write up a case study for each site to generate insights
2. Select categories and dimension to look for similarities and differences
3. List similarities and differences between pairs of cases for cross-case analysis
4. Divide the data by their sources
5. Create a logic model

The above methods were applied to ensure that all the data was ready for comparison between the field notes and recordings. These insights were then organised and presented case-by-case in this thesis (see Chapter 5). The creation of a logic model (Yin 2014) was done through applying ANT principles to form the actor-network of each organisation. A logic and time-series model of each case was developed to provide an overall understanding of the insights obtained. The cross-case synthesis was conducted as part of the Evaluation step, explained in the next section and elaborated on in Chapter 6. Overall, a combination of the above techniques enabled a holistic CPPSSDM reference model to be developed.

3.5 Step 5 – Evaluation

This section explains the fifth step of the DSRM implemented in this research, which involved measuring the usefulness of the developed artefact. The Evaluation step involves observing and measuring the effectiveness of a developed artefact in that it enables comparison of the results of the Demonstration step (Step 4) with the objectives (Step 2). This evaluation helped refine and modify the proposed CPPSSDM reference model using the data from the case studies and practitioners' feedback. This step was implemented in combination with Step 4 by adhering to the iterative nature of DSRM and is explained fully in Chapter 6.

The design method reference model proposed in this thesis was intended to be useful to both customers and providers in their collaborative design of the CPPSS. Appropriately, as explained in the research plan in Section 2.8, the evaluation of this design method reference model ensured its utility. This confirmation was displayed when comparing it to real-world practices and acknowledged by the CPPSS practitioners who participated in the research.

The main research approach used in this thesis was the case studies. So, the first part of the Evaluation step was achieved by performing case study synthesis and comparing the data with the proposed design method to find the congruence between them. This part formed the researcher's understanding of the utility of the design method compared to real-world practices.

The second part of this step was accomplished using the feedback and appraisal of the refined CPPSSDM reference model by the CPPSS development practitioners. This part was used as a supplement to the case study insights by providing enhanced understanding of the clarity and utility of the reference model from the practitioners' perspective. As the evaluation of an artefact not limited by the DSRM methodology, a purposeful survey of practitioners who are involved in the development of similar solutions was conducted as an attempt to explain the findings further. This survey enabled the practitioners to understand the utility of the refined design method compared to their real-world knowledge and expertise. The case study findings and the refined CPPSSDM reference model were presented to the CPPSS practitioners for their evaluation. The process also expanded to include the perspectives of practitioners outside the case study organisation. This step was considered a valuable contribution to the design method development because it provided a perspective outside that of the researcher and enabled the utility and clarity of the design method to be demonstrated further.

A satisfaction survey is one of the methods used in design science research methodology to evaluate the utility of an artefact (Peffers et al., 2007). Thus, in addition to the case studies, a survey method was chosen for this research to understand how the practitioners made sense of the proposed design method and how useful they found it. One of the functions of this integration is to achieve methodological triangulation of the research undertaken (Bryman, 2006; Jonsen & Jehn, 2009). In this research, the survey produced answers to the following questions:

1. What does the proposed design mean to the practitioners?
2. Where can they apply this proposed design method?
3. How useful is the proposed design method?

3.5.1 Data Requirements

One of the ways to implement triangulation is to use the various practitioners of the field of application to check the developed artefact (Jonsen & Jehn, 2009). Here the participants act as the judges of the research outcomes and provide their views of the artefact. This approach seemed the most logical way of evaluating the artefact in this research, as the CPPSS practitioners themselves were given a chance to appraise it. This approach was developed based on the criteria of implementation, priority and integration put forth by Creswell and Creswell

(2017). In this research, the participants were asked to provide feedback on each stage of the design method in the form of ratings and comments.

The rating questions were about the *utility* and *clarity* of each stage of the design method. As mentioned previously in this thesis, the CPPSSDM was developed to be a holistic method of designing a CPPSS through the collaboration of all the actors. As a result, for the design method to be effective in achieving this aim, the actors must find *utility* in using it, bearing in mind that the importance of *utility* has been demonstrated in previous research into designing PSS and CPPSS (Poeppelbuss & Durst, 2019). *Utility* has also been used as an evaluation measure of theory on service innovation (Chew, 2016), of a design science research method (Hevner & Chatterjee, 2010) and DSRM implementation (Carcary, 2011). Therefore, one of the key factors that the participants were asked was to rate was the *utility* of the CPPSSDM.

The *utility* of the design method could be achieved only when the participants understood how the design method was to be implemented. So, in addition to the *utility*, there was a need to understand the *clarity* of the CPPSSDM reference model. Thus, the other rating factor given to the participants was the *clarity* of using the four steps of the design method. The answers to the questions gave the researcher an insight into what the participants learnt from each step of the proposed design method and how it could be improved.

3.5.2 Selection Criteria

The selection of respondents is a vital aspect of data collection (Eisenhardt, 1989). Respondent selection for this research was based on two aspects, as stated by Hennink et al. (2010). The first was to define the right respondents to survey, and the second was to identify the strategies to recruit these respondents. Once these two steps were addressed in this research, the selected practitioners were invited to participate in the survey.

As emphasised throughout the thesis, the design method enables both customers and providers to co-create value. Appropriately, customers and providers involved in practising CPPSS design and implementation were recruited for the evaluation of the refined CPPSSDM reference model. Both practitioners from the case studies and practitioners external to the case studies were selected to take part in the survey, to ensure that the design method was useful to all possible practitioners regardless of whether they were part of the Demonstration step. Furthermore, an appraisal from both categories of practitioner helped to triangulate the design method.

The selection criteria were developed by consulting the industry and research experts in the field of CPPSS. Based on the criteria, the respondents for the evaluation process had to:

- be involved in the design and implementation of CPPSS either as a operator, manager, designer, or provider. This criterion ensured that the respondent responded from a first-hand experience.
- have at least two years of experience in their respective industry. This criterion ensured that the respondent is not unfamiliar or inexperienced working with CPPSS.
- have at least a basic understanding and experience of designing solutions. Since the research is focused on CPPSS design, this criterion was important.
- be involved in business-to-business relationship since this research is concerned about CPPSS design in a business-business relationship.
- be willing to understand the proposed design method and share his/her views based on their knowledge and expertise. It was important that the respondent understands the concept and be able to provide critical feedback.

3.5.3 Data Collection

The data was collected using a satisfaction survey, which is one of the recommended ways to evaluate an artefact (Peffers et al., 2007). The survey initially asked the respondents about their industry, expertise, experience, skills, and role to understand his/her perspective. Following that, it asked the respondents questions that generated the evaluation data.

The survey first asked the respondents to rate the *utility* and *clarity* of each of the four steps of the design method on a 5-point Likert scale. These ratings helped determine the respondents' agreement or disagreement with the respective design stage. The survey then asked them to explain how the proposed design method could be useful to them and how he/she could implement each of the four steps in their workplace. It also asked them to suggest how the design method could be improved, sharing the knowledge gained from their own experience to describe how each of the steps could be modified to perform better. Further details of this step are provided in Chapter 6. A copy of the survey questionnaire can be found in Appendix VII.

The survey questionnaire was designed through the consultation with appropriate research experts, the reviewed literature, and the survey guidelines like Brace (2018) and Krosnick (2018). Both close-end and open-end questions were used to obtain a better insight from the industry practitioners as the respondents were experts in their field. A total of 12 completed survey responses were obtained from a pool of 24 interested respondents. The reasoning behind this sample size and the data gathering is explained further in Sections 6.3.1 and 6.3.2, respectively. As the sample size was small and the data gathered was expert opinions, quantitative analysis was not recommended, and therefore the focus was placed on the qualitative analysis of the responses. The analysis helped enhance the reference model to its final form. The demographic information of the respondents is presented in Table 39 of Chapter 6. The responses provided constructive feedback and appreciation for all four stages of the reference model (see Section 6.3). This information helped establish the CPPSSDM reference model and polish it to its final form (see Section 6.4). The responses from the respondents were coded using the convention shown in Table 17.

Table 17: Feedback Respondent quote codes

Respondent Group	**Respondent Code**
Operator/End-user	FO
Engineer/Designer	FE
Manager/Leader	FM
Operator and Manager	FOM
Engineer and Manager	FEM
All-rounder	FOEM

3.6 Step 6 – Communication

The sixth and last step of a DSRM is to communicate the new knowledge (Hevner et al., 2004). This step involves describing the problem and its importance, the artefact and its utility, the rigour of the design and its effectiveness to researchers and other relevant audiences (Peffers et al., 2007). So far, multiple channels have been used to communicate the progress and findings of this research. The initial communication was through the presentation and publication of the SLR in two international conferences (see Rizvi & Chew (2018a, 2018b)). These findings were then communicated with the potential case organisations to gain their interest in the research problem. The four most interested organisations were then enrolled on the case studies. The case studies involved further communication that linked theory and practice between the researcher and the practitioners. The case study findings were then communicated through three more presentations and publications in international conferences (see Rizvi et al., 2019a, 2019b, 2021). These findings were also regularly communicated among the faculty through departmental research presentations and competitions. All these communications enriched the research with insightful feedback, ideas and awareness. Apart from the above, this research communication also led to an international collaboration that developed of an integrated design framework for service-centric PSS (see Yip et al., 2019 and Section 7.4.3). So, overall, a total of six international conference publications and presentations have been accomplished, and more publications are underway.

3.7 Conclusion of Chapter 3

The purpose of this research was to develop a theory- and practice-based CPPSSDM, that is, a design method that was service-oriented, customer-centric, holistic and capable of co-creating value by catering to the evolving needs of customers.

The six-step design science research method (DSRM) was chosen to execute this aim. The theoretical base for the design method was set using the literature review on PSS and CPPSS design. The method was demonstrated through the case study of four organisations involved in the design and implementation of CPPSS. The case study was conducted using semi-structured interviews with the designers, managers and users of CPPSS in the case organisations. The data obtained from these cases were then analysed to help refine the theoretical CPPSSDM and the refined CPPSSDM was evaluated further using a survey with a mix of original case study participants and other practitioners. The data from the survey also helped create an additional refinement to the design method.

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Chapter 4 – Development of the Design Method

4.0 Introduction

Chapter 3 provided a detailed explanation of the DSRM followed in this research. This chapter describes the third step of the research method, as shown in Figure 15. The third step is the *design and development*, where an artefact solving the problem is created in the form of constructs, models, methods, or instantiations (Peffers et al., 2007). Accordingly, this chapter describes how the knowledge gained from the reviewed literature and relevant foundational theories was used to develop a holistic design method for a PSS and CPPSS. This chapter also proposes definitions and models for the PSS, CPS and CPPSS that were used while developing the design method.

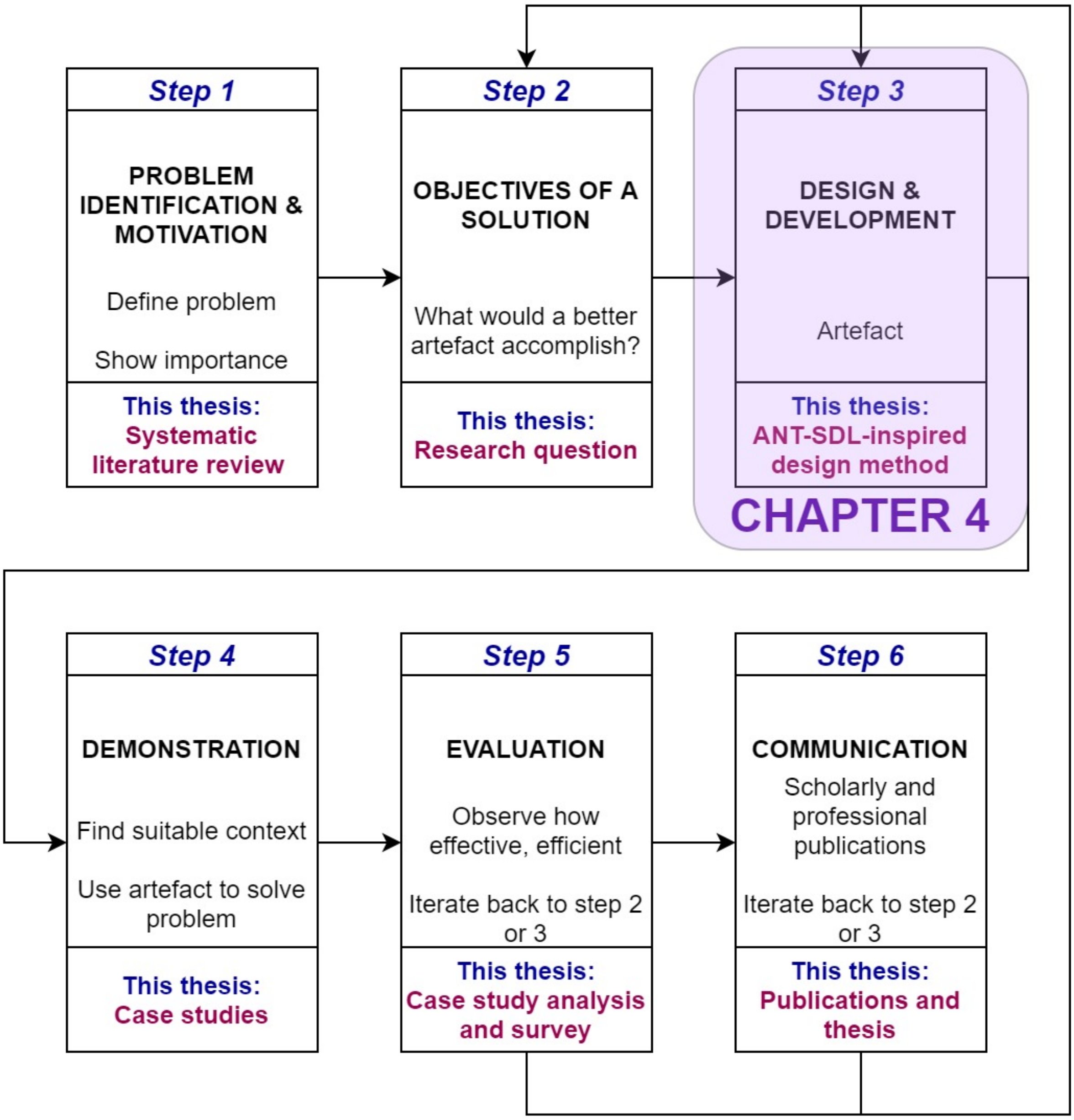

Figure 15: Step 3 of design science research method (adapted from Peffers et al., 2006; Peffers et al., 2007)

This chapter is divided into five sections, as shown in Figure 16. Section 4.1 introduces the foundational theories (i.e., SDL and ANT) employed in developing the conceptual design method. These theories are then utilised with the SLR to develop the definition, meta-models and design methods for a PSS and CPPSS in Section 4.2 and Section 4.3, respectively. The implications and limitations of the proposed design method are discussed in Section 4.4. The chapter concludes with Section 4.5.

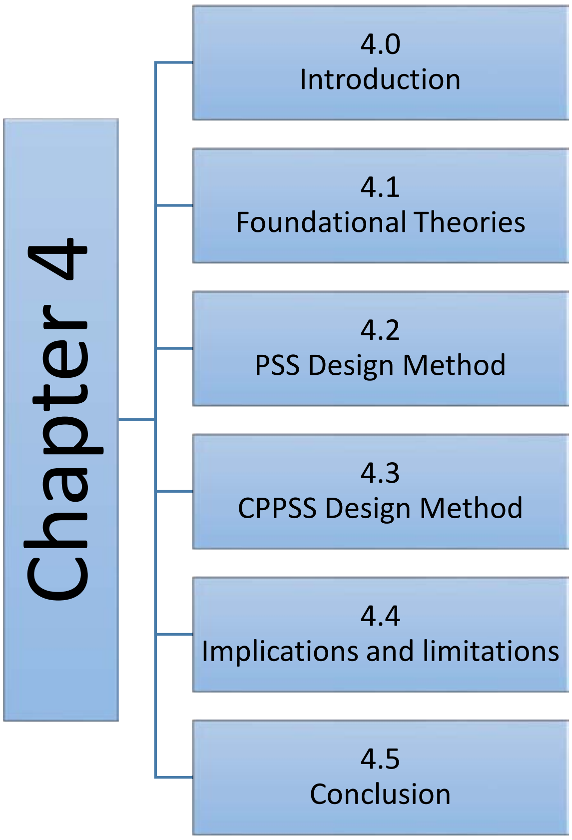

Figure 16: Structure of Chapter 4

4.1 Foundational Theories

The reviewed literature on PSS, CPPSS and value co-creation showed that many authors refer to the concept of SDL in defining and designing a PSS and CPPSS. Therefore, SDL forms the first foundation theory of this thesis. Several researchers have also discussed the concept of the *actor* and the actor network, consisting of such entities as provider, customer, services and other stakeholders. The second foundational theory of this thesis is therefore the actor-network theory (ANT). This section explains these two theories and then proposes a theory inspired by ANT and SDL to design a PSS and CPPSS.

4.1.1 Service-Dominant Logic (SDL)

SDL was theorised by initiating an examination of the ways in which businesses need to co-create value with their stakeholders (Vargo & Lusch, 2004). SDL proposes that service, including the goods purchased and used by customers as the delivery mechanism for services, is the fundamental basis of exchange (Reim et al., 2015; Vargo & Lusch, 2016). Through SDL, the concept of value co-creation was expanded from its limited focus on companies and customers to a broader view that takes into account the role of multiple actors, always including the beneficiary (Vargo & Lusch, 2016). Recent studies on SDL consider value co-creation interactions between these actors as an actor-to-actor orientation, which finds support from ANT. The concept of SDL aligns itself to that of a PSS, and several researchers have treated the terms as similar (Barquet et al., 2013; Reim et al., 2015). Many others have used SDL as an enabler of value co-creation in the design and development of a PSS (Kowalkowski, 2010; Smith et al., 2014).

Vargo and Lusch (2004) argue that traditional goods-dominant logic is insufficient for understanding current economic exchange and marketing as it is primarily focused on tangible resources, embedded value and transactions. SDL attempts to bring about a paradigm shift by advocating the concepts of value co-creation rather than the value-in-exchange of goods-dominant logic. SDL moves the focus to intangible resources, value co-creation and relationships among the actors based on the foundational premise that actors are fundamentally concerned with the exchange of service (application of competencies – knowledge, skills, and resources) for the benefit of an actor. Service is the process of integrating such competencies towards solving a problem. In other words, service is exchanged for service, and all businesses must be service-oriented.

The term *service-oriented* refers to the ability to anticipate, recognise and deliver the needs of an actor. It involves interacting with customers by focusing on improving services and revisiting relationships as customers' needs evolve. From the organisation's perspective, service-orientation means to proactively engage in service-giving practices, processes and procedures in the belief that service contributes significantly to the creation of superior value, customer satisfaction, competitive advantage, growth, and profitability (Lytle & Timmerman, 2006). In service-oriented systems, values are built upon relationships among the actors rather than on the transactions observed in product-oriented systems. According to SDL, a service-oriented perspective is inherently customer-centric (Vargo et al., 2008). SDL fosters changing the mindset that instead of businesses marketing to customers, businesses must be customer-centric by marketing with customers in a shared value-network.

The term *customer-centric* refers to a system of keeping customers at the centre of a business and marketing strategy. Thus, SDL is a mindset for a unified understanding of the purpose and nature of markets and businesses (Vargo & Lusch, 2011). Customer-centric marketing emphasises understanding and satisfying the needs, wants and resources of individual customers rather than those of mass markets (Sheth et al., 2000).

This research took these SDL perspectives as the basis for defining a PSS and CPPSS and uses ANT (discussed in Section 4.1.2) to build the design method.

4.1.2 Actor-Network Theory (ANT)

ANT was developed to understand the processes behind the creation of innovation and knowledge (Cressman, 2009; Wickramasinghe et al., 2010). ANT helps people appreciate how things are structured and organised (Law, 1992). ANT is a theory of agency that encourages researchers examining how things are structured and organised to also explore their social effects (Law, 1992). ANT views all human and non-humans in the world as actors that continuously generate webs of relationships and states that all actors are located within the effect of these webs of relations (Law, 2009). The connections or relationships among actors can be examined as part of a "flattened topography", forcing all actors to be placed side-by-side regardless of their level of categorisation (Latour, 2005). ANT believes that truth is just a perception, and it changes with time (Cressman, 2009; Montenegro & Bulgacov, 2014). When considering SDL, value co-creation involves dynamic capabilities to address changes in environments (Preikschas et al., 2017). Further value co-creation is also considered dynamic in nature (Osborne, 2018). Thus, value co-creation can take inspiration from ANT for its perception of the concept of truth and be a useful tool to understand the value co-creation process in a service-centric CPPSS.

The successful design, development and operation of a CPPSS depends not only on human entities but also on non-human entities such as machines and technology. The relationship between customers, providers and their partners would not exist without the presence of non-human actors. As explained in Latour (1987), the ANT approach is 'science and technology in the making' as opposed to 'ready-made science and technology'. The fundamental purpose of ANT is to investigate and theorise about how networks emerge, what associations exist, how they are composed and maintained, how actors are enrolled into a network and how networks achieve temporary stability (Cresswell et al., 2010). The works of Latour (2005) and Law (2009) have shown that ANT helps in the understanding of how a system is dynamically maintained and what the socio-technical actors are that define the success or failure of a system. ANT is a socio-technical constructivist theory that is focused on the connections and reconnections that form and reform between human and non-human actors. An actor (sometimes also called *actant*) in ANT is an element that influences the space around itself, makes other elements dependent upon it and translates their will into a language of its own (Callon & Latour, 1981). Thus, the actor also serves as a bridge (i.e. mediator) between other actors (Uden & Francis, 2009). An actor is any human and non-human element that is a source of action in a given network.

The ANT approach explains how actors adapt to changes through a translation process. Translation involves creating convergences and homologies by relating things that were previously different (Callon & Latour, 1981). It is a process by which actors are related in a socio-technical network by assigning their identities and negotiating the possibility of their interaction and the margins of manoeuvre (Callon, 1986; Cressman, 2009). This process involves aligning the interests of all actors in the network with that of the focal actor (Callon, 1986; Walsham, 1997). The ANT translation process consists of four stages; namely, *Problematisation*, *Interessement*, *Enrolment* and *Mobilisation* (Callon, 1986). In this thesis, these translation stages are performed by the human actors based on their interactions with other human and non-human actors.

Problematisation involves the focal actor defining the problem and aligning all the other actors' interests so as to develop the required solution (Callon, 1986; Shin, 2016). The solution, depending on the field of research, for example, could be technology (Greenhalgh & Stones, 2010), project management (Burga & Rezania, 2017) or sustainable tourism (Dedeke, 2017). During the *Interessement* stage, the focal actor executes various strategies to convince other actors to accept its definition of their respective interests in solving the problem (Callon, 1986; Shin, 2016). The *enrolment* stage occurs when other actors accept the interests that were defined by the focal actor, who coordinates the roles to be performed by each of them (Callon, 1986; Greenhalgh & Stones, 2010). Finally, *Mobilisation* ensures that all actors are engaged in fulfilling the agreed upon roles, practices and relationships in the network (Callon, 1986; Greenhalgh & Stones, 2010). During this stage, when the operation stabilises, a black box may be formed, where the network can be simplified as a single point actor (Tatnall, 2005). A black box is created when the system functions in harmony and no longer requires to be represented as a complex network. As explained by Cressman (2009), a black box can be a system like a car or a computer that operates as expected to make its complex network and socio-technical relationships invisible. The tabulation of the four translation stages and their features are provided in Table 18.

Table 18: The four translation stages of ANT (adapted from Callon (1986); Bengtsson & Lundström (2013); Andrade & Urquhart (2010))

Translation Stage	Functions
Problematisation	The primary actor identifies the problem, assesses initial requirements, and gauges the actors who can contribute towards the solution.
Interessement	The primary actor works towards building the network by convincing other actors about the benefits of joining it. The network is formed by negotiating the roles of each actor.
Enrolment	The actors accept the negotiated roles assigned to them. This step creates the actor network that works towards solving the problem.
Mobilisation	The solution is deployed as all actors engage in fulfilling the promised roles. This step monitors the interests, practices and relationships in the network to keep it stable.

In the context of this thesis, the translation process of ANT helps us understand how customers and providers recognise a problem, develop a value perception, create interest among others and then join a network of actors to achieve a solution. Interviews were used in this thesis to find how value co-creation connects customers and providers. The actors identified from the interviews were strategically followed to develop the network of human and non-human actors that would form a CPPSS (Cressman, 2009). As suggested by Law and Callon (1988), this approach helped to map how actors define and distribute roles and subsequently mobilise others to play their assigned roles.

4.1.3 ANT-SDL Model of Value Co-creation

In SDL, the term '*actor*' is a generic term used to represent the entities or parties that are involved in exchange relationships and co-creation processes (Lusch & Vargo, 2006a; Vargo & Lusch, 2008b). The actors are involved in integrating resources, exchanging service for service and co-creating value (Lusch & Vargo, 2014). This representation means human entities such as customers and providers are SDL actors. However, SDL neglects the influence and involvement of the non-human entities. This concern was pointed out by Storbacka et al. (2016, p. 3010) in their statement: “Consequently, actors need to be viewed not only as humans, but also as machines/technologies, or collections of humans and machines/technologies, including organisations.”.

ANT on the other hand gives equal importance to the human and non-human actors in any social-technical system. As a result, both the actors, humans and non-human, have equal influence on one another to initiate change and during the change process. This change helps a researcher or practitioner understand how various actors combine to achieve a goal.

Service-dominant logic, as discussed in Chapter 2, section 4.1.1, has precipitated debates about business models for companies to co-create values with their internal and external stakeholders. Co-creation can be understood as a set of activities where companies construct the opportunity to create value with customers, resulting in the fulfilment of customers’ needs within the agreement and constraints of customers, providers and suppliers (Durugbo & Pawar, 2014; Grönroos, 2008).

The co-creation of value is dynamic, as value is generated through the configuration of resources, including people, organisations, languages, laws, technologies and other service systems (Spohrer et al., 2008). This view of the interaction of resources within a network was summarised in a recent update of SDL as an actor-to-actor (A2A) orientation thus: “Value co-creation is coordinated through actor-generated institutions and institutional arrangements.” (Vargo & Lusch, 2016, p. 8). One can therefore find support for the SDL value-network view of value co-creation from the actor-network concept in ANT.

As discussed in section 4.1.2, ANT proposes that the actors related to an area of interest include both humans and non-humans and that all actors connect continuously, forming an extended network. In the context of this thesis, actor network refers to the network of value co-creation, which is dynamic, involving changes in resource configurations. As the ANT approach to the modelling of an actor adapting to change is called translation (Callon, 1986), the ANT translation process provides a framework that facilitates the value co-creation process in CPPSS design.

As explained in section 4.1.1, SDL proposes that value is always co-created by multiple actors, including the beneficiary. All actors are thus '*resource integrators*' who do not compete against each other but collaborate to improve mutual performance and co-create value. This process ensures that the dynamic needs of the customer are addressed with matching service delivery. Here, collaboration is achieved through fairness supported by open communication among the actors.

ANT helps to elaborate on this process with the statement that when a network is formed, the actor must continue working in the network; otherwise, the network would perish. For example, in Michelin's value co-creation process of delivering tyre management solutions to US armed forces (see Stahel (2010)), the network would perish if either Michelin or the US armed forces stopped working for the solution. ANT suggests that the connections among actors are formed based on their dependence on each other. SDL suggests maintaining a long-term relationship for value co-creation is achieved through actor-generated institutions and institutional arrangements. Taking inspiration from these two suggestions, this thesis advocates the formation of relationships among the actors based on mutually-agreed dependencies and regulations.

As previously discussed, SDL promotes the concept of value-in-use. The value of a service is dependent on the context, which leads to the concept of value-in-context, with the context defined as a set of unique actors with unique reciprocal links among them (Chandler & Vargo, 2011). In ANT, black boxes are broken whenever the current system or context becomes unstable. The reaction to changes in the SDL perspective is like breaking the black box in the ANT perspective. The value offering, the value proposition and the solution all change when the context changes. This understanding shows yet again the close relationship between ANT and SDL. The combined concept inspired by actor-network theory and service-dominant logic is demonstrated in Figure 17.

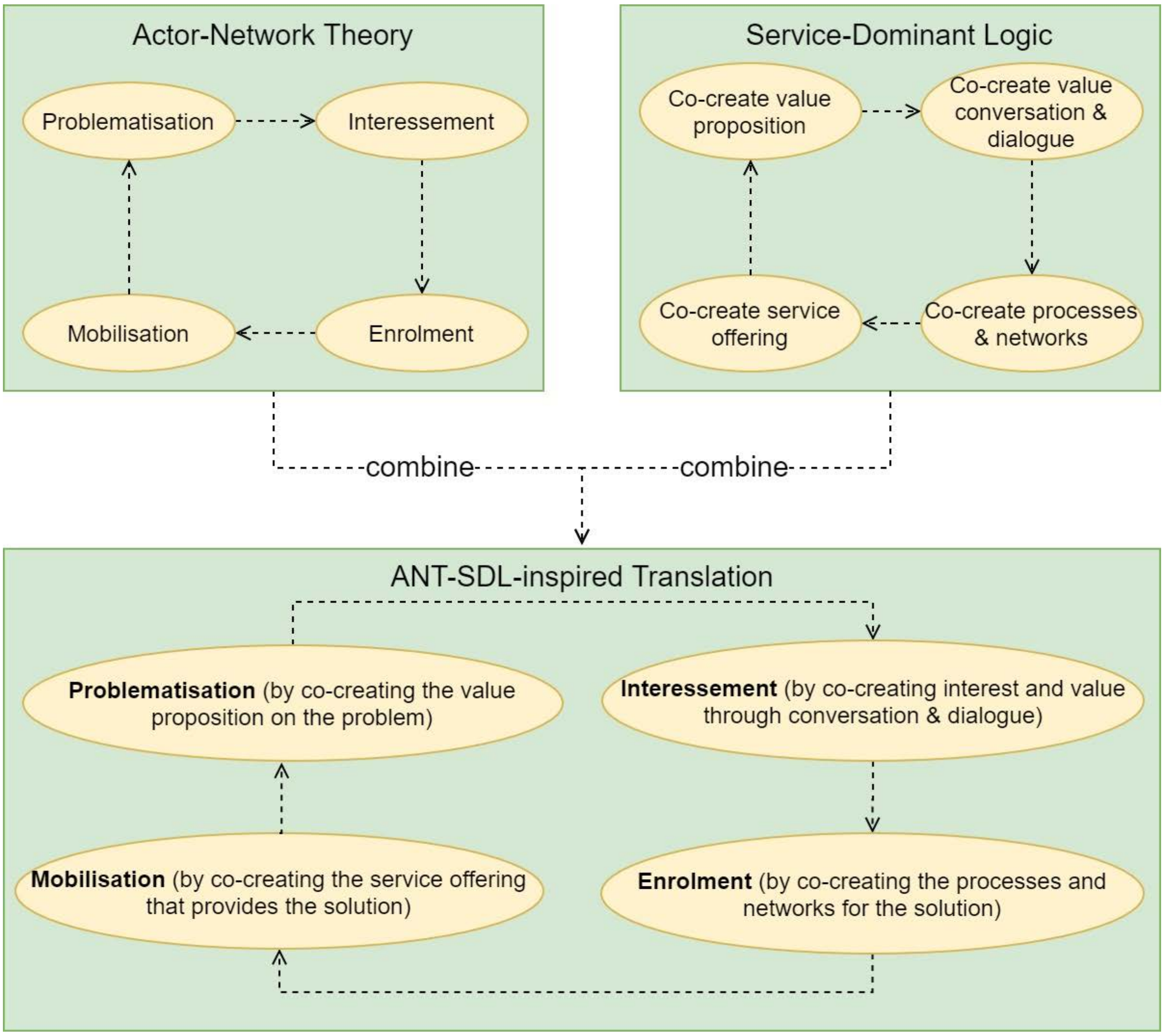

Figure 17: ANT-SDL inspired translation

The value co-creation process in SDL also recognises that there is no fixed actor as a customer or a provider, but all actors are co-creators. Service is directly or indirectly exchanged for service between actors during the actor engagement process to achieve a mutually committed objective or strategy (Lusch & Vargo, 2006b). The role of provider or beneficiary changes based on the context, and in each context, the value is determined by the beneficiary (Ekman et al., 2016). The value-in-use is manifested by the experience of the beneficiary, by personalisation and by relationship (Ranjan & Read, 2016). Value-in-use is further understood from the ANT approach, which explains that every actor or network has its frame of reference and definition of growth (Latour, 1996). Table 19 summarises the crucial concepts of ANT and SDL and their corresponding ANT-SDL concept. This combined approach was implemented in this research to propose the PSS design method.

Table 19: ANT and SDL concepts

	ANT	**SDL**	**ANT-SDL**
Field	Science and technology	Business and Marketing	Product-service system as a socio-technical system
Principle	Everything is related/connected	Everything is service	Everything is connected through service
Participants	Human and non-human actors	Human actors	Human and non-human actors involved in value co-creation
Outcome	Socio-technical system stability	Value co-creation	Socio-technical value co-creation
Order	No hierarchy	Hierarchy	Hybrid hierarchy
Operative	Connections	Co-creation	Co-creation through connections
Actor role	Multiple	Single or multiple	Multiple
Relations	The actor must continue to work	Value is always co-created	Value co-creation is a continuous process
Control	Dependence	Institution	Institutionalised dependence between actors

4.2 Product-Service Systems Design Method (PSSDM)

The review of extant literature for this research led to the identification of some knowledge gaps. Synthesis of the reviewed literature then led to the development of integrated definitions and design methods for PSS and CPPSS according to a DSRM. The SDL perspective influenced the ANT approach to form an ANT-SDL-inspired approach, which is explained further in the following sections. This research is one of the very few that has used a combination of the two concepts to develop an artefact.

As discussed in the previous sub-section, SDL and ANT have different views of who and what are considered as *actors*. This thesis combines the two different views of the *actor* concept in the modelling of a PSS as a socio-technical system. It defines an *actor* as someone or something that is directly or indirectly involved in the exchange relationships and that influences other actors in value co-creation. Research shows that the actors in the context of value co-creation have three research perspectives: volume and variety, combinations and machine/technology as *actors* (Storbacka et al., 2016). Based on the above insights, the properties of the actor for this research were:

- An *actor* can be a human entity (e.g. a user, an organisation, or a firm) or a non-human entity (e.g. the technology/machine).
- An *actor* can be something that influences the decision-making and value co-creation process. This entity can be the physical nature of the customer, the emotional values, the cultural nature, the pre-existing co-creation network or any other influence.

For example, a flight booking can be influenced by the traveller's:

- physical condition (airline's reputation in assisting physically challenged customers),
- emotional/cultural link to the airline (a customer may prefer airline or crew from his/her cultural background),
- travel plans (the traveller may have business/personal relationships at a particular location that may make him/her chose specific stopovers for a trip).

In this research, the human *actors* involved in the design of the PSS and CPPSS were providers and customers (beneficiaries). In a business-to-business context, the customer generally has or consists of end-users who are involved in operating the PSS or CPPSS solution. Apart from the end-users, managers and designers interact with each other to develop the PSS or CPPSS. These designers and managers form a subset of both the provider and the customer and equally contribute to the design. Additionally, the provider as an *actor* is the one who represents the organisation and its entities by being the organisation's owner, head-manager or a representative.

4.2.1 Defining PSS as a Socio-technical System

A socio-technical system is a system that involves complex interactions between humans, machines (technology) and environment (context) (Baxter & Sommerville, 2011). Relating this description of the socio-technical system to a product-service system, one can recognise a holistic PSS must consist of human, technological and contextual entities. Meier et al. (2010) realised this fact and claimed that a PSS represents a knowledge-intensive socio-technical system. Appropriately, new PSSs must not be developed from a technical aspect alone, but from a socio-technical aspect (Hollauer et al., 2015). A socio-technical system design perspective is seen to bring about a higher chance of successful delivery of solutions (Fabrizio Ceschin, 2015), as well as improvements in the sustainability and environmental aspects of that PSS (Roy, 2000). For example, the online platforms designed for customers to create their own shoe designs (Ramaswamy, 2008), application of specific parts (Thomke & Von Hippel, 2002), software (Prahalad & Ramaswamy, 2000) or travel plans (Grissemann & Stokburger-Sauer, 2012) require an understanding of the interactions between humans, software and hardware components, the skills involved and their effects on one another. The above examples further emphasise the socio-technical nature of a PSS. ANT is one of the recognised approaches to explain the socio-technical systems while SDL is the approach that explains value co-creation. As a result, implementing ANT- and SDL- inspired-concepts in designing a PSS and CPPSS becomes logical and inevitable.

This research proposes an integrative definition of a PSS by drawing understanding from the extant literature, as discussed in Chapter 2. This integrative definition caters to all the terms that were found to be vital in PSS domains and satisfies the notion of PSS described by various researchers. The definition proposed is as follows:

A product-service system (PSS) is a socio-technical system consisting of a network of actors who integrate their resources in terms of product and service offering to co-create value-in-use for mutual benefit aligned with the customer needs while improving the socio-economic and environmental impact on all actors throughout its lifecycle.

4.2.2 Modelling PSS

ANT suggests that the analysis must start from the actor that is central to the research. The first axiom and foundational premises of SDL suggest that service is the fundamental basis of all exchange (Vargo & Lusch, 2017). Thus, this research to propose a service-oriented PSS takes service as the central actor. In PSS and SDL, the solution to a customer problem is attained by combining the resources of the actors to functionalise the service. This research identifies the service, the beneficiary (customer), the provider and the product as the actors in a service-centric PSS, based on extant literature and ANT. In line with ANT, the above actors all influence one another and work together towards value co-creation. Figure 18 shows the service-oriented PSS actor-network model based on the proposed definition.

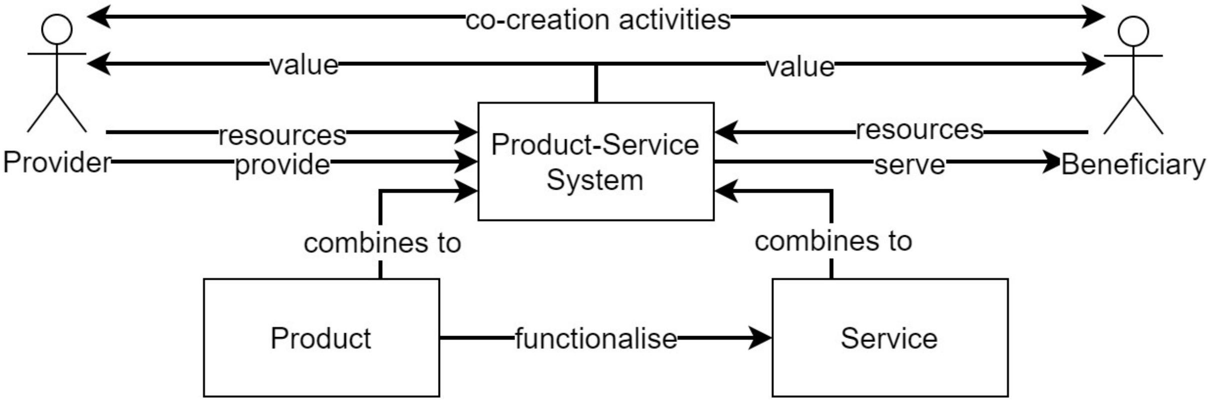

Figure 18: PSS actor-network model

4.2.3 Designing PSS

After studying numerous PSS design methods using the SLR method (see Chapter 2), it was decided that the proposed PSS design method (PSSDM) should take a lifecycle approach, taking into consideration the interactions of all the actors involved in value co-creation. The PSS lifecycle was divided into the beginning of life (BOL), middle of life (MOL) and end of life (EOL), with the PSSDM framework inspired by the ANT-SDL concepts listed in Table 19.

The PSSDM follows the SDL, as each service instance consists of co-creation activities involving multiple actors that always include the beneficiary, who determines the value. Each actor has its perspective of the network, benefits and goals. This design method consists mainly of two categories of actors. The first category is the *initiator*, who observes the problem and initiates the design process. The *initiator* can be the customer who is facing a problem in the current system or the provider who is looking to proactively co-create new or improved solutions. The second category of actors is the *follower*, who follows the *initiator*'s definition of the problem and works towards co-creating the solution. The PSSDM follows the four translation stages of ANT, which are iterative in each stage of the PSS lifecycle.

1. *Problematisation* involves identifying a problem in the existing actor network or system by at least one actor.

2. *Interessement* involves propagating the information about the identified problem to other actors in and beyond the actor network.
3. *Enrolment* involves recruiting suitable and interested actors in the problem-solving process to form a new actor network consisting of old and new actors.
4. *Mobilisation* involves establishing the actor network and actuating the solution.

After a certain period, customer dynamics and demand may change, leading to the identification of a new problem. The PSSDM can then be reinitiated to solve the new problem. In the PSSDM, the four stages involve the value co-creation activities performed by the actors (customer/beneficiary, provider, service and product) towards developing the PSS. Figure 19 illustrates the proposed PSSDM.

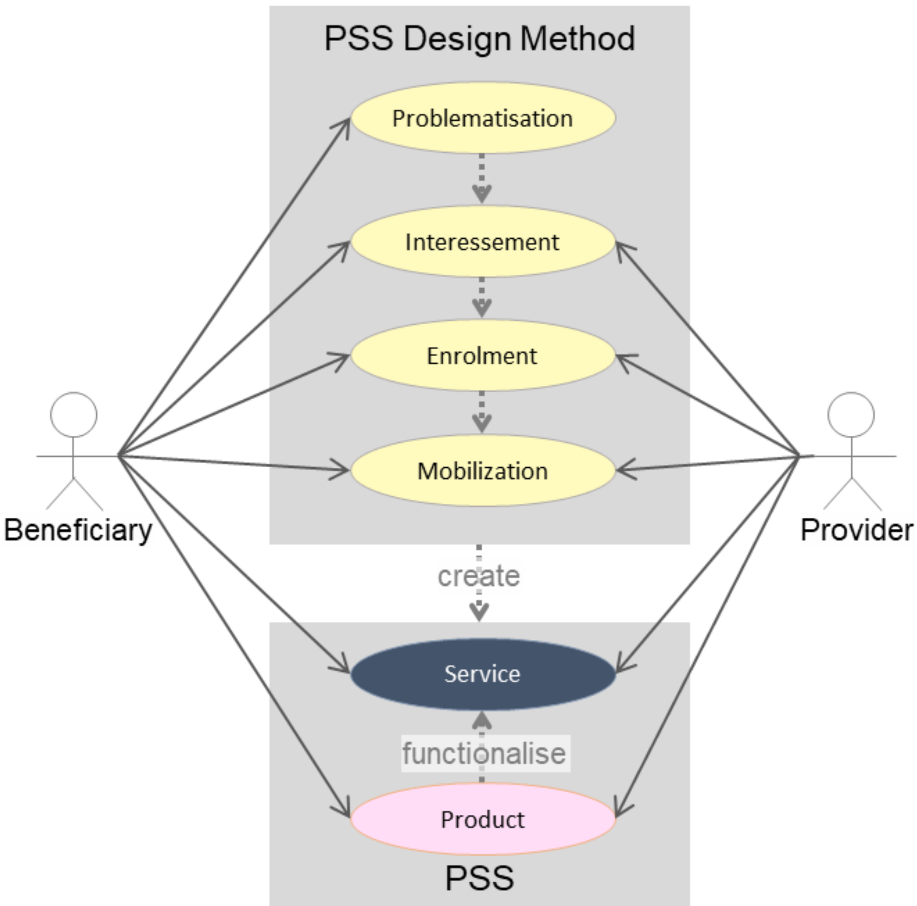

Figure 19: PSS Design Method Reference Model (Yip et al., 2019)

The proposed design method is in congruence with the lifecycle approach of PSS design. Table 20 maps the intended outcomes from PSSDM implementation to the three phases of a PSS lifecycle. The BOL is concerned with understanding the problems and finding their possible solutions. The MOL helps maintain the solution through continuous improvements and value adding. The EOL starts with the recognition that the solution is obsolete and facilitates the decision over its future.

Table 20: PSSDM congruence with PSS Lifecycle approach (Yip et al., 2019)

Lifecycle	**The intended PSSDM outcomes**
BOL	• Understand the actors' problems and demands • Identify actors' resources • Create a value proposition • Develop a solution
MOL	• Obtain continuous customer response and feedback • Improve customer/service experience and PSS performance • Add value through dynamic innovation to solve changing customer needs
EOL	• Recognise if the PSS is no longer valuable or sustainable • Decide the fate of PSS - reuse, recondition, remanufacture, recycle or retire

As discussed previously in Section 2.4.3, value co-creation, being a multi-stakeholder activity, requires trust between all the actors to develop a strong relationship (Chew & Gottschalk, 2013; Pera et al., 2016). Trust is also an essential factor that influences the PSS (Kuo et al., 2010; Sattari et al., 2020), integrated project delivery (Walker & Lloyd-Walker, 2019), SDL (Greer at al., 2017; Shula et al., 2020) and ANT (Murphy, 2006; Pieters, 2011). Consequently, the researcher understands that the ANT-SDL based design method also requires trust among the participating actors to develop the PSS solution. However, studying the factor of trust is beyond the scope of this thesis and its research questions. So, this thesis assumes the required amount of trust between the participating actors' design methods in the solution network. This assumption has been a part of this conceptual reference model development, its demonstration (Chapter 5) and evaluation (Chapter 6).

4.2.3.1 Problematisation and Interessement

Problematisation is the stage when the focal actor (customer or the provider) defines the problem and identifies other actors with interests consistent with its own (Al-Abdullah, 2015). If a customer faces a problem with an existing system or needs a new one, the customer becomes the *initiator*. Similarly, if the provider proactively notices a problem in the existing system or identifies an opportunity for a new PSS, the provider becomes the *initiator*.

In a PSS setting, a customer may have previously been involved with various actors in value creation to form a black box. However, humans, businesses and customer demands are dynamic, and value co-creation is based on this dynamic environment. The co-creation process starts with the emergence of a new problem of a changed customer need that requires a new service solution. Accordingly, initiation of the design process by identifying the problem, the requirements and the priorities becomes the value co-creating activities of this stage. The actors of this stage are thus the *initiator* and the *follower* of the design process.

The second stage of ANT is *Interessement*, where attempts are made to persuade other actors to accept the definitions and the needs defined by the central actor (Al-Abdullah, 2015). In a PSS, *Interessement* comprises the efforts by the *initiator* to create interest among other actors by conveying the problem, assessing the requirements and ideating possible solutions. As shown by Numata et al. (2015) and Uden and Francis (2009), this stage involves identifying the potential actors in the form of partners to collaborate with, customers to target for, and operators to use the particular solution. This task is achieved by interaction, connection and collaboration with concerned actors (customers and providers). The interested providers create the value proposition based on the current context of the network, of itself and of the customer. As per SDL, the provider can make the value proposition only, while it depends on the customer to determine the value and accept the offer (Edvardsson et al., 2011). So, the actors in this stage consist of the *initiator* and the potential actors. Value co-creation activities by these actors in this stage develop the value proposition. Figure 20 shows the inclusion of the *Problematisation* and *Interessement* stages in the PSS design method. The green parts consist of the value co-creating activities while the pink part consist of the value co-creating actors.

Once the customer problem is identified and the interest in solving it is generated, actors need to develop and implement it. However, the actors (provider and customer) may already be part of their complex networks and solving the current customer problem may require them to form a new actor-network. This network is formed by implementing the next two ANT stages. In these two stages, the selected actors enrol into the network by co-creating the solution and then mobilise the network by implementing the solution. These two steps are discussed in the following section.

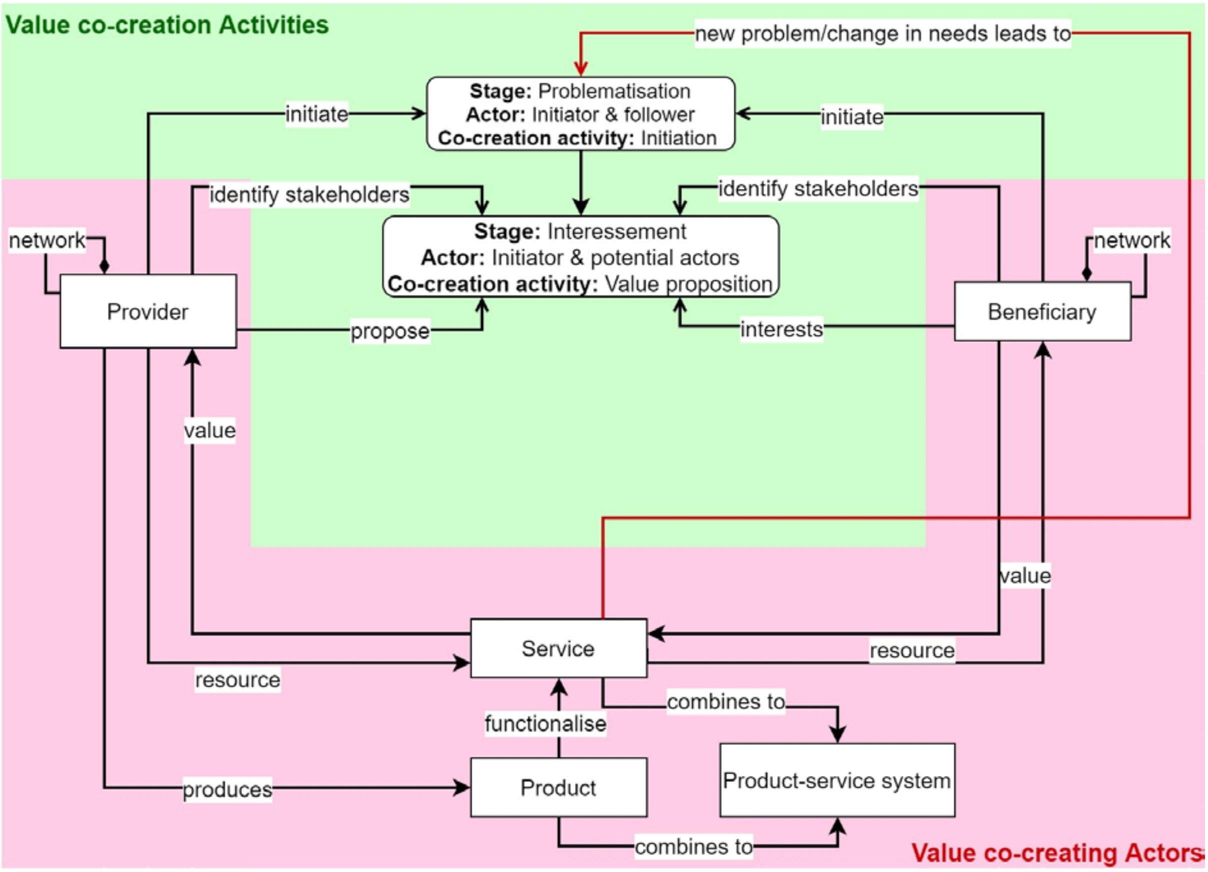

Figure 20: PSS Design Method - *Problematisation* and *Interessement*

4.2.3.2 Enrolment and Mobilisation

The third stage of ANT translation is the *Enrolment* process, which occurs when the network reforms following the actors' acceptance of their roles as defined by the *initiator* (Callon, 1986). The most suited among the interested actors in a PSS are chosen by the initiator to enrol in the system by forming a value co-creation network. This network involves human and non-human actors. A relationship is established between the customers and the providers who then determine the service value-chain in the system (Numata et al., 2015). *Enrolment* depends on the *initiator*, the central actor (customer), the context and how those actors fit into that context. The customer solution is thus co-produced with the capabilities, resources, culture and strategy of the central actor or customer. The actors also decide on the business model to be implemented in that context. The mutually-agreed business model governs the partnerships. Thus, the actors involved in this stage are the customer and the enrolled actors consisting of provider, designer and managers who perform the value co-creating activity of co-production.

Finally, *Mobilisation* is the stage in which the solution gains network-wide acceptance and is black-boxed with the new actors incorporated (Callon, 1986). These actors agree and start the process of value co-creation, where they work together to create the desired value from their respective perspectives (Qu et al., 2016). As shown by Numata et al. (2015), the network is maintained at fixed intervals by the *initiator*, who may initiate changes in the status quo. To maintain this network, service-orientation is practised through value co-creation by encouraging knowledge sharing, skill development and value identification among the actors in the network. During value co-creation, the value-in-use is more inclined to be in the customer's control since the customer is the more active actor during service usage.

Changes in the circumstances of the customer generate varying needs. The changing circumstance may be of three kinds as listed below. A more detailed explanation is provided in the following section (Section 4.2.4).

1. Changing circumstance in the form of a problem that needs a new PSS solution starts BOL (see Section 2.3.1).
2. Changing circumstance in the form of a reconfiguration or maintenance of the PSS solution during implementation, delivery and support in the MOL (see Section 2.3.2).
3. Changing circumstance in the form of reuse, recycle or retirement of the PSS solution based on the evolution of the customer problem leading to EOL (see Section 2.3.3).

Regardless of the type of changing circumstance, each new problem arises from the existing solution and initiates the *Problematisation* stage of the PSS design method. Thus, the proposed PSS design method addresses the changing business contexts to formulate new services that cater to dynamic needs. From the discussion above, it is understood that all actors in the network participate in this stage towards mobilising the customer solution. This participation leads to the generation of value-in-use, which is the value co-creating activity of this stage. Figure 21 shows the inclusion of the *Enrolment* and the *Mobilisation* stage into the reference model of the PSSDM. Continuing with the earlier convention, the green parts consist of the value co-creating activities while the pink part consists of the value co-creating actors.

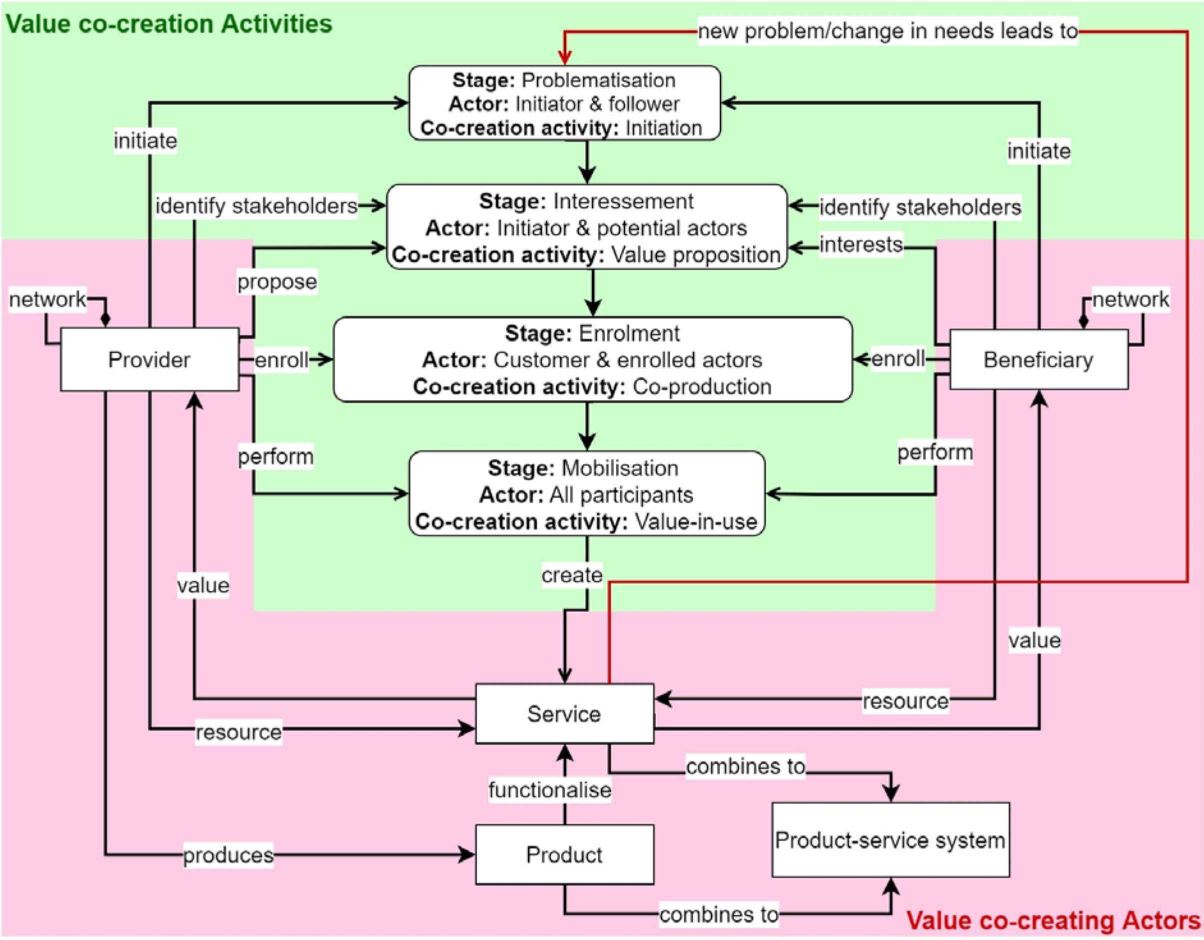

Figure 21: ANT-SDL-inspired PSSDM reference model

This design method was tweaked further to make it more standardised and streamlined. Previous discussions (in Sections 4.2.3 and 4.3.2.1) have made it clear that the initiator identifies the new problem or change in needs. So, the apparent line connecting the *service* to the *Problematisation* stage can be considered redundant and deleted accordingly. However, the change is circumstances is one of the factors that connect the customers and the providers. In this factor, the customers experience the circumstance as a new problem while the providers are informed about it as a new need. So, this connection was added to the PSSDM reference model. The streamlined PSSDM reference model is illustrated in Figure 22.

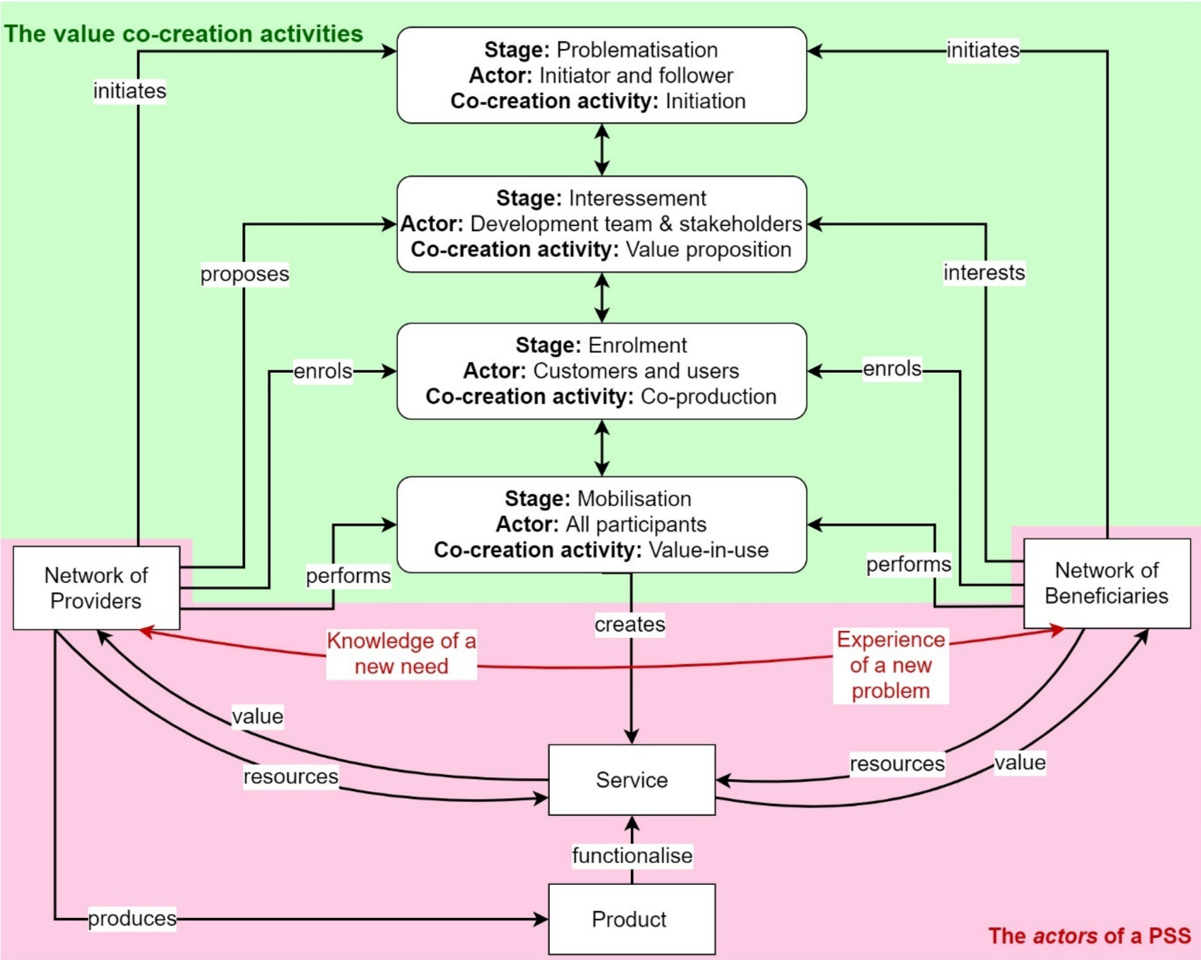

Figure 22: Streamlined ANT-SDL-inspired PSSDM reference model (Rizvi et al., 2019b)

4.2.4 Congruence of PSS Design Method and PSS Lifecycle

The proposed PSS design method is consistent with the lifecycle approach, which was found to be the most holistic and overarching PSS design method. The three stages of the lifecycle from the perspective of the proposed design method are discussed below.

4.2.4.1 Beginning of life (BOL)

In the lifecycle approach, the BOL phase is where problems are identified, needs are analysed, ideas are generated and requirements are evaluated. This stage covers the *initiator*, the stakeholder and the value proposition of the PSS design method. The *initiator* is the actor who is aware of customer needs. The needs are the route to the value creation in the PSS. The providers create appropriate service offerings by combining the resources and the product

(Hara et al., 2009). The customers' needs lead to requirement elicitation, generation, identification and analysis. The design activities within the BOL phase are iterative. At the end of the BOL phase, actors' interests are understood, the value proposition is created, and the solution is developed. The completion of this phase prepares the actors for the next phase of resources integration.

Once the network of interested stakeholders is formed, the PSS is designed by combining the respective resources, knowledge and skills. It involves processes such as solution selection (Dewberry et al., 2013; Song & Sakao, 2017; Zhu et al., 2015), decision making (Geng et al., 2011; Pezzotta et al., 2016), assessment of sustainability, value, risks and design (Alonso-Rasgado & Thompson, 2006; Bertoni et al., 2016; Chou et al., 2015; Peruzzini et al., 2014). The resultant PSS forms the service offer, which can create value for and with all the involved stakeholders.

4.2.4.2 Middle of life (MOL)

The MOL phase consists of activities performed during the implementation and commissioning of a new PSS. During this phase, the customer interacts with the new PSS and generates value-in-use for the actors involved from the offered services (Sassanelli et al., 2016; Schweitzer & Aurich, 2010; Tran & Park, 2014). Customer experience, defined as an ongoing and iterative process that requires continuous analysis and improvement of the PSS by the providers, is a crucial part of value co-creation that providers must seek. Value is co-created optimally when the value-creating process involving customer, provider and interface are aligned (Payne et al., 2008). The customer's satisfaction and degree of involvement determine the strength of the relationship. Through the appraisal of the functional and emotional outcomes of the PSS, value-in-use is generated in the MOL phase (Sandström et al., 2008). This process continues until the actors recognise that the PSS is no longer sustainable and initiate the next phase. Overall, this stage involves service innovation, design of new PSSs and solution delivery.

4.2.4.3 End of life (EOL)

The EOL stage of the PSS design deals with the final fate of the PSS. The PSS can be reused, remanufactured, recycled or retired, based on the context (Sakao & Mizuyama, 2014; Sassanelli et al., 2016). The EOL decision is also a value co-creation process. An actor may no longer find value in a service and decide to end the relationship. New actors may enter the network to complete the EOL. The EOL thus uses all four stages of the proposed design method. An *initiator* initiates the EOL process and obtains the interests of the concerned actors. The EOL decision is then collectively made and executed accordingly.

4.3 Cyber-Physical Product-Service System Design Method

4.3.1 Defining CPPSS

Based on the extant literature, as discussed in Section 2.6.1, this thesis proposes the definition for CPPSS as follows;

A CPPSS is defined as a product-service system equipped with cyber-physical capabilities to enable value co-creation using its technology and intelligence yielding higher efficiency, usability and appeal.

The actor-network model derived from this definition is shown in Figure 23. A CPPSS may seem closely related to smart products that are described as an entity designed to provide improved simplicity and openness through improved interaction (Mühlhäuser, 2007). However, in reality, the CPPSS is a broader field which adds the service, value, actor-network and environmental aspects to smart products. Thus, smart products are more like a CPS from a technological perspective. This classification is essential because a smart product is a product equipped with cyber-physical capabilities. In comparison, a CPPSS is a PSS that is equipped with cyber-physical capabilities. Thus, equivalent to use of the term '*smart*' in describing smart products, CPPSS can reciprocally be termed a smart PSS.

4.3.2 Modelling CPPSS

The PSS actor-network model, discussed in Section 4.2, is based on the principles of ANT and SDL. The same principles were applied to develop the actor-network model for a CPPSS, with service once again kept as the core of the model, resulting in a service-oriented CPPSS.

Just like the PSS, the CPPSS solution to a customer problem is attained by combining the resources of the actors. The entities, consisting of service, beneficiary (customer), provider, PSS, CPS and CPPSS are identified as the actors in a service-oriented CPPSS, and all these actors work in sync to co-create value-in-use.

In line with the PSS actor-network model, the service is functionalised by the product and this service enables the CPPSS to serve the customer. The service is also continuously analysed and managed by the cyber part of the CPS to respond to the changing needs of the customer. The sensors and actuators enable this function in the physical part of the CPS. Thus, in the CPPSS, the CPS regulates the PSS to serve the customer by providing solutions to the problem. Figure 23 shows the service-oriented CPPSS actor-network model.

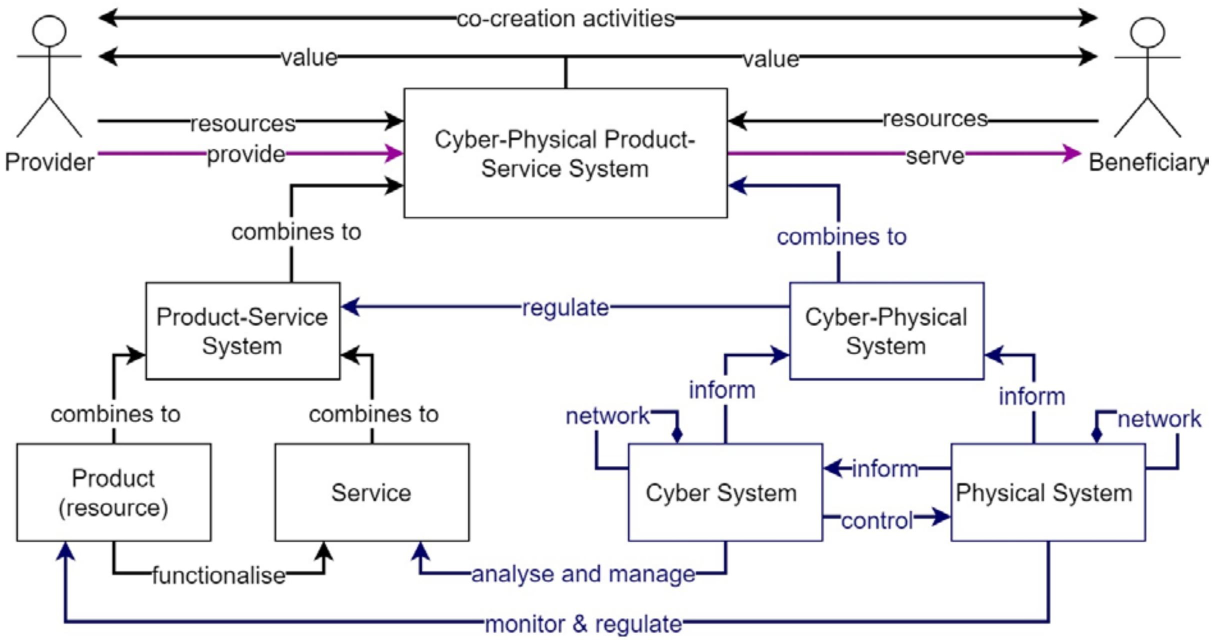

Figure 23: CPPSS actor-network model

4.3.3 Designing CPPSS

The proposed CPPSSDM reference model was developed from the ANT-SDL-inspired PSS design method. The design method consists of four stages of translation. The cyber-physical capabilities are used to monitor, analyse, regulate, manage, and control the PSS services. These capabilities also enable the actors to interact with the CPPSS to provide experiences, feedback, and other information that offer valuable information for continuous improvement (Dutra & Silva, 2016; Marilungo et al., 2016; Scholze, Correia, Stokic et al., 2016; Wiesner et al., 2016). The feedback also leads to a customer-centric framework for value co-creation (Zheng et al., 2016). Customer-centricity is achieved by utilising the information and feedback to detect evolving customer needs and adapt appropriate CPPSS solutions dynamically. The CPPSSDM derived is illustrated in Figure 24.

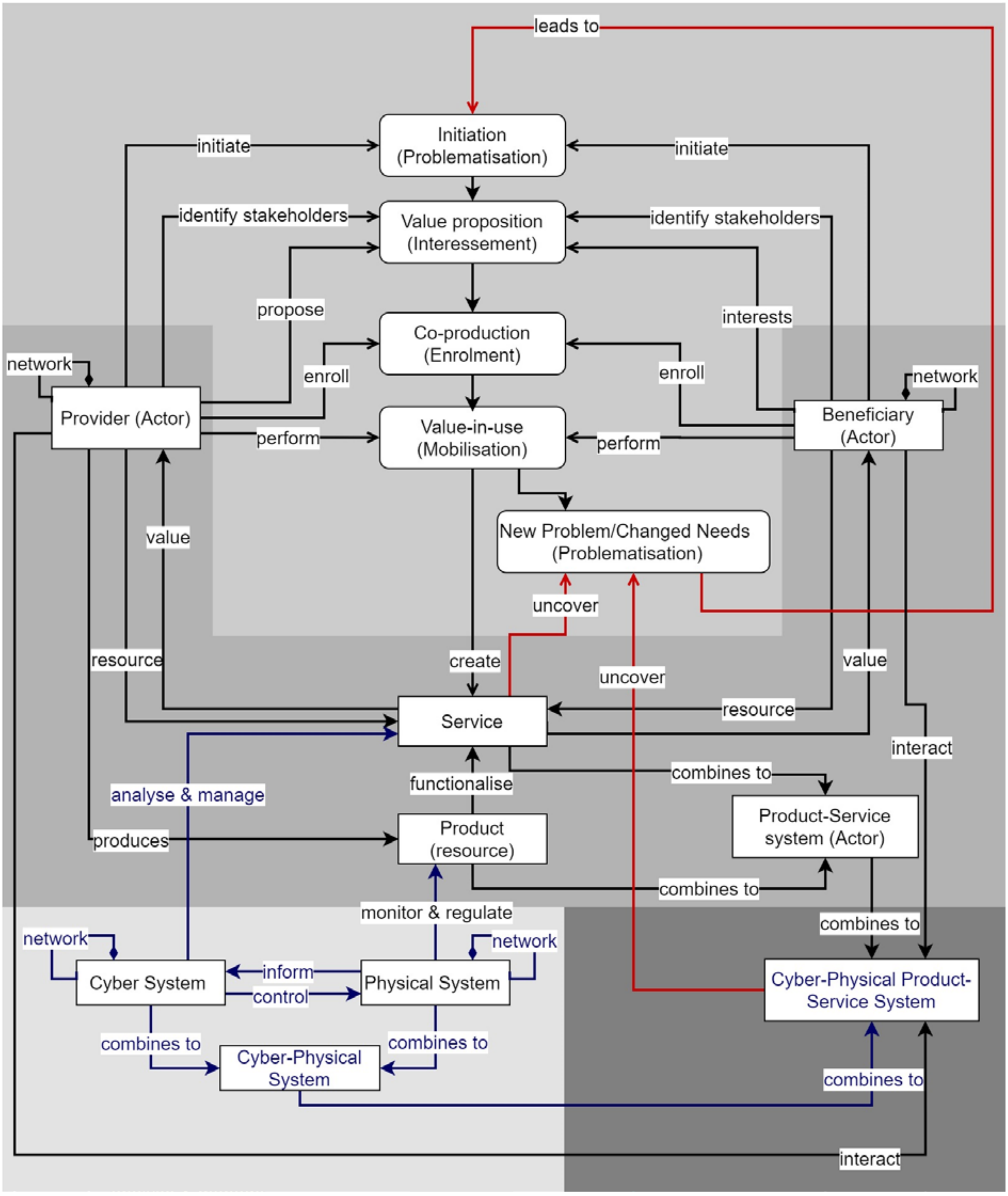

Figure 24: CPPSSDM Reference Model

This research's design method was simplified to be easily understandable by the case study participants and informants, as illustrated in Figure 25. This simplification of the design method was performed according to the PSSDM reference model developed in Section 4.2.3 and the simplified PSSDM illustrated in Figure 19. The simplified version consists of actors, constituents and the four steps of the design method. The four steps are assigned a central theme in brackets, which helps the actors understand the focus. This simplified version of the design method was used throughout the remainder of the thesis.

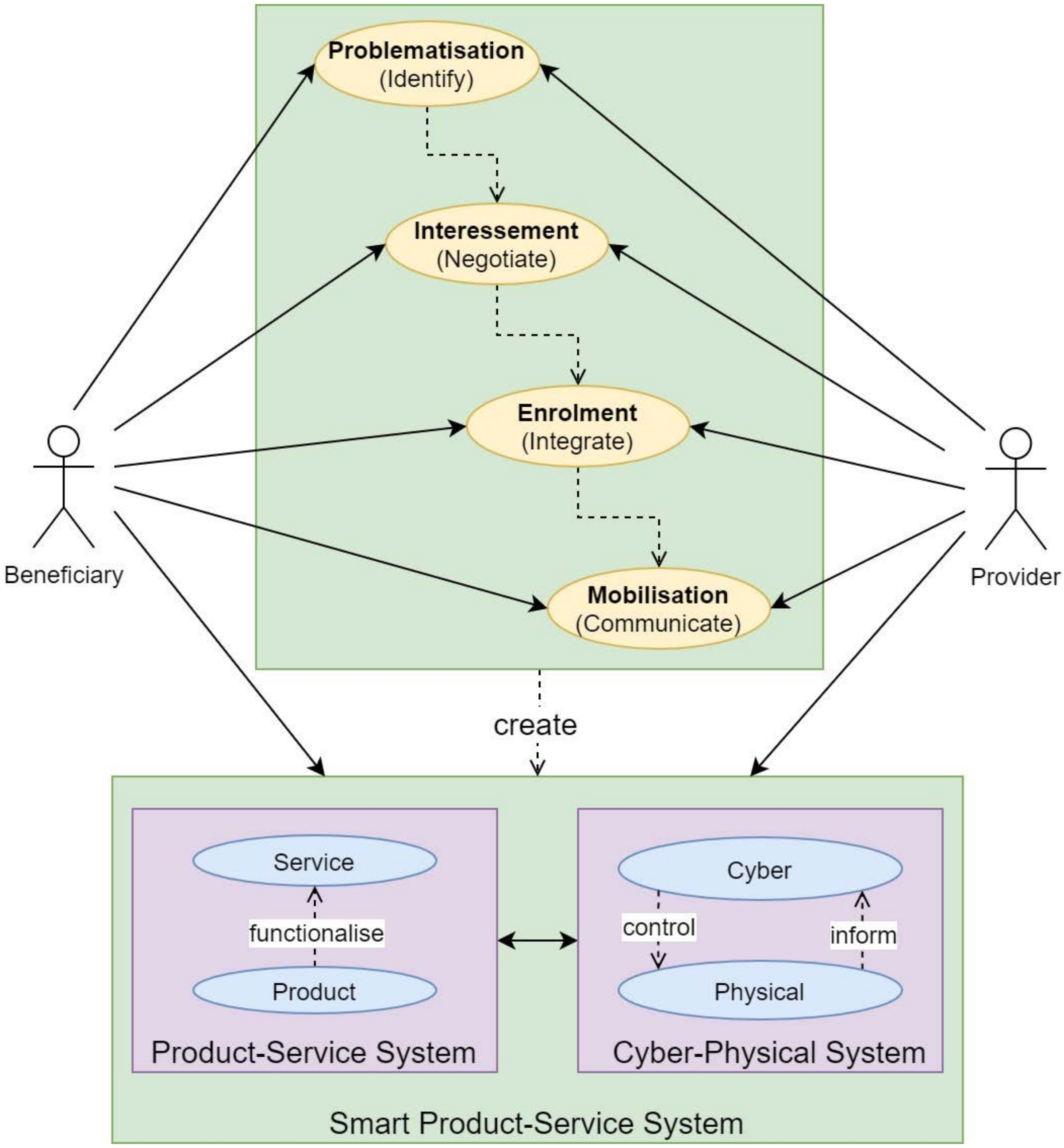

Figure 25: Simplified CPPSSDM Reference Model

4.4 Implications and Limitations of the Conceptual CPPSSDM

This research has focused on finding the processes necessary to co-create value in the customer-provider encounter domains (Durugbo & Pawar, 2014). These processes were used to design the appropriate PSS and CPPSS that could solve customer problems and the design method that was developed based on these co-creation processes has been described in this chapter.

The design method was developed using the knowledge gained from the reviewed literature and the foundational theories. Based on these concepts, it is believed that the design method can provide a holistic approach towards co-creating and co-designing a PSS and CPPSS. It divides the value of co-creation activities into four specific stages that are co-executed by the actors (customers and providers) towards designing the solution. This design method implies that the selection of a specific engineering design technique, business model, value preposition and other factors are at the discretion of the collaboration between the actors in the system. Furthermore, the non-human parts present in the current PSS, CPS and CPPSS also influence the way any future CPPSS is designed.

Despite the conceptual strengths of the proposed design method, the underlying mechanisms of the value co-creation processes in each of the four steps remain unclear. The roles, tasks and responsibilities of the stakeholders/actors in the CPPSS actor network are yet to be defined. To address this limitation, this research implemented the fourth step of the DSRM, that is, to demonstrate the design method and learn from this experience. The Demonstration step was accomplished by conducting case studies with participants that revealed the intrinsic techniques applied in the real world to co-create value. These techniques were then mapped to the proposed design method to form the refined CPPSSDM reference model.

4.5 Conclusion of Chapter 4

The conceptual CPPSSDM developed in this chapter is based on the principles of SDL and ANT. The definitions, models and design methods were proposed consistent with the available literature on a PSS and CPPSS. The CPPSS lifecycle is also explainable using this design method. The next step of this research was to demonstrate the design method in the real world and obtain data that could refine it further. The next chapter presents the case studies approach, where data collected through semi-structured interviews revealed the internal value co-creation activities performed by the actors in a CPPSS.

Chapter 5 – Demonstration of the Design Method

5.0 Introduction

The fourth step of DSRM is the Demonstration, where the artefact is applied to solve the problem using an appropriate activity. Following that, the fifth step is Evaluation, where the artefact is observed and measured as to how well it solves the problem (Peffers et al., 2007). This chapter includes the fourth step of this research method, as shown in Figure 25.

In this chapter, the conceptual CPPSSDM reference model proposed in Chapter 4 was used as the lens through which to understand how a real-world CPPSS is designed. Four case studies were introduced and examined according to the value co-creation activities performed in designing the solutions.

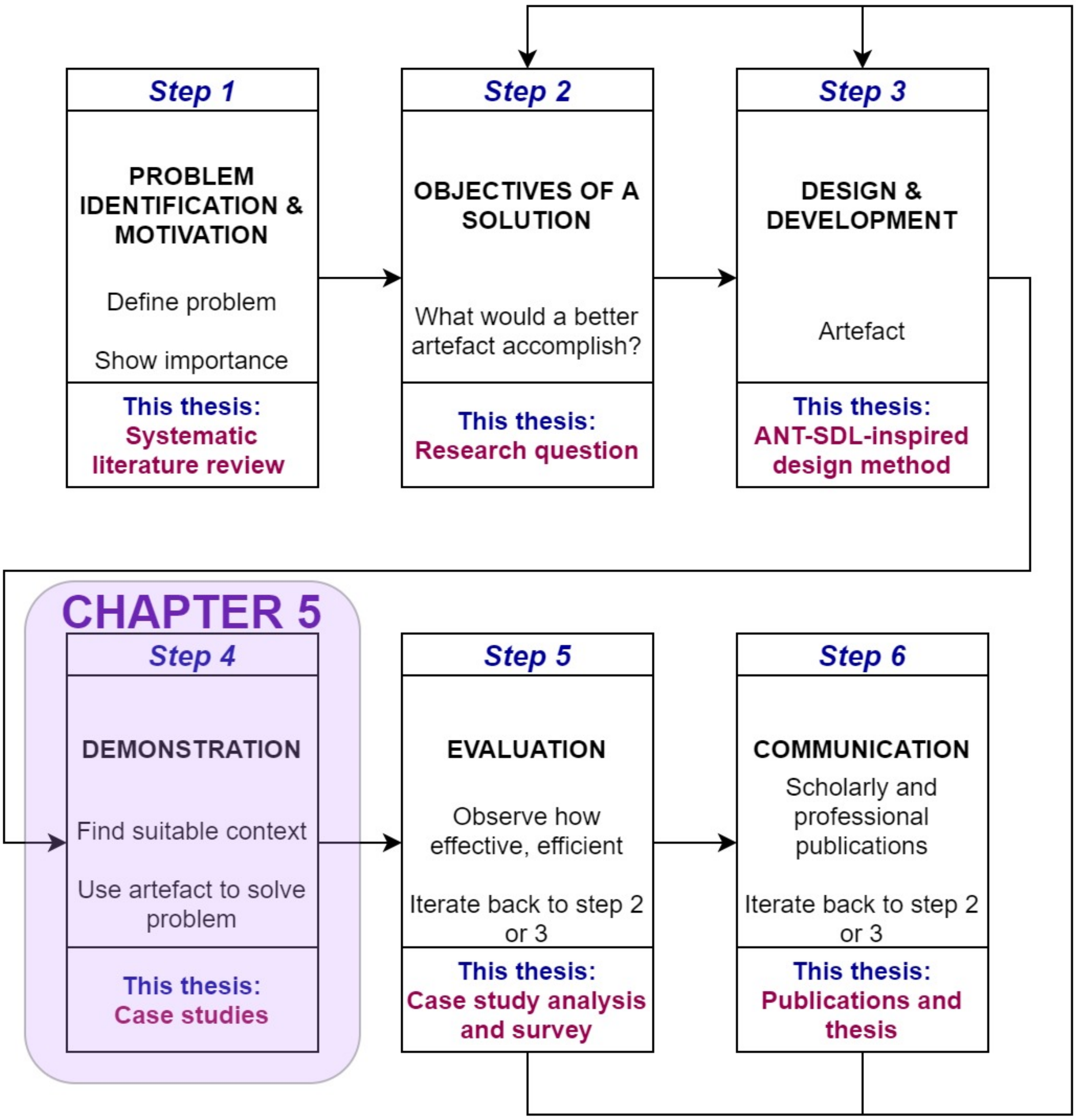

Figure 26: Steps 4 of the DSRM (adapted from Peffers et al., 2006; Peffers et al., 2007)

This chapter is divided into six sections, as shown in Figure 26. Section 5.1 elaborates on the cases selected for this research. Sections 5.2, 5.3, 5.4 and 5.5 respectively discuss the four cases. The concluding remarks of this chapter are in Section 5.6.

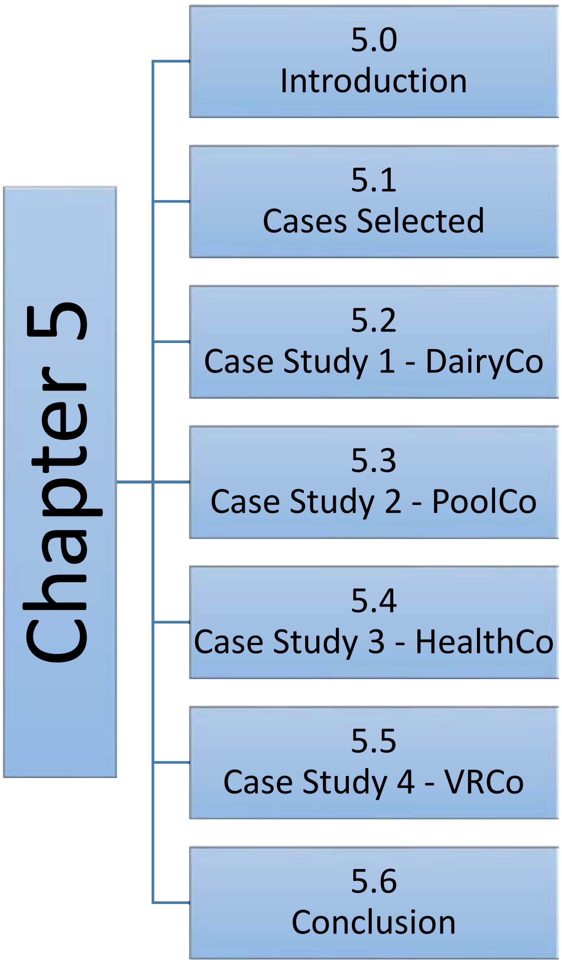

Figure 27: Structure of Chapter 5

5.1 The Case Studies

This research conducted case studies to understand the CPPSS design and implementation practices in the real world. These case studies helped execute the fourth and fifth steps of the DSRM by demonstrating and evaluating the feasibility of the proposed design method. Four case study organisations, codenamed DairyCo, PoolCo, HealthCo and VRCo, were implemented. As the name suggests, these organisations were involved in dairy manufacturing, pool management, health informatics and virtual reality technology, respectively.

The size of these organisations varied between large scale, small scale and start-up. More importantly, these organisations were involved in co-creating a CPPSS, either as a customer or a provider, to solve a particular problem in a business-to-business context. This thesis followed the design processes involved in developing new solutions for evolving customer problems in their respective field. As a result, the data collected were only connected to the BOL and MOL of the CPPSS. The case studies were conducted using the semi-structured interview approach explained in section 3.3. The interviews were then transcribed and analysed to find the inter- and intra-case themes related to value co-creation.

The following four sections discuss the company selection procedure, the methodology for collecting the data and the initial findings from each case. Overall, this chapter gives an understanding of the practitioner's perspective on CPPSS design. The cross-case analysis is provided in Chapter 6.

5.2 Case Study 1 – DairyCo

5.2.1 Introduction

DairyCo was a major dairy processing and packaging company in Australia that owned some of the country's most iconic brands of milk-based products. DairyCo purchased more than a billion litres of milk from more than five hundred dairy farmers around the country every year. It caters not only to local demands but also exports milk and its derivatives to other countries. The subject for this case study was a DairyCo site that was using a CPPSS for processing and packaging flavoured milk. This site had recently invested heavily in installing new manufacturing systems. After these systems had been commissioned, the site was actively making changes based on the evolving demands of the operators, management and the industry.

The components in this CPPSS comprised the equipment, machines, tools and software provided for the processing and packaging of DairyCo's dairy products. These components enabled smart sensing and actuating of tasks through supervisory control and data acquisition

(SCADA) systems. The ownership of the CPPSS was transferred to DairyCo, with the suppliers, as per the agreement, providing such value-added services as troubleshooting, software/hardware upgrades, maintenance and performance improvements. Based on this information, the CPPSS implemented at this site could be considered a product-oriented type of business in a business-to-business context. As shown in Table 21, the above features of DairyCo matched the selection criteria discussed in Section 3.4.2 and the company was chosen as the first case study for this research.

Table 21: DairyCo Selection Criteria

	Selection Criteria	**DairyCo Observation**
1	Implementation of CPPSS	As Customer and *Initiator*
2	Interaction with actors	Co-designed solution with providers
3	Open to share knowledge, experience and opinions	Various personnel participated in interviews
4	Operation of business	Local markets and few exports
5	Relationship of business	Business-to-business

5.2.2 Participants

DairyCo had the policy to have a dedicated in-house team that would co-ordinate with the providers in every solution design and implementation it undertook. DairyCo made sure that the team always consisted of subject matter experts in engineering, management and operations. The DairyCo participants were chosen from each of these sections of the organisation and are listed in Table 22.

Table 22: DairyCo Participants

No.	**Participant group**	**Participants**	**Average experience at DairyCo**
1	Management	2	17 years
2	Engineering	3	10.5 years
3	Operator	3	12 years

5.2.3 Developing DairyCo’s CPPSS

The requirement for a new CPPSS was conceived at DairyCo when the business recognised growing demand in the flavoured milk market and required new systems to cater to that demand. As initiation, the management created the base plan, specifying metrics such as the number of bottles per minute, silo capacities and floor space required to meet the growth target. The management found this case study site met with those requirements best and decided to revamp it according to the new manufacturing capabilities.

As the focal actor, DairyCo floated the metrics on size and capabilities in a tender process that invited different suppliers to propose solutions through collaboration. After analysing the offerings, DairyCo decided to procure each section of the packaging lines from a different supplier and combine them through the co-design process. The design process in DairyCo was highly iterative, and after various alterations, the processing and packaging lines were functional and able to deliver the expected targets. Value-in-use was generated by gathering performance and waste management data that were then used to continuously improve the processing and packaging lines based on the demands of the operators and industry. DairyCo claimed that these value-in-use activities saved about $2M every year through process improvements and waste reduction.

5.2.4 Actors and Actions

The inferences drawn from the various tasks and relationships observed in DairyCo's solution design could be categorised into the four design stages of the ANT-SDL model. The four main actor groups (i.e., managers, engineers/designers, providers, and operators) and their actions are shown in Figure 28. These inferences were mainly for the BOL of the CPPSS and are briefly discussed below.

- *Problematisation*: The managers predicted the product demand based on customer metrics. The engineers predicted the production requirements based on the current issues informed by the operators. This prediction persuaded DairyCo to look for collaborators in developing the new systems.

- *Interessement*: The managers then floated tenders to draw the attention of potential collaborators. This process led the interested providers to negotiate their relationship with DairyCo and then move into the solution development process.
- *Enrolment*: The solution was co-designed by integrating the knowledge and expertise of the providers and the operators while adhering to the agreed-upon requirements set forth by DairyCo. This new CPPSS would solve the concerned problems.
- *Mobilisation*: The solution was then implemented through communication between the actors. Providers and engineers communicated the information about the improvements in the new system while the operators learnt the operating procedure of this new CPPSS.

During MOL, with the usage of this CPPSS, managers communicated the priorities of the evolving challenges, leading to identifying new problems and reiterating the design process.

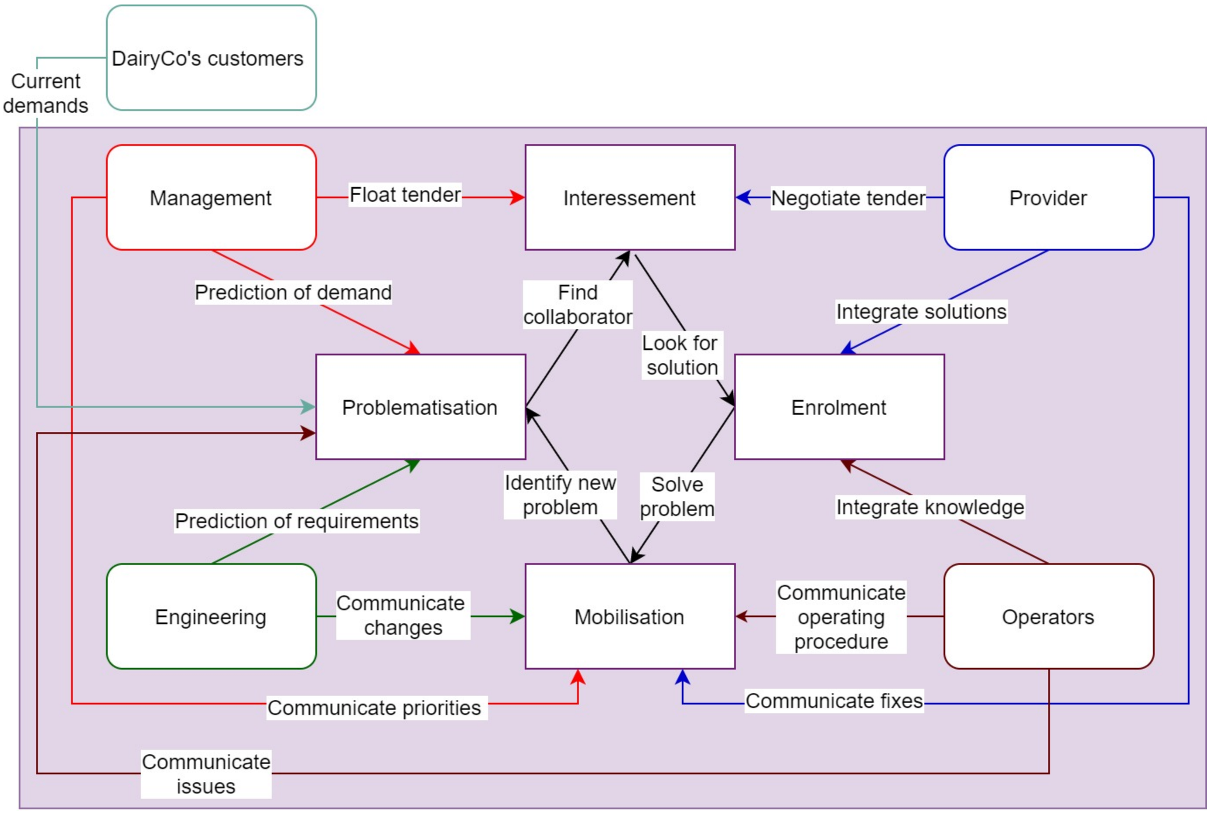

Figure 28: DairyCo Actors and Actions

These design processes were then simplified and presented in comparison with the CPPSSDM reference model, shown in Figure 29. The bold blue text signifies the case-specific steps. The four components of the CPPSS are discussed below. A more detailed discussion on the findings is provided in the next section (Section 5.2.4).

- *Product*: The product was a combination of hardware and software systems that functionalised the solution of processing and packaging milk-based beverages.
- *Service*: The facilities like troubleshooting, system upgrades, maintenance, data analysis and performance improvements formed the services that helped enhance the solution.
- *Cyber*: The web and cloud technologies that enabled the human-machine interface and SCADA formed the cyber part of the solution.
- *Physical*: The sensors, actuators, machines and HMIs constituted the physical part of the solution.

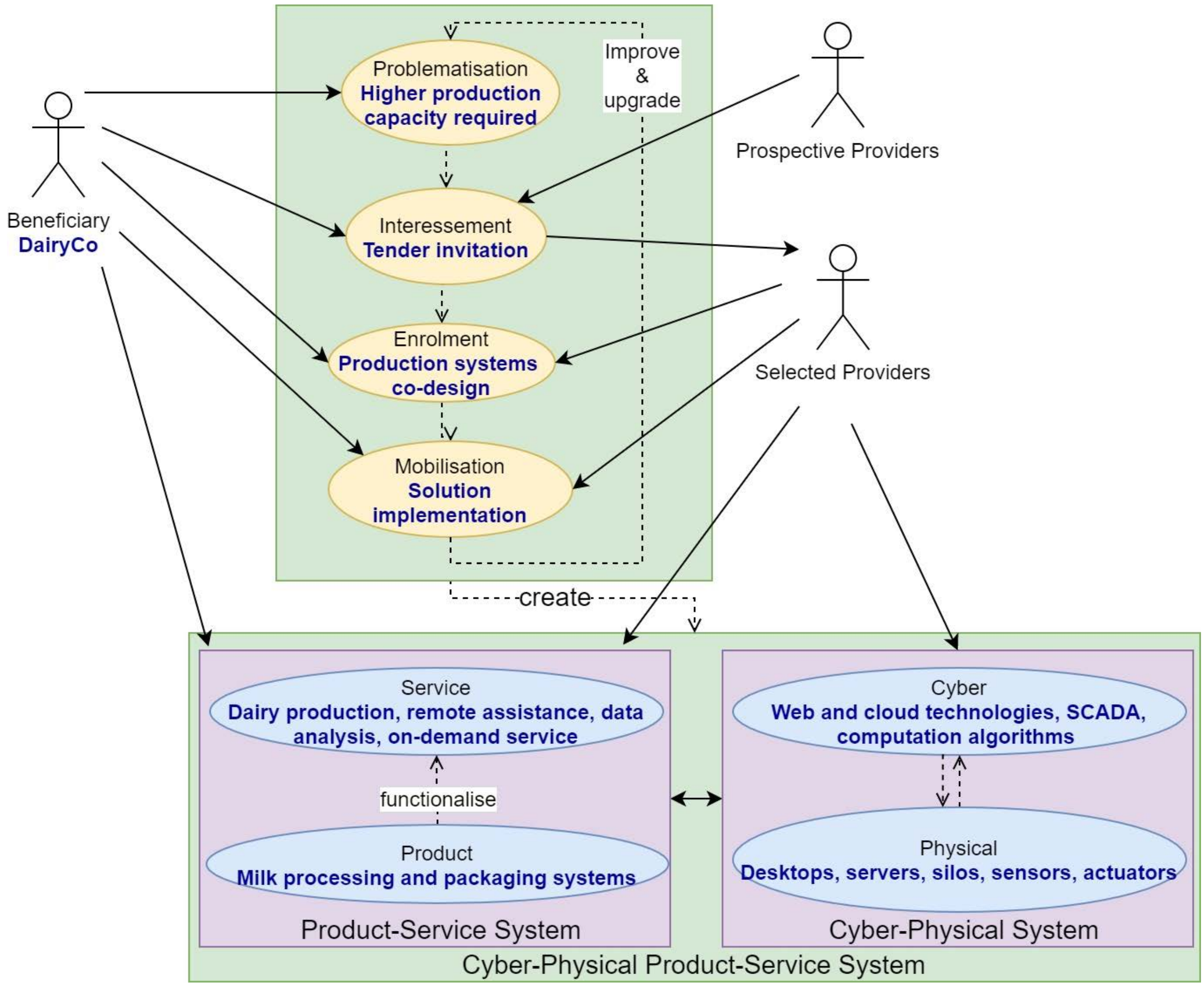

Figure 29: DairyCo CPPSSDM

5.2.5 Findings

5.2.5.1 Problematisation

From the interviews, it was identified that the *Problematisation* stage was dependent not only on the current customer demand but also on the future expectations of the business. Although present and future demands were incorporated during the *Problematisation* stage, the business seemed to have predicted a lower volume of demand than actually occurred. This flaw led to the CPPSS being run at full capacity to meet current demand (which was later addressed by adding more modules into the CPPSS). This fact is demonstrated in the quotes below.

> *"So that's one of the constraints we had, but that was only because the capacity that was predicted was going to be so much lower" – DO1*

And reinforced by:

"Besides, it's not ideal. we're (this site) running ... really at its maximum capacity." – DM2

5.2.5.2 Interessement

The *Interessement* stage was dependent on the value perceived by the stakeholders in joining the actor network. Constraints such as size and flexibility dominated the *Interessement* stage.

"... is really the best and also the smallest footprint, i.e. their size was the smallest." – DE1

The *Interessement* stage was also governed by such factors as the quality of the CPPSS, the reputation of the brand and its compliance with world standards.

"I mean these strengths of course to grow our brand" – DO1

"We came up with basically the line automation standards to support ... we aligned with ISA which is the International Society of Automation" – DE2

"So, it was it was always customer focus for quality improvement" – DE3

5.2.5.3 Enrolment

During the *Enrolment* stage, the factors of goodwill and customer loyalty appeared to play a major role in the selection of collaborators.

"And you kind of rely on their goodwill that it is gonna be done through site acceptance testing" – DE1

"So, you have to be firm in the faith. So as long as people are abiding by the rules, they are open and honest (in) doing their job." – DE2

The constraints in the *Enrolment* stage were the difficulty in sharing common goals and the geographical distribution of different stakeholders. For example, DairyCo was concerned about the lack of availability of local and physical after-hours support from the providers.

> *"I think during the project, there was not enough emphasis on making sure that we have after-hours support or local support from suppliers." – DE1*

Furthermore, once a relationship was established to form an actor network, that actor network seemed to be involved in solving future problems. For example, DairyCo formed partnerships with the providers directly or indirectly based on the complexity of the solution. This partnership continued throughout the life of the solution.

> *"… we generally partner with an integrator who supports us with integration (in processing). And in the packaging, we work directly with the various suppliers." – DM2*

5.2.5.4 Mobilisation

The *Mobilisation* stage was the most complicated as it involved communication between the CPPSS modules from different providers to provide a holistic solution to the customer problem. The initial finding of this case study showed that communication between the CPPSS actors was of utmost importance.

> *"So, there was a constant talk between us (operators), the providers and the commissioning team for what we wanted and what could be improved."- DO2*

> *" … So, in essence, there is a very big lack of open communication space between those three levels of engineering and maintenance" – DO1*

5.2.6 DairyCo Summary

The actors involved in the value co-creation process were the managers, operators, engineers and suppliers. In some instances, DairyCo had to deal with the providers directly and in others deal with them indirectly through an integrator. All the participants valued the brand image, improvements and competitive difference while supporting one another in the value co-creation process. The analysis of the data obtained from DairyCo provided an insight into the various value co-creation activities practised, limitations of the current practices and the opportunities to improve. Figure 28 shows the various tasks and factors involved while Table 23 lists the key findings for each stage in implementing the CPPSSDM for DairyCo.

Table 23: Key findings for each stage of the CPPSSDM in the DairyCo case study

Stage	**Key VCC Themes**	**Components of the themes**
Problematisation	Prediction	• Predicted future capacity to be produced • Requirements to fulfil predictions • Site size and dimensions • Preferences of quality of products and time to market
Interessement	Tender	• The best solution found through negotiation • Issues discussed through regular meetings • Brand image influences on stakeholder selection • Some issues suffered negligence
Enrolment	Integration	• Location of each actor • Education requirements for resident personnel • Certain tasks outsourced • Generic systems' customisation • Agreement/disagreement on issues and their solutions • Loyalty and relationships between actors
Mobilisation	Communication	• The priority of different tasks and requirements • Handover of changes made within the system • Skill development of personnel through training • Temporary fixes to issues • Issue escalations through the chain of command • Emotional investment on the system and the team

5.3 Case Study 2 – PoolCo

5.3.1 Introduction

PoolCo was a pioneer in providing solutions for swimming pools, spas, aquaculture and water purification systems. It was established in the early 1980s and now had a global reach covering North America, Europe and Asia. Moreover, it had one of the largest outlet networks in Australia and New Zealand. To cater to the growing demand for pool management solutions, the company had launched a software application that helped customers monitor their pools and enhanced their interactions with PoolCo. This software application enabled value co-creation through pool quality management, customer feedback, remote monitoring, easy scheduling and pool status tracking.

The product component of the CPPSS developed by PoolCo consisted of a software application and related hardware. These products helped PoolCo and its customers identify the services required for the management of their pools. PoolCo had created multiple customer profiles to cater to different kinds of categories of customers. The service components of PoolCo's CPPSS ranged from pool care advice to DIY customers to total pool care or à la carte services to time-poor customers. The software application developed and owned by PoolCo was used to provide these services to its customers. This information confirmed that the CPPSS type is dependent on customer choice. Based on a customer's requirements, the CPPSS implemented could be product-oriented (advice and à la carte services) or result-oriented (total care) in a business-to-consumer context.

As shown in Table 24, PoolCo's features matched the selection criteria discussed in Section 3.4.2, and thus it was chosen as the second case for this research.

Table 24: PoolCo Selection Criteria

	Selection Criteria	PoolCo Observation
1	Implementation of CPPSS	As provider and *initiator*
2	Interaction with actors	Co-designed solution with customers, franchisees and application developers
3	Open to share knowledge, experience and opinions	Various PoolCo personnel, franchisees and application developers participated in interviews
4	Operation of business	Local markets
5	Relationship of business	Business-to-consumer

5.3.2 Participants

The development of the PoolCo CPPSS involved mainly three members of the company who represented the marketing, technical and logistic aspects of the solution. The provider consisted of a team of engineers and designers who collaborated with the PoolCo personnel to design the desired solution. PoolCo also made sure that the expertise of its franchisees was included by regularly taking their feedback and suggestions. A diverse sample of subjects was selected to represent each of the actors in this CPPSS. The participants of PoolCo are listed in Table 25.

Table 25: PoolCo Participants

S. No.	Participant group	Participants	Average experience at PoolCo
1	Management	1	20 years
2	Engineering	2	9 years
3	Operator	1	20 Years

5.3.3 Developing PoolCo's CPPSS

As an initiative to give customers more flexibility and power to monitor and manage their own pools, PoolCo decided to build a robust software application. To understand the feasibility and customer expectations, PoolCo collaborated with a local public university to survey its customers, which resulted in the creation of three major customer profiles and their respective needs and expectations. This survey was the first phase of PoolCo's solution design process.

In the second phase, PoolCo used the information from the first phase to develop the software application, in collaboration with a team from another local public university. This university team was added to the actor network because of its ability to design software applications and because PoolCo wanted to develop the solution with government support.

The team developed a software application that helped analyse pool water by measuring the chemical interactions. The application also enabled the water condition to be diagnosed and the corrective measures to be implemented. Furthermore, it streamlined customer interactions with minimal data entry and simplified customer support by recording transactions, testing activities and service history. On the franchisees' side, the application helped these retail outlets schedule technical support and access remote assistance.

5.3.4 Actors and Actions

The inferences drawn from the various tasks and relationships observed in PoolCo's solution design could be categorised into the four design stages of the ANT-SDL model. The four main actor groups (i.e., managers, franchisees, providers, and operators/end-users) and their actions are shown in Figure 30. The first phase consisted of the actors and tasks shown with the green background, while the second phase is shown with the purple background. These phases were a part of the BOL of the CPPPS, and inferences are briefly discussed below.

- *Problematisation*: PoolCo's managers proactively looked to find customer problems and sought ideas to improve sales and services. Accordingly, they looked for collaborators to find customer demands and appropriate solutions.
- *Interessement*: PoolCo's managers tested the feasibility of their ideas in the first phase while developed the demand-specific solution in the second phase. In both phases, they approached appropriate providers for the task. The end-users and franchisees shared

their requirements and needs in this stage. All these actor information are combined to look for the customer solution.

- *Enrolment*: The solution was co-designed by integrating all the information obtained about the requirements and needs for the solution. Regular meetings between the designers and PoolCo helped keep the goals on track.
- *Mobilisation*: The solution was then realised using communication between the actors.

During the MOL, the end-users request their required service, and the franchisees provided the appropriate service while the PoolCo managers monitored the system. New problems were identified over time, and the design process was reinitiated.

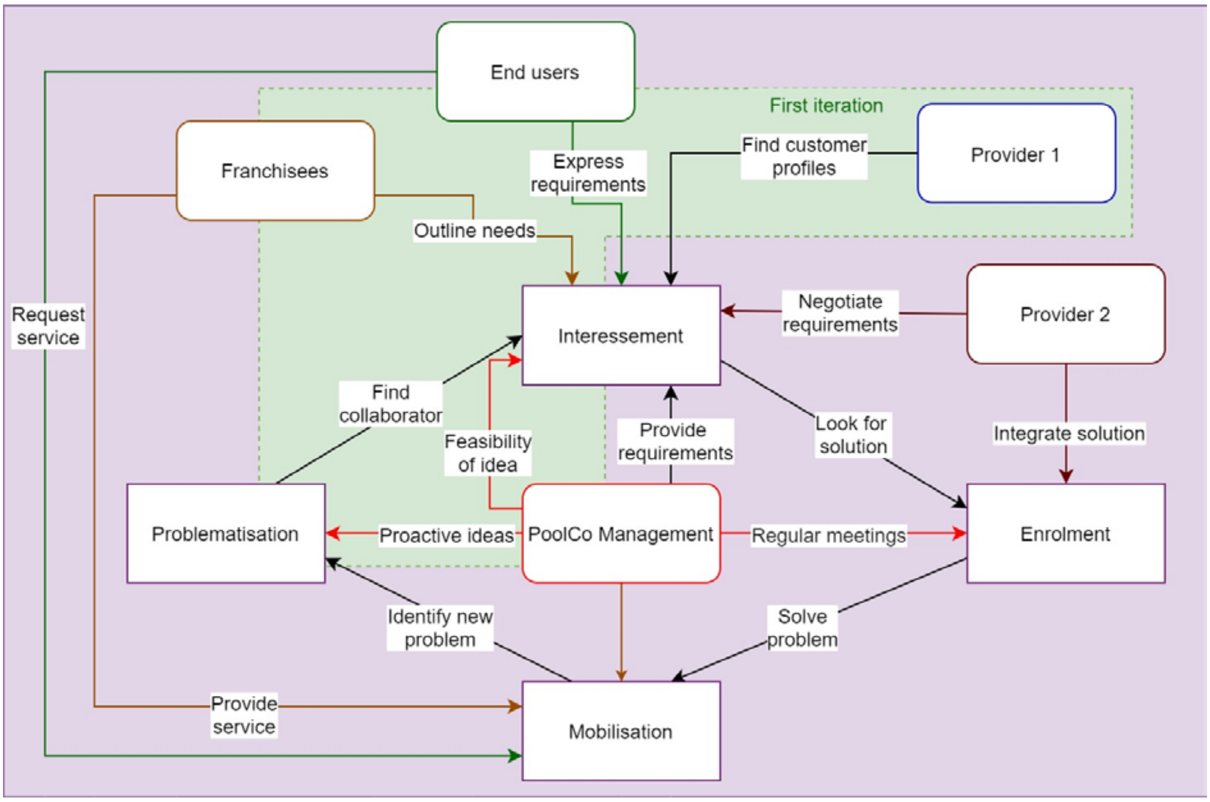

Figure 30: PoolCo Actors and Actions

Figure 31 describes the various stages of the above design process compared to the CPPSSDM. The bold blue texts signify the case-specific steps. The four components of the CPPSS are discussed below.

- *Product*: The software application, capable of monitoring the pool conditions and enabling communication between the actors.
- *Service*: The service was the pool monitoring and management solutions for the end-users and usage demand information for PoolCo.
- *Cyber*: The cloud technologies and computation algorithms that enabled communication between pool management systems and actors formed the cyber part.
- *Physical*: The sensors, actuators, hand-held devices and desktops constituted the physical part of the solution.

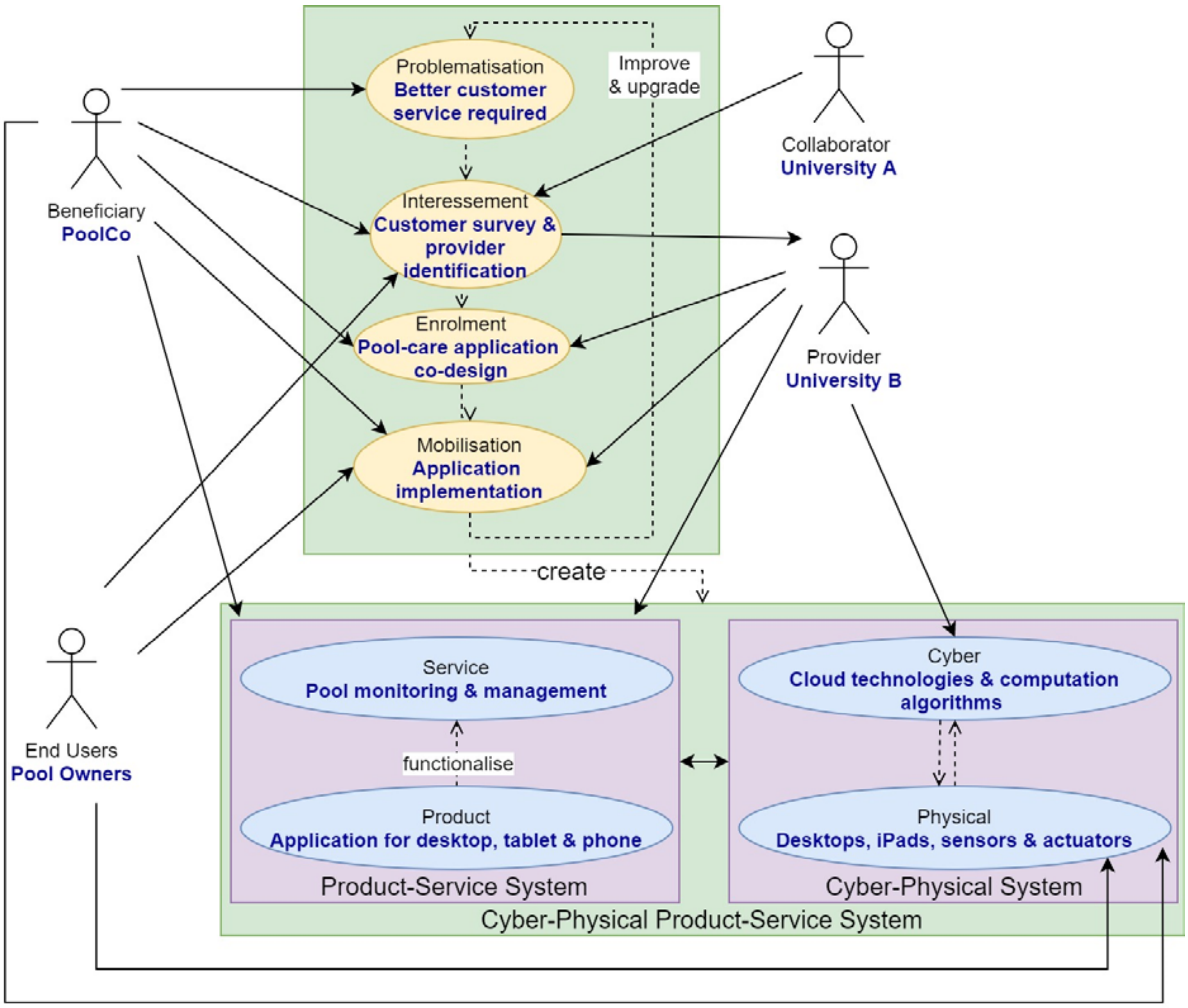

Figure 31: PoolCo CPPSSDM

5.3.5 Findings

5.3.5.1 Problematisation

PoolCo had clear targets in its *Problematisation* stage, which made the CPPSS development easy. The factors that governed the focus of this stage were:

Business ambitions of PoolCo:

> *"So, we're saying well, instead of waiting for something to go wrong, how can we create technology that tells you before it goes wrong or keeps the pool in perfect condition, so it doesn't go wrong." – PM1*

> *"I started to find out there were many needs and requirements of the [current] software ... we started to evaluate what were the best options to try to move ahead." – PE2*

The expertise of the franchisee:

> *"I had a lot of input from my staff ... If you don't have an input on how to develop it, you'll get the pool where I want it and not [where] you want it. [But maybe it] isn't the perfect system. So, if we have more people doing inputting it'll be a much better system." – PO1*

> *"We've loved franchisees being a network for a long time. So, we've built out a lot of that knowledge." – PM1*

The localisation of the customers:

> *"In Australia, there are 1.2M pools in the ground ... it didn't seem logical to go to all areas of Australia. [Pools are] predominately on the East Coast [and] so it made sense to focus on the East Coast." – PM1*

And the brand image:

[“Our] brand recognition is very high. And I think from memory 87 per cent of the customer surveys has recognised that [our] brand.” – PM1

5.3.5.2 Interessement

The *Interessement* stage consisted of four stakeholder groups, the franchisees, potential end-users, potential software application developers and the PoolCo organisation (or personnel).

PoolCo took the initiative to create awareness of the problem among its customers and understand their interest in having a software application.

“So, we had this whole idea, and we said, ‘Let's go out to the market (and) find out what people think of pools [and] IoT … and maybe value what were they willing to pay.’” – PM1

The franchisees were also approached to obtain their views:

“But when the new [application] was coming, I first had dealings with him (PM1)” – PO1

“There were certain documents collected by the franchise business managers … outlining their most important needs and features they would like to see [in the software application]” – PE2

PoolCo also evaluated the options between working with local firms and international firms to develop the software application.

So, we started to consider what were the options. We evaluated working with a local firm or an overseas firm. – PE2

One crucial aspect discovered during this stage was that most of the customers were from the older segment of the population, and they required generation-specific customisation.

"[The] generation that owns pools and spas are the older generation. So, they admitted they are a bit more afraid of technology and especially fear of privacy. They want to be in control." – PM1

Based on the above observations, PoolCo took the initiative to understand the ease of control, level of privacy and time commitment of its customers to co-create an appropriate software application and value proposition.

"If something (chemical) is dosing, [some customers insist] 'I want to know what is going on.' And some will just say, 'Look, I just want to swim in it, and you take care of it.' So, you got different types of customers." – PM1

"This is a very different look ... How do I (customer) guarantee myself a blue pool? Well, you can guarantee a blue pool if you follow my (PoolCo's) advice. If you download the app that tells you what's going on." – PM1

5.3.5.3 Enrolment

In the *Enrolment* stage, PoolCo collaborated with a software application development team to share the requirements and co-design the CPPSS. This development team was a research department of a local public university.

"(We) found out that a university was willing to work with the industry and they came on board." – PE2

The aim of the collaboration was shared among the actors.

"They wanted to take a desktop application and make a cloud version of that and then connect the pool monitoring systems and things like that to that as well." – PE1

"What we're trying to improve is how we make the interaction with the users easier." – PE2

"[We worked to] create better software that enables more open communication with the customer." – PM1

The co-design process had a strong emphasis on transparent communication, involving a series of weekly and monthly meetings.

"Sometimes, it was every week. Sometimes it was once a month ... We didn't set an exact frequency for meetings … but it happened quite frequently. Some meetings, the whole team was there and then some meetings the technical guys travelled to the company site, and sometimes they came here." – PE1

The franchisees were also consulted regularly for their feedback.

"So, I started looking into it. It's nowhere near ready to go (and I suggested you) needed to do this … I had a lot of communication with [PoolCo] and made the process much easier." – PO1

"… they've (franchisees) asked us for all sort of other features and logic to being implemented. So, they (providers) did some system integration work." – PE1

5.3.5.4 Mobilisation

The software application was mobilised enabling customers to use the information technology to communicate pool-related queries and obtain support to keep their pool in the desired condition ("keep the pool blue") throughout the year.

"We provide the customer with a tool so that they can use [it] to keep the pool blue through the whole of the year." – PM1

"If you jump into [our] program, we will support you telling you exactly what you need for the whole year ... you can guarantee yourself a blue pool if you follow my advice" – PE2

With the CPPSS, PoolCo could obtain vital pool usage information and status. The feedback option and end-user forums were also employed to detect changes in customer needs.

"We are starting to understand more of what our typical customer profile is. [For example,] What is the most common sanitiser? … type of pool? … What is the percentage of customers that we are reaching and then we can start to know about adding sales and other stuff." – PE2

PoolCo also collaborated actively with its franchisees, customers and providers to make improvements in the system based on the observed demands and trends.

"There was room for improvement … [PoolCo says] If you don't like it, write it down, tell me why, and we'll see what we can do." – PO1

".. if we have a more homogeneous group all working together continuously evaluating and giving feedback, the progress will probably be faster, or the experience will be better." – PE2

"... we're gathering all this feedback coming through on the software feedback mechanism." – PM1

"... there was some feedback that was passed to my guys from the customers ... our guys constantly gave feedback about the performance of the system ... and how maybe some things can be better ..." – PE1

5.3.6 PoolCo Summary

The factors that the participants seemed to value in the co-creation process were competitive difference, holistic approach, expertise, cost-effectiveness and building a long-term relationship. PoolCo's research of their customers showed that customers valued privacy, safety and tailored advice. Figure 30 shows the various tasks and factors involved in implementing the CPPSSDM for PoolCo. Table 26 lists the key findings for each stage of the CPPSSDM from this case-study organisation.

Table 26: Key PoolCo findings for each stage of the CPPSSDM

Stage	**Key VCC Themes**	**Components of the themes**
Problematisation	Proactive approach	• Value proposition • Innovative ideas • Customer demands • Competitive difference
Interessement	Feasibility & Negotiation	• Customer expectations • Customer interest • Customer loyalty • Franchisee experience • Customer profiles and groups • Provider inferences
Enrolment	Technology & Inclusion	• Development of the best solution with the latest technology • Regular meeting and updates • Active feedback
Mobilisation	Communication	• Data analysis and trend • Provision of customised advice and service • Identification of new improvements required

5.4 Case Study 3 – HealthCo

5.4.1 Introduction

HealthCo is a unique IT solution provider that provides information and communications technology (ICT) products and consulting services to help professionals manage policies and procedures in the health industry. Founded in Australia in 2013 by three IT professionals, HealthCo has spread its reach to Europe and Australasia. The company has involved its customers in developing smart solutions by sharing their resources and expertise in their fields and over the years, it has developed a strong relationship with its customers through long-term collaborations and interdependence. HealthCo provides several products and services that cater to various needs of the modern health industry to offer the best possible outcomes to patients.

One of the main CPPSSs offered by HealthCo is an easy-to-use application that provides safe and efficient mobile bedside solution for hospitals. This product is a patient safety application that helps hospitals improve patient care by managing the clinical documentation of observations, treatments and assessments of patients. The applications enable early detection of deteriorations in a patient's health and trigger a timely clinical response. The application has features including risk scoring, threat alerts, task management, real-time patient data, team collaboration, policy compliance and reporting and is being used by several hospitals in the United Kingdom, Australia and New Zealand. Based on feedback from the hospitals in these distinct geographical locations, HealthCo is continuously improving its offering through regular interactions and connection. The improvements are delivered to customers through subscription services, which provide HealthCo with a regular income. The CPPSS here is a product-oriented model as the customer pays a one-time fee for the application and an additional subscription for customer support. The features above match the selection criteria set in Section 3.4.2. The comparison is shown in Table 27, on the basis of which HealthCo was chosen as the third case study organisation.

Table 27: HealthCo Selection Criteria

	Selection Criteria	HealthCo Observation
1	Implementation of CPPSS	As Provider and *Follower*
2	Interaction with actors	Co-designed solution with customers and users
3	Open to share knowledge, experience and opinion	Various personnel participated in interviews
4	Operation of business	Local and international markets
5	Relationship of business	Business-to-business

5.4.2 Participants

HealthCo used a small team to design and develop its system. This team generally consisted of three or four HealthCo employees who collaborated with a selected customer to develop the solution. This researcher was able to interview two team members. The participants in the HealthCo case study are listed in Table 28.

Table 28: HealthCo Case study Participants

	Participant group	Participants	Average experience at HealthCo
1	Management	1	16 years
2	Engineering	1	5 years

5.4.3 Developing HealthCo's CPPSS

The CPPSS studied was initially developed as a response to a hospital tender floated by the Nation Health Service (NHS) in the UK to improve patient outcomes. As per the targets set by the NHS, this hospital needed a solution to reduce the paperwork, to support ward workflow and to enable the clinical staff on the wards to deliver better patient care. More precisely, the CPPSS aimed to relieve the burden of paperwork and reduce the number and size of the reports that nurses had to do. This solution was also expected to help nurses know the status of their patients at any point in time. For example, if a nurse needed to know which doctor needed to be called to treat a patient with a given set of symptoms, the CPPSS should be able to immediately name the doctor based on hospital policy rather than the nurse having to go through policy documents manually. So, the hospital initiated the design process as the *initiator* and HealthCo, as the *follower*, took the above requirements and developed the CPPSS through various value co-creation activities. The CPPSS was then tested, evaluated and deployed to solve these problems.

The CPPSS contained all the forms that nurses were expected to fill out for each patient. It was designed to process all the information in the forms to give each patient a health score and to continuously compare that score with the hospital's policy and hospital practice to schedule the required patient care tasks for the nurses. The system could also generate alarms based on a patient's health rating and call the appropriate doctor to attend to any emergency. The CPPSS developed was a great success, and numerous hospitals in the UK, Australia and New Zealand have adopted the solution.

5.4.4 Actors and Actions

The inferences about the actors, relationships and design stages implemented by HealthCo could be categorised into the four design stages of the ANT-SDL model. The four main actor groups (i.e., managers, engineers/designers, customer and operators/end-user) and their actions are demonstrated in Figure 32. These inferences form the BOL of the CPPSS and are briefly discussed below.

- *Problematisation*: The customers (hospitals) found the hospital could improve performance by eliminating specific issues. HealthCo managers also continuously identified issues that could be eliminated to improve performance. Based on the issue, the actor initiates the design process.
- *Interessement*: The managers and customers then negotiated contracts and requirements, respectively. On completing the negotiations, the actors started looking for the solution to the identified problems.

- *Enrolment*: The solution was co-designed by integrating the end-user's knowledge and HealthCo's engineering expertise. This new CPPSS would solve the concerned problems in the form of a web application that maintains hospital policies.
- *Mobilisation*: The solution was then communicated by the engineers while the end-users extracted the value-in-use.

During MOL of this CPPSS, the managers continuously shared the possibilities in the solution and extracted reactions from the end-users. This stage also enabled the discovery of new problems to be solved.

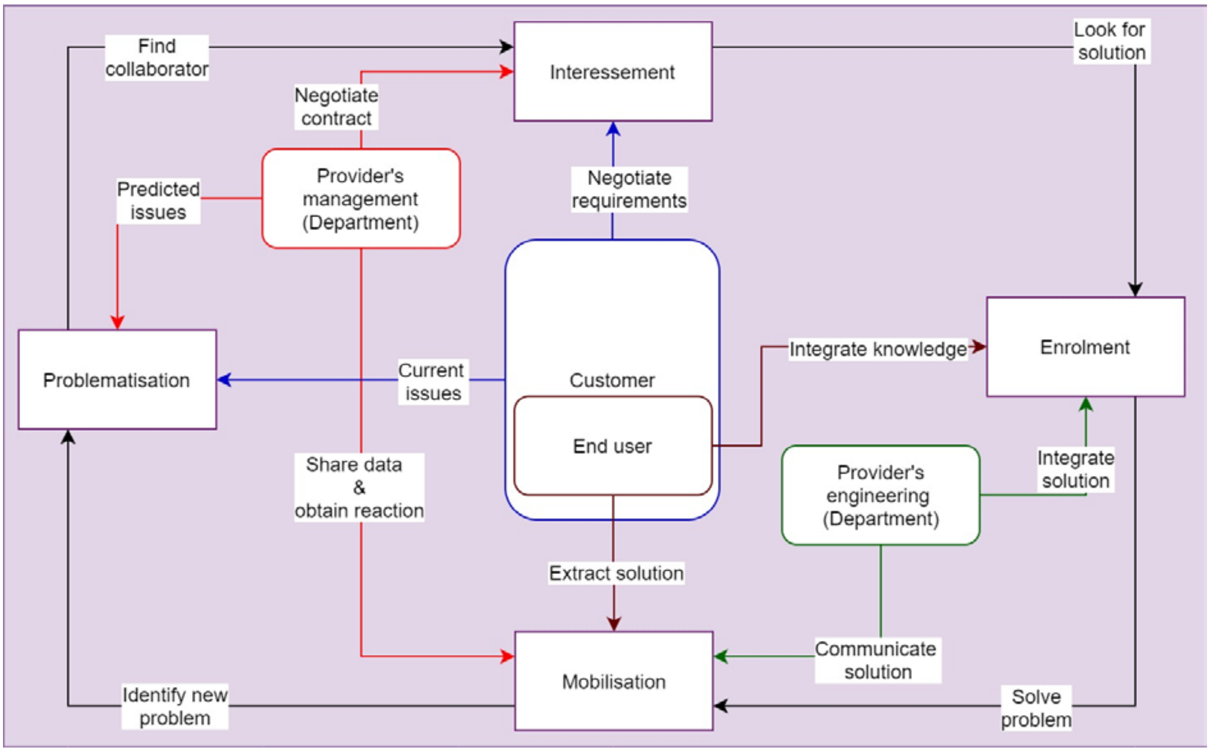

Figure 32: HealthCo Actors and Actions

These design processes were then correlated with the conceptual CPPSSDM reference model to represent and explain HealthCo's design process, as shown in Figure 33. The four components of the CPPSS are discussed below.

- *Product*: The web-based application, capable of eliminating the paperwork and maintaining the hospital policies to improve patient outcomes.

- *Service*: The service was the management of patient-care tasks, hospital policy adherence, training of hospital staff and regular system upgrades.
- *Cyber*: The web technologies and computation algorithms that enabled communication between concerned actors and devices formed the cyber part.
- *Physical*: The hand-held devices, iPads and desktops constituted the physical part of the solution.

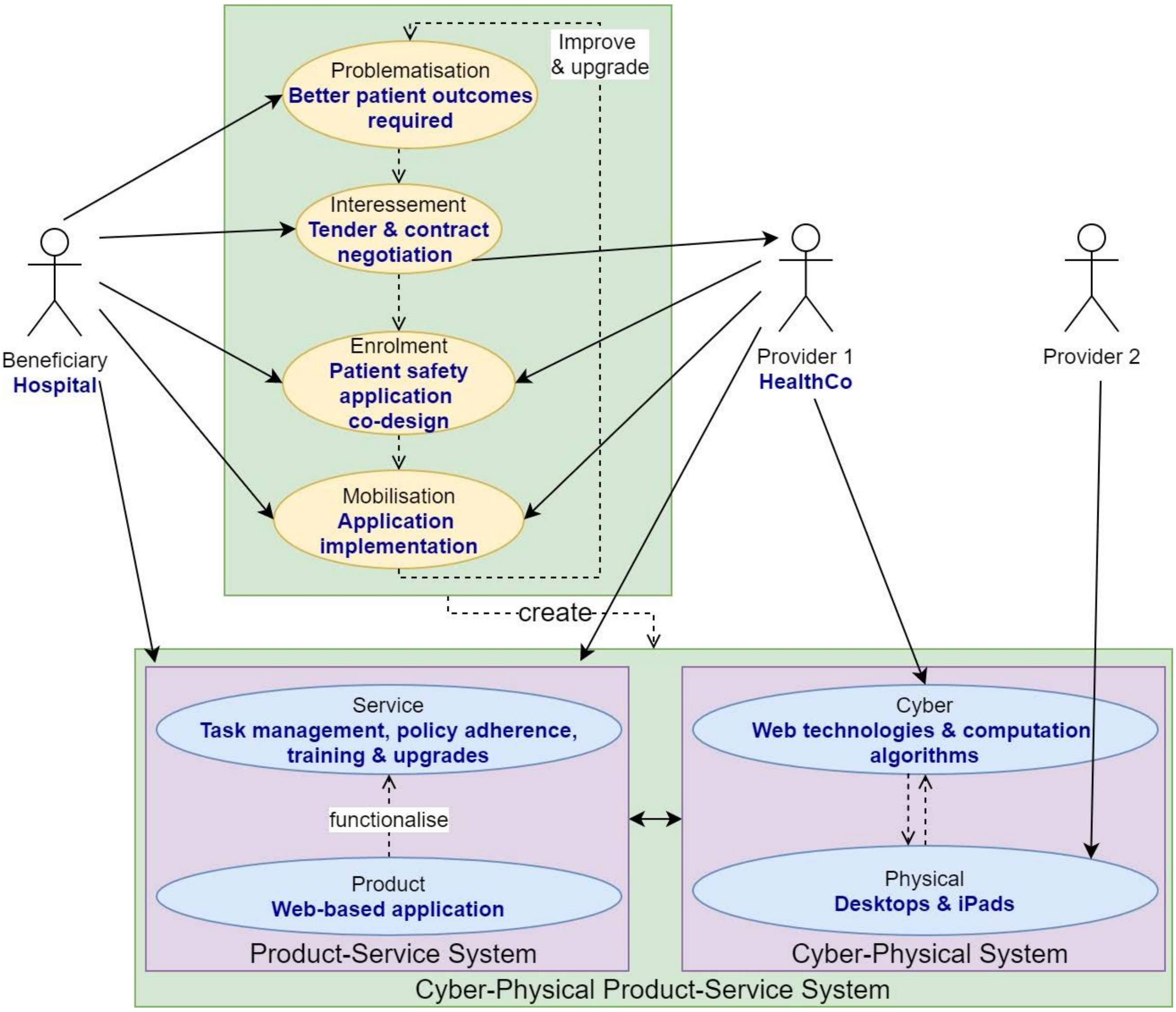

Figure 33: HealthCo CPPSSDM

5.4.5 Findings

The design and development of the HealthCo CPPSS can be shown to have followed the four stages of the CPPSSDM iteratively.

5.4.5.1 Problematisation

The *Problematisation* stage mainly involved finding a problem in the current system. This task was performed by both HealthCo (provider) and the hospitals (customer), based on the situation. When the hospital identified a problem, its requirements were discussed with HealthCo.

"... those problem areas that they're trying to resolve ... that allows us to sort of expand and enhance the product." – HE1

"... (hospitals) specify the requirements for us (HealthCo) to push them through the quoting process." – HM1

The requirements could originate from two different types of customers. The first type was the new customers demanding a holistic solution to their problems. As outlined by the UK government (NHS), its new health quality penalty scheme would impact hospitals' funding based on their outcomes. Obtaining an holistic solution to the patient care problem would help hospitals continue to secure their government funding.

"... in a number of circumstances ... the government mandates that they (hospitals) must do this assessment according to a (approved) flow." – HM1

"... if they (new customers) come out with ... a request for tender or a service ... I put forward to show what we can do and offer." – HE1

The second type was existing customers who were already using HealthCo's solutions. These customers would come across new issues from time to time and ask HealthCo to solve them.

"... primarily with the customer, they're creating value by using the system, suggesting enhancements ... and (we) review it." – HE1

In some instances, problems were identified by HealthCo itself and they would then proactively develop the solution. This proactive approach helped HealthCo find solutions to problems before the customer demanded them and enabled the company to expand its markets.

"However, there's been some of the core things that we've started to do where we know it's for the good of the product anyway." – HM1

"We (HealthCo) see another opportunity (in) another department (of the same hospital) … (we) say, 'Hey you've got another problem. I reckon we can solve it' … and then get some repeat business." – HE1

"We'll be looking to do multi-language support … and run it in Dutch or German or French or whatever else." – HM1

5.4.5.2 Interessement

The *Interessement* of new customers was obtained either through responding to the tenders floated by the hospitals or by visiting the hospitals to introduce HealthCo's offerings.

"We may look to … the tenders that are out for the same product at the moment because they are potential clients telling us what they want." – HE1

"… take the product down and pitch it to the user group and also to new clients." – HM1

HealthCo ensured prompt and professional service to its customers and conducted regular online and offline meetings with its customers to gain insight into the latest problems they were facing.

"We're very proud that we've never lost a site … we like to think that's because we give them a good all-round service." – HM1

"We generally do that through workshops … all clients (get) together … (we ask) 'Hey look what's working for you' and 'What do you think is missing? What could be improved?'" – HE1

"If they (hospitals) were happy with what the team delivered … they generally ask for those people again … you really become a trusted advisor to them." – HE1

HealthCo also enabled its clients to communicate with each other through user groups, forums, polls and chats to identify customer problems and priorities.

"So, they again collaborate with each other. To facilitate that, we run the user group for them…. it helps us again feed into the product roadmap." – HM1

"It works very well. Engagement back with the user group through … chat forum, run polls, informal chats with the end-users …" – HM1

5.4.5.3 Enrolment

Enrolment in HealthCo's CPPSS design was initiated when the customer demanded a new or improved system, and they agreed to pay for the services involved. HealthCo developed its solution according to this demand.

"So, it was developed in response to a tender that ACT Health put out." – HE1

"So, if our clients want something built into the product, we design a platform, we give them a quote and they will pay for that." – HM1

During the *Enrolment* phase, the design, and modifications of the CPPSS always involved the customers and end-users in collaboration. The customers were repeatedly asked for their feedback in every stage of the process to obtain the best possible outcomes. HealthCo also enrolled customers from different parts of the world in each design process to obtain a more inclusive solution.

"There is very little development that hasn't taken at least one client's input to design … we want to get one from this side of the world and one from the UK so that we know that whatever we develop is applicable in both settings." – HM1

"Each customer is slightly different, and their approach to implement the product is different as well … I give time … spending time with them and delivering high-quality work is always a good one ... (It) helps solidify that relationship." – HE1

"… the people who are our clients. Yes, they absolutely get a say in what comes next and so on and so forth." – HM1

HealthCo has used the customer inputs to make its system highly configurable for various settings.

"We have used a philosophy all the way through … to have maximum configurability. That's allowed us to move from site to site where each site does things differently." – HM1

Consequently, HealthCo developed a system that is easy to train, learn and operate.

> *"We've always tried to make the user interface really intuitive. So, training a new user is about 20 minutes, tops. That's because we use really common paradigms for data capture." – HM1*

The *Enrolment* stage has been shown to have various iterations to meet the changing needs of customers triggered by varying circumstances or unpredicted requirements. Furthermore, there were differences in the requirements of hospitals in different regions.

> *"Customer may say, 'Oh no, we want to make these changes.' (Then) We change the scripts; we update the database and do some more testing and on and on this would go." – HM1*

> *"And as we progressed through implementations in New Zealand, we found that there were different requirements for how they wanted to manage patients." – HE1*

5.4.5.4 Mobilisation

The *Mobilisation* stage involves the release of the CPPSS for the client's use and accepting the payment accordingly.

> *"It was designed so that the nurses would take the observations of a patient ... We then apply risk scoring algorithms across that ... (and) force hospital policy based on their risk score." – HM1*

The information about the forms and procedures adopted by each customer was shared among all the customers. This openness enabled other customers to extract value from each other and find the best solution to various patient care-related issues.

"Most of our sites (are) paying to develop or customise two or three forms but they get access to 30 or 40 or 50. So, it's a small price to pay for the overall value that that's opened up to you." – HM1

"(we are) providing them with additional features that they might find useful by just including it in that package." – HE1

During this stage, as the healthcare industry progresses, customers come up with new issues that require new solutions. HealthCo iteratively solves new problems that arise over time.

"It's nursing-led, it's not technology. And that nursing team tends to manage the system and provide guidance and bring forward new requirements." – HM1

"(We) have a chat with the customer about how that might work and then try to get it on the roadmap for a future release." – HE1

HealthCo also releases free system updates at regular intervals to customers who have subscribed to them.

"We release a new version every four months that clients don't have to take every version if they don't need to." – HM1

Combining all the above efforts, HealthCo is highly focused on continuous improvement. This focus not only enables it to hold on to existing customers but also to explore new markets.

"So, it's got to be continuous development, and while we're continually developing, we'll always look for new markets and new opportunities." – HM1

In the future, HealthCo also plans to analyse the patient observation and treatment data generated from each hospital to uncover new trends in patient care and help them find better solutions to various existing problems.

“Let's pop some stats in there around discharge times or the number of transfers that may not have access their current solutions.” – HE1

“We're very keen ... to pick up our data set and see what we can learn through an AI platform or machine learning platform. I'm absolutely positive there are algorithms that can vastly improve on the existing ones.” – HM1

5.4.6 HealthCo Summary

As HealthCo’s CPPSS solution was being utilised, new issues and problems emerged in the changing environment of public hospitals and patient care. The emergence of such problems triggers a reiteration of the design method towards finding new solutions. In addition to the safety, risk and privacy factors, HealthCo observed that its customers highly valued reduction in patient length of stay. This reduction had a positive effect on waiting times and management of beds.

“I'm helping patients get better sooner and go home earlier. And that's very fulfilling to know that.” – HM1

HealthCo strove to meet its customers’ needs through sharing performance data, improving its services towards better healthcare and designing solutions with high configurability. HealthCo was also active in providing good customer service to gain better reviews, believing that better reviews would help the company obtain new customers.

"... ensuring that you (HealthCo) are delivering on that project and it's all going well because those people will become references for you in the future." – HE1

In addition to its regular subscription fees and one-off deployment fees, HealthCo gained further financial value through the provision of improvement or modification services. Table 29 lists the key findings for each stage of HealthCo's CPPSSDM, while Figure 32 shows the various tasks and factors involved in implementing the model.

Table 29: Key findings of each stage of HealthCo's CPPSSDM

Stage	**Key VCC Themes**	**Components of the themes**
Problematisation	Actual, Prediction	• Customer responses • Provider proactivity • Customer and government healthcare targets
Interessement	Tender, Contract	• Online and offline discussions • Negotiation to find the best solution • Annual meeting to discuss issues • Marketing and customer reviews
Enrolment	Integration	• Intensive customer team involvement in the design • Configurability • Intuitiveness • User-friendly system • Revision of requirements
Mobilisation	Communication	• Patient status scoring • Customer feedback • Dynamic system improvements • Addition of extra features • Data sharing

5.5 Case Study 4 – VRCo

5.5.1 Introduction

VRCo was an innovative start-up organisation involved in designing human-computer interaction solutions through virtual reality technology. The company concentrated on two major problems of virtual reality, namely, the lack of intuitive locomotion and the absence of the sense of touch. Appropriately, two CPPSSs were developed to solve each of these problems. Of these two, the virtual locomotive board was implemented more extensively and so was chosen to be studied in this research.

The company had customers who implemented its CPPSS in entertainment, gaming, rehabilitation and real estate. At the time of this research, the company was forming new relationships with numerous other stakeholders to develop a customised solution by implementing its CPPSS. The CPPSS were sold to the customers who enjoyed the regular upgrades, modifications, and maintenance according to their application-specific needs. VRCo provided both product-oriented and use-oriented CPPSSs. The CPPSS was product-oriented when it was owned by the customer and serviced by VRCo (the provider). The CPPSS was use-oriented when it was leased to the customer to provide VRCo with regular rental income.

The features described above matched the selection criteria set in Section 3.4.2 and as shown in Table 30, hence the choice of VRCo as the last case study organisation for this research.

Table 30: VRCo Selection Criteria

	Selection Criteria	**VRCo Observation**
1	Implementation of CPPSS	As Provider and *Initiator*
2	Interaction with actors	Co-designed solution with customers
3	Open to share knowledge, experience and opinion	Various personnel participated in interviews
4	Operation of business	Local markets
5	Relationship of business	Business-to-business

5.5.2 Participants

VRCo comprised a small team involved in solving virtual reality problems. Three subjects participated in interviews. Two of them were the CEO/co-founders and engineers of the start-up company while the third was a test operator. All were actively involved in developing the solution and marketing it to potential customers. They are listed in Table 31.

Table 31: VRCo Participants

S. No.	Participant group	Participants	Average experience at VRCo
1	Management and Engineering	2	2 years
2	Operator	1	15 years

5.5.3 Developing VRCo's CPPSS

VRCo was a start-up and the idea to develop a CPPSS came from its co-founders. The team had noticed the lack of *real-feel locomotion* [10] in virtual reality technology and they realised that providing intuitive locomotion could create value for numerous industries. The entertainment industry could play movies with real motion effects; the gaming industry could create games with real-life movements; the real estate industry could showcase properties with almost-real movement across the floors and the rehabilitation profession could train patients to walk or run, to name a few. As initiation, VRCo developed the idea into a prototype and started communicating with potential customers to gain their interest. Once customers were enrolled, and using their feedback and field-specific requirements, VRCo developed customised

[10] *Real-feel locomotion* is a kind of locomotion where the person does not move in real life but uses a VR gear/module to provide a sense of movement. In the case of VRCo, a circular disk platform is used in addition to the VR module. The person steps on the disk while using the VR module. The disk provides a smooth omnidirectional locomotion by hovering around the virtual world to give a real feel of movement.

locomotion boards. VRCo was also involved in understanding customers' evolving demands and modifying its CPPSS accordingly.

5.5.4 Actors and Actions

Figure 34 shows the design process used by the VRCo's team and concerned actors to develop the CPPSS solution categorised into the four design stages of the ANT-SDL model. The three main actor groups were providers (VRCo – managers and engineers), investors and end-users. The inferences about the BOL are briefly discussed below.

- *Problematisation*: The providers identified the issue in virtual locomotion and predicted a potential in its solution. This discovery influenced the initiation of the design process by looking for collaborators in developing the new solution.
- *Interessement*: The providers then approached various potential investors and customers by negotiating the benefits of the solution. The interested actors then formed a network that started looking for possible solutions.
- *Enrolment*: The solution was co-designed by integrating the investors' investments, end-users' knowledge, and provider's expertise.
- *Mobilisation*: The providers developed customised solutions and communicated them to the appropriate end-users.

During the MOL, the investors extracted returns on investment while the provider looked for more opportunities to solve customer problems. These opportunities were through finding new customers with problems in their field (new to the providers) and current customers with new problems in the same system.

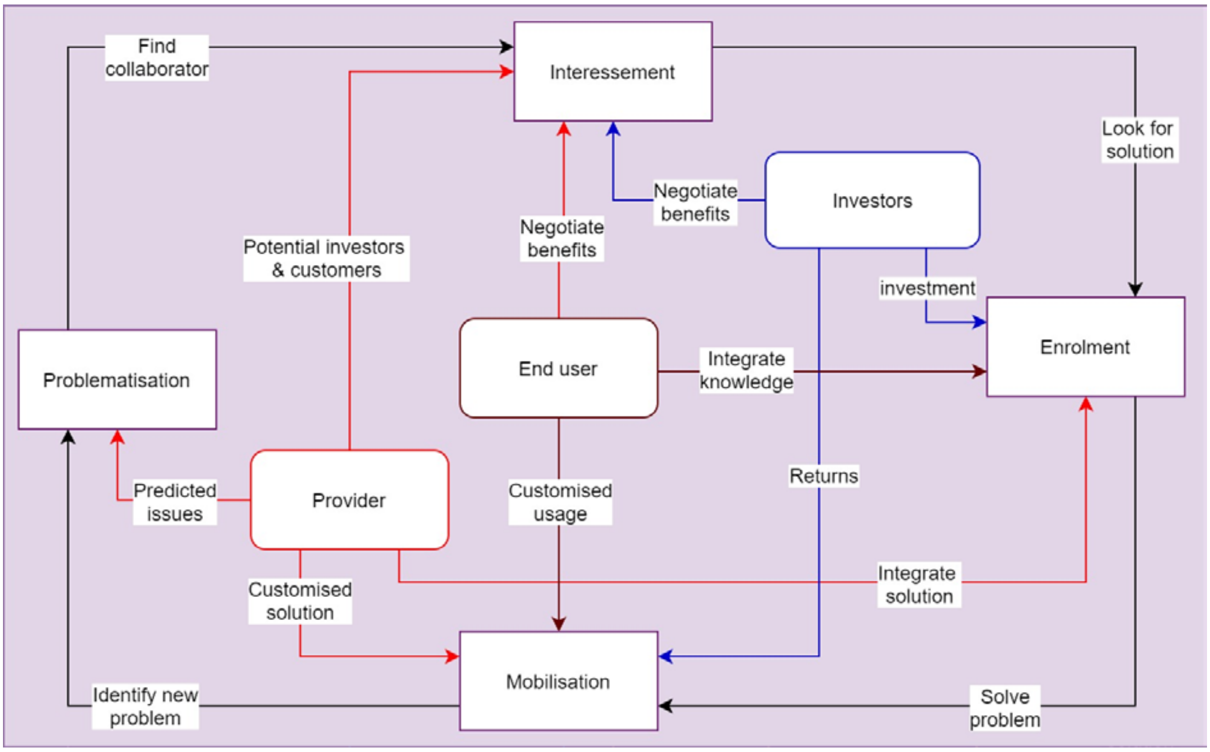

Figure 34: VRCo Actors and Actions

VRCo's design processes were correlated with the conceptual CPPSSDM reference model to represent the CPPSS design process as shown in Figure 35. The four components of the CPPSS are discussed below.

- *Product*: The product was the hardware and software for the virtual locomotion system that created real effects on the virtual environment's movements.
- *Service*: The service was developing the application-specific customised virtual locomotion system based on the customer requirements.
- *Cyber*: The integration software and computation algorithms that enabled functioning and communication between the VR and locomotion systems formed the cyber part of the solution.
- *Physical*: The versatile and portable locomotion board formed the physical part of the solution.

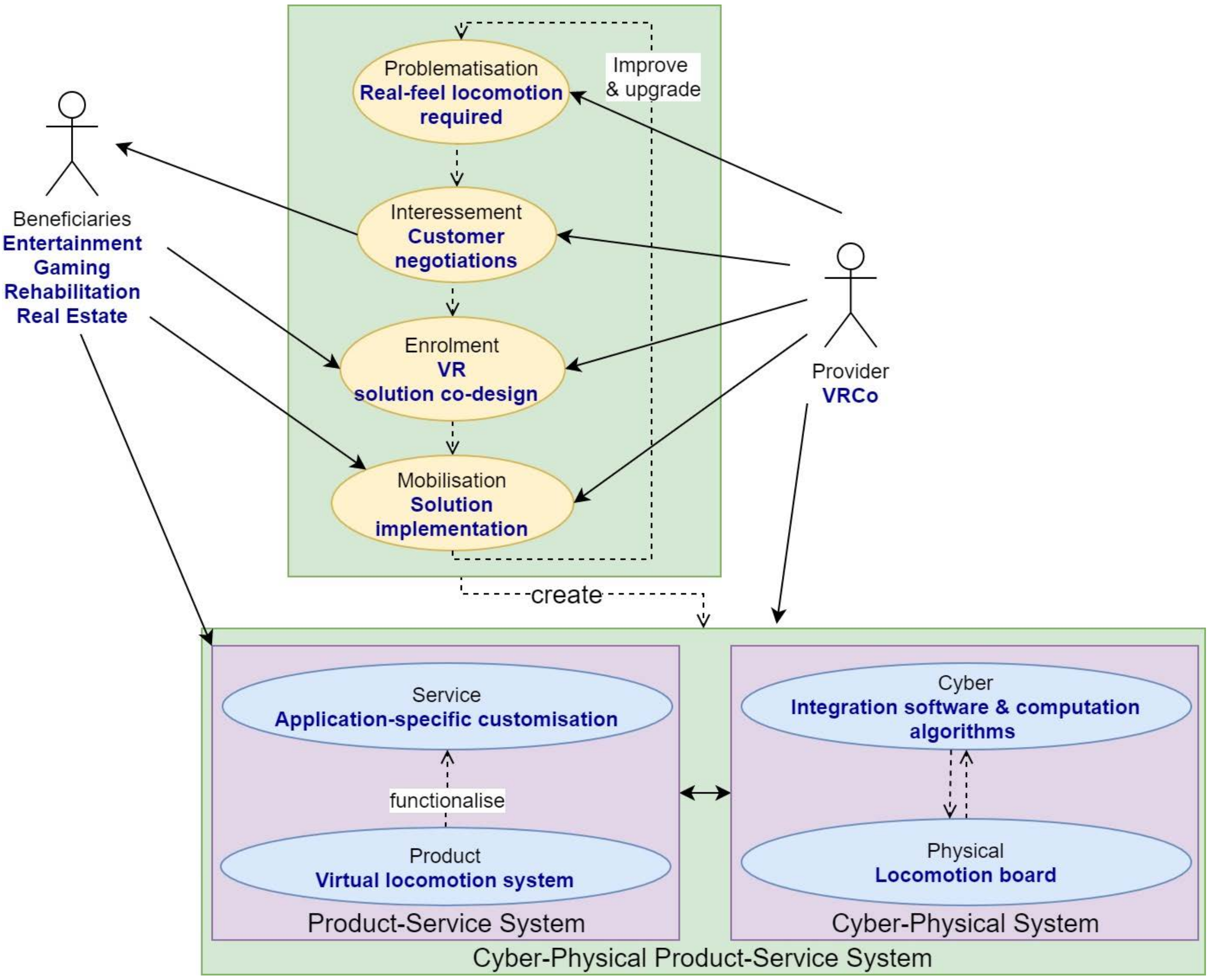

Figure 35: VRCo CPPSSDM

5.5.5 Findings

In this case study, the provider performed the role of initiator, making it unique in comparison to the previous three cases.

5.5.5.1 Problematisation

The *Problematisation* stage consisted mainly of identifying the problem based on the skills and expertise of the co-founders and discussing it among themselves.

> *"So, we started the company by asking those questions about what's the best way to engage with a virtual space around you. How do you interact with objects to use your hands or body?" – VEM1*

This step was mainly initiated due to the mutual interest in virtual reality and biomedical engineering among the co-founders.

"(The co-founders) just wanted to make interfaces for VR more immersive ... they found that that locomotion is a big deal, that no one really solved the problem with the locomotion VR." – VEM2

The co-founders also realised that developing a VR locomotion device was appropriate for the current industrial context.

"We (initially) were starting with the hand because that was my background. But we realised that this was way too early for the industry ... that was the pathway to the current product, which is this hoverboard." – VEM1

5.5.5.2 Interessement

The co-founders formed a team with a few interested interns, and this idea was developed further by building the prototypes.

"You create something new; you believe that it's gonna change the world. You can't change the world by yourself. You need to create a team around you that cares as much as you are motivated." – VEM1

"When I joined the company, there was a lot of interns, and there were three co-founders." – VEM2

The company then conveyed the idea to potential investors and buyers to gain their interest and attract funding.

"It's really about communication and talking to those people (about) the value of your product." – VEM2

"You have to make other people care. Because that's the only way you can actually change the world." – VEM1

However, the co-founders initially met various difficulties in creating awareness. Communication formed the most challenging and most crucial part of co-creating value.

"In talking to people, (sometimes) they don't really see the point … the tough challenge is communication, and the easy challenge is the lack of money." – VEM1

The co-founders met numerous business organisations to create a market for this innovative CPPSS solution. VRCo shipped the CPPSS locally and internationally to interested parties and expected to get feedback from them.

"But with a very innovative product, you are struggling to find your market." – VEM2

"I meet people who I think would be interested … then the conversation starts, and it may end up just meeting (and) giving them demos of the product … we've shipped overseas without even meeting the people … and after three months we expect some kind of meaningful feedback." – VEM1

5.5.5.3 Enrolment

During *Enrolment*, the VRCo team communicated with its customer organisations to understand their requirements and collaborated with researchers to find more possibilities for their CPPSS.

"I actually saw (VRCo) on Indiegogo (crowdfunding website) … this (VRCo) provided a different alternative to navigate around a virtual environment that I hadn't seen before. So, I pledged on Indiegogo." – VO1

The organisations that had expressed some interest were in the field of entertainment, rehabilitation, navigation, research and architecture.

"My interest was in navigation. They (VRCo) provided us with a prototype, and I was interested in building some environments, and evidence base of the hoverboard actually is better." – VO1

"We found one customer for architecture who wants to move around houses. We found one customer for rehab. They want to use it for balance therapy. We found this customer at the university (who) will use it for research." – VEM1

VRCo realised that each field of application had a different set of expectations and constraints. For example, the rehabilitation application required multiple sensors to be fitted to the CPPSS device to collect vital data of the patient's movements. In contrast, an entertainment application required devices to create special effects that would enhance the entertainment experience.

"With the rehab … if you can create solutions that measure people's balance that we could use as a way of assessment, (create) a dashboard that allows a patient to stand on it, they do a series of exercises and we record the centre of mass." – VEM1

"We ended up having a very strong interest in the entertainment market. We had game-based VR applications … that could be direct sales, renting or subscription." – VEM2

5.5.5.4 Mobilisation

The *Mobilisation* was accomplished through mutual collaboration between VRCo and its customers. Once again, a clear understanding of how to use the CPPSS and generate value from it formed a vital part of this stage. VRCo made sure that the customers were trained in how to use the CPPSS and extract value.

> *"People are confused about how to use it. So, we're showing them how to use the device … we focus on having (a) tutorial that takes away the need for an attendant." – VEM1*

> *"(We) see studios who specialise in making arcade games. We talk with them and see what they think of the industry, what they like and everything … we just go with what they want with them. That's the way to convince your customers to agree with [you]" – VEM2*

> *"When a new technology like the board comes out, that's very useful because it allows us to start building a relationship with the company and potentially generate some research data which we could then publish." – VO1*

One of the values generated was the monetary returns that were earned through the sale and service of the CPPSS, satisfying the goals of the investors.

> *"Those arcades actually make a lot of money … they raised money, and they started to grow, and make better things." – VEM2*

> *"How can they do, whatever their business is, better and make more money and then how can they have a healthier business? … Our ultimate*

customers (are) the everyday people and that's what they focus on eventually." – VEM1

The other value was obtaining the device usage information and identifying opportunities to improve.

"So, from that (VRCo's) perspective, it's (usage of the CPPSS), basically it's free research for the company, and we have novel interaction devices to test." – VO1

"But what's really soon coming is a tracking number. So, eye tracking will be key in knowing what people look at, what they want and what they do. It's really about, like, customer behaviour." – VEM2

Using this data, VRCo planned to improve the CPPSS and add more innovative features.

"You want to improve your product every time; you say, 'Why not just refine your model?' Make sure the next customers are going to be even happier." – VEM1

During the process of co-creating this CPPSS, VRCo personnel also gained experience in techniques to attract new customers and thus expand its markets. This stage also enabled customers to encounter new problems that initiated the design method iteratively towards modifications and enhancements.

"And I guess over the (time), we learnt a lot about both the market and the available technologies. But I think what matters the most is that we know the people from the industry (with) the most influence." – VEM2

"I kind of started to understand the pattern and recognise what works and what doesn't." – VEM1

5.5.6 VRCo Summary

The value co-creating actors identified in VRCo were the providers, investors, and end-users. Being a novel solution provider, the VRCo founders had to create awareness about their solution among the other actors. The factors that the members of VRCo valued the most were mutual understanding, integration of resources and customer feedback. Interactions with the investors and customers made VRCo realise that clear communication is a vital part of value co-creation to understand customer requirements, investor expectations and solution constraints. The co-creation process also enabled the providers to explore more market potential for their solution by gaining expertise to attain customer satisfaction. The key findings for each stage of VRCo's CPPSSDM are shown in Table 32, and the corresponding tasks and factors involved in implementing it are shown in Figure 34.

Table 32: Key findings of each stage of VRCo's CPPSSDM

Stage	**Key VCC Themes**	**Components of the themes**
Problematisation	Actual, Prediction	• Provider's proactivity • Customer's responses
Interessement	Tender, Contract	• Approaching potential stakeholders • Negotiation to form a relationship
Enrolment	Integration	• Integration of customer knowledge and requirements • User-friendly system • Obtaining investment funding
Mobilisation	Communication	• Customisation • Generating returns to investors • Additional features

5.6 Conclusion of Chapter 5

This chapter discussed the case studies that were conducted to understand the practices involved in the design and implementation of a CPPSS and to demonstrate the proposed design method. The four case studies, comprising a dairy manufacturer, pool management, healthcare informatics and virtual reality technology, were presented with an analysis of their design methods, which were compared with the CPPSSDM reference method proposed in this research. The comparison showed that the reference model proposed in this research could explain and represent their design processes in an organised and comprehensive way. The case studies also provided an insight into the detailed intricacies of each of the four stages of the CPPSSDM: *Problematisation* depended on the combination of current and predicted requirements; *Interessement* depended on the use of tender and contracts, *Enrolment* depended on the integration of resources and *Mobilisation* depended on communicating solutions. The combined knowledge gained through the case studies helped refine the conceptual design method reference model.

The next chapter presents the cross-case analysis and the feedback obtained from practitioners. It also presents a discussion of all the data obtained in this research to bring about the refined design method.

Chapter 6 – Evaluation of the Design Method

6.0 Introduction

The fifth step of the DSRM is *evaluation*, where the artefact is observed and measured according to how well it solves the problem, as shown in Figure 36 (Peffers et al., 2007). This chapter presents the fifth step of the DSRM in this research by evaluating the CPPSSDM reference model developed in Chapter 4 and demonstrated in Chapter 5.

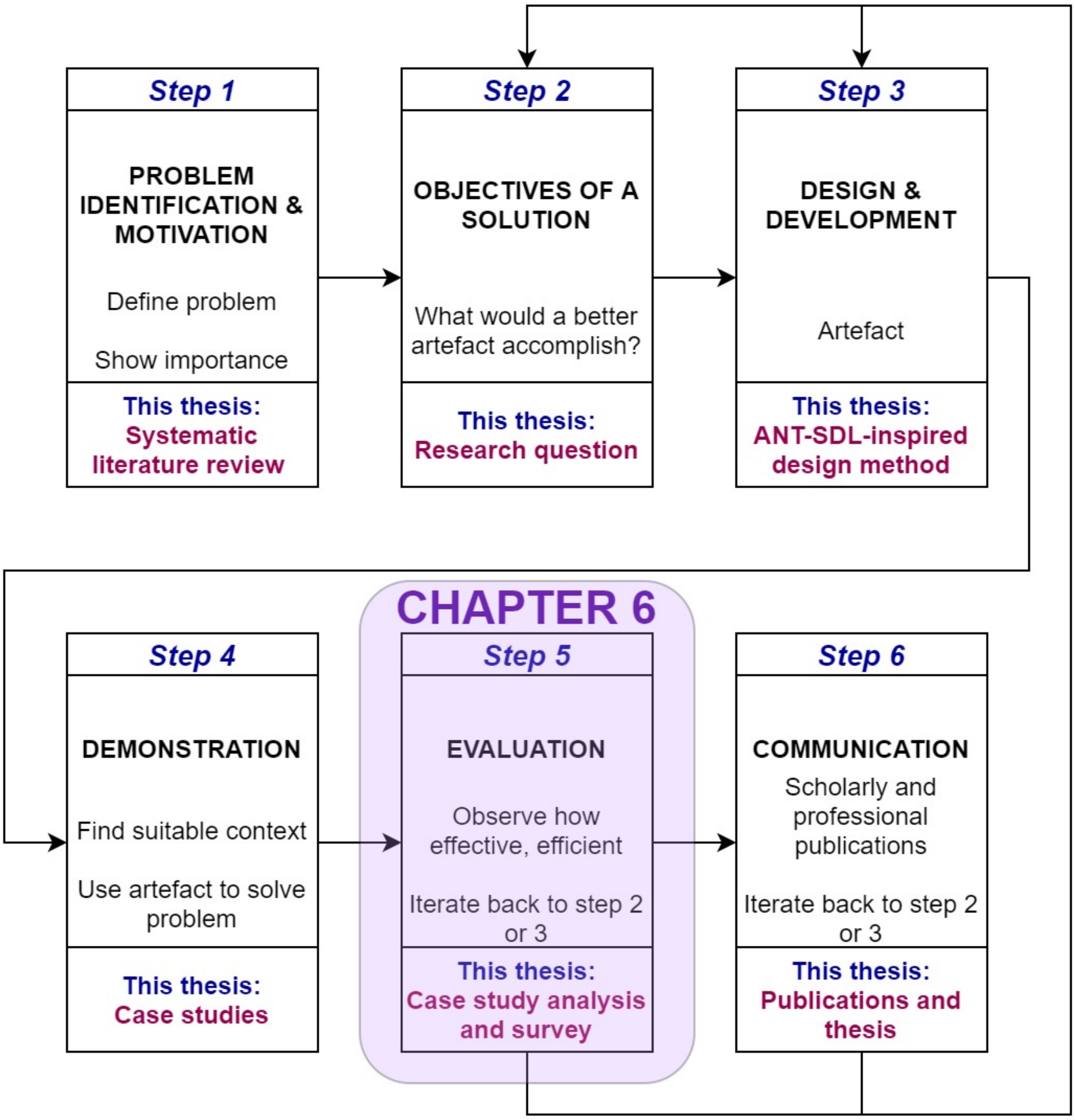

Figure 36: Step 5 of design science research method (adapted from Peffers et al., 2006; Peffers et al., 2007)

As discussed in Chapter 2, a review of the literature showed that businesses need a method to design a CPPSS solution for customers that can dynamically adapt to the changing needs of the market and the environment (Crossan & Apaydin, 2010; M. Kim et al., 2015). However, such an integrated design method is yet to be developed (Chew, 2016). Consequently, this research used the concepts of SDL and ANT to propose a holistic CPPSSDM to meet market need. The design method proposed in Chapter 4 was demonstrated in Chapter 5 using the data gathered from the four case studies conducted for this research. The purpose of Chapter 6 is to present how the design method was refined further so that it could be useful for customers and providers. This chapter also identifies the roles, tasks and activities to be performed by the managers, designers, users and providers of a CPPSS in co-creating the solution.

This chapter is organised into five parts, as shown in Figure 37. The cross-case analysis is presented in Section 6.1. The design method formulated from the inferences of the four cases and their cross-case analysis is shown in Section 6.2. Section 6.3 presents the scientific methodology used to obtain the practitioners' evaluation and the data obtained. Section 6.4 analyses the suggestions and shows how they were incorporated into the CPPSSDM reference model. Section 6.5 concludes this chapter.

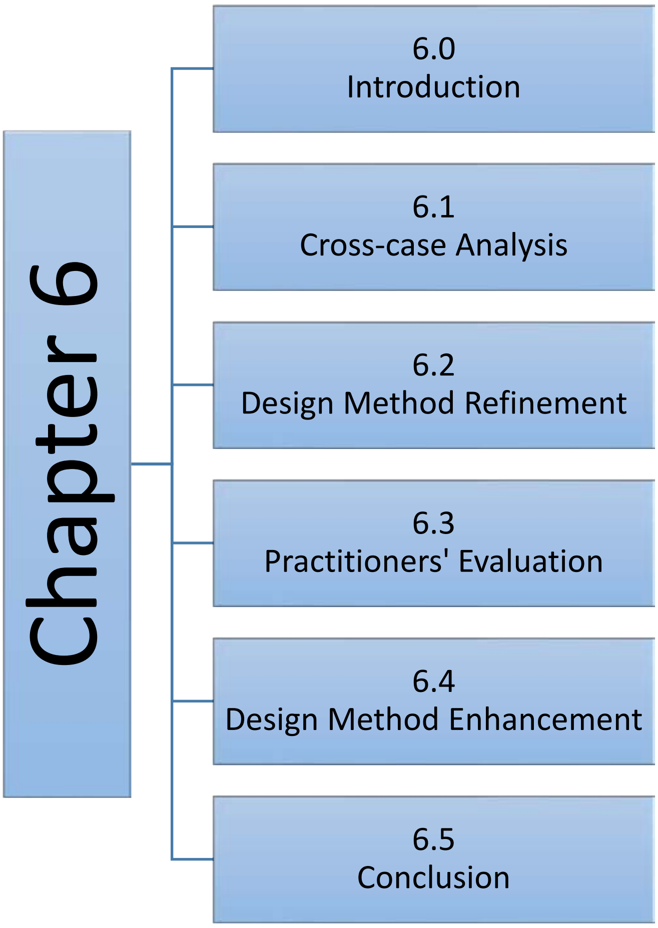

Figure 37: Structure of Chapter 6

6.1 Cross-Case Analysis

6.1.1 General Portfolio

The objective of the cross-case analysis was to compare the four case studies – DairyCo, PoolCo, HealthCo and VRCo – so as to understand the similarities and differences of applying the proposed CPPSSDM reference model in these organisations. The four case-study organisations are listed in Table 33. These case organisations differed in terms of their industry sector, organisation size and business model. They were all involved in the design and implementation of a CPPSS, either as a provider or a customer. A total of 18 semi-structured interviews were conducted to help demonstrate the CPPSSDM.

Table 33: Summary of case study subjects

Case	Industry sector	Participants	Organisation size	CPPSS since	Location	Mean interview duration (in minutes)
DairyCo	Dairy processing and packaging	9	Large	2016	Sydney	64:54
PoolCo	Pool management and water purification	4	Medium	2017	Sydney	42:23
HealthCo	Health tracking and management	2	Medium	2011	Melbourne	70:43
VRCo	Virtual reality technologies	3	Small	2017	Sydney	70:24
	Total	18				61:27

6.1.2 Comparing the Organisations

The CPPSS complexity in each organisation was very different from the others (see Table 34) and the diversity of the case-study organisations allowed different aspects of the CPPSSDM to be examined.

Table 34: CPPSS offering by each organisation

Case	CPPSS	Complexity	Initiator	Offering	Role	Business Model
DairyCo	Software, Hardware and Service	High	DairyCo	Processing and packaging solution	Customer	Product-oriented
PoolCo	Software, Hardware and Service	Low	PoolCo	Mobile application	Provider & Customer	Product/result-oriented
HealthCo	Software and Service	Medium	Hospitals (Customer)	Web-based application	Provider	Product-oriented
VRCo	Hardware and Service	Low	VRCo	Virtual locomotion device	Provider	Product/use-oriented

Below are some observations of the case-study organisations and their approaches to CPPSS design and implementation:

- PoolCo was a relatively small business. It worked on a less complex CPPSS than those designed by DairyCo and HealthCo. PoolCo also had smaller targets in its *Problematisation* stage, which made its CPPSS development simpler. Unlike other three organisations studied in this research, PoolCo was a customer when designing the CPPSS with the developers but was a provider when implementing the CPPSS with the pool owners.
- The geographical distribution of the stakeholders played a significant role in the functional requirements of the CPPSS. DairyCo faced numerous service issues due to geographical barriers between its production site and its service providers. HealthCo had to modify its offerings and conduct long-distance communication based on the country where it was used. Later, it had to hire employees in customer locations to provide face-to-face communication and service.
- Being a start-up organisation, VRCo had to conduct numerous campaigns to create awareness and attract funding for the business. VRCo could co-design an application-specific solution only when the customer agreed to fund it. This enabled VRCo to improve its CPPSS and co-create value with customers by developing customised solutions.
- The complexity of each CPPSS affected the time the case-study organisations took to design and implement their systems. The level of complexity also depended on the case study organisation's willingness to be flexible in adapting to evolving customer demands.
- Each of the four case studies produced a product-oriented CPPSS as this was the most straightforward business model, although PoolCo added an option for a result-oriented CPPSS, and VRCo added an option for a use-oriented CPPSS.
- All the organisations, be they provider or customer, placed importance on improving customer value, brand image, customer reviews and data analysis of performance. These were vital factors in gaining a competitive advantage that would lead to market expansion.

6.1.3 Comparing the Design Methods

The design processes implemented by the four case-study organisations were compared with the CPPSSDM reference model of this thesis to identify the internal mechanisms required to execute the CPPSSDM. In each of the four stages of the proposed design method, it was observed that each organisation met its challenge(s) by using appropriate action(s). A comparison of the challenges and actions of each case study is listed in Table 35.

Table 35: Comparing the four stages of design method between cases

	Problematisation		***Interessement***		***Enrolment***		***Mobilisation***	
Case	**Challenge**	**Action**	**Challenge**	**Action**	**Challenge**	**Action**	**Challenge**	**Action**
DairyCo	Meet growing demand	Predict volume	Find providers	Tender	Select providers	Evaluate quality	Performance and waste	Continuous data analysis
PoolCo	Manage pools better than their competitors	Survey owners	Develop application	Find developer	Find a solution	Collaborate	Measure pool usage and status	Data collection
HealthCo	Improve patient outcomes	Reduce paperwork	Find provider	Tender	Find a solution	Convey demands	Openness and awareness	Share policies
VRCo	Create the sensation/ experience of locomotion in virtual reality	Develop prototype	Find buyers and investors	Marketing	Customisation	Collaborate	Evolving demands	Flexible customisation

Each of the case studies consisted of a multitude of actors involved in CPPSS design and implementation but the roles played by the organisation varied from case to case. These aspects are listed in Table 36.

Table 36: Main features of the cases observed

Case	Role	Actors
DairyCo	Customer & *Initiator*	1. DairyCo (designers, maintenance, managers & operators) 2. Providers (designers & CPPSS)
PoolCo	Customer, Provider & *Initiator*	1. PoolCo (managers, engineers & CPPSS) 2. Providers (researchers & developers) 3. Customers (pool owners) 4. Franchisees (maintenance & service providers)
HealthCo	Provider & *Follower*	1. HealthCo (designers, service providers & CPPSS) 2. Customers (hospitals) 3. Operators (nurses)
VRCo	Provider & *Initiator*	1. VRCo (designers, managers and service providers & CPPSS) 2. Customers (managers & operators) 3. Investors

During each CPPSS design and implementation process, the organisations demonstrated particular strengths and weaknesses, as listed in Table 37.

Table 37: Strength and weakness of each case

Case	Strength	Weakness
DairyCo	A large pool of actors to collaborate	A high degree of CPPSS complexity, leading to several issues after Mobilisation
PoolCo	Close monitoring of customers	No direct contact with the end-users
HealthCo	Direct interaction with the end-users	Difficulty in modifying and communicating solutions with geographically diverse customers
VRCo	Highly flexible in meeting users' needs	Lack of recognition of the CPPSS among public

6.2 CPPSSDM Refinement

The four case studies provided insight into the practitioner's world of CPPSS design and implementation. They helped gather detailed information on the intricacies of how value is co-created among actors to design, implement and improve a CPPSS. They also confirmed that their activities aligned with the four translation stages (*Problematisation*, *Interessement*, *Enrolment* and *Mobilisation*) of the CPPSSDM reference model. This section provides a brief discussion of the key findings from the case studies. These findings are then integrated into the proposed CPPSSDM.

Several themes emerged from the case study analysis (intra and cross) that could inform the conceptual CPPSSDM reference model developed in Chapter 4. Among these themes, the most fundamental ones were selected to refine the reference model further. These themes were selected by analysing the influence they can deliver and the frequency of occurrence among the cases. These themes are listed and discussed below.

1. The significant role of communication in value co-creation

   As informed by the research question (see Sections 1.1.2 and 2.8.1) and various discussions throughout the thesis (see Sections 2.4, 2.8.3, 4.2.3 and 4.3.3), value co-creation is a central focus of this research. Communication formed a significant part of the CPPSS design process among all four cases (see Sections 5.2.5.4, 5.3.5.3, 5.3.5.4, 5.4.5.2, 5.5.5.2 and 5.5.5.3). Thus, communication was selected as one of the themes to refine the CPPSSDM reference model. The refinement is discussed in Section 6.2.1.

2. The initiation factors of the design process

   The role of the *initiator* and significance of initiation was discussed in Section 4.2.3. Initiation is a value co-creating activity that leads to the implementation of the CPPSSDM whenever a new need is identified in the network. Among all four cases, it was observed that the design process was instigated only once an actor (customer or provider) identified a problem and took up the role of the *initiator* (see Sections 5.2.1, 5.2.3, 5.3.1, 5.3.3, 5.4.1, 5.4.3, 5.5.1, 5.5.3 and 6.1.3). Initiation was thus selected as one of the CPPSSDM reference model refinement themes to address the importance. Further details are provided in Section 6.2.2.

3. The roles played by each actor in the design process

   Apart from initiation, each actor in the network must perform specific actions towards the design and implementation of the CPPSS. All four case studies have revealed the value perception of the actor helped determine its participation and role in the network. The roles and activities of each actor formed a vital part of the smooth functioning of the design process in each of its four stages, as shown in Section 5.2.4, 5.3.4, 5.4.4 and 5.5.4. So, including this theme to refine the reference model was an obvious choice. Further details are provided in Section 6.2.3 and again in Section 6.4.2 (after evaluation).

4. The task and goals of each design stage

   The central focus of each design stage was provided in Section 4.2.3.2, Section 4.3.3, Figure 21 and Figure 25 while developing the conceptual reference model. In addition to these foci, the four case studies revealed the type of communication, actor tasks and goals involved in each design stage. These testimonies are observed throughout the findings discussed in Sections 5.2.5, 5.3.5, 5.4.5 and 5.5.5. These tasks and goals are vital in making the reference model robust, transparent, and appropriately included in the refinement process. Further details are explained in Sections 6.2.4 and 6.4.3 (post-evaluation).

5. The iterative nature of the design process

   One of the aims of the research question was to develop a design method adaptable to the dynamic needs of the customers (see Sections 1.1.2 and 2.8.1). This aspect was also highlighted in the SLR (Sections 2.2, 2.4, 2.6), research methodology (Sections 3.2, 3.3 and 3.4) and conceptual reference model development (Sections 4.1, 4.2.3 and 4.3.3). This adaptability was achieved by making the design method iterative. In agreement with the reviewed literature and conceptual model, this iterative nature was observed in all four case studies. Each case showed that the customers and providers interacted towards continuous improvement based on the changing needs and context. To address the aim of the research question and the theme observed in all four cases, the iterative nature of the reference model was also included in the refinement process. This process is explained further in Section 6.2.5.

The above findings enabled the design method to be more elaborate and instructive by providing vital details for each stage of the method. These findings are organised in Table 38 according to the four stages of the design method. Incorporating all the case study inferences also helped refine the CPPSSDM reference model, as displayed in Figure 38 and explained in Section 6.2.6. Further details of these findings are discussed in the following sub-sections.

6.2.1 Value Co-creation and Communication

Communication was identified as one of the most vital parts of the design process as it was implemented in all of its four stages. Communication, in particular, facilitated value co-creation by revealing and addressing the dynamic needs of the customers. In the case study analysis, communication was observed to be of two types: active and passive.

Active communication took place during the in the *Interessement* and *Enrolment* stages, where the actors actively communicated with each other to attract interest in a problem and solve it. Value co-creation was attained by the interaction between actors from different sections and perspectives of the system; in other words, this communication was performed through negotiations, tenders, feedback, co-design and the integration of resources. For example, active communication efforts helped DairyCo negotiate a higher level of customisation of its CPPSS and decide between outsourcing various design tasks or keeping them in house. In the case of PoolCo, active communication through the survey helped the company understand both customer needs and franchisee opinions, which led to the design of a well-informed and better solution. The active communication in the discussion portals of HealthCo helped the company to identify customer pain points and create a highly configurable CPPSS. VRCo's active communication in various technology events enabled it to harness the interest in and awareness of its CPPSS among its potential customers, which translated into customised solutions and greater market reach. As seen above, active communication, which involved regular discussions, meetings, progress evaluation and active feedback in all the case study organisations, helped the actors integrate their resources, knowledge, skills and expertise to develop the most viable solutions. As a result, collaboration and sharing resources were considered significant and highly valued by all the actors.

Passive communication occurred during the *Problematisation* and *Mobilisation* stages when the actors discussed how to operate the existing system and detect new problems. Value co-creation was achieved when each actor examined the existing CPPSS from his or her perspective. In *Problematisation*, the *initiator* gathered the required information on the problem before the design process (and the active communication) could be initiated, while in *Mobilisation*, the value-in-use of the CPPSS generated data on usage, market trends, system performance and customer behaviour, which uncovered new customer problems. In the case studies, each organisation used the data generated from the use of its CPPSS to identify usage patterns, performance shortfalls, waste excesses and improvement opportunities. This identification then enabled the provider to initiate appropriate communication and design processes to bring about changes, improvements and additions to the existing systems. For example, DairyCo reduced its milk wastage through leaner processing techniques, PoolCo created customer profiles using customer habit analysis, HealthCo built a patient scoring algorithm to trigger treatment escalations based on the hospital policies and VRCo planned to track customer eye movements to develop customer behaviour profiles.

6.2.2 Initiation

It was observed that the design process was triggered based on the value perceived by the actors in solving a specific problem. This value perception helped the actors develop a priority list of problems and decide which problems were worth solving. These priorities enabled the actors to actively negotiate requirements, targets, expectations, contractual terms and conditions and monetary relationships. In addition, intensive customer involvement through various communication channels such as meetings, emails, demonstrations and workshops resulted in better design outcomes.

Any actor, whether provider or customer, could initiate the design process. In the DairyCo case study, it was the end-users (i.e., the CPPSS operator) who initiated most of the communication, while in the VRCo case study, it was VRCo (the provider) who initiated the communication by creating awareness about their CPPSS. The PoolCo case study showed that, based on the context, the same organisation could be an *initiator* and a *follower*. As a customer, PoolCo initiated the communication and conveyed the issues to the provider (software application developer) and as a provider, PoolCo followed up the issues flagged by the pool owners and franchisees. In the case of HealthCo, both customers (the hospitals) and provider (HealthCo) initiated the design process whenever they identified a new problem. Once the problems were conveyed among the actors, active communication helped them develop the solution through resource and knowledge integration.

6.2.3 Actor Roles

There were clear roles that emerged from the analysis. The customer's role was to list its requirements and to provide its expert knowledge in the respective field. The provider's role was to come up with possible solutions, with training and technical expertise. These resources were then integrated to create the optimal solution for the identified problem. Communication through policy, training and media was used to continuously update the actor network about the improvements and changes in the system. Subscription services were shown to be beneficial to both customers and providers in the value co-creation process. The customer was assured of continued support while the provider enjoyed a regular income with access to valuable information about the system operation, which helped it identify opportunities for improvements and optimisation.

6.2.4 Tasks and Goals

The conceptual design method reference model provided the primary goals for each stage of the design process, as discussed in Section 4.3.3. The case studies helped discover the tasks and goals performed by the actors in each of the four stages.

1. The *Problematisation* stage involved passive communication to identify the requirements in response to the problem and then setting the priorities for which problems were to be communicated to the actor network.
2. Active communication took place among the actors during the *Interessement* stage to convey concerns and negotiate the relationships and roles to be performed by each actor.
3. As the actors enrolled in the actor network to execute *Enrolment*, they actively communicated to integrate their knowledge and resources to develop the new or improved CPPSS.
4. This solution was then shared among all the concerned actors by moving into *Mobilisation*. The use of this CPPSS was passively communicated to detect a new problem or opportunities for improvement, which themselves enabled the initiation of the design process.

6.2.5 Iterative Nature

As the observations above confirm, the case studies showed that the design process was highly iterative. The design method required continuous iterations between the four stages from the initial design of the CPPSS through the various improvements to its final form. These iterations ensured a comprehensive co-creation of value and co-design of the solution through the collaboration of customers (including end-users), providers, designers and managers. This iterative characteristic was included in the refined design method by incorporating a loop that connected the *Mobilisation* stage to the *Problematisation* stage. This feedback loop enabled new customer problems to be detected during the value-in-use process in the *Mobilisation* stage. The loop then fed that customer problem into the *Problematisation* stage to start a new iteration of the CPPSS design.

6.2.6 Refined CPPSSDM

The conceptual reference model was refined using the five factors discussed in the previous sections (Sections 6.2.1 to 6.2.5). The simplified conceptual reference model proposed in Section 4.3 and illustrated in Figure 25 has a few drawbacks from the case studies. These are listed below.

- It did not denote the value co-creating activities that helped translate from one design stage to another.
- The central theme of each design stage was expressed in a single word rather than an elaborative sentence.
- The iterative nature of the design method was not highlighted due to the absence of a feedback

Reflecting on the major themes of the case study and the drawbacks of the conceptual reference model, the design method was refined at each of its four stages. The refined explanation of the four stages is provided below.

- *Problematisation*: As discussed in the previous sections, initiation is a vital part of the design method. Initiation is a value co-creation activity in the *Problematisation* stage through passive communication to identify the problems and set their priorities. Initiation helps to transform from *Problematisation* of the evolved needs to *Interessement* of the actors.
- *Interessement*: In this stage, the needs/problems identified in the previous stage is conveyed to the potential actors and appropriate relationships are negotiated through active communication. The actors co-create value proposition to transform from *Interessement* of the actors to the *Enrolment* of the chosen actors.
- *Enrolment*: The actors chosen to enrol into the network collaborate through active communication to integrate their resources in developing the solution. The participating actors perform the co-creating activity of co-development to transform from *Enrolment* of the chosen actors to the *Mobilisation* of the co-designed solution.
- *Mobilisation*: The solution co-designed by the actors is implemented and monitored by the network through passive communication to ensure that the identified problem is being solved. The actors co-create value-in-use of the solution during the usage of this solution. Value-in-use also enables actors to detect new problems to be solved. So, value-in-use helps transform from *Mobilisation* of the co-designed solution to *Problematisation* of the evolved needs.

The refinements are discussed above, and the previous sections are presented in Table 38. The refined CPPSSDM reference model is illustrated in Figure 38.

Table 38: Activities in each design method stage based on the four stages of CPPSSDM reference model

Stage	**Communication**	**Activity**	**Value co-creation**	**Explanation**	**Example**
Problemat	Passive	Identify & Set	Initiation	Identify the requirements to set the priorities of the problems	Predictions, customer profiles and goal analysis.
Interessement	Active	Convey & Negotiate	Value proposition	Convey concerns and negotiate relationships and roles	Survey, tenders, contracts and agreements.
Enrolment	Active	Integrate & Develop	Co-development	Integrate knowledge and resources to co-design solution	Integrated experiences, expertise in the co-design process.
Mobilisation	Passive	Share & Study	Value-in-use	Share the changes and monitor the value-in-use network from human and non-human sources	Workshops, emails, training to share changes. Study market trends and usage patterns to identify opportunities.

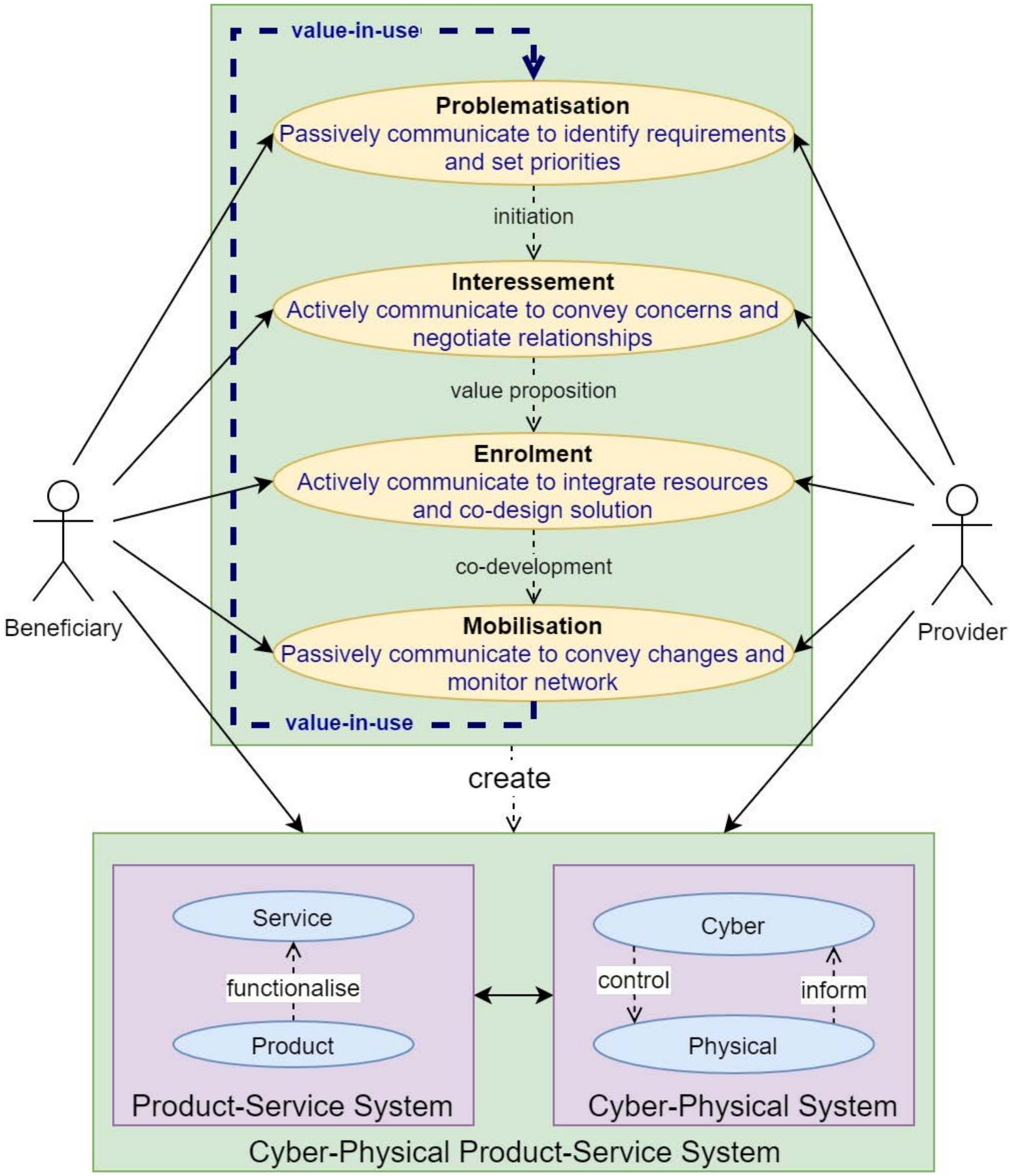

Figure 38: Refined CPPSSDM (refinements shown in blue text)

6.3 Practitioners' Evaluation

6.3.1 Survey

A presentation about the foundational concepts and proposed reference model of the CPPSSDM created in this research was compiled and then recorded as a short video presentation (6 minutes and 42 seconds) to enable convenient sharing of knowledge. A survey questionnaire based on this presentation was also developed and then converted to an online version to enable respondents to submit their responses remotely.

The participants for the survey were chosen using the strict selection criterion discussed in Section 3.5.2. As can be noticed from the selection criteria, the survey was not meant for the general public, but the practitioners involved in designing and implementing CPPSS. Furthermore, the literature reviewed in Section 2.6 has shown that CPPSS is a novel system. So, the potential respondents of this survey were from a small group of industry practitioners. The practitioners who had previously participated in the case study interviews and fitted the selection criteria for the satisfaction survey were classified as internal respondents. The external respondents were the practitioners who had not participated in the case study (Chapter 5). External respondents were selected by following the same selection criteria and identifying them through various channels. The channels included information technology alliances (e.g., IoT Alliance), personal contacts and design innovation workshops involving multiple organisations. The 36 potential respondents, both internal and external, were then contacted through various means such as emails, phone calls and physical meetings to discuss the intention of the survey. A total of 24 interested respondents were emailed with the video and the survey questionnaire to obtain their reaction on the proposed design method. Of these respondents, 12 completed the survey. The following sections discuss the data obtained.

6.3.2 Data Gathered

The main aim of the survey was to evaluate the utility and clarity of each of the four steps of the CPPSSDM reference model. The survey was conducted such that data redundancies would be kept to a minimum. So, practitioners from varied industries and positions were included in the survey to get diversity in the knowledge generation. The sample size was periodically expanded based on the new knowledge being generated from each practitioner response. The survey was concluded once the researcher realised that redundancies were getting accumulated with the increment in sample size. The sample size was also governed by the resource and time constraints of the doctoral program and its timeline (Lenth, 2001). The background data of the 12 respondents included their positions in their respective organisations, the skills they possessed, their experience in their industry, the type of industry and its size. The background data obtained are summarised in Table 39.

Table 39: Survey data

Characteristics	Category	Number
Participant's Role	Operator/End-user	2
	Engineer/Designer	0
	Manager/Leader	7
	Operator and Manager	1
	Engineer and Manager	1
	All-rounder	1
Organisation Size	Start-Up	1
	Local	1
	National	1
	Multinational	9
Experience (in years)	Current organisation	Mean – 11.83, Median – 7.5
	Lifetime	Mean – 20.5, Median – 22
Participant Involvement	Participated in a case study	9
	Did not participate in a case study	3

All the stages of the design method were rated 3 or above (out of 5) on the Likert scale (see Section 3.5.3) by 11 of the 12 respondents. The feedback showed that the respondents not only understood the design method and its usability but also wanted a few improvements. These improvements were provided as suggestions in the survey and are analysed in the next sections. In the following sub-sections, each of the four stages of the design method is discussed separately in terms of the practitioner responses. The responses in each section were divided into two parts as discussed below. Section 6.4 synthesises this qualitative evaluation and describes the changes made to the design method as a result.

- What the respondents learnt

  This section presents the knowledge that the respondents' gained about the CPPSSDM reference model. It notes the approval ratings received for the clarity and utility of the reference model and the appreciations provided by the respondents.

- What the respondents suggested

  This section presents respondents' suggestions for the design method improvements in the given design stage (*Problematisation*, *Interessement*, *Enrolment* and *Mobilisation*). It also discusses their implications for the reference model.

6.3.3 Problematisation

6.3.3.1 What the respondents learnt

The themes that surfaced from the responses for the *Problematisation* stage were feedback, value proposition and collaboration. The respondents also acknowledged (appreciation) that the design method was a useful tool for them, and it represented a collaborative design method. Most of the respondents rated the utility and clarity of this stage to be 4 to 5 (out of 5), signifying a high level of approval.

The respondents acknowledged the feedback loop in the design process as significant for understanding the customer problem and improving the system. They said the value proposition, which is an activity of the *Interessement* stage, was connected to the customer problem. The comments confirmed how important a clear understanding of the problem is, for creating an effective value proposition. The collaboration between the actors in the design process was also found to be vital to CPPSS design. The proposed design method has also paid attention to the importance of collaboration throughout the design process. The respondents also highlighted the importance of collaboration. The relevant comments are listed in Table 40.

Table 40: Respondents' reactions to *Problematisation*

Reaction	Comments
Appreciation	*"Great tool for problem-solving."* – FM2 *"It's a subset phase of current participatory design practice."* – FOEM1
Importance of feedback	*"Positive feedback is very important."* – FOM1 *"Feedback is necessary in order to improve products and services."* – FO1 *"Better feedback loop between end-users and providers for understanding the problem."*– FEM1 *"Share knowledge and expertise, also provide feedback."* – FO2
Value proposition	*"I think the basis of design is always to detect a problem. The value proposition should be worked backwards."* – FM1 *"I think the clear definition of the problem is critical; without this, we cannot expect to meet client needs, and will always result in missed opportunities."* – FM3 *"Detect the problem and develop the value proposition."* – FM5
Collaboration	*"Collaborative identification of pressure point/wastes in our process."* – FM4 *"YES! The team involvement which would create the necessary engagement for Problematisation [by] looking at the problem in a robust manner."* – FM6

6.3.3.2 What the respondents suggested

When asked for suggestions for improvements, some respondents acknowledged that the *Problematisation* stage was clear enough while others asked for some improvements. The responses could be divided into three categories: appreciation, rigour and clarity. These comments are organised in Table 41.

Among the suggested improvements, the first theme that surfaced was the importance of customer/user participation in the design process by disclosing their pain points, conflicts and feedback by having direct access to the providers. This theme was consistent with the customer-centric theme of this research. However, direct access may not always be possible, as explained later in Section 6.4.2. Some of the respondents wanted to include more features and suggested tools that could help execute *Problematisation* better. However, the development of such tools fell beyond the scope of the thesis, so was accordingly explained in Section 6.4.1 and marked as such in the table. The suggestions that could be incorporated into the design method are marked as resolved in the table and are explained in Section 6.4. Any confusing comments were clarified with the respondents through various channels like emails and meetings.

Table 41: Respondents' suggestions for *Problematisation*

Suggestion	Comments	Incorporation
Appreciation	*"Nothing. A very detailed methodical approach."* – FM6	NA
Rigour	*"Users should have direct access to the providers."* – FO1	Resolved
	"The most challenging is getting the customer feedback, so I'll develop tools to motivates the customers to provide feedback." – FM5 *"More participation by other users." – FOM1* *"Disclose pain points is practical, but we could replace it with conflicts and restriction of the system." – FO2*	Beyond the scope
	"More expansion into problematic areas." – FM2	Clarified
Clarity	*"I wasn't too clear in regard to set and evaluate targets."* – FM1 *"The diagram is not clear that the Designer and Management are connected."* – FOEM1	Clarified

	"Is there a template/tool to ID opportunities?" – FM4	Beyond the scope

6.3.4 Interessement

6.3.4.1 What the respondents learnt

In terms of ratings, the responses from the *Interessement* stage were more polarised compared to the other three stages. Although most respondents had a favourable view, some also provided critical feedback. They were able to identify its usefulness in their field of work. Some respondents were also able to relate the concepts to their practical knowledge. The comments could be categorised as appreciation and recognition as listed below in Table 42.

Table 42: Respondents' reactions to *Interessement*

Reaction	Comments
Appreciation	*"Designer learning from the user experience is a good point."* – FM1 *"Goals are needed in order to have the product meet the required specifications."* – FO1 *"Multi-skilling."* – FM2 *"I needed to listen and understand more about developments."* – FOM1 *"How to potentially get better service from our partners etc."* – FM4 *"(I learnt) how the users need a collaborator to facilitate the process."* – FM5
Recognition	*"It's a bit like requirements elicitation with expectation management."* – FOEM1 *"Outline needs and express requirements."* – FO2

6.3.4.2 What the respondents suggested

Among the suggestions provided by the respondents, user participation emerged once again as a prominent theme. The informants wanted the users/customers to have more involvement in the design process and flexibility in accessing the providers. It is a theme that aligned with the aim of this thesis, which is to develop a customer-centric CPPSS design method.

A few respondents asked for examples and clarification for some of the terms or activities mentioned in the presentation. Such respondents were directly consulted through appropriate channels of communication and provided with further explanations about the concepts. The suggestions concerning more participation and access between actors were incorporated into the enhanced design method and marked as resolved. The enhancements are discussed in Sections 6.4.2 and 6.4.3. Overall, the suggestion could be categorised as agreement with the study and rigour of the design method, as listed in Table 43.

Table 43: Respondents' suggestions for *Interessement*

Suggestion	Comments	Incorporation
Agreement with the study	*"More participation by users."* – FOM1 *"More input from the end-user."* – FM4 *"Users having direct access to the providers to give their feedback."* – FO1 *"Having more personnel involved."* – FM2	Resolved
Rigour	*"Needs further clarification of what is meant by negotiating tender."* – FM1	Clarified
	"I get what the Interessement step is meant to achieve, but I'm still not clear on it." – FEM1	Clarified

6.3.5 Enrolment

6.3.5.1 What the respondents learnt

The *Enrolment* stage responses generally showed a positive reaction to the design method. It was rated higher than the previous two stages, with most of the ratings being 4 or 5 (out of 5). The respondents appreciated the emphasis this step puts on regular assessment, communication and feedback between the actors to develop the best possible CPPSS solution for a given problem. Few of the respondents could easily relate the concepts and activities to the knowledge and expertise available to them in their field/organisation. A few of the respondents wanted more clarification on the implementation of this step; those clarifications that were within the scope of this research were provided and the remaining clarifications were held over as material for future research. The respondents' comments relevant to the Enrolment stage are categorised into the appreciation of the design method, recognition of available knowledge and interest to learn more, as shown in Table 44.

Table 44: Respondents' reactions to *Enrolment*

Reaction	Comments
Appreciation	*"The more communication, the better the outcome."* – FOM1 *"That users should be actively giving their feedback."* – FO1 *"One needs to be switched on with knowledge."* – FM2 *"Upskilling of staff."* – FM7 *"Team initiating"* – FM6 *"Good for defining bespoke and COTS (consumer off-the-shelf) approach."* – FOEM1 *"Regular assessment of progress."* – FO2 *"(I learnt) How important is the education/learning feedback from the customer to able to achieve or solve the problem."*– FM5
Recognition	*"The tight co-working implied around this step; I think is quite good. It is something we strive to do with our partners."* – FM3
Interest	*"Why is the provider educating the customer?"* – FM1 *"I understand this step is relating to the solution development phase but not clear on the roles of the actors."* – FEM1

6.3.5.2 What the respondents suggested

Among the suggestions provided by the survey respondents, some wanted to see more open communication and connectedness between the users and the providers. These suggestions were resolved by clarifying the actor roles and responsibilities in the enhanced design method (see Sections 6.4.2 and 6.4.3). One of the proposals to improve this step was to have a rating system. This suggestion was also resolved and discussed as a bridge between end-users and providers in Section 6.4.3. Another set of respondents made detailed suggestions to give greater importance to risk management and to change the name of the step. However, including the concepts of risk management fell outside the scope of the research (see Section 6.4.5), while changing the name of this step would mean disrupting the uniformity of the academic terminologies (see Section 6.4.4). These clarifications were conveyed to the respective respondents through various communication channels, such as emails and meetings. In summary, the responses were categorised into open communication, rating system and risk management, as shown in Table 45. The resolutions, clarifications and arguments are discussed further in Section 6.4.

Table 45: Respondents' suggestions for *Enrolment*

Suggestion	Comments	Incorporation
Open Communication	*"More communication."* – FOM1 *"Users having access to the providers."* – FO1 *"Upskilling of staff."* – FM7	Resolved
Rating System	*"Possibly have a rating system based on scores."* – FM2	Resolved
Risk Management	*"Make risk management more explicit. This is required for resource allocation/decision making."* – FOEM1	Beyond the scope
	"I would suggest, based on your description, that "Engagement" is a better name for this step … imply an ongoing relationship throughout product development." – FM3	Clarified
Clarity	*"Does the provider have direct interaction with the user or via the designer and management?"* – FM1	Clarified

6.3.6 Mobilisation

6.3.6.1 What the respondents learnt

The *Mobilisation* stage obtained the highest rating of the four stages of the design method for both clarity and utility. Almost all the respondents had a constructive understanding of this step when relating it to their field of work. Some respondents could relate this step to the knowledge they possess in their own field of expertise. Overall, the respondents found the feedback loop, customer involvement, flexibility in communication and value extraction most significant. One of the respondents doubted whether the design method could be implemented in a business-to-consumer (B2C) setting, as shown in the comment below. However, since this research was specific to business-to-business relationships, designing consumer products may not be suitable for such an application. The responses were categorised into the appreciation of the design method, recognition of prior learning, the significance of *Mobilisation* and confusion about B2C application, as shown in Table 46.

Table 46: Respondents' reactions to *Mobilisation*

Reaction	Comments
Appreciation	*"Customised solutions are necessary for product development."* – FO1 *"I implemented the system with a positive outlook and got a positive result."* – FOM1 *"Good change management process."* – FOEM1 *"Request solutions and extract values."* – FO2
Recognition	*"Very like a PDCA (plan-do-check-act) cycle."* – FM4
Significance	*"An active feedback loop is good for future product design and improvements."* – FM1 *"More flexibility with effectiveness."* – FM2

	"Improving training and communication to the customers involved in the process." – FM5 *"That this is the implementation phase of product delivery and that there is a loop here through feedback from the customer."* – FEM1 *"Network comms."* – FM6 *"The importance of customer engagement."* – FM7
Confusion	*"While this works for complex products (thinking of IT to a large degree), I am not sure how this might translate to a consumer product (e.g. TV)"* – FM3

6.3.6.2 What the respondents suggested

The survey respondents generally seemed satisfied with the *Mobilisation* stage. They appreciated the emphasis applied on customer feedback and were keen to connect the customers/users directly to the providers. This interest was resolved by enhancing the design method with mode clarity and organised structure, as discussed in Sections 6.4.2 and 6.4.5. The confusion residing in any of the survey respondents was also clarified through the suitable communication channel. The comments were thus classified as clarity of *Mobilisation* and are organised in Table 47. Further explanation and arguments in response to the comments are provided in Section 6.4.

Table 47: Respondents' suggestions for *Mobilisation*

Suggestion	Comments	Incorporation
Clarity	*"Direct feedback to the providers."* – FO1	Resolved
	"I am a little confused about whether the provider obtains customer feedback directly or via management and designer." – FM1	Clarified

6.3.7 Other Comments

At the end of the survey, the respondents were given a chance to provide any further comments on the overall presentation video and the CPPSSDM reference model. Several respondents expressed both their appreciation and their concerns in response. Most of the responses were appreciative comments in addition to the one that asked for further enhancements, as shown in Table 48. The suggested enhancement was to have more iterations in each step and change the term ‘cyber’ to ‘virtual’, as shown below. In response, as explained throughout this thesis, the design method is highly iterative, but the stages were clarified further during the enhancement discussed in Section 6.4. Regarding terminology, once again, changing the terms could lead to derailment from academic uniformity. Further justification and reasoning are discussed in Section 6.4.

Table 48: Respondents’ further comments

Reaction	Comments
Appreciation	*“Overall, the system is easy to understand, straightforward and efficient.”* – FO2 *“Excellent proposal, I think it makes the process of creating product/services more dynamic. It also goes straight to the point, which is offering a solution to the customer. I think the product or service has more possibilities of being successful when [they] reach the market using these types of methodologies.”* – FM5 *“Well done … good luck :)”* – FM3 *“Very interesting would be keen to see the execution of the process steps. Well done!”* – FM6 *“Whilst I am a customer that needs to be pleased, I also have customers that rely on me to utilise the system to please them, I am happy with the outcome.”* – FOM1
Clarity	*“Seems strange that problems from the user are not highlighted earlier. Initially, it seems very waterflow [sic], but the feedback loop at the end was a relief. Probably pay to have some iteration within each phase and how this could be managed would be useful. Do you really mean "Cyber"? Would "Virtual" be better.”* – FOEM1

6.4 CPPSSDM Enhancement

The respondents in the evaluation survey made various suggestions and comments to improve the design method. Those comments and feedback are addressed in the following Sections 6.4.1

to 6.4.5. The enhancements made to the reference model based on these suggestions are discussed in Section 6.4.6.

6.4.1 Design Tools

A common respondent suggestion made in all four stages was for tools that would enable them to execute their design processes. These tools would help motivate their customers to provide feedback, identify opportunities, rate problems/solutions and enhance *actor* participation. This thesis has listed several tools that could be implemented in the design method, specifically in Sections 2.2.2 (PSS), 2.3 (lifecycle), 2.6.2 (CPPSS), 4.2.3 (ANT-SDL) and 4.2.4 (ANT-SDL lifecycle). However, classifying these design tools for each stage of the design method is another research project and thus falls beyond the scope of this thesis. In the context of this thesis, however, the CPPSSDM users did have the flexibility to select and implement tools based on their knowledge, expertise and context.

Some respondents wanted further clarification of certain aspects of the design method. Although this thesis has an elaborate explanation of the design method, not all information could be included in the video presentation. Thus, to address their concerns, interested respondents were contacted through one-to-one conversation.

6.4.2 Actor Roles

Actors must develop the value proposition adequately. In some situations, it may not be possible to segregate the roles of the four *actors*, that is, provider, designer, manager and end-user. In such situations, the *actor* may be entrusted with a combination of any of the above four roles, as was observed among the respondents during the evaluation, and an example of which is shown in Table 17. In such a scenario, the responsibilities and tasks of that *actor* are expanded.

6.4.3 Actor Responsibilities

It is important that the value proposition between the customer and the provider should be agreed at an organisational, big-picture level. This is because, in a business-to-business environment, the provider has better access to the customer and a better understanding of the overall value proposition than each of the other *actors* (such as a designer, manager or operator) individually. As explained in Section 4.2, the manager and the designers generally work as a subset of the customer or provider and based on their position, have a limited view of the value perspective.

It is essential to emphasise that it is the provider's responsibility to develop or investigate the CPPSS solution based on the context and economics of the customer problem. The solutions delivered by the provider to customers over time help create a brand image that can result in a competitive edge. As these CPPSS solutions evolve with emerging customer problems, the providers must continuously educate their end-users about the new features. It would be ideal if the provider had access to the end-users, but this may not always be possible. In such cases, the managers and the designers form the bridge between the provider organisation and the end-user organisation. As suggested by one of the respondents, the providers and end-users could implement a rating system for each other's responses and concerns, which would help to create the feedback loop. Most of the respondents shared this suggestion.

6.4.4 Terminologies

The design method in this research was developed using the principles of ANT and SDL specifically to design CPPSSs. The terms and techniques were adopted from the relevant literature on PSS, CPS, CPPSS, ANT and SDL. However, some of the respondents found these terms non-intuitive and suggested the terms be changed. Although, to maintain academic uniformity, the name of each step must remain as is, the explanation of these steps was improved to create awareness and make better sense to real-world practitioners. The design method diagram was also improved to provide the themes and *actor* activities in each of the steps, as shown in Figure 38. It is intended that this design method will be developed further as a practitioner's guide to designing CPPSSs. Since this guide will be more practice-oriented, it will adopt the terms suggested by practitioners. The guide is expected to clarify the design method further and become more useful to both customers and providers of CPPSS.

6.4.5 Risk Management

Risk management forms a vital part of solution development in managing the actors' resource allocation and decision making. To obtain optimal outcomes, this aspect requires all *actors* to contribute to risk identification, risk assessment and risk mitigation, but a further description of risk management falls beyond the scope of this research.

6.4.6 Enhanced CPPSSDM

The refined CPPSSDM reference model was enhanced using the five themes from the practitioners' evaluation (Sections 6.4.1 to 6.4.5). Responses of the practitioners were based on the CPPDM reference model discussed in Section 6.2 and illustrated in Figure 38. Although the design method received several appreciative reactions, it also gathered a few deficiencies which required enhancements. The flaws that were addressed in this research are listed below.

- The reference model did not convey the tasks, roles and responsibilities of each actor in the network.
- The constituents and the segregation between the customer and provider weren't clear
- The iterative communication link between actors within each stage wasn't denoted.
- The focus of each stage needed more simplicity. It did not denote the value co-creating activities that helped translate from one design stage to another.

- The illustration did not clearly show the circular or iterative nature of the reference model and the stage-specific communication technique.

The reflection over the themes and flaws discussed above helped develop a circular CPPSSDM reference model that would enable continuous improvement in the design and implementation of CPPSSDM. Each design stage is detailed with the four actor groups on the customer and provider sides. The designers and the managers formed the bridge between the customer and the provider sides of the actor-network. These four actor groups iteratively interact with each other while performing their respective tasks, roles and responsibilities. Their collaborative and collective value co-creating activities help them to translate from one design stage to another. The focus of each stage and actor-specific activities are presented in Table 49. The enhanced CPPSSDM reference model is illustrated in Figure 39.

Table 49: Actor-specific activities in the Enhanced CPPSSDM Reference Model

	Problematisation	*Interessement*	*Enrolment*	*Mobilisation*
Focus	Proactively identify problems	Negotiate the value proposition	Integrate resources and knowledge	Communicate solutions & issues
Provider	• Detect problem • Develop value proposition	• Understand customer expectation • Approach potential collaborators • Negotiate relationship/pact	• Educate the customer • Integrate solution • Locate actors and solve issues	• Communicate solutions to the network • Obtain customer feedback • Provide customised solution and service
Designer	• Discover improvement opportunity • Assess requirements and constraints	• Negotiating the best solution • Learn from user experience	• Develop the best solution • Involve customers • Customize solutions	• Communicate updates • Dynamic system improvement • Identify new requirements
Manager	• Analyse and predict demand • Set and evaluate targets	• Negotiate contract • Regular revision of goals • Study customers' reactions	• Outsourcing appropriate tasks • Develop relationships • Obtain investment	• Communicate priorities • Analyse feedback, data and trend • Training & skill development
User	• Share knowledge and expertise • Disclose pain points & feedback	• Outline needs • Express requirements • Approach potential collaborators	• Maintain loyalty to the network • Regular assessment of progress • Actively provide feedback & knowledge	• Escalate issues • Request solution and extract value • Customised usage

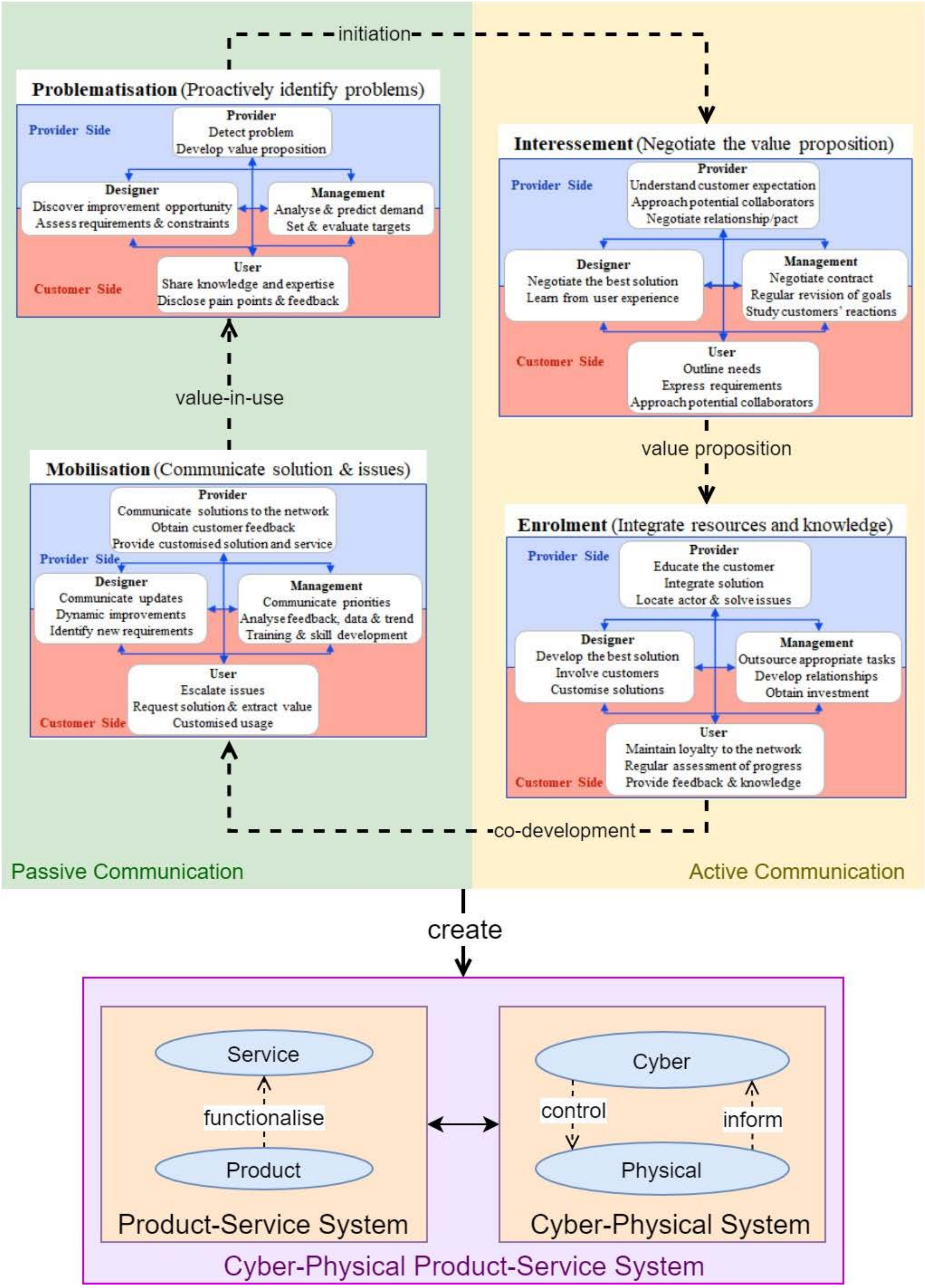

Figure 39: Enhanced CPPSSDM Reference Model

6.5 Conclusion of Chapter 6

This chapter has discussed the refinement and enhancement of the conceptual CPPSSDM reference model using the data obtained from case studies and surveys. The case studies helped identify the improvement opportunities in the conceptual design method. In response, appropriate refinement helped bring out the iterative and value co-creating activities of each stage of the design method. The reaction provided by the evaluation surveys detected further enhancement possibilities for the CPPSSDM.

The survey responses affirmed the strength of this design method and provided several suggestions for its improvement. The responses and suggestions were analysed and addressed according to their merit. The overall outcomes were then incorporated into the design method that has resulted in an enhanced reference model. The design method is now equipped with a clear distinction between customer and provider, the segregation of four groups of actors and their corresponding tasks and activities. This design method, which is backed by theoretical knowledge and practical data, has been evaluated by appropriate practitioners of CPPSS design, implementation and operation. The next concluding chapter summarises the knowledge gained by the research, the responses to the research questions and the implications.

Chapter 7 – Conclusion and Future Work

7.0 Introduction

This thesis developed a holistic design method reference model for CPPSS using the DSRM. This chapter summarises the research described in the previous chapters and the results in terms of theoretical and practical contributions; it also suggests future research opportunities arising from the research.

This chapter is arranged in seven parts, as shown in Figure 40. Following this Introduction (Section 7.0), it summarises the Thesis in Section 7.1 and then discusses in Section 7.2, the knowledge gained by addressing the research questions of this study. The achievements and implications of the research are discussed in Section 7.3 and the limitations are presented in Section 7.4. Section 7.5 sheds light on the future implementation of this research and the last part, Section 7.6, provides a summary and concluding remarks.

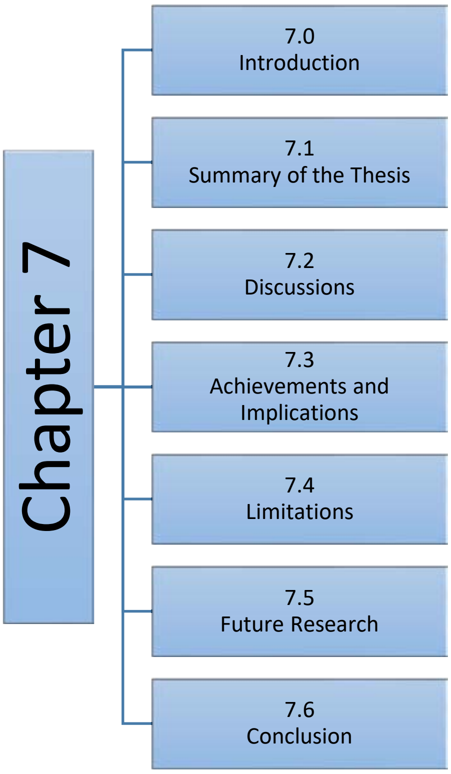

Figure 40: Structure of Chapter 7

7.1 Summary of this Thesis

A systematic literature review (SLR) was conducted to obtain more in-depth knowledge about PSS, CPPSS and related concepts. SLR is a review process that differs from traditional reviews by being replicable, scientific and transparent (Cook et al., 1997). Previous researchers have shown that SLR ensures reduced bias and enhanced data analysis (Reim et al., 2015). Thus, SLR was chosen in this research to explore the knowledge gaps and research trends in PSS and CPPSS definition and design methods (details are given in Chapter 2) to set the scene for the research. Following the SLR guidelines defined by Kitchenham (2004), an abbreviated list of the findings, which are reported in more detail in Chapter 2, are:

1. PSS definitions are numerous, diverse and at times, conflicting.
2. A service-oriented design method for PSS is nascent.
3. Customer value co-creation process in PSS is underexplored.

4. The lifecycle approach is the most holistic and overarching PSS design method and other, narrower-focused methods tend to fit within stages of it.
5. The literature has not dealt with a CPPSS structure or design method, which could leverage the technological superiority of a CPPSS to deliver all the intended stakeholder benefits.

The knowledge gained and the gap that surfaced from the SLR clarified the problem and motivated this research to develop a reference model for service-oriented and customer-centric CPPSSDM. The SLR helped develop a new integrated PSS and CPPSS definition that accentuated the customer value co-creation requirement. The SLR analysis was combined with actor-network theory and service-dominant logic to propose the CPPSSDM conceptually and analytically for PSS and CPPSS. This combination provided the models for PSS and CPPSS in line with their definitions that explicated the service-oriented and customer-centred activities performed by the actor-network. By incorporating the product lifecycle approach, these models were developed further into a CPPSSDM that was capable of adapting to evolving customer needs.

The third, fourth and fifth steps of the DSRM (Design, Demonstration And Evaluation), which are presented in chapters 4, 5 and 6 respectively, were iterative in developing the artefacts. These iterations ensured that the artefacts were evaluated in practical application. The case study research method was implemented to understand how industry practitioners were involved in designing CPPSS in a business-to-business context (see Chapter 5). The case study phase consisted of four cases of CPPSS design and implementation. The data was gathered using semi-structured interviews with the designers, managers and users of each of the CPPSSs. Case analysis insights were then used to evaluate and refine the proposed CPPSSDM (see Chapter 6). The refined CPPSSDM was presented to some users, designers and managers of CPPSS to obtain their feedback, reactions and suggestions (see Chapter 6). These responses from practitioners helped to enhance the CPPSSDM further. The enhanced CPPSSDM is the outcome of this research.

7.2 Designing CPPSS Through Value Co-creation

7.2.1 Introduction

The concept of value co-creation, the unit of analysis in this thesis, has developed over the last decade as a critical concept in service marketing and management to keep businesses competitive (Saarijärvi et al., 2013). However, the methods for implementing it are still unclear (Breidbach & Maglio, 2016). PSS is one of the systems that implement value co-creation, and these systems are evolving into CPPSS thanks to the inclusion of cyber-physical technologies. This investigation into the design of CPPSS to co-create value is therefore very timely.

Following the SLR, this thesis combined the principles of SDL and ANT to develop a reference model for CPPSSDM. Four case studies were then implemented to refine the design method, providing valuable insight into the practitioner's world of CPPSS design and implementation. The case studies also helped this researcher obtain detailed information on the intricacies of value co-creation among stakeholders to design, implement and improve CPPSS during value-in-use. The design method refined from this knowledge was then evaluated further, using a survey to bring about its eventual form. All the tasks accomplished in this research contributed towards finding answers to the research questions raised in Chapter 2. The overarching research question was:

How could a service-oriented CPPSS be designed through value co-creation to make it adaptable to customers' dynamic needs?

This research question was sub-divided into two:

What are the perceived values of a CPPSS?

How could value be co-created in the CPPSS environment?

7.2.2 Discussion

7.2.2.1 CPPSSDM & the case studies

The analysis of the case studies and the subsequent survey showed that each actor in the network had their perception of value. This observation is consistent with ANT, which says that the actor in a network defines his/her interest in solving a problem (Callon, 1986; Shin, 2016). The observation also supports SDL, as all the actors were involved in finding the solution to various problems through the exchange of services rather than through valuing products alone.

The findings from the case studies show that the perception of value is subjective and dependent on four factors: (1) the context of the CPPSS design, (2) the context of the field of application, (3) the actor's role in the network and (4) the expectations from the CPPSS solution. Some aspects of value found to be important to the customers were safety, privacy, quality and customer service. The providers, while honouring these customer values, viewed brand image, customer reviews and data analysis of customer/machine behaviour as essential values that could help them expand the market through a competitive edge. Overall, the ability to collaborate in delivering the highest performance by sharing resources and skills were perceived by all actors as a common value.

The case studies showed that a decision to co-create value was taken based on the data and patterns observed in both the human and non-human actors of the network. The analysis of this data in each case-study organisation helped the actors identify current problems and look for appropriate solutions. The case studies also showed that the design process could be initiated either by the customer or the provider. Once the design process was triggered by the respective *initiator* in each case study, the design method was implemented to leverage the design of a new solution. This design method involves several value co-creation activities, as explained in chapters 4 to 6, to achieve the goals set by the participants.

The four case studies participants and the survey respondents represented organisations of various sizes and dealing with different complexities. However, the common theme identified by all the participants was the benefit of implementing value co-creation when designing and using a CPPSS. Moreover, shortcomings in the performance of each case study organisations' design processes were seen to be a result of negligence or avoidance of value co-creation activities. Consequently, the implementation of value co-creation activities was shown to be beneficial to all the actors involved in the design.

Practising value co-creation enables customers and providers to share their needs towards developing the required solution. The data analysis of the four case studies in this research showed that most of the shortcomings in the design and implementation of CPPSS could be eliminated using value co-creation practices. Some examples of the shortcomings in the design process found in this research are as follows:

- DairyCo's miscalculation of demand predictions. This could have been minimised if the customer data had been better analysed and communicated to the designers and operators.
- PoolCo's inability to connect directly to its end-users of led to a few flaws in the user-friendliness and interactive feedback capabilities of its software application. These could have been minimised by continuous consultation with end-users during the design process.
- The geographical diversity of HealthCo's customers hindered the focus of the customer-provider relationship, which led to difficulty in communicating problems and solutions.

This was minimised by positioning dedicated HealthCo employees close to the hospital to strengthen the relationship and improve the design process.

- Initially, VRCo did not know the size of its market and consequently was unaware of potential customers' application-specific problems; this prevented them from developing customised customer solutions. This shortcoming was minimised when VRCo took the initiative to participate in more customer-provider connecting events such as technology/trade events and workshops.

In each of the four case study organisations, the re-design required due to the above shortcomings led to a few negative impacts such as waste of time, effort and money, as well as lower performance. The survey respondents repeatedly emphasised the importance of customer feedback, the customer-provider relationship, the involvement of more actors and mutual communication. The observations about value co-creation discussed in this section support the argument that value co-creation could be appropriate for CPPSS design and implementation.

7.2.2.2 CPPSSDM & the literature

The analysis of the reviewed literature on PSS and CPPSS design revealed a few gaps that were attempted to be addressed in this thesis. The PSS design literature mainly focussed on design methods and design tools as explained in Section 2.2.2. The CPPSSDM developed in this research is consistent with most of the design methods available in the literature (see Section 2.2.2.1), as listed below.

- Lifecycle – CPPSSDM is congruent with the lifecycle approach as explained in Section 4.2.4.
- MEPSS – Similar to MEPSS, the CPPSSDM consists of a toolkit that guides designing solution. However, the CPPSSDM includes the customers and other actors in the network and focus on the overall lifecycle of the solution

- Modularisation – The CPPSSDM has four iterative design stages that could be considered reusable modules that are implemented based on the contextual requirements.
- Service Engineering – Continuously improving existing solutions by developing new solutions in response to customers' needs is one of the main focuses of the CPPSSDM, just like that of service engineering. However, CPPSSDM also adds the activities of value co-creating to obtain a more inclusive solution.
- Service Modelling – Each stage of the CPPSSDM take input from the previous stage and feeds into the next stage, like the concepts of service modelling. In addition, CPPSSDM includes the customer-provider (or actor-actor) interactions to develop a customised solution.
- Visualisation – Although visual scenarios and situations are not discussed in CPPSSDM, these aspects can be considered and consulted while implementing each of the four stages.

The list above shows that CPPSSDM can be considered a multidimensional design method that is coherent with other design methods. This property of the CPPSSDM makes it a versatile design method that can employ multiple design tools to accomplish its design stages and goals. So, practitioners can implement the design tools reviewed in the literature (see Section 2.2.2.2) and beyond. Developing and analysing such tools fall beyond the scope of this thesis, but recommendations were provided in Section 6.4.1 and planned to be researched in the future.

7.2.3 Answer to the Research Question

The combination of the proposed ANT-SDL-inspired CPPSSDM reference model, the case study observations and the survey responses showed that the decisions taken by each actor to co-create value was based on the data and patterns obtained from the human and non-human actors of the network. The analysis of the performance and usage data helped the stakeholders identify current problems. However, the value perceived by the actors in the solution to those problems determined their decision to initiate the design process. When answering the research question about the perceived values of a CPPSS were, it was found that actors valued various factors like brand image, competitive difference, holistic approach, long-term relationship, customized solution, and customer satisfaction as discussed in Sections 5.2.6, 5.3.6, 5.4.6 and 5.5.6. In response to the value perception, either the customer or the provider could initiate this process to find appropriate solutions. This research confirmed the literature that the value is generated through value co-creation and value-in-use.

The findings from the four case studies showed communication was a vital part of value co-creation among the actors in the CPPSS environment. As the literature suggests, communication helps identify the dynamic customer demand emerging from the issues faced at a particular time. This research found that communication was of two kinds: active and passive. The provider or the customer could initiate active communication. Passive communication, undertaken through the analysis of machine performance and customer behaviour, was integral to identifying changing customer environments and new business opportunities. All case organisations used the data generated from their systems to bring about further improvements.

This thesis extracted knowledge from the available literature, case studies, and survey responses to develop a design method reference model. This reference model addresses the main research question on how a service-oriented CPPSS adaptable to customers' dynamic needs could be designed through value co-creation. The literature showed that the lifecycle approach could provide a holistic procedure from the inception of the problem to the implementation of the solution. However, the application of the lifecycle approach wasn't observed in the CPPSS design. So, this research addressed this gap by developing a reference model using actor-network theory and service-dominant logic. This design method provides a holistic procedure in designing CPPSS throughout its lifecycle. The contributions of this research to the literature are listed in Table 50.

Table 50: Summary of Contributions

Research Questions	**Knowledge in Reviewed Literature**	**Contribution**
RQ1: What are the perceived values of a CPPSS?	Various types of value identified. Especially, value co-creation and value-in-use.	Confirmed the literature.
RQ2: How could value be co-created in the CPPSS environment?	Forecasted and suggested but sparingly implemented.	Added to the literature by finding ways to co-create value.
How could a service-oriented CPPSS be designed through value co-creation to make it adaptable to customers' dynamic needs?	Lifecycle approach proposed by various researchers, but not holistic, not for CPPSS and not from an ANT-SDL perspective.	Added to the literature by developing the CPPSSDM.

The final CPPSSDM reference model created in this research is a design method that is backed by both theory and practice. The research provides a cross-disciplinary study on the theories from business and technology by combining product-service systems and cyber-physical systems, respectively. The definitions and distinctions of PSS and CPPSS is also developed to offer a clear understanding of their scope. So, the actors from different spheres of organisations can collaborate in developing the solution. Practitioners can compare their design practices with this reference model to extract guidance and directions. This reference model enhances value co-creation by advocating active and passive communication in the network. As the reference model defines the roles and responsibilities of each actor, communication enables value co-creation that leads to a more robust integration of actors and resources.

The inspiration from ANT and SDL provides a design method that enables a systematic, flexible and organised design process for practitioners and stakeholders. This inspiration also gives a new research direction for the scientific community. Researchers are encouraged to extend the available academic knowledge by developing stage-specific (*Problematisation, Interessement, Enrolment and Mobilisation*) tools that cater to the industries involved in CPPSS design and implementation. Most importantly, the design method is congruent with the lifecycle of CPPSS. This unity makes it a holistic process from the identification of a problem to the deployment of the solution. The design method also enables continuous improvement through the iterative application of the four design steps. The above contributions of this reference model are listed in Table 51. Further details are discussed in the following sections.

Table 51: Contributions of the CPPSSDM Reference Model

Theoretical and Literature	Methodological	Practical
Cross-disciplinary synthesis of business and technology. Clearer definitions and distinctions between PSS and CPPSS.	Actors from business and technology collaborate to develop the solution.	Useful reference model for customers, providers, designers and end-users alike.
Active and passive communication for better value co-creation.	Value co-creation approach leads to better actor-actor integration.	Clear definition of roles and responsibilities of each actor.
Inspired by the concepts of ANT and SDL to develop a new research direction.	Inspired by the concepts of ANT and SDL to develop a robust design method.	A systematic, organised, dynamic and flexible design process.
The design method reference model developed is congruent with a lifecycle approach.	Adopting a lifecycle approach leads to an holistic design process.	Being iterative, it can address continuous changes in customer demand and CPPSS environment.

7.3 Findings and Implications

This aim of this research was to examine how changing societal requirements could be detected and captured to co-create value in the design of a CPPSS. The four case studies conducted to evaluate the proposed design method in practice were also discussed with 12 practitioners through a survey. Findings from both the case studies and the survey helped to refine the proposed ANT-SDL-inspired CPPSSDM reference model.

This research also generated awareness among the CPPSS practitioners included in the study about this design method and its benefits and informal communication following the interviews revealed that some of the practitioners who participated in the research were implementing the design method into their design practices. In addition to this, the research has created an awareness in the academic community through six conference publications and presentations in various countries. All these outcomes have contributed to the sixth and the last step of DSRM, *Communication*, as shown in Figure 41.

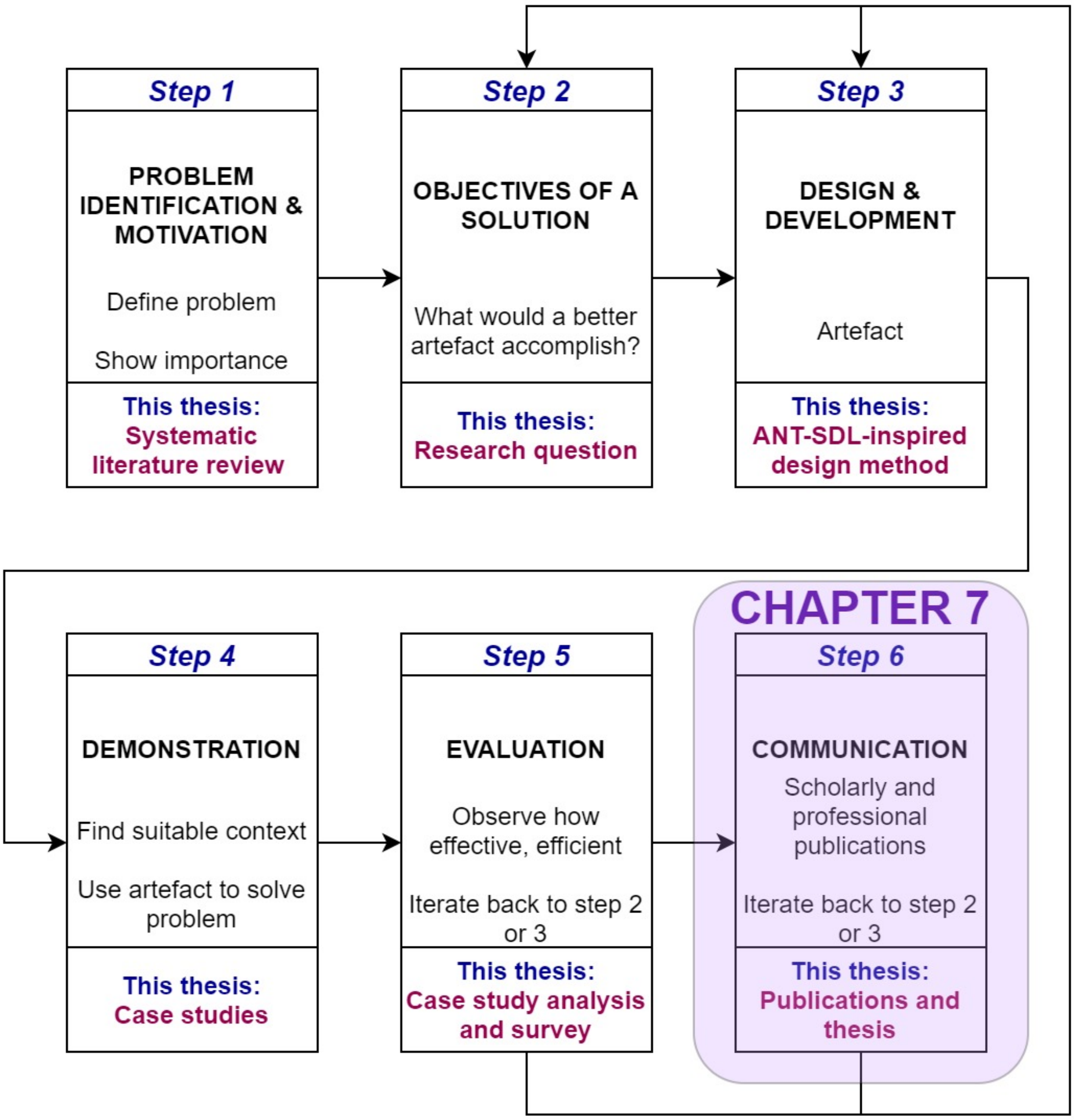

Figure 41: Step 6 of design science research method (adapted from Peffers et al., 2006; Peffers et al., 2007)

7.3.1 Theoretical Implications

7.3.1.1 ANT-SDL combination

This research covered several topics from the literature during its journey to develop a holistic CPPSSDM reference model. It successfully combined the principles of actor-network theory and service-dominant logic to form a new ANT-SDL inspired concept. Although many researchers have discussed the possibilities of this combination (e.g., Storbacka et al. (2012), Vargo & Lusch (2016), and Wieland et al. (2015)), only a handful of them have explored these possibilities by developing a combined concept, for example, Yip et al. (2015). However, Yip et al. (2015) developed the approach used to clarify the design specification and applied it to beginning-of-life only. On the contrary, the reference model developed in this thesis provides a holistic CPPSS design process for the whole lifecycle, i.e., beginning-of-life, middle-of-life, and end-of-life. In addition, the PSS discussed by Yip et al. (2015) was advanced by this research to a CPPSS context.

In the ANT-SDL inspired concept, SDL provides the principles for value co-creation as defined by Vargo & Lusch (2016). So, all actors are treated as resource integrators, and all economies are considered service economies where service is exchanged for service. ANT provides the principles for actor dynamics in the actor-network. As per ANT, everything is a continuously generated effect of the webs of connections and reconnections between human and non-human actors within which they are located (Law 2009). So, truth changes with time, and that brings about new problems in any given system. This combined concept was then implemented to develop a theoretical design method. Thus, this research advances the knowledge by expanding on the combined ANT and SDL concepts, a novel approach.

7.3.1.2 PSS and CPPSS knowledge

The thesis has provided a detailed explanation and discussion of the concepts of PSSs and CPPSSs. The literature analysis provided a systematic review of terminologies, definitions and design processes for these systems. The analysis of 35 different PSS definitions led to a new definition for PSS, emphasising its socio-technical nature, actors-network, resource integration, value co-creation, and lifecycle. Concurrently, a definition for CPPSS was also developed by emphasizing the combined characteristics of product-service systems and cyber-physical systems. These two definitions provided a more holistic understanding of the two concepts. These definitions were then supported by appropriate PSS and CPPSS models that provided a relationship between their internal components. These models were then implemented in the ANT-SDL inspired concept to form the design method reference model for PSS and CPPSS. The definitions, models, and design methods reviewed, compared, analysed and developed in this research contribute to the literature of PSS, CPPSS and design science. Furthermore, this research also contributes to the CPPSS design by applying the concepts of value co-creation and lifecycle approach in the design process.

7.3.2 Managerial Implications

The case studies and the survey evaluations demonstrated the usefulness and practical robustness of the design method developed in this research.

7.3.2.1 Usability

The design method was effective in explaining the design and implementation processes, as shown in the case studies. The practitioners found the design method clear and easy to implement. The data analysis and the discussions presented in the previous chapters show that the design method was found to be useful by customers, providers, managers, end-users and designers alike in co-creating value. Thus, the practical contribution of this thesis is the implementation of an ANT-SDL-inspired CPPSSDM reference model that can be adapted to customers' dynamic needs through value co-creation.

7.3.2.2 Applying value co-creation

Value co-creation helps all actors in a CPPSS environment to participate in and contribute to its design and implementation. The actors who participated in the value co-creation actor network can also extract value-in-use while operating the solution. A good understanding of the design steps provides actors with the knowledge, tools and skills to make better resource management and marketing strategy decisions. The four-step ANT-SDL-inspired design method provides these actors with a systematic approach to achieve these goals. This design method combines the four design focuses of activity, actors, context and objective found in the literature. The design method helps the actors design a CPPSS with characteristics that are mutually acceptable and capable of addressing the customer problems. Each step of the design method is assigned a central theme (i.e., of the actor's focus) as listed below.

- Problematisation – Proactively identify problems
- Interessement – Negotiate value proposition
- Enrolment – Integrate resources and knowledge
- Mobilisation – Communicate solutions and issues

The four steps also clearly define the activities of each actor on the provider and customer side involved in designing the CPPSS solution. These themes and activities provide transparency about the actor roles and responsibilities of the provider, designer, manager and user to achieve the common goal of solving a customer problem.

Any actor in the network can initiate the design process towards solving a customer problem. The CPPSS design method can be initiated and implemented repeatedly to cater to changing customer needs, or to create a new CPPSS to meet new customer requirements. Deciding between improvement and redevelopment is done collaboratively to formulate the most effective design of a CPPSS solution.

7.4 Limitations of the Design Method

There are four main limitations among the various limitations suggested about this research and the CPPSSDM reference model. These limitations are discussed below.

7.4.1 Procedural tools

As indicated by the survey respondents, tthe CPPSS practitioners were looking for procedural tools to guide them in internal operationalising the CPPSSDM. The proposal of tools to support the operationalisation of each CPPSSDM stage (*Problematisation, Interessement, Enrolment and Mobilisation*) is beyond the scope of this thesis. However, as listed and discussed in Section 2.2.2 and Section 6.4.1, readily available tools can be implemented by the practitioners while following the four stages of CPPSSDM.

Two types of tools were presented in the literature review. The first type helps practitioners to understand and prioritise the problems. Some of these tools are AHN/ANP, Kano model, Kansei engineering, QFD and TRIZ. The second type helps practitioners develop the solution to the identified problems. Some examples of these tools are interaction map, lifecycle simulator, PSS board, PSSCA, service blueprint and service CAD. Practitioners are encouraged to use these tools based on their requirements, context and experience.

7.4.2 Novelty

The second limitation comes from the fact that the proposed CPPSSDM is new. Therefore, only the organisations that participated in this research's case studies have attempted to implement the CPPSSDM. To address the lack of full implementation of CPPSSDM, a program of knowledge dissemination and further studies is planned. International collaboration is also being conducted to explore the possibilities of implementation and advancement.

7.4.3 Case-study specialisation

It is apparent from the four case studies presented in Chapter 5, that the research was spread across a range of industries. As per the aim of this thesis, the spread allowed the development of a generalizable CPPSSDM reference model that any CPPSS related industry or practitioner could implement. However, the spread of the case study industries also came a cost of difficulties in comparing and contrasting industry-specific results. So, the third limitation of this research was that the differences between different industrial fields were not considered and assumed to be similar.

7.4.4 Unconsidered factors

The CPPSSDM developed in this thesis was theoretically and practically (by case studies) shown to be congruent with the lifecycle approach of the PSS and CPPSS. However, the cases studied in this research were mainly focused on BOL and MOL of the CPPSS. Thus, the EOL of the case study CPPSS solutions were not covered by this thesis. This skip was since studying the EOL would be possible only when the CPPSS solution reached its end of life and required recycled, retired, or remanufactured. CPPSS, being a new technology, reaching EOL is a rare occurrence and can be studied only in the future.

As noted in Section 2.4.3, co-creation of value requires trust between the actors involved in the actor-network. Trust facilitates the formation of a strong relationship among actors and enables the smooth functioning of the solution. However, as discussed in Section 4.2.3, including the trust factor in the CPPSSDM reference model fell outside the scope of this research. So, the thesis assumed an ample level of trust between the actors in the design process.

7.5 Future Research

7.5.1 Scientific community

As mentioned at the end of section 7.3 above, this design method is known only to a handful of practitioners. One of the plans is to publish the data and the outcomes of this research in international peer-reviewed journals and at conferences to create awareness, obtain feedback and improve the method. Six peer-reviewed conference papers have been presented and published so far. These publications helped advance the research among the scientific community. More publications will enable the further propagation of this research.

7.5.2 Industrial implementation

Additional implementations with practitioners are needed to advance the CPPSDM reference model further. The reactions obtained from the case studies and survey have already created an interest among the participants. This interest is expected to proliferate through more industry engagement and sharing the benefits of implementing this design method. Such implementation will also provide vital data for this research to progress further. So, more industry engagement through CPPSSDM implementation and comparison case studies is planned.

Industry-specific data would also help develop a customised CPPSS design method. Plans include the study of industry-specific applications and appropriate modification of the CPPSSDM. This kind of study will enable developing a specialised CPPSSDM and compare the design processes implemented within specific industries.

7.5.3 Tool development

As discussed in Section 6.4 and Section 7.3, developing step-by-step or procedural tools is the logical next step. These tools would make the CPPSSDM more robust by helping organisations operationalise CPPSSDM. In fact, an attempt was made to adopt the PSS characterisation approach developed by Yip et al. (2015) as a procedural tool to operationalise CPPSSDM. The preliminary results showed the PSS characterisation approach could only support three of the four steps in CPPSSDM (Yip et al., 2019). Further research is necessary and planned to advance the development of procedural tools.

7.5.4 Study other factors

As discussed in the limitations of this research, EOL and trust factors weren't studied further in this research (see section 7.4.4). So, a study on these factors would enable expansion and a better understanding of the multi-actor design process of CPPSS solutions. The study would enhance the industrial usability of the CPPSSDM reference model.

7.6 Conclusion of Chapter 7

Most businesses create value, expand markets and achieve a competitive edge by satisfying its customers in the best possible way. In pursuit of this, the role and focus of businesses are evolving back to customer-provider collaboration, a collaboration that diminished with the inception of the mass production technologies. Businesses have started to realise that service holds the value to their customers rather than the product itself. As businesses are becoming more service-centric, there is an urgent need for researchers to develop service-centric design methods to guide industry practitioners.

This research aimed to find the answer to the research question, *'How could a service-oriented CPPSS be designed through value co-creation to make it adaptable to customers' dynamic* *needs?'*. The six steps of the DSRM were adopted to guide the research through case studies with four companies. The research led to the development of the four-step CPPSSDM reference model consisting of *Problematisation*, *Interessement*, *Enrolment* and *Mobilisation*. This method was then evaluated by practitioners, whose recognition of its strengths and whose valuable feedback produced direction for its further refinement.

This research has made two key contributions. In terms of a theoretical contribution, it adds to the new research direction of combining the concepts of ANT and SDL in CPPSS design by demonstrating how these foundational theories could be combined. In terms of a practical contribution, the four-step CPPSSDM reference model has shown itself to be useful in supporting organisations to design CPPSSs that address customer problems.

Further communication and implementation of the design method are needed to create awareness, generate discussion and further improve the CPPSSDM reference model. Additional research is essential to develop the step-by-step procedures and guidelines for practitioners.

References

Abramovici, M., Göbel, J. C., & Neges, M. (2015). Smart engineering as enabler for the 4th industrial revolution. In M. Fathi (Ed.), *Integrated systems: Innovations and applications* (pp. 163-170). https://doi.org/10.1007/978-3-319-15898-3_10

Akao, Y. (1990). *QFD: Quality function deployment: integrating customer requirements into product design*. Productivity Press.

Akasaka, F., Nemoto, Y., Kimita, K., & Shimomura, Y. (2012). Development of a knowledge-based design support system for Product-Service Systems. *Computers in Industry, 63*(4), 309-318. https://doi.org/10.1016/j.compind.2012.02.009

Akmal, S., Shih, L. H., & Batres, R. (2014). Ontology-based similarity for product information retrieval. *Computers in Industry, 65*(1), 91-107. https://doi.org/10.1016/j.compind.2013.07.011

Al-Abdullah, M. (2015). *An actor-network theory approach in investigating the information systems perspective of anti-money laundering compliance through a case study of the Foreign Account Tax Compliance Act (FATCA) implementation in a Jordanian local bank*. [Doctoral dissertation, Virginia Commonwealth University]. VCU University Archives. https://doi.org/10.25772/HMH7-TF90

Alix, T., & Zacharewicz, G. (2012). Product-service systems scenarios simulation based on G-DEVS/HLA: Generalized discrete event specification/high level architecture. *Computers in Industry, 63*(4), 370-378. https://doi.org/10.1016/j.compind.2012.02.011

Alonso-Rasgado, T., & Thompson, G. (2006). A rapid design process for Total Care Product creation. *Journal of Engineering Design, 17*(6), 509-531. https://doi.org/10.1080/09544820600750579

Alonso-Rasgado, T., Thompson, G., & Elfström, B.-O. (2004). The design of functional (total care) products. *Journal of Engineering Design, 15*(6), 515-540. https://doi.org/10.1080/09544820412331271176

Andrade, A. D. & Urquhart, C. (2010), The affordances of actor network theory in ICT for development research, *Information Technology & People, 23*(4), 352-374. https://doi.org/10.1108/09593841011087806

Annarelli, A., Battistella, C., & Nonino, F. (2016). Product service system: A conceptual framework from a systematic review. *Journal of Cleaner Production, 139*, 1011-1032. https://doi.org/10.1016/j.jclepro.2016.08.061

Armstrong, C. M., Niinimäki, K., Kujala, S., Karell, E., & Lang, C. (2015). Sustainable product-service systems for clothing: Exploring consumer perceptions of consumption alternatives in Finland. *Journal of Cleaner Production, 97*, 30-39. https://doi.org/10.1016/j.jclepro.2014.01.046

Atzori, L., Iera, A., & Morabito, G. (2010). The internet of things: A survey. *Computer Networks, 54*(15), 2787-2805. https://doi.org/10.1016/j.comnet.2010.05.010

Aurich, J. C., Fuchs, C., & Wagenknecht, C. (2006). Life cycle oriented design of technical Product-Service Systems. *Journal of Cleaner Production, 14*(17), 1480-1494. https://doi.org/10.1016/j.jclepro.2006.01.019

Aurich, J. C., Schweitzer, E., & Mannweiler, C. (2008). Integrated Design of Industrial Product-Service Systems. In M. Mitsuishi, K. Ueda, F. Kimura (Eds.), *Manufacturing Systems and Technologies for the New Frontier* (pp. 543-546). Springer, London. https://doi.org/10.1007/978-1-84800-267-8_111

Bagheri, B., Yang, S., Kao, H.-A., & Lee, J. (2015). Cyber-physical Systems Architecture for Self-Aware Machines in Industry 4.0 Environment. *IFAC-PapersOnLine, 48*(3), 1622-1627. https://doi.org/10.1016/j.ifacol.2015.06.318

Baines, T., Lightfoot, H., Benedettini, O., & Kay, J. (2009). The servitization of manufacturing. A review of literature and reflection on future challenges. *Journal of Manufacturing Technology Management, 20*(5), 547-567. https://doi.org/10.1108/17410380910960984

Baines, T. S., Lightfoot, H. W., Evans, S., Neely, A., Greenough, R., Peppard, J., Roy, R., Shehab, E., Braganza, A., & Tiwari, A. (2007). State-of-the-art in product-service systems. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 221*(10), 1543-1552. https://doi.org/10.1243/09544054JEM858

Ballantyne, D., & Varey, R. J. (2008). The service-dominant logic and the future of marketing. *Journal of the Academy of Marketing Science, 36*, 11-14. https://doi.org/10.1007/s11747-007-0075-8

Banerjee, A., Kandula, S., Mukherjee, T., & Gupta, S. K. (2012). BAND-AiDe: A Tool for Cyber-Physical Oriented Analysis and Design of Body Area Networks and Devices. *ACM Transactions on Embedded Computing Systems (TECS), 11*(S2), 49:1-49:29. https://doi.org/10.1145/2331147.2331159

Barquet, A. P. B., de Oliveira, M. G., Amigo, C. R., Cunha, V. P., & Rozenfeld, H. (2013). Employing the business model concept to support the adoption of product-service systems (PSS). *Industrial Marketing Management, 42*(5), 693-704. https://doi.org/10.1016/j.indmarman.2013.05.003

Baxter, D., Roy, R., Doultsinou, A., Gao, J., & Kalta, M. (2009). A knowledge management framework to support product-service systems design. *International Journal of Computer Integrated Manufacturing, 22*(12), 1073-1088. https://doi.org/10.1080/09511920903207464

Baxter, G., & Sommerville, I. (2011). Socio-technical systems: From design methods to systems engineering. *Interacting with Computers, 23*(1), 4-17. https://doi.org/10.1016/j.intcom.2010.07.003

Becker, J., Beverungen, D. F., & Knackstedt, R. (2010). The challenge of conceptual modeling for product-service systems: status-quo and perspectives for reference models and modeling languages. *Information Systems and e-Business Management, 8*, 33-66. https://doi.org/10.1007/s10257-008-0108-y

Bengtsson, F., & Lundström, J. E. (2013, December 15-18). *ANT-Maps: Visualising Perspectives of Business and Information Systems* [Paper presentation]. Proceedings of the 34th International Conference on Information Systems, ICIS2013, Milan, Italy.

Berkovich, M., Leimeister, J. M., Hoffmann, A., & Krcmar, H. (2014). A requirements data model for product service systems. *Requirements Engineering, 19*, 161-186. https://doi.org/10.1007/s00766-012-0164-1

Bertoni, A., Bertoni, M., & Isaksson, O. (2013). Value visualization in Product Service Systems preliminary design. *Journal of Cleaner Production, 53*, 103-117. https://doi.org/10.1016/j.jclepro.2013.04.012

Bertoni, A., Bertoni, M., Panarotto, M., Johansson, C., & Larsson, T. C. (2016). Value-driven product service systems development: Methods and industrial applications. *CIRP Journal of Manufacturing Science and Technology, 15*, 42-55. https://doi.org/10.1016/j.cirpj.2016.04.008

Beuren, F. H., Ferreira, M. G. G., & Miguel, P. A. C. (2013). Product-service systems: a literature review on integrated products and services. *Journal of Cleaner Production, 47*, 222-231. https://doi.org/10.1016/j.jclepro.2012.12.028

Boehm, M., & Thomas, O. (2013). Looking beyond the rim of one's teacup: a multidisciplinary literature review of Product-Service Systems in Information Systems, Business

Management, and Engineering & Design. *Journal of Cleaner Production, 51*, 245-260. https://doi.org/10.1016/j.jclepro.2013.01.019

Bohn, J., Coroamă, V., Langheinrich, M., Mattern, F., & Rohs, M. (2005). Social, Economic, and Ethical Implications of Ambient Intelligence and Ubiquitous Computing. In W. Weber, J.M. Rabaey, & E. Aarts (Eds.), *Ambient Intelligence* (pp. 5-29). Springer, Berlin. https://doi.org/10.1007/3-540-27139-2_2

Brace, I. (2018). *Questionnaire design: How to plan, structure and write survey material for effective market research (4th Ed.)*. Kogan Page Limited.

Brandstotter, M., Haberl, M., Knoth, R., Kopacek, B., & Kopacek, P. (2003, December 8-11). *IT on demand – towards an environmental conscious service system for Vienna (AT)* [Paper presentation]. 2003 EcoDesign 3rd International Symposium on Environmentally Conscious Design and Inverse Manufacturing, Tokyo, Japan. https://doi.org/10.1109/ECODIM.2003.1322776

Breidbach, C. F., & Maglio, P. P. (2016). Technology-enabled value co-creation: An empirical analysis of actors, resources, and practices. *Industrial Marketing Management, 56*, 73-85. https://doi.org/10.1016/j.indmarman.2016.03.011

Broy, M., Cengarle, M. V., & Geisberger, E. (2012). Cyber-Physical Systems: Imminent Challenges. In R. Calinescu, & D. Garlan (Eds.) *Large-Scale Complex IT Systems. Development, Operation and Management. Monterey Workshop 2012. Lecture Notes in Computer Science, 7539* (pp. 1-28). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-34059-8_1

Bryman, A. (2006). Integrating quantitative and qualitative research: how is it done? *Qualitative Research, 6*(1), 97-113. https://doi.org/10.1177/1468794106058877

Burga, R., & Rezania, D. (2017). Project accountability: An exploratory case study using actor–network theory. *International Journal of Project Management, 35*(6), 1024-1036. https://doi.org/10.1016/j.ijproman.2017.05.001

Callon, M. (1986). The Sociology of an Actor-Network: The Case of the Electric Vehicle. In M. Callon, J. Law, A. Rip (Eds.) *Mapping the Dynamics of Science and Technology* (pp. 19-34). Palgrave Macmillan, London. https://doi.org/10.1007/978-1-349-07408-2_2

Callon, M., & Latour, B. (1981). Unscrewing the big Leviathan: how actors macro-structure reality and how sociologists help them to do so. In K.D. Knorr-Cetina & A.V. Cicourel (Eds.) *Advances in Social Theory and Methodology: Toward an Integration of Micro- and Macro-Sociologies* (pp. 277-303). Routledge & Kegan Paul, Boston.

Cao, X., Cheng, P., Chen, J., & Sun, Y. (2013). An Online Optimization Approach for Control and Communication Codesign in Networked Cyber-Physical Systems. *IEEE Transactions on Industrial Informatics, 9*(1), 439-450. https://doi.org/10.1109/TII.2012.2216537

Carcary, M. (2011). Design Science Research: The Case of the IT Capability Maturity Framework (IT CMF). *Electronic Journal of Business Research Methods, 9*(2), 109-118.

Cardenas, A. A., Amin, S., & Sastry, S. (2008, June 17-20). *Secure Control: Towards Survivable Cyber-Physical Systems* [Paper presentation]. ICDCS'08: 28th International Conference on Distributed Computing Systems Workshops, Beijing, China. https://doi.org/10.1109/ICDCS.Workshops.2008.40

Carreira, R., Patrício, L., Jorge, R. N., & Magee, C. L. (2013). Development of an extended Kansei engineering method to incorporate experience requirements in product-service system design. *Journal of Engineering Design, 24*(10), 738-764. https://doi.org/10.1080/09544828.2013.834038

Catulli, M., Cook, M., & Potter, S. (2017). Consuming use orientated product service systems: A consumer culture theory perspective. *Journal of Cleaner Production, 141*, 1186-1193. https://doi.org/10.1016/j.jclepro.2016.09.187

Cavalieri, S., & Pezzotta, G. (2012). Product–Service Systems Engineering: State of the art and research challenges. *Computers in Industry, 63*(4), 278-288. https://doi.org/10.1016/j.compind.2012.02.006

Chan, K. W., Yim, C. K., & Lam, S. S. K. (2010). Is Customer Participation in Value Creation a Double-Edged Sword? Evidence from Professional Financial Services across Cultures. *Journal of Marketing, 74*(3), 48-64. https://doi.org/10.1509/jmkg.74.3.048

Chandler, J. D., & Vargo, S. L. (2011). Contextualization and value-in-context: How context frames exchange. *Marketing Theory, 11*(1), 35-49. https://doi.org/10.1177/1470593110393713

Chang, D., Gu, Z., Li, F., & Jiang, R. (2019). A user-centric smart product-service system development approach: A case study on medication management for the elderly. *Advanced Engineering Informatics, 42*, 100979. https://doi.org/10.1016/j.aei.2019.100979

Chang, F., Zhou, G., Cheng, W., Zhang, C., & Tian, C. (2019). A service-oriented multi-player maintenance grouping strategy for complex multi-component system based on game theory. *Advanced Engineering Informatics, 42*, 100970. https://doi.org/10.1016/j.aei.2019.100970

Charinsarn, T. (2009, 7-10 July). *DEVELOPING AN e-BUSINESS STRATEGY FOR LESS-MATURE ORGANIZATIONS-A Design Research Approach*. In Proceedings of the International Conference on e-Business (ICETE 2009 - Vol. 1, pp. 215-222), Milan, Italy. SCITEPRESS. https://doi.org/10.5220/0002190902150222

Chen, D., Chu, X., Yang, X., Sun, X., Li, Y., & Su, Y. (2015). PSS solution evaluation considering sustainability under hybrid uncertain environments. *Expert Systems with Applications, 42*(14), 5822-5838. https://doi.org/10.1016/j.eswa.2015.04.003

Chen, C. W. (2018). Guidance on the Conceptual Design of Sustainable Product–Service Systems. *Sustainability, 10*(7), 2452. https://doi.org/10.3390/su10072452

Cheng, Z., Tan, Y., & Lim, Y. (2016). Design and evaluation of hybrid temperature control for cyber-physical home systems. *International Journal of Modelling, Identification and Control, 26*(3), 196-206. https://doi.org/10.1504/IJMIC.2016.080295

Cherdantseva, Y., & Hilton, J. (2013, 2-6 September). *A reference model of information assurance & security* [Paper Presentation]. In 2013 International Conference on Availability, Reliability and Security (pp. 546-555), Regensburg, Germany. https://doi.org/10.1109/ARES.2013.72

Chew, E. K. (2016). iSIM: An integrated design method for commercializing service innovation. *Information Systems Frontiers, 18*, 457-478. https://doi.org/10.1007/s10796-015-9605-y

Chew, E. K. (Ed.), Gottschalk, P. (2013). *Knowledge Driven Service Innovation and Management: IT Strategies for Business Alignment and Value Creation*. Hershey, PA, USA: IGI Global.

Chou, C. J., Chen, C. W., & Conley, C. (2015). An approach to assessing sustainable product-service systems. *Journal of Cleaner Production, 86*, 277-284. https://doi.org/10.1016/j.jclepro.2014.08.059

Clayton, R. J., Backhouse, C. J., & Dani, S. (2012). Evaluating existing approaches to product-service system design: A comparison with industrial practice. *Journal of Manufacturing Technology Management, 23*(3), 272-298. https://doi.org/10.1108/17410381211217371

Collopy, P. D., & Hollingsworth, P. M. (2011). Value-driven design. *Journal of Aircraft, 48*(3), 749-759. https://doi.org/10.2514/1.C000311

Colombo, A. W., Karnouskos, S., Kaynak, O., Shi, Y., & Yin, S. (2017). Industrial Cyberphysical Systems: A Backbone of the Fourth Industrial Revolution. *IEEE Industrial Electronics Magazine, 11*(1), 6-16. https://doi.org/10.1109/MIE.2017.2648857

Cook, D. J., Greengold, N. L., Ellrodt, A. G., & Weingarten, S. R. (1997). The Relation between Systematic Reviews and Practice Guidelines. *Annals of Internal Medicine, 127*(3), 210-216. https://doi.org/10.7326/0003-4819-127-3-199708010-00006

Cooper, R. G. (1994). Third-Generation New Product Processes. *The Journal of Product Innovation Management, 11*(1), 3-14. https://doi.org/10.1111/1540-5885.1110003

Cressman, D. (2009). *A brief overview of actor-network theory: Punctualization, heterogeneous engineering & translation*. ACT Lab/Centre for Policy Research on Science and Technology (CPROST), School of Communication, Simon Fraser University, Burnaby, British Columbia, Canada. http://summit.sfu.ca/system/files/iritems1/13593/0901.pdf

Cresswell, K. M., Worth, A., & Sheikh, A. (2010). Actor-Network Theory and its role in understanding the implementation of information technology developments in healthcare. *BMC Medical Informatics and Decision Making, 10*, 67. https://doi.org/10.1186/1472-6947-10-67

Creswell, J. W., & Creswell, J. D. (2017). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (5th ed.). SAGE Publications.

Creswell, J. W., Hanson, W. E., Clark Plano, V. L., & Morales, A. (2007). Qualitative Research Designs: Selection and Implementation. *The Counseling Psychologist, 35*(2), 236-264. https://doi.org/10.1177/0011000006287390

Crossan, M. M., & Apaydin, M. (2010). A Multi-Dimensional Framework of Organizational Innovation: A Systematic Review of the Literature. *Journal of Management Studies, 47*(6), 1154-1191. https://doi.org/10.1111/j.1467-6486.2009.00880.x

Crotty, M. (1998). *The Foundations of Social Research: Meaning and Perspective in the Research Process* (1st ed.). SAGE Publications.

De, S., Zhou, Y., Abad, I.L., & Moessner, K. (2017). Cyber-Physical-Social Frameworks for Urban Big Data Systems: A Survey. *Applied Sciences, 7*(10), 1017. https://doi.org/10.3390/app7101017

Dedeke, A. N. (2017). Creating sustainable tourism ventures in protected areas: An actor-network theory analysis. *Tourism Management, 61*, 161-172. https://doi.org/10.1016/j.tourman.2017.02.006

Denzin, N. K., & Lincoln, Y. S. (2011). *The SAGE Handbook of Qualitative Research* (4th ed.). SAGE Publications.

Dewberry, E., Cook, M., Angus, A., Gottberg, A., & Longhurst, P. (2013). Critical Reflections on Designing Product Service System. *The Design Journal, 16*(4), 408-430. https://doi.org/10.2752/175630613X13746645186089

Dillon, T. S., Zhuge, H., Wu, C., Singh, J., & Chang, E. (2011). Web-of-things framework for cyber–physical systems. *Concurrency and Computation: Practice and Experience, 23*(9), 905-923. https://doi.org/10.1002/cpe.1629

Dodds, W. B. (1999). Managing customer value. *American Journal of Business, 14*(1), 13-22. https://doi.org/10.1108/19355181199900001

Durugbo, C. (2014). Strategic framework for industrial product-service co-design: findings from the microsystems industry. *International Journal of Production Research, 52*(10), 2881-2900. https://doi.org/10.1080/00207543.2013.857054

Durugbo, C., & Pawar, K. (2014). A unified model of the co-creation process. *Expert Systems with Applications, 41*(9), 4373-4387. https://doi.org/10.1016/j.eswa.2014.01.007

Durugbo, C., Tiwari, A., & Alcock, J. R. (2011). A review of information flow diagrammatic models for product–service systems. *The International Journal of Advanced Manufacturing Technology, 52*, 1193-1208. https://doi.org/10.1007/s00170-010-2765-5

Dutra, D. d. S., & Silva, J. R. (2016). Product-Service Architecture (PSA): toward a Service Engineering perspective in Industry 4.0. *IFAC-PapersOnLine, 49*(31), 91-96. https://doi.org/10.1016/j.ifacol.2016.12.167

Edvardsson, B., Ng, G., Zhi Min, C., Firth, R., & Yi, D. (2011). Does service-dominant design result in a better service system? *Journal of Service Management, 22*(4), 540-556. https://doi.org/10.1108/09564231111155114

Eisenhardt, K. M. (1989). Building Theories from Case Study Research. *Academy of Management Review, 14*(4), 532-550. https://doi.org/10.5465/amr.1989.4308385

Eisenhardt, K. M., & Graebner, M. E. (2007). Theory Building From Cases: Opportunities And Challenges. *Academy of Management Journal, 50*(1), 25-32. https://doi.org/10.5465/amj.2007.24160888

Ekman, P., Raggio, R. D., & Thompson, S. M. (2016). Service network value co-creation: Defining the roles of the generic actor. *Industrial Marketing Management, 56*, 51-62. https://doi.org/10.1016/j.indmarman.2016.03.002

Evans, S., Partidário, P. J., & Lambert, J. (2007). Industrialization as a key element of sustainable product-service solutions. *International Journal of Production Research, 45*(18-19), 4225-4246. https://doi.org/10.1080/00207540701449999

Eyisi, E., Zhang, Z., Koutsoukos, X., Porter, J., Karsai, G., & Sztipanovits, J. (2013). Model-Based Control Design and Integration of Cyberphysical Systems: An Adaptive Cruise Control Case Study. *Journal of Control Science and Engineering, 2013*, Article ID 678016, 15. https://doi.org/10.1155/2013/678016

Fargnoli, M., De Minicis, M., & Tronci, M. (2012, May 21-24). *Product's Life Cycle Modelling For Eco-Designing Product-Service Systems* [Paper presentation]. In D. Marjanović, M. Štorga, N. Pavković & N. Bojčetić (Eds.), DS 70: Proceedings of DESIGN 2012, the 12th International Design Conference (pp. 869-878), Dubrovnik, Croatia.

Fernández, D. M., & Wieringa, R. (2013). Improving Requirements Engineering by Artefact Orientation. In J. Heidrich, M. Oivo, A. Jedlitschka, M.T. Baldassarre (Eds.), *International Conference on Product Focused Software Process Improvement PROFES 2013, Lecture Notes in Computer Science, 7983*, pp. 108-122. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-39259-7_11

Fisher, D., & Smith, S. (2011). Cocreation is chaotic: What it means for marketing when no one has control. *Marketing Theory, 11*(3), 325-350. https://doi.org/10.1177/1470593111408179

Flores-Vaquero, P., Tiwari, A., Alcock, J., Hutabarat, W., & Turner, C. (2016). A product-service system approach to telehealth application design. *Health Informatics Journal, 22*(2), 321-332. https://doi.org/10.1177/1460458214558313

Freitag, M. (2014). Service Engineering and Lifecycle Management for IT-Services. In S. Wiesner, C. Guglielmina, S. Gusmeroli, G. Doumeingts (Eds.), *Manufacturing Service Ecosystem*, (pp. 33-40). Mainz Verlag.

Frow, P., McColl-Kennedy, J. R., Hilton, T., Davidson, A., Payne, A., & Brozovic, D. (2014). Value propositions: A service ecosystems perspective. *Marketing Theory, 14*(3), 327-351. https://doi.org/10.1177/1470593114534346

Frow, P., Nenonen, S., Payne, A., & Storbacka, K. (2015). Managing Co-creation Design: A Strategic Approach to Innovation. *British Journal of Management, 26*(3), 463-483. https://doi.org/10.1111/1467-8551.12087

Garetti, M., Rosa, P., & Terzi, S. (2012). Life Cycle Simulation for the design of Product–Service Systems. *Computers in Industry, 63*(4), 361-369. https://doi.org/10.1016/j.compind.2012.02.007

Geerts, G. L. (2011). A design science research methodology and its application to accounting information systems research. International journal of accounting Information Systems, 12(2), 142-151. https://doi.org/10.1016/j.accinf.2011.02.004

Geng, X., & Chu, X. (2012). A new importance–performance analysis approach for customer satisfaction evaluation supporting PSS design. *Expert Systems with Applications, 39*(1), 1492-1502. https://doi.org/10.1016/j.eswa.2011.08.038

Geng, X., Chu, X., Xue, D., & Zhang, Z. (2010). An integrated approach for rating engineering characteristics' final importance in product-service system development. *Computers & Industrial Engineering, 59*(4), 585-594. https://doi.org/10.1016/j.cie.2010.07.002

Geng, X., Chu, X., Xue, D., & Zhang, Z. (2011). A systematic decision-making approach for the optimal product-service system planning. *Expert Systems with Applications, 38*(9), 11849-11858. https://doi.org/10.1016/j.eswa.2011.03.075

Gentile, C., Spiller, N., & Noci, G. (2007). How to Sustain the Customer Experience:: An Overview of Experience Components that Co-create Value With the Customer. *European Management Journal, 25*(5), 395-410. https://doi.org/10.1016/j.emj.2007.08.005

Geum, Y., & Park, Y. (2011). Designing the sustainable product-service integration: a product-service blueprint approach. *Journal of Cleaner Production, 19*(14), 1601-1614. https://doi.org/10.1016/j.jclepro.2011.05.017

Gillham, B. (2000). *The Research Interview*. Continuum.

Goedkoop, M. J., Van Halen, C. J., Te Riele, H., & Rommens, P. J. (1999). *Product service systems, ecological and economic basics.* Report for Dutch Ministries of Environment (VROM) and Economic Affairs (EZ), 36, 1-122.

Grace, D., & Iacono, J. L. (2015). Value creation: an internal customers' perspective. *Journal of Services Marketing, 29*(6/7), 560-570. https://doi.org/10.1108/JSM-09-2014-0311

Gray, D. E. (2013). *Doing Research in the Real World* (3rd ed.). SAGE Publications.

Greenhalgh, T., & Stones, R. (2010). Theorising big IT programmes in healthcare: Strong structuration theory meets actor-network theory. *Social Science & Medicine, 70*(9), 1285-1294. https://doi.org/10.1016/j.socscimed.2009.12.034

Greer, C. R., Lusch, R. F., & Hitt, M. A. (2017). A service perspective for human capital resources: A critical base for strategy implementation. *Academy of Management Perspectives, 31*(2), 137-158. https://doi.org/10.5465/amp.2016.0004

Grissemann, U. S., & Stokburger-Sauer, N. E. (2012). Customer co-creation of travel services: The role of company support and customer satisfaction with the co-creation performance. *Tourism Management, 33*(6), 1483-1492. https://doi.org/10.1016/j.tourman.2012.02.002

Grönroos, C. (2008). Service logic revisited: who creates value? And who co-creates? *European Business Review, 20*(4), 298-314. https://doi.org/10.1108/09555340810886585

Grönroos, C., & Voima, P. (2013). Critical service logic: making sense of value creation and co-creation. *Journal of the Academy of Marketing Science, 41*, 133-150. https://doi.org/10.1007/s11747-012-0308-3

Gunes, V., Peter, S., Givargis, T., & Vahid, F. (2014). A Survey on Concepts, Applications, and Challenges in Cyber-Physical Systems. *KSII Transactions on Internet and Information Systems, 8*(12), 4242-4268. https://doi.org/10.3837/tiis.2014.12.001

Gunter, C. A., Gunter, E. L., Jackson, M., & Zave, P. (2000). A reference model for requirements and specifications. *IEEE Software, 17*(3), 37-43. https://doi.org/10.1109/52.896248

Guzzo, D., Trevisan, A. H., Echeveste, M., & Costa, J. M. H. (2019). Circular innovation framework: Verifying conceptual to practical decisions in sustainability-oriented product-service system cases. *Sustainability, 11*(12), 3248. https://doi.org/10.3390/su11123248

Hakanen, T., Helander, N., & Valkokari, K. (2017). Servitization in global business-to-business distribution: The central activities of manufacturers. *Industrial Marketing Management, 63*, 167-178. https://doi.org/10.1016/j.indmarman.2016.10.011

Hammervoll, T., Halse, L. L., & Engelseth, P. (2014). The role of clusters in global maritime value networks. *International Journal of Physical Distribution & Logistics Management, 44*(1-2), 98-112. https://doi.org/10.1108/IJPDLM-11-2012-0335

Hara, T., Arai, T., Shimomura, Y., & Sakao, T. (2009). Service CAD system to integrate product and human activity for total value. *CIRP Journal of Manufacturing Science and Technology, 1*(4), 262-271. https://doi.org/10.1016/j.cirpj.2009.06.002

Hehenberger, P., Vogel-Heuser, B., Bradley, D., Eynard, B., Tomiyama, T., & Achiche, S. (2016). Design, modelling, simulation and integration of cyber physical systems: Methods and applications. *Computers in Industry, 82*, 273-289. https://doi.org/10.1016/j.compind.2016.05.006

Hennink, M., Hutter, I., & Bailey, A. (2010). *Qualitative Research Methods*. SAGE Publications.

Herterich, M. M, and M. Mikusz. (2016, 11-14 december). *"Looking for a Few Good Concepts and Theories for Digitized Artifacts and Digital Innovation in a Material World"*[Paper presentation]. International Conference of Information Systems. Dublin, Ireland.

Herterich, M. M., Uebernickel, F., & Brenner, W. (2015). The Impact of Cyber-physical Systems on Industrial Services in Manufacturing. *Procedia CIRP, 30*, 323-328. https://doi.org/10.1016/j.procir.2015.02.110

Hevner, A., & Chatterjee, S. (2010). Design Science Research in Information Systems. In *Design Research in Information Systems* (pp. 9-22). Springer. https://doi.org/10.1007/978-1-4419-5653-8_2

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design Science in Information Systems Research. *MIS Quarterly, 28*(1), 75-105. https://doi.org/10.2307/25148625

Holbrook, M. B. (1999). Introduction to consumer value. In M. B. Holbrook (Ed.), *Consumer value: A framework for analysis and research*, 1-28. Routledge. https://doi.org/10.4324/9780203010679

Hollauer, C., Venkataraman, S., & Omer, M. (2015, July 27-30*). A Model to Describe Use Phase of Socio-Technical Sphere of Product-Service Systems* [Paper presentiton]. In C. Weber, S. Husung, G. Cascini, M. Cantamessa, D. Marjanovic, F. Rotini (Eds.), DS 80-7 Proceedings of the 20th International Conference on Engineering Design (ICED15) Vol 7: Product Modularisation, Product Architecture, Systems Engineering, Product Service Systems, Milan, Italy.

Horvath, I., & Gerritsen, B. H. (2012, May 7-11). *Cyber-Physical Systems: Concepts, Technologies and Implementation Principles* [Paper presentation]. In I. Horváth, Z. Rusák, A. Albers and M. Behrendt (Eds.), Proceedings of Tools and Methods of Competitive Engineering Symposium (TMCE 2012), Karlsruhe, Germany.

Hoy, M. B. (2018) Alexa, Siri, Cortana, and More: An Introduction to Voice Assistants. *Medical Reference Services Quarterly, 37*:1, 81-88. https://doi.org/10.1080/02763869.2018.1404391

Hu, F., Lu, Y., Vasilakos, A. V., Hao, Q., Ma, R., Patil, Y., Zhang, T., Lu, J., Li, X., & Xiong, N. N. (2016). Robust Cyber–Physical Systems: Concept, models, and implementation. *Future Generation Computer Systems, 56*, 449-475. https://doi.org/10.1016/j.future.2015.06.006

Hu, X., Chu, T. H., Chan, H. C., & Leung, V. C. (2013). Vita: A Crowdsensing-Oriented Mobile Cyber-Physical System. *IEEE Transactions on Emerging Topics in Computing, 1*(1), 148-165. https://doi.org/10.1109/TETC.2013.2273359

Hussain, R., Lockett, H., & Vasantha, G. V. A. (2012). A framework to inform PSS Conceptual Design by using system-in-use data. *Computers in Industry, 63*(4), 319-327. https://doi.org/10.1016/j.compind.2012.02.013

Igba, J., Alemzadeh, K., Gibbons, P. M., & Henningsen, K. (2015). A framework for optimising product performance through feedback and reuse of in-service experience. *Robotics and Computer-Integrated Manufacturing, 36*, 2-12. https://doi.org/10.1016/j.rcim.2014.12.004

Isaksson, O., Larsson, T. C., & Rönnbäck, A. Ö. (2009). Development of product-service systems: challenges and opportunities for the manufacturing firm. *Journal of Engineering Design, 20*(4), 329-348. https://doi.org/10.1080/09544820903152663

Jiang, P., Ding, K., & Leng, J. (2016). Towards a cyber-physical-social-connected and service-oriented manufacturing paradigm: Social Manufacturing. *Manufacturing Letters, 7*, 15-21. https://doi.org/10.1016/j.mfglet.2015.12.002

Jin, J., Gubbi, J., Marusic, S., & Palaniswami, M. (2014). An Information Framework for Creating a Smart City Through Internet of Things. *IEEE Internet of Things Journal, 1*(2), 112-121. https://doi.org/10.1109/JIOT.2013.2296516

Jonsen, K., & Jehn, K. A. (2009). Using triangulation to validate themes in qualitative studies. *Qualitative Research in Organizations and Management, 4*(2), 123-150. https://doi.org/10.1108/17465640910978391

Joore, P., & Brezet, H. (2015). A Multilevel Design Model: the mutual relationship between product-service system development and societal change processes. *Journal of Cleaner Production, 97*, 92-105. https://doi.org/10.1016/j.jclepro.2014.06.043

Kanji, G. K. (1990). Total quality management: the second industrial revolution. *Total Quality Management, 1*(1), 3-12. https://doi.org/10.1080/09544129000000001

Kawaguchi, T., Murata, H., Fukushige, S., & Kobayashi, H. (2019). Scenario Analysis of Car- and Ride-Sharing Services Based on Life Cycle Simulation. *Procedia CIRP, 80*, 328-333. https://doi.org/10.1016/j.procir.2019.01.051

Kennedy, E., & Guzmán, F. (2016). Co-creation of brand identities: consumer and industry influence and motivations. *Journal of Consumer Marketing, 33*(5), 313-323. https://doi.org/10.1108/JCM-07-2015-1500

Kepuska, V., & Bohouta, G. (2018, 8-10 January). *Next-generation of virtual personal assistants (microsoft cortana, apple siri, amazon alexa and google home)* [Paper presentation]. In 2018 IEEE 8th annual computing and communication workshop and conference (CCWC), (pp. 99-103), Las Vegas, NV, USA. https://doi.org/10.1109/CCWC.2018.8301638

Khaitan, S. K., & McCalley, J. D. (2015). Design Techniques and Applications of Cyberphysical Systems: A Survey. *IEEE Systems Journal, 9*(2), 350-365. https://doi.org/10.1109/JSYST.2014.2322503

Khalifa, A. S. (2004). Customer value: a review of recent literature and an integrative configuration. *Management Decision, 42*(5), 645-666. https://doi.org/10.1108/00251740410538497

Kim, H.-W., Chan, H. C., & Gupta, S. (2007). Value-based Adoption of Mobile Internet: An empirical investigation. *Decision Support Systems, 43*(1), 111-126. https://doi.org/10.1016/j.dss.2005.05.009

Kim, K.-J., Lim, C.-H., Heo, J.-Y., Lee, D.-H., Hong, Y.-S., & Park, K. (2016). An evaluation scheme for product–service system models: development of evaluation criteria and case studies. *Service Business, 10*, 507-530. https://doi.org/10.1007/s11628-015-0280-3

Kim, M., Song, J., & Triche, J. (2015). Toward an integrated framework for innovation in service: A resource-based view and dynamic capabilities approach. *Information Systems Frontiers, 17*, 533-546 https://doi.org/10.1007/s10796-014-9505-6

Kim, S., & Park, Y. (2012). A TRIZ-based Approach to Generation of Service-supporting Product Concepts. *International Journal of Industrial and Manufacturing Engineering, 6*(2), 487-490. https://doi.org/10.5281/zenodo.1084822

Kim, S., Son, C., Yoon, B., & Park, Y. (2015). Development of an Innovation Model Based on a Service-Oriented Product Service System (PSS). *Sustainability, 7*(11), 14427-14449. https://doi.org/10.3390/su71114427

Kim, S., & Yoon, B. (2012). Developing a process of concept generation for new product-service systems: a QFD and TRIZ-based approach. *Service Business, 6*, 323-348. https://doi.org/10.1007/s11628-012-0138-x

Kimita, K., Shimomura, Y., & Arai, T. (2009a). A customer value model for sustainable service design. *CIRP Journal of Manufacturing Science and Technology, 1*(4), 254-261. https://doi.org/10.1016/j.cirpj.2009.06.003

Kimita, K., Shimomura, Y., & Arai, T. (2009b). Evaluation of customer satisfaction for PSS design. *Journal of Manufacturing Technology Management, 20*(5), 654-673. https://doi.org/10.1108/17410380910961046

Kindström, D., Kowalkowski, C., & Sandberg, E. (2013). Enabling service innovation: A dynamic capabilities approach. *Journal of Business Research, 66*(8), 1063-1073. https://doi.org/10.1016/j.jbusres.2012.03.003

Kitchenham, B. (2004). Procedure for undertaking systematic reviews. *Joint Technical Report: Computer Science Department, Keele University (TR/SE-0401) and National ICT Australia Ltd. (0400011T. 1).*

Kitchenham, B. & Charters, S. (2007). Guidelines for performing systematic literature reviews in software engineering, Version 2.3. *Technical report EBSE-2007-01, Keele University and University of Durham*.

Kohtamäki, M., & Rajala, R. (2016). Theory and practice of value co-creation in B2B systems. *Industrial Marketing Management, 56*, 4-13. https://doi.org/10.1016/j.indmarman.2016.05.027

Komoto, H., & Tomiyama, T. (2008). Integration of a service CAD and a life cycle simulator. *CIRP Annals-Manufacturing Technology, 57*(1), 9-12. https://doi.org/10.1016/j.cirp.2008.03.001

Kowalkowski, C. (2010). What does a service-dominant logic really mean for manufacturing firms? *CIRP Journal of Manufacturing Science and Technology, 3*(4), 285-292. https://doi.org/10.1016/j.cirpj.2011.01.003

Kraus, S., Breier, M., & Dasí-Rodríguez, S. (2020). The art of crafting a systematic literature review in entrepreneurship research. *International Entrepreneurship and Management Journal, 16*(3), 1023-1042. https://doi.org/10.1007/s11365-020-00635-4

Krosnick J.A. (2018) Questionnaire Design. In: Vannette D., Krosnick J. (Eds.) *The Palgrave Handbook of Survey Research*. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-319-54395-6_53

Krucken, L., & Meroni, A. (2006). Building stakeholder networks to develop and deliver product-service-systems: practical experiences on elaborating pro-active materials for communication. *Journal of Cleaner Production, 14*(17), 1502-1508. https://doi.org/10.1016/j.jclepro.2006.01.026

Kuechler, W., & Vaishnavi, V. (2008). The emergence of design research in information systems in North America. *Journal of Design Research, 7*(1), 1-16. https://doi.org/10.1504/JDR.2008.019897

Kuhlenkötter, B., Bender, B., Wilkens, U., Abramovici, M., Göbel, J. C., Herzog, M., Hypki, A., & Lenkenhoff, K. (2017, August 21-25). *Coping with the challenges of engineering smart product service systems-Demands for research infrastructure* [Paper presentation]. In A. Maier, S. Škec, H. Kim, M. Kokkolaras, J. Oehmen, G. Fadel, F. Salustri, M. Van der Loos (Eds.), DS 87-3 Proceedings of the 21st International Conference on Engineering Design (ICED 17) Vol 3: Product, Services and Systems Design, Vancouver, Canada.

Kuhlenkötter, B., Wilkens, U., Bender, B., Abramovici, M., Süße, T., Göbel, J., Herzog, M., Hypki, A., & Lenkenhoff, K. (2017). New Perspectives for Generating Smart PSS Solutions – Life Cycle, Methodologies and Transformation. *Procedia CIRP, 64*, 217-222. https://doi.org/10.1016/j.procir.2017.03.036

Kuijken, B., Gemser, G., & Wijnberg, N. M. (2017). Effective product-service systems: A value-based framework. *Industrial Marketing Management, 60*, 33-41. https://doi.org/10.1016/j.indmarman.2016.04.013

Kumar, V. R. S., Shanmugavel, M., Ganapathy, V., & Shirinzadeh, B. (2015). Unified meta-modeling framework using bond graph grammars for conceptual modeling. *Robotics and Autonomous Systems, 72*, 114-130. https://doi.org/10.1016/j.robot.2015.05.003

Kuo, T. C., Ma, H. Y., Huang, S. H., Hu, A. H., & Huang, C. S. (2010). Barrier analysis for product service system using interpretive structural model. *The International Journal of Advanced Manufacturing Technology, 49*(1-4), 407-417. https://doi.org/10.1007/s00170-009-2399-7

La, H. J., & Kim, S. D. (2010, August 18-20). *A Service-Based Approach to Designing Cyber Physical Systems* [Paper presentation]. IEEE/ACIS 9th International Conference on Computer and Information Science (ICIS), Yamagata, Japan. https://doi.org/10.1109/ICIS.2010.73

Lai, C.-F., Ma, Y.-W., Chang, S.-Y., Chao, H.-C., & Huang, Y.-M. (2011). OSGi-based services architecture for Cyber-Physical Home Control Systems. *Computer Communications, 34*(2), 184-191. https://doi.org/10.1016/j.comcom.2010.03.034

Latour, B. (1987). *Science in Action: How to follow scientists and engineers through society*. Harvard University Press.

Latour, B. (1996). On actor-network theory: A few clarifications. *Soziale welt*, *47*(4) 369-381.

Latour, B. (2005). *Reassembling the Social: An Introduction to Actor-Network-Theory*. Oxford University Press.

Law, J. (1992). Notes on the theory of the actor-network: Ordering, strategy, and heterogeneity. *Systems Practice, 5*, 379-393. https://doi.org/10.1007/BF01059830

Law, J. (2009). Actor network theory and material semiotics. In B.S. Turner (Ed.), *The New Blackwell Companion to Social Theory* (pp. 141-158). https://doi.org/10.1002/9781444304992.ch7

Law, J., & Callon, M. (1988). Engineering and Sociology in a Military Aircraft Project: A Network Analysis of Technological Change. *Social Problems, 35*(3), 284-297. https://doi.org/10.2307/800623

Lay, G., Schroeter, M., & Biege, S. (2009). Service-based business concepts: A typology for business-to-business markets. *European Management Journal, 27*(6), 442-455. https://doi.org/10.1016/j.emj.2009.04.002

Lee, A. R., & Kim, K. K. (2018). Customer benefits and value co-creation activities in corporate social networking services. *Behaviour & Information Technology, 37*(7), 675-692. https://doi.org/10.1080/0144929X.2018.1474252

Lee, C.-H., Chen, C.-H., & Trappey, A. J. (2019). A structural service innovation approach for designing smart product service systems: Case study of smart beauty service. *Advanced Engineering Informatics, 40*, 154-167. https://doi.org/10.1016/j.aei.2019.04.006

Lee, C., Lin, B., Ng, K., Lv, Y., & Tai, W. (2019). Smart robotic mobile fulfillment system with dynamic conflict-free strategies considering cyber-physical integration. *Advanced Engineering Informatics, 42*, 100998. https://doi.org/10.1016/j.aei.2019.100998

Lee, E. A. (2008, May 5-7). *Cyber Physical Systems: Design Challenges*. 11th IEEE International Symposium on Object and Component-Oriented Real-Time Distributed Computing (ISORC), Orlando, FL, USA. https://doi.org/10.1109/ISORC.2008.25

Lee, E. A. (2015). The Past, Present and Future of Cyber-Physical Systems: A Focus on Models. *Sensors, 15*(3), 4837-4869. https://doi.org/10.3390/s150304837

Lee, E. A., & Seshia, S. A. (2014). *Introduction to Embedded Systems - A Cyber-Physical Systems Approach* (1.5 ed.). LeeShehia.org.

Lee, E. A., & Seshia, S. A. (2017). *Introduction to Embedded Systems: A Cyber-Physical Systems Approach* (2nd ed.). MIT Press.

Lee, J., Bagheri, B., & Kao, H.-A. (2015). A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters, 3*, 18-23. https://doi.org/10.1016/j.mfglet.2014.12.001

Lee, J., & Kao, H.-A. (2014, April 23-25). *Dominant Innovation Design for Smart Products-Service Systems (PSS): Strategies and Case Studies* [Paper presentation]. 2014 Annual SRII Global Conference, San Jose, CA, USA. https://doi.org/10.1109/SRII.2014.25

Lenth, R. V. (2001). Some practical guidelines for effective sample size determination. *The American Statistician, 55*(3), 187-193. https://doi.org/10.1198/000313001317098149

Leitão, P., Colombo, A. W., & Karnouskos, S. (2016). Industrial automation based on cyber-physical systems technologies: Prototype implementations and challenges. *Computers in Industry, 81*, 11-25. https://doi.org/10.1016/j.compind.2015.08.004

Levy, Y., & Ellis, T. J. (2006). A Systems Approach to Conduct an Effective Literature Review in Support of Information Systems Research. *Informing Science: The International Journal of an Emerging Transdiscipline, 9*, 181-212. https://doi.org/10.28945/479

Li, A. Q., & Found, P. (2017). Towards Sustainability: PSS, Digital Technology and Value Co-creation. *Procedia CIRP, 64*, 79-84. https://doi.org/10.1016/j.procir.2017.05.002

Li, H., Ji, Y., Gu, X., Qi, G., & Tang, R. (2012). Module partition process model and method of integrated service product. *Computers in Industry, 63*(4), 298-308. https://doi.org/10.1016/j.compind.2012.02.015

Li, R., Verhagen, W. J., & Curran, R. (2020). Stakeholder-oriented systematic design methodology for prognostic and health management system: Stakeholder expectation definition. *Advanced Engineering Informatics, 43*, 101041. https://doi.org/10.1016/j.aei.2020.101041

Liedtke, C., Baedeker, C., Hasselkuß, M., Rohn, H., & Grinewitschus, V. (2015). User-integrated innovation in Sustainable LivingLabs: an experimental infrastructure for researching and developing sustainable product service systems. *Journal of Cleaner Production, 97*, 106-116. https://doi.org/10.1016/j.jclepro.2014.04.070

Lim, C. H., Kim, K. J., Hong, Y. S., & Park, K. (2012). PSS Board: a structured tool for product-service system process visualization. *Journal of Cleaner Production, 37*, 42-53. https://doi.org/10.1016/j.jclepro.2012.06.006

Liu, B., Zhang, Y., Zhang, G., & Zheng, P. (2019). Edge-cloud orchestration driven industrial smart product-service systems solution design based on CPS and IIoT. *Advanced Engineering Informatics, 42*, 100984. https://doi.org/10.1016/j.aei.2019.100984

Liu, C. H., Chen, M. C., Tu, Y. H., & Wang, C. C. (2014). Constructing a sustainable service business model: An S-D logic-based integrated product service system (IPSS). *International Journal of Physical Distribution & Logistics Management, 44*(1/2), 80-97. https://doi.org/10.1108/IJPDLM-02-2013-0039

Liu, X., Dong, M., Ota, K., Hung, P., & Liu, A. (2016). Service Pricing Decision in Cyber-Physical Systems: Insights from Game Theory. *IEEE Transactions on Services Computing, 9*(2), 186-198. https://doi.org/10.1109/TSC.2015.2449314

Liu, Y., Peng, Y., Wang, B., Yao, S., & Liu, Z. (2017). Review on cyber-physical systems. *IEEE/CAA Journal of Automatica Sinica, 4*(1), 27-40. https://doi.org/10.1109/JAS.2017.7510349

Liu, Z., & Ming, X. (2019). A methodological framework with rough-entropy-ELECTRE TRI to classify failure modes for co-implementation of smart PSS. *Advanced Engineering Informatics, 42*, 100968. https://doi.org/10.1016/j.aei.2019.100968

Lusch, R. F., & Vargo, S. L. (2006a). Service-dominant logic: reactions, reflections and refinements. *Marketing Theory, 6*(3), 281-288. https://doi.org/10.1177/1470593106066781

Lusch, R. F., & Vargo, S. L. (2006b). *The Service-Dominant Logic of Marketing: Dialog, Debate, and Directions*. New York: Routledge. https://doi.org/10.4324/9781315699035

Lusch, R. F., & Vargo, S. L. (2014). *Service-Dominant Logic: Premises, Perspectives, Possibilities*. Cambridge University Press.

Lusch, R. F., Vargo, S. L., & Tanniru, M. (2010). Service, value networks and learning. *Journal of the Academy of Marketing Science, 38*, 19-31. https://doi.org/10.1007/s11747-008-0131-z

Lytle, R. S., & Timmerman, J. E. (2006). Service orientation and performance: an organizational perspective. *Journal of Services Marketing, 20*(2), 136-147. https://doi.org/10.1108/08876040610657066

MacDermott, Á., Lea, S., Iqbal, F., Idowu, I., & Shah, B. (2019, 24-26 June). *Forensic analysis of wearable devices: Fitbit, Garmin and HETP Watches* [Paper presentation]. In 2019 10th IFIP International Conference on New Technologies, Mobility and Security (NTMS), Canary Islands, Spain. https://doi.org/10.1109/NTMS.2019.8763834

Macdonald, E. K., Kleinaltenkamp, M., & Wilson, H. N. (2016). How Business Customers Judge Solutions: Solution Quality and Value in Use. *Journal of Marketing, 80*(3), 96-120. https://doi.org/10.1509/jm.15.0109

MacKenzie, C. M., Laskey, K., McCabe, F., Brown, P. F., Metz, R., & Hamilton, B. A. (2006). Reference model for service oriented architecture 1.0. *OASIS standard, 12*(S 18).

Maglio, P. P., & Spohrer, J. (2007). Fundamentals of service science. *Journal of the Academy of Marketing Science, 36*, 18-20. https://doi.org/10.1007/s11747-007-0058-9

Maher, C., Ryan, J., Ambrosi, C. & Edney, S. (2017). Users' experiences of wearable activity trackers: a cross-sectional study. *BMC Public Health 17,* 880. https://doi.org/10.1186/s12889-017-4888-1

Manzini, E., & Vezzoli, C. (2003). A strategic design approach to develop sustainable product service systems: examples taken from the 'environmentally friendly innovation' Italian prize. *Journal of Cleaner Production, 11*(8), 851-857. https://doi.org/10.1016/S0959-6526(02)00153-1

Manzini, E., Vezzoli, C., & Clark, G. (2001). Product Service Systems. Using an Existing Concept as a New Approach to Sustainability. *Journal of Design Research, 1*(2), 12-18. https://doi.org/10.1504/JDR.2001.009811

March, S. T., & Smith, G. F. (1995). Design and natural science research on information technology. *Decision Support Systems, 15*(4), 251-266. https://doi.org/10.1016/0167-9236(94)00041-2

Marcos-Cuevas, J., Nätti, S., Palo, T., & Baumann, J. (2016). Value co-creation practices and capabilities: Sustained purposeful engagement across B2B systems. *Industrial Marketing Management, 56*, 97-107. https://doi.org/10.1016/j.indmarman.2016.03.012

Marilungo, E., Coscia, E., Quaglia, A., Peruzzini, M., & Germani, M. (2016). Open Innovation for Ideating and Designing New Product Service Systems. *Procedia CIRP, 47*, 305-310. https://doi.org/10.1016/j.procir.2016.03.214

Marilungo, E., Papetti, A., Germani, M., & Peruzzini, M. (2017). From PSS to CPS Design: A Real Industrial Use Case Toward Industry 4.0. *Procedia CIRP, 64*, 357-362. https://doi.org/10.1016/j.procir.2017.03.007

Martinez, V., Bastl, M., Kingston, J., & Evans, S. (2010). Challenges in transforming manufacturing organisations into product-service providers. *Journal of Manufacturing Technology Management, 21*(4), 449-469. https://doi.org/10.1108/17410381011046571

Mason, J. (2017). *Qualitative Researching* (3rd ed.). SAGE Publishing.

Massoomi, M. R., & Handberg, E. M. (2019). Increasing and evolving role of smart devices in modern medicine. *European Cardiology Review, 14*(3), 181. https://dx.doi.org/10.15420%2Fecr.2019.02

Matschewsky, J., Sakao, T., & Lindahl, M. (2015). ProVa – Provider Value Evaluation for Integrated Product Service Offerings. *Procedia CIRP, 30*, 305-310. https://doi.org/10.1016/j.procir.2015.02.096

Maussang, N., Zwolinski, P., & Brissaud, D. (2009). Product-service system design methodology: from the PSS architecture design to the products specifications. *Journal of Engineering Design, 20*(4), 349-366. https://doi.org/10.1080/09544820903149313

McKay, A., & Kundu, S. (2014). A representation scheme for digital product service system definitions. *Advanced Engineering Informatics, 28*(4), 479-498. https://doi.org/10.1016/j.aei.2014.07.004

Mehrsai, A., Henriksen, B., Røstad, C. C., Hribernik, K. A., & Thoben, K.-D. (2014). Make-to-XGrade for the Design and Manufacturing of Flexible, Adaptive, and Reactive Products. *Procedia CIRP, 21*, 199-205. https://doi.org/10.1016/j.procir.2014.03.147

Meier, H., Roy, R., & Seliger, G. (2010). Industrial Product-Service Systems—IPS^2. *CIRP Annals, 59*(2), 607-627. https://doi.org/10.1016/j.cirp.2010.05.004

Mikusz, M. (2014). Towards an Understanding of Cyber-physical Systems as Industrial Software-Product-Service Systems. *Procedia CIRP, 16*, 385-389. https://doi.org/10.1016/j.procir.2014.02.025

Miles, M. B., Huberman, A. M. & Saldaña, J. (2018). *Qualitative Data Analysis: A Methods Sourcebook* (4th ed.). SAGE Publications, Inc.

Minguez, J., Baureis, D., & Neumann, D. (2012). A reference architecture for agile product-service systems. *CIRP Journal of Manufacturing Science and Technology, 5*(4), 319-327. https://doi.org/10.1016/j.cirpj.2012.09.007

Mohamed Shaffril, H.A., Samsuddin, S.F. & Abu Samah, A. (2021). The ABC of systematic literature review: the basic methodological guidance for beginners. *Quality & Quantity, 55*, 1319–1346. https://doi.org/10.1007/s11135-020-01059-6

Mont, O. (2000). *Product-service systems*. Naturvårdsverket (Swedish Environmental Protection Agency).

Mont, O. K. (2002). Clarifying the concept of product–service system. *Journal of Cleaner Production, 10*(3), 237-245. https://doi.org/10.1016/S0959-6526(01)00039-7

Montenegro, L. M., & Bulgacov, S. (2014). Reflections on actor-network theory, governance networks, and strategic outcomes. *BAR-Brazilian Administration Review, 11*(1), 107-124. http://dx.doi.org/10.1590/S1807-76922014000100007

Morelli, N. (2006). Developing new product service systems (PSS): methodologies and operational tools. *Journal of Cleaner Production, 14*(17), 1495-1501. https://doi.org/10.1016/j.jclepro.2006.01.023

Morelli, N. (2009). Service as value co-production: reframing the service design process. *Journal of Manufacturing Technology Management, 20*(5), 568-590. https://doi.org/10.1108/17410380910960993

Morris, A. (2015). *A Practical Introduction to In-depth Interviewing*. SAGE Publications.

Mourtzis, D., Vlachou, E., Zogopoulos, V., Gupta, R. K., Belkadi, F., Debbache, A., & Bernard, A. (2018). Customer feedback gathering and management tools for product-service system design. *Procedia CIRP, 67*, 577-582. https://doi.org/10.1016/j.procir.2017.12.264

Mühlhäuser, M. (2007, November 7-10). *Smart products: An introduction* [Paper presentation]. In M. Mühlhäuser, A. Ferscha, E. Aitenbichler (Eds.), Constructing Ambient Intelligence, European Conference on Ambient Intelligence, Communications in Computer and Information Science (pp. 158-164), *11*, Darmstadt, Germany. https://doi.org/10.1007/978-3-540-85379-4_20

Müller, P., & Stark, R. (2010, May 17-20). *A GENERIC PSS DEVELOPMENT PROCESS MODEL BASED ON THEORY AND AN EMPIRICAL STUDY* [Paper presentation]. In D. Marjanović, M. Štorga, N. Pavković & N. Bojčetić (Eds.), DS 60: Proceedings of DESIGN 2010, the 11th International Design Conference (pp. 361-370), Dubrovnik, Croatia.

Murphy, J. T. (2006). Building trust in economic space. *Progress in human geography, 30*(4), 427-450. https://doi-org.ezproxy.lib.uts.edu.au/10.1191%2F0309132506ph617oa

Nagamachi, M. (1995). Kansei Engineering: A new ergonomic consumer-oriented technology for product development. *International Journal of Industrial Ergonomics, 15*(1), 3-11. https://doi.org/10.1016/0169-8141(94)00052-5

Neely, A. (2008). Exploring the financial consequences of the servitization of manufacturing. *Operations Management Research, 1*, 103-118. https://doi.org/10.1007/s12063-009-0015-5

Nemoto, Y., Akasaka, F., & Shimomura, Y. (2015). A framework for managing and utilizing product–service system design knowledge. *Production Planning & Control, 26*(14-15), 1278-1289. https://doi.org/10.1080/09537287.2015.1033493

Ng, I., Parry, G., Smith, L., Maull, R., & Briscoe, G. (2012). Transitioning from a goods-dominant to a service-dominant logic: Visualising the value proposition of Rolls-Royce. *Journal of Service Management, 23*(3), 416-439. https://doi.org/10.1108/09564231211248480

Ng, I. C., Parry, G., Smith, L., & Maull, R. (2010). Value co-creation in Complex Engineering Service Systems: Conceptual Foundations. In *University of Exeter Business School: Discussion Papers in Management, 10*(04), 1-19.

Numata, E., Hosono, S., Sakaki, H., Izukura, S., Kimita, K., & Shimomura, Y. (2015). Disciplines for Designing PSS Actor Network. *Procedia CIRP, 30*, 408-414. https://doi.org/10.1016/j.procir.2015.03.009

Obschonka, M. (2018). The Industrial Revolution left psychological scars that can still be seen today. *Harvard Business Review*, 1-6.

Offermann, P., Blom, S., Schönherr, M., & Bub, U. (2010). Artifact Types in Information Systems Design Science – A Literature Review. In R. Winter, J.L. Zhao, S. Aier (Eds.), *Global Perspectives on Design Science Research: DESRIST 2010, Lecture Notes in Computer Science, 6105*, (pp. 77-92). Springer. https://doi.org/10.1007/978-3-642-13335-0_6

Okoli, C. (2015). A guide to conducting a standalone systematic literature review. *Communications of the Association for Information Systems, 37*, 879-910. https://doi.org/10.17705/1CAIS.03743

Okoli, C., & Schabram, K. (2010). A Guide to Conducting a Systematic Literature Review of Information Systems Research. *Sprouts: Working Papers on Information Systems, 10*(26), 1-51.

Osborne, S. P. (2018). From public service-dominant logic to public service logic: are public service organizations capable of co-production and value co-creation? *Public Management Review, 20*(2), 225-231. https://doi.org/10.1080/14719037.2017.1350461

Pan, S., Zhong, R. Y., & Qu, T. (2019). Smart product-service systems in interoperable logistics: Design and implementation prospects. *Advanced Engineering Informatics, 42*, 100996. https://doi.org/10.1016/j.aei.2019.100996

Park, Y., Geum, Y., & Lee, H. (2012). Toward integration of products and services: Taxonomy and typology. *Journal of Engineering and Technology Management, 29*(4), 528-545. https://doi.org/10.1016/j.jengtecman.2012.08.002

Patton, M. Q. (2014). *Qualitative Research & Evaluation Methods Integrating Theory and Practice (*4th ed.). SAGE Publications.

Pawar, K. S., Beltagui, A., & Riedel, J. C. K. H. (2009). The PSO triangle: designing product, service and organisation to create value. *International Journal of Operations & Production Management, 29*(5), 468-493. https://doi.org/10.1108/01443570910953595

Payne, A., & Holt, S. (2001). Diagnosing Customer Value: Integrating the Value Process and Relationship Marketing. *British Journal of Management, 12*(2), 159-182. https://doi.org/10.1111/1467-8551.00192

Payne, A. F., Storbacka, K., & Frow, P. (2008). Managing the co-creation of value. *Journal of the Academy of Marketing Science, 36*, 83-96. https://doi.org/10.1007/s11747-007-0070-0

Peffers, K., Rothenberger, M., Tuunanen, T., & Vaezi, R. (2012). Design Science Research Evaluation. In K. Peffers, M. Rothenberger, B. Kuechler (Eds.), *Design Science Research in Information Systems. Advances in Theory and Practice: DESRIST 2012, Lecture Notes in Computer Science, 7286*, (pp. 398-410). https://doi.org/10.1007/978-3-642-29863-9_29

Peffers, K., Tuunanen, T., Gengler, C. E., Rossi, M., Hui, W., Virtanen, V., & Bragge, J. (2006, February 24-25). *Design Science Research Process: A Model for Producing and Presenting Information Systems Research* [Paper presentation]. In Proceedings of International Conference on Design Science Research in Information Systems and Technology: DESRIST 2006, pp. 83-106, Claremont, CA, USA.

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A Design Science Research Methodology for Information Systems Research. *Journal of Management Information Systems, 24*(3), 45-77. https://doi.org/10.2753/MIS0742-1222240302

Penzenstadler, B., & Eckhardt, J. (2012, September 25-25). *A Requirements Engineering content model for Cyber-Physical Systems* [Paper presentation]. 2012 Second IEEE International Workshop on Requirements Engineering for Systems, Services, and Systems-of-Systems (RESS), Chicago, IL, USA. https://doi.org/10.1109/RES4.2012.6347692

Pera, R., Occhiocupo, N., & Clarke, J. (2016). Motives and resources for value co-creation in a multi-stakeholder ecosystem: A managerial perspective. *Journal of Business Research, 69*(10), 4033-4041. https://doi.org/10.1016/j.jbusres.2016.03.047

Peruzzini, M., & Germani, M. (2014). Design for sustainability of product-service systems. *International Journal of Agile Systems and Management, 7*(3/4), 206-219. https://doi.org/10.1504/IJASM.2014.065355

Peruzzini, M., Marilungo, E., & Germani, M. (2014, May 19-22). *SUSTAINABLE PRODUCT-SERVICE DESIGN IN MANUFACTURING INDUSTRY* [Paper presentation]. In D. Marjanović, M. Štorga, N. Pavković & N. Bojčetić (Eds.), DS 77: Proceedings of the DESIGN 2014 13th International Design Conference (pp. 955-964), Dubrovnik, Croatia.

Peruzzini, M., Marilungo, E., & Germani, M. (2015). Structured requirements elicitation for product-service system. *International Journal of Agile Systems and Management, 8*(3/4), 189-218. https://doi.org/10.1504/IJASM.2015.073516

Petrick, J. F. (2002). Development of a Multi-Dimensional Scale for Measuring the Perceived Value of a Service. *Journal of Leisure Research, 34*(2), 119-134. https://doi.org/10.1080/00222216.2002.11949965

Pezzotta, G., Pirola, F., Pinto, R., Akasaka, F., & Shimomura, Y. (2015). A Service Engineering framework to design and assess an integrated product-service. *Mechatronics, 31*, 169-179. https://doi.org/10.1016/j.mechatronics.2015.05.010

Pezzotta, G., Pirola, F., Rondini, A., Pinto, R., & Ouertani, M.-Z. (2016). Towards a methodology to engineer industrial product-service system–Evidence from power and automation industry. *CIRP Journal of Manufacturing Science and Technology, 15*, 19-32. https://doi.org/10.1016/j.cirpj.2016.04.006

Phumbua, S., & Tjahjono, B. (2012). Towards product-service systems modelling: a quest for dynamic behaviour and model parameters. *International Journal of Production Research, 50*(2), 425-442. https://doi.org/10.1080/00207543.2010.539279

Pieters, W. (2011). Explanation and trust: what to tell the user in security and AI?. *Ethics and information technology, 13*(1), 53-64. https://doi.org/10.1007/s10676-010-9253-3

Pigosso, D. C. A., & McAloone, T. C. (2016). Maturity-based approach for the development of environmentally sustainable product/service-systems. *CIRP Journal of Manufacturing Science and Technology, 15*, 33-41. https://doi.org/10.1016/j.cirpj.2016.04.003

Pinho, N., Beirão, G., Patrício, L., & Fisk, R. P. (2014). Understanding value co-creation in complex services with many actors. *Journal of Service Management, 25*(4), 470-493. https://doi.org/10.1108/JOSM-02-2014-0055

Pivoto, D. G., de Almeida, L. F., da Rosa Righi, R., Rodrigues, J. J., Lugli, A. B., & Alberti, A. M. (2021). Cyber-physical systems architectures for industrial internet of things applications in Industry 4.0: A literature review. *Journal of Manufacturing Systems, 58*, 176-192. https://doi.org/10.1016/j.jmsy.2020.11.017

Poeppelbuss, J., & Durst, C. (2019). Smart Service Canvas – A tool for analyzing and designing smart product-service systems. *Procedia CIRP, 83*, 324-329. https://doi.org/10.1016/j.procir.2019.04.077

Power, W. (Ed.) (2009). *Life Cycle Management: How business uses it to decrease footprint, create opportunities and make value chains more sustainable*. United Nations

Environment Programme (UNEP) & Society of Environmental Toxicology and Chemistry (SETAC): Lifecycle Initiative.

Prahalad, C. K., & Ramaswamy, V. (2000). Co-opting Customer Competence. *Harvard Business Review, 78*(1), 79-90.

Prahalad, C. K., & Ramaswamy, V. (2004a). Co-creating unique value with customers. *Strategy & Leadership, 32*(3), 4-9. https://doi.org/10.1108/10878570410699249

Prahalad, C. K., & Ramaswamy, V. (2004b). Co-creation experiences: The next practice in value creation. *Journal of Interactive Marketing, 18*(3), 5-14. https://doi.org/10.1002/dir.20015

Preikschas, M. W., Cabanelas, P., Rüdiger, K., & Lampón, J. F. (2017). Value co-creation, dynamic capabilities and customer retention in industrial markets. *Journal of Business & Industrial Marketing, 32*(3), 409-420. https://doi.org/10.1108/JBIM-10-2014-0215

Qu, M., Yu, S., Chen, D., Chu, J., & Tian, B. (2016). State-of-the-art of design, evaluation, and operation methodologies in product service systems. *Computers in Industry, 77*, 1-14. https://doi.org/10.1016/j.compind.2015.12.004

Raddats, C., & Kowalkowski, C. (2014). A reconceptualization of manufacturers' service strategies. *Journal of Business-to-business Marketing, 21*(1), 19-34. https://doi.org/10.1080/1051712X.2013.857500

Rajkumar, R. R., Lee, I., Sha, L., & Stankovic, J. (2010, June 13-18). *Cyber-physical systems: the next computing revolution* [Paper presentation]. Proceedings of the 47th Design Automation Conference, Anaheim, CA, USA. https://doi.org/10.1145/1837274.1837461

Ramaswamy, V. (2008). Co-creating value through customers' experiences: the Nike case. *Strategy & Leadership, 36*(5), 9-14. https://doi.org/10.1108/10878570810902068

Ranjan, K. R., & Read, S. (2016). Value co-creation: concept and measurement. *Journal of the Academy of Marketing Science, 44*, 290-315. https://doi.org/10.1007/s11747-014-0397-2

Regazzoni, D., Pezzotta, G., Persico, S., Cavalieri, S., & Rizzi, C. (2013). Integration of TRIZ Problem Solving Tools in a Product-Service Engineering Process. In Y. Shimomura, K. Kimita (Eds.), *The Philosopher's Stone for Sustainability* (pp. 399-404). Springer. https://doi.org/10.1007/978-3-642-32847-3_67

Reim, W., Parida, V., & Örtqvist, D. (2015). Product–Service Systems (PSS) business models and tactics – a systematic literature review. *Journal of Cleaner Production, 97*, 61-75. https://doi.org/10.1016/j.jclepro.2014.07.003

Remmen, A., Jensen, A. & Frydendal, J. (2007). *Life Cycle Management: A Business Guide To Sustainability*. United Nations Environment Programme (UNEP).

Rese, M., Karger, M., & Strotmann, W. C. (2009). The dynamics of Industrial Product Service Systems (IPS2) - using the Net Present Value Approach and Real Options Approach to improve life cycle management. *CIRP Journal of Manufacturing Science and Technology, 1*(4), 279-286. https://doi.org/10.1016/j.cirpj.2009.05.001

Rese, M., Strotmann, W.-C., & Karger, M. (2009). Which industrial product service system fits best?: Evaluating flexible alternatives based on customers' preference drivers. *Journal of Manufacturing Technology Management, 20*(5), 640-653. https://doi.org/10.1108/17410380910961037

Rexfelt, O., & Hiort af Ornäs, V. (2009). Consumer acceptance of product-service systems: Designing for relative advantages and uncertainty reductions. *Journal of Manufacturing Technology Management, 20*(5), 674-699. https://doi.org/10.1108/17410380910961055

Richards, L., & Morse, J. M. (2012). *README FIRST for a User's Guide to Qualitative Methods* (3rd ed.). SAGE Publications.

Richter, A., Sadek, T., & Steven, M. (2010). Flexibility in industrial product-service systems and use-oriented business models. *CIRP Journal of Manufacturing Science and Technology, 3*(2), 128-134. https://doi.org/10.1016/j.cirpj.2010.06.003

Ridder, H. G. (2017). The theory contribution of case study research designs. *Business Research, 10*, 281-305. https://doi.org/10.1007/s40685-017-0045-z

Rizvi, M., & Chew, E. (2018a, June 10-13). *Designing Service-Centric Product-Service Systems* [Paper presentation]. 25th Innovation and Product Development Management Conference (IPDMC), Porto, Portugal.

Rizvi, M. A. K., & Chew, E. (2018b, May 21-24). *TOWARDS SYSTEMATIC DESIGN OF CYBER-PHYSICAL PRODUCT-SERVICE SYSTEMS* [Paper presentation]. In D. Marjanović, M. Štorga, S. Škec, N. Bojčetić & N. Pavković (Eds.), DS92: Proceedings of the DESIGN 2018 15th International Design Conference (pp. 2961-2974), Dubrovnik, Croatia. https://doi.org/10.21278/idc.2018.0248

Rizvi, M. A. K.; Yip, M. H.; Chew, E. K. (2019a, June 10-11). *Designing for Changing Societal Requirements - An Integrated Design Framework for Product-Service Systems* [Paper presentation]. 26th Innovation and Product Development Management Conference (IPDMC), Leicester, UK.

Rizvi, M. A. K.; Yip, M. H.; Chew, E. K. & Carnemolla, P. K. (2019b, December 15-18) *Designing Through Value Co-creation: A Study of Actors, Practices and Possibilities* [Paper presentation]. 2019 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Macao, China. https://doi.org/10.1109/IEEM44572.2019.8978902

Rizvi, M. A. K.; Yip, M. H.; Sankaran, S., Carnemolla, P. K. (2021, June 16-18). *Value co-creation in developing sustainable cyber-physical product service systems: Applying design science research method* [Paper presentation]. EURAM 2021 Online Conference: Reshaping capitalism for a sustainable world, Montreal, Quebec, Canada.

Robinson P, Lowe J. (2015). Literature reviews vs systematic reviews. *Australian and New Zealand Journal of Public Health, 39*(2), 103. https://doi.org/10.1111/1753-6405.12393

Rowley, J., & Slack, F. (2004). Conducting a literature review. *Management Research News, 27*(6), 31–39. https://doi.org/10.1108/01409170410784185

Roy, R. (2000). Sustainable product-service systems. *Futures, 32*(3-4), 289-299. https://doi.org/10.1016/S0016-3287(99)00098-1

Roy, R., & Cheruvu, K. S. (2009). A competitive framework for industrial product-service systems. *International Journal of Internet Manufacturing and Services, 2*(1), 4-29. https://doi.org/10.1504/IJIMS.2009.031337

Saarijärvi, H., Kannan, P. K., & Kuusela, H. (2013). Value co-creation: theoretical approaches and practical implications. *European Business Review, 25*(1), 6-19. https://doi.org/10.1108/09555341311287718

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences, 1*(1), 83-98. https://www.inderscienceonline.com/doi/abs/10.1504/IJSSci.2008.01759

Sakao, T., & Lindahl, M. (2012). A value based evaluation method for Product/Service System using design information. *CIRP Annals - Manufacturing Technology, 61*(1), 51-54. https://doi.org/10.1016/j.cirp.2012.03.108

Sakao, T., & Mizuyama, H. (2014). Understanding of a product/service system design: a holistic approach to support design for remanufacturing. *Journal of Remanufacturing, 4*, Article 1. https://doi.org/10.1186/2210-4690-4-1

Sakao, T., & Shimomura, Y. (2007). Service Engineering: a novel engineering discipline for producers to increase value combining service and product. *Journal of Cleaner Production, 15*(6), 590-604. https://doi.org/10.1016/j.jclepro.2006.05.015

Sakao, T., Shimomura, Y., Sundin, E., & Comstock, M. (2009). Modeling design objects in CAD system for Service/Product Engineering. *Computer-Aided Design, 41*(3), 197-213. https://doi.org/10.1016/j.cad.2008.06.006

Sampigethaya, K., & Poovendran, R. (2013). Aviation Cyber–Physical systems: Foundations for Future Aircraft and Air Transport. *Proceedings of the IEEE, 101*(8), 1834-1855. https://doi.org/10.1109/JPROC.2012.2235131

Sánchez-Fernández, R., & Iniesta-Bonillo, M. Á. (2007). The concept of perceived value: a systematic review of the research. *Marketing Theory, 7*(4), 427-451. https://doi.org/10.1177/1470593107083165

Sanders, E. B.-N., & Stappers, P. J. (2008). Co-creation and the new landscapes of design. *CoDesign: International Journal of CoCreation in Design and the Arts, 4*(1), 5-18. https://doi.org/10.1080/15710880701875068

Sandström, S., Edvardsson, B., Kristensson, P., & Magnusson, P. (2008). Value in use through service experience. *Managing Service Quality: An International Journal, 18*(2), 112-126. https://doi.org/10.1108/09604520810859184

Sangiovanni-Vincentelli, A., Damm, W., & Passerone, R. (2012). Taming Dr. Frankenstein: Contract-based Design for Cyber-Physical Systems. *European Journal of Control, 18*(3), 217-238. https://doi.org/10.3166/ejc.18.217-238

Sanislav, T., & Miclea, L. (2012). Cyber-Physical Systems - Concept, Challenges and Research Areas. *Journal of Control Engineering and Applied Informatics, 14*(2), 28-33. http://www.ceai.srait.ro/index.php?journal=ceai&page=article&op=view&path%5B%5D=1292

Santamaria, L., Escobar-Tello, C., & Ross, T. (2016). Switch the channel: using cultural codes for designing and positioning sustainable products and services for mainstream audiences. *Journal of Cleaner Production, 123*, 16-27. https://doi.org/10.1016/j.jclepro.2015.09.130

Sassanelli, C., Pezzotta, G., Pirola, F., Terzi, S., & Rossi, M. (2016). Design for Product Service Supportability (DfPSS) Approach: A State of the Art to Foster Product Service System (PSS) Design. *Procedia CIRP, 47*, 192-197. https://doi.org/10.1016/j.procir.2016.03.233

Sattari, S., Wessman, A., & Borders, L. (2020). Business model innovation for sustainability: An investigation of consumers' willingness to adopt product-service systems. *Journal of Global Scholars of Marketing Science, 30*(3), 274-290. https://doi.org/10.1080/21639159.2020.1766369

Sauerwein, E., Bailom, F., Matzler, K., & Hinterhuber, H. H. (1996, February 19-23). *The Kano model: How to delight your customers* [Paper presentation]. International Working Seminar on Production Economics, pp. 313-327, Innsbruck, Austria.

Schenkl, S. A., Rösch, C., & Mörtl, M. (2014). Literature study on factors influencing the market acceptance of PSS. *Procedia CIRP, 16*, 98-103. https://doi.org/10.1016/j.procir.2014.01.013

Scholze, S., Correia, A., Stokic, D., Nagorny, K., & Spindler, P. (2016). Tools for Human-Product Collaborative Development of Intelligent Product Service Systems. In H. Afsarmanesh, L. Camarinha-Matos & A. Lucas Soares (Eds.), *Collaboration in a Hyperconnected World: PRO-VE 2016. IFIP Advances in Information and Communication Technology, 480* (pp. 373-384). Springer. https://doi.org/10.1007/978-3-319-45390-3_32

Scholze, S., Correia, A. T., & Stokic, D. (2016). Novel Tools for Product-service System Engineering. *Procedia CIRP, 47*, 120-125. https://doi.org/10.1016/j.procir.2016.03.237

Schweitzer, E., & Aurich, J. (2010). Continuous improvement of industrial product-service systems. *CIRP Journal of Manufacturing Science and Technology, 3*(2), 158-164. https://doi.org/10.1016/j.cirpj.2010.04.002

Seneviratne, S., Hu, Y., Nguyen, T., Lan, G., Khalifa, S., Thilakarathna, K., ... & Seneviratne, A. (2017). A survey of wearable devices and challenges. *IEEE Communications Surveys & Tutorials, 19*(4), 2573-2620. https://doi.org/10.1109/COMST.2017.2731979

Shafighi, N., & Shirazi, B. (2017). Ontological Map of Service Oriented Architecture Based on Zachman. *Research in Economics and Management, 2*(4), 33-45. https://doi.org/10.22158/rem.v2n4p33

Shakir, M. (2002). The selection of case studies: strategies and their applications to IS implementation case studies. *Research Letters in the Information and Mathematical Sciences, 3*, 191-198.

Shao, S., Xu, G., & Li, M. (2019). The design of an IoT-based route optimization system: A smart product-service system (SPSS) approach. *Advanced Engineering Informatics, 42*, 101006. https://doi.org/10.1016/j.aei.2019.101006

Sheth, J. N., Sisodia, R. S., & Sharma, A. (2000). The antecedents and consequences of customer-centric marketing. *Journal of the Academy of Marketing Science, 28*, 55-66. https://doi.org/10.1177/0092070300281006

Shi, J., Wan, J., Yan, H., & Suo, H. (2011, November 9-11). *A survey of cyber-physical systems* [Paper presentation]. 2011 International Conference on Wireless Communications and Signal Processing (WCSP), Nanjing, China. https://doi.org/10.1109/WCSP.2011.6096958

Shikata, N., Gemba, K., & Uenishi, K. (2013). A competitive product development strategy using modular architecture for product and service systems. *International Journal of Business and Systems Research, 7*(4), 375-394. https://doi.org/10.1504/IJBSR.2013.056704

Shimomura, Y., Hara, T., & Arai, T. (2009). A unified representation scheme for effective PSS development. *CIRP Annals - Manufacturing Technology, 58*(1), 379-382. https://doi.org/10.1016/j.cirp.2009.03.025

Shimomura, Y., Nemoto, Y., & Kimita, K. (2015). A method for analysing conceptual design process of product-service systems. *CIRP Annals - Manufacturing Technology, 64*(1), 145-148. https://doi.org/10.1016/j.cirp.2015.04.035

Shin, D.-H. (2016). Application of actor-network theory to network neutrality in Korea: Socio-ecological understanding of network dynamics. *Telematics and Informatics, 33*(2), 436-451. https://doi.org/10.1016/j.tele.2015.10.002

Shostack, G. L. (1984). Designing services that deliver. *Harvard Business Review, 62*(1), 133 - 139.

Shostack, L. G. (1982). How to Design a Service. *European Journal of Marketing, 16*(1), 49-63. https://doi.org/10.1108/EUM0000000004799

Shulga, L. V., Busser, J. A., Bai, B., & Kim, H. (2021). The Reciprocal Role of Trust in Customer Value Co-Creation. *Journal of Hospitality & Tourism Research, 45*(4), 672-696. https://doi.org/10.1177%2F1096348020967068

Smith, L., Maull, R. S., & Ng, I. C. L. (2014). Servitization and operations management: a service dominant-logic approach. *International Journal of Operations & Production Management, 34*(2), 242-269. https://doi.org/10.1108/IJOPM-02-2011-0053

Song, W., & Sakao, T. (2016). Service conflict identification and resolution for design of product–service offerings. *Computers & Industrial Engineering, 98*, 91-101. https://doi.org/10.1016/j.cie.2016.05.019

Song, W., & Sakao, T. (2017). A customization-oriented framework for design of sustainable product/service system. *Journal of Cleaner Production, 140*(3), 1672-1685. https://doi.org/10.1016/j.jclepro.2016.09.111

Sonnemann, G., Gemechu, E. D., Remmen, A., Frydendal, J., & Jensen, A. A. (2015). Life Cycle Management: Implementing Sustainability in Business Practice. In G. Sonnemann & M. Margni (Eds.), *Life Cycle Management. LCA Compendium – The Complete World of Life Cycle Assessment*, pp. 7-21. Springer, Dordrecht. https://doi.org/10.1007/978-94-017-7221-1_2

Spohrer, J., Maglio, P. P., Bailey, J., & Gruhl, D. (2007). Steps toward a science of service systems. *Computer, 40*(1), 71-77. https://doi.org/10.1109/MC.2007.33

Spohrer, J., Vargo, S. L., Caswell, N., & Maglio, P. P. (2008, January 7-10). *The Service System Is the Basic Abstraction of Service Science* [Paper presentation]. Proceedings of the 41st Annual Hawaii International Conference on System Sciences (HICSS 2008), Waikoloa, HI, USA. https://doi.org/10.1109/HICSS.2008.451

Stacey, P. K., & Tether, B. S. (2015). Designing emotion-centred Product Service Systems: The case of a cancer care facility. *Design Studies, 40*, 85-118. https://doi.org/10.1016/j.destud.2015.06.001

Stahel, W.R. (2010). *The Performance Economy* (2nd ed.). Palgrave Macmillan, London. https://doi.org/10.1057/9780230274907

Stojkoska, B. L. R., & Trivodaliev, K. V. (2017). A review of Internet of Things for smart home: Challenges and solutions. *Journal of Cleaner Production, 140*, 1454-1464. https://doi.org/10.1016/j.jclepro.2016.10.006

Storbacka, K., Brodie, R. J., Böhmann, T., Maglio, P. P., & Nenonen, S. (2016). Actor engagement as a microfoundation for value co-creation. *Journal of Business Research, 69*(8), 3008-3017. https://doi.org/10.1016/j.jbusres.2016.02.034

Storbacka, K., Frow, P., Nenonen, S. and Payne, A. (2012). Designing Business Models for Value Co-Creation. In S.L. Vargo and R.F. Lusch (Ed.), *Special Issue – Toward a Better Understanding of the Role of Value in Markets and Marketing* (Review of Marketing Research, Vol. 9), 51-78. Emerald Group Publishing Limited, Bingley. https://doi.org/10.1108/S1548-6435(2012)0000009007

Sun, H. B., Mo, R., & Chang, Z. Y. (2009). Study on Product Service Oriented Enterprise Servitization Methods. In D. Guo, J. Wang, Z. Jia, R. Kang, H. Gao & X. Wang (Eds.), *Materials Science Forum, 626–627*, 747–752. https://doi.org/10.4028/www.scientific.net/msf.626-627.747

Sundin, E., Lindahl, M., & Ijomah, W. (2009). Product design for product/service systems: Design experiences from Swedish industry. *Journal of Manufacturing Technology Management, 20*(5), 723-753. https://doi.org/10.1108/17410380910961073

Sutanto, A., Yuliandra, B., Tjahjono, B., & Hadiguna, R. A. (2015). Product-service system design concept development based on product and service integration. *Journal of Design Research, 13*(1), 1-19. https://doi.org/10.1504/JDR.2015.067224

Sweeney, J. C., & Soutar, G. N. (2001). Consumer perceived value: The development of a multiple item scale. *Journal of Retailing, 77*(2), 203-220. https://doi.org/10.1016/S0022-4359(01)00041-0

Sztipanovits, J., Koutsoukos, X., Karsai, G., Kottenstette, N., Antsaklis, P., Gupta, V., Goodwine, B., Baras, J., & Wang, S. (2012). Toward a Science of Cyber–Physical System Integration [Paper presentation]. *Proceedings of the IEEE, 100*(1), 29-44. https://doi.org/10.1109/JPROC.2011.2161529

Tan, A. R., Matzen, D., McAloone, T. C., & Evans, S. (2010). Strategies for designing and developing services for manufacturing firms. *CIRP Journal of Manufacturing Science and Technology, 3*(2), 90-97. https://doi.org/10.1016/j.cirpj.2010.01.001

Tatnall, A. (2005). Actor-Network Theory in Information Systems Research. In M. Khosrow-Pour (Ed.), *Encyclopedia of Information Science and Technology*,42-46. IGI Global. https://doi.org/10.4018/978-1-59140-553-5.ch009

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal, 18*(7), 509-533. https://doi.org/10.1002/(SICI)1097-0266(199708)18:7<509::AID-SMJ882>3.0.CO;2-Z

Tellis, G. J., & Gaeth, G. J. (1990). Best Value, Price-Seeking, and Price Aversion: The Impact of Information and Learning on Consumer Choices. *Journal of Marketing, 54*(2), 34-45. https://doi.org/10.1177/002224299005400203

Terzi, S., Bouras, A., Dutta, D., Garetti, M., & Kiritsis, D. (2010). Product lifecycle management - from its history to its new role. *International Journal of Product Lifecycle Management, 4*(4), 360-389. https://doi.org/10.1504/IJPLM.2010.036489

Thomas, O., Walter, P., & Loos, P. (2008). Design and usage of an engineering methodology for product-service systems. *Journal of Design Research, 7*(2), 177-195. https://doi.org/10.1504/JDR.2008.020854

Thomke, S., & Von Hippel, E. (2002). Customers as Innovators: A New Way to Create Value. *Harvard Business Review, 80*(4), 74-81.

Tomiyama, T. (2001, December 11-15). *Service engineering to intensify service contents in product life cycles* [Paper presentation]. Proceedings of Second International Symposium on Environmentally Conscious Design and Inverse Manufacturing, Tokyo, Japan. https://doi.org/10.1109/ECODIM.2001.992433

Toro, C., Martirena, I. B., Martínez, C., Larrucea, X., Ayerbe, A., del Ser, J., Calvo, I., Etxeberria, I., González, P., Zulueta, E., Amundarain, A., Beriain, A., Solar, H., Illarramendi, M. & Etxeberria, L. (2015, November 26-27). *CPS for Product Service Systems – Architecture and preliminary application scenarios* [Paper presentation]. Virtual Concept International Workshop, San Sebastian, Spain.

Tran, T., & Park, J. Y. (2015). Development of a Strategic Prototyping Framework for Product Service Systems Using Co-creation Approach. *Procedia CIRP, 30*, 1-6. https://doi.org/10.1016/j.procir.2015.02.102

Tran, T., & Park, J. Y. (2016). Development of a novel set of criteria to select methodology for designing product service systems. *Journal of Computational Design and Engineering, 3*(2), 112-120. https://doi.org/10.1016/j.jcde.2015.10.001

Tran, T. A., & Park, J. Y. (2014). Development of integrated design methodology for various types of product — service systems. *Journal of Computational Design and Engineering, 1*(1), 37-47. https://doi.org/10.7315/JCDE.2014.004

Trevisan, L., & Brissaud, D. (2016). Engineering models to support product–service system integrated design. *CIRP Journal of Manufacturing Science and Technology, 15*, 3-18. https://doi.org/10.1016/j.cirpj.2016.02.004

Tseng, M. M., & Hu, S. J. (2014). Mass Customization. In *The International Academy for Production Engineering*, L. Laperrière, G. Reinhart (Eds.), *CIRP Encyclopedia of Production Engineering* (pp. 836-843). Springer. https://doi.org/10.1007/978-3-642-20617-7_16701

Tukker, A. (2004). Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. *Business Strategy and the Environment, 13*(4), 246-260. https://doi.org/10.1002/bse.414

Tukker, A. (2015). Product services for a resource-efficient and circular economy – a review. *Journal of Cleaner Production, 97*, 76-91. https://doi.org/10.1016/j.jclepro.2013.11.049

Tukker, A., & Tischner, U. (Eds.). (2006). *New Business for Old Europe: Product-Service Development, Competitiveness and Sustainability*. Greenleaf Publishing, Routledge.

Uden, L., & Francis, J. (2009). Actor-Network Theory for Service Innovation. *International Journal of Actor-Network Theory and Technological Innovation (IJANTTI), 1*(1), 23-44. https://doi.org/10.4018/jantti.2009010102

Uhlmann, E., Hohwieler, E., & Geisert, C. (2017). Intelligent production systems in the era of Industrie 4.0–changing mindsets and business models. *Journal of Machine Engineering, 17*(2), 5-24.

Vaishnavi, V.K. (2007). *Design Science Research Methods and Patterns: Innovating Information and Communication Technology* (1st ed.). Auerbach Publications. https://doi.org/10.1201/9781420059335

Valencia, A., Mugge, R., Schoormans, J. P., & Schifferstein, H. N. (2015). The Design of Smart Product-Service Systems (PSSs): An Exploration of Design Characteristics. *International Journal of Design, 9*(1), 13-28.

Valencia, A., Mugge, R., Schoormans, J. P., & Schifferstein, H. N. (2014, September 2-4). *Challenges in the design of smart product-service systems (PSSs): Experiences from practitioners* [Paper presentation]. Proceedings of the 19th DMI: Academic Design Management Conference. Design Management in an Era of Disruption, London, UK.

Van Halen, C., Vezzoli, C., & Wimmer, R. (2005). *Methodology for Product Service System Innovation: How to Develop Clean, Clever and Competitive Strategies in Companies*. Koninklijke Van Gorcum BV, The Netherlands.

Vandermerwe, S., & Rada, J. (1988). Servitization of business: Adding value by adding services. *European Management Journal, 6*(4), 314-324. https://doi.org/10.1016/0263-2373(88)90033-3

Vargo, S. L. (2009). Toward a transcending conceptualization of relationship: a service-dominant logic perspective. *Journal of Business & Industrial Marketing, 24*(5/6), 373-379. https://doi.org/10.1108/08858620910966255

Vargo, S. L., & Lusch, R. F. (2004). Evolving to a New Dominant Logic for Marketing. *Journal of Marketing, 68*(1), 1-17. https://doi.org/10.1509/jmkg.68.1.1.24036

Vargo, S. L., & Lusch, R. F. (2008a). From goods to service(s): Divergences and convergences of logics. *Industrial Marketing Management, 37*(3), 254-259. https://doi.org/10.1016/j.indmarman.2007.07.004

Vargo, S. L., & Lusch, R. F. (2008b). Service-dominant logic: continuing the evolution. *Journal of the Academy of Marketing Science, 36*, 1-10. https://doi.org/10.1007/s11747-007-0069-6

Vargo, S. L., & Lusch, R. F. (2011). A Service-Dominant Logic for Marketing. In P. Maclaran, M. Saren, B. Stern & M. Tadajewski (Eds.), *The Sage Handbook of Marketing Theory*, (pp. 219-234). SAGE Publications. https://doi.org/10.4135/9781446222454.n12

Vargo, S. L., & Lusch, R. F. (2010). From Repeat Patronage to Value Co-Creation in Service Ecosystems: A Transcending Conceptualization of Relationship. *Journal of Business Market Management, 4*, 169-179. https://doi.org/10.1007/s12087-010-0046-0

Vargo, S. L., & Lusch, R. F. (2016). Institutions and axioms: an extension and update of service-dominant logic. *Journal of the Academy of Marketing Science, 44*, 5-23. https://doi.org/10.1007/s11747-015-0456-3

Vargo, S. L., & Lusch, R. F. (2017). Service-dominant logic 2025. *International Journal of Research in Marketing, 34*(1), 46-67. https://doi.org/10.1016/j.ijresmar.2016.11.001

Vargo, S. L., Maglio, P. P., & Akaka, M. A. (2008). On value and value co-creation: A service systems and service logic perspective. *European Management Journal, 26*(3), 145-152. https://doi.org/10.1016/j.emj.2008.04.003

Vasantha, G. V. A., Roy, R., Lelah, A., & Brissaud, D. (2012). A review of product–service systems design methodologies. *Journal of Engineering Design, 23*(9), 635-659. https://doi.org/10.1080/09544828.2011.639712

Verleye, K. (2013). *Ready for a Co-Creative Economy? Implications of Customer Engagement in Value Creation for High-Contact and Technology-Based Service Interfaces* [Doctoral Dissertation, Vlerick Business School, Ghent University]. University Press. http://hdl.handle.net/20.500.12127/4719

Vezzoli, C., Kohtala, C., Srinivasan, A., Xin, L., Fusakul, M., Sateesh, D., & Diehl, J.C. (2017). *Product-Service System Design for Sustainability* . Routledge. https://doi.org/10.4324/9781351278003

Vijaykumar, A. V. G., Komoto, H., Hussain, R., Roy, R., Tomiyama, T., Evans, S., Tiwari, A., & Williams, S. (2013). A manufacturing framework for capability-based product-service systems design. *Journal of Remanufacturing, 3*, Article 8. https://doi.org/10.1186/2210-4690-3-8

Von Hippel, E. (1976). The dominant role of users in the scientific instrument innovation process. *Research Policy, 5*(3), 212-239. https://doi.org/10.1016/0048-7333(76)90028-7

Walker, D. H. T. and Lloyd-Walker, B. M. (2019). Characteristics of IPD: A Framework Overview. In Walker, D., & Rowlinson, S. (Eds.), *Routledge Handbook of Integrated Project Delivery*, pp. 20-40. Routledge, Abingdon, Oxon. https://doi.org/10.1201/9781315185774

Wallin, J., Parida, V., & Isaksson, O. (2015). Understanding product-service system innovation capabilities development for manufacturing companies. *Journal of Manufacturing Technology Management, 26*(5), 763-787. https://doi.org/10.1108/JMTM-05-2013-0055

Walls, J. G., Widmeyer, G. R., & El Sawy, O. A. (1992). Building an Information System Design Theory for Vigilant EIS. *Information Systems Research, 3*(1), 36-59. https://doi.org/10.1287/isre.3.1.36

Walsham, G. (1997). Actor-Network Theory and IS Research: Current Status and Future Prospects. In A.S. Lee, J. Liebenau & J.I. DeGross (Eds.), *Information Systems and Qualitative Research. IFIP — The International Federation for Information Processing*. Springer, Boston. https://doi.org/10.1007/978-0-387-35309-8_23

Wan, J., Chen, M., Xia, F., Di, L., & Zhou, K. (2013). From machine-to-machine communications towards cyber-physical systems. *Computer Science and Information Systems, 10*(3), 1105-1128. https://doi.org/10.2298/CSIS120326018W

Wan, J., Zhang, D., Zhao, S., Yang, L., & Lloret, J. (2014). Context-aware vehicular cyber-physical systems with cloud support: architecture, challenges, and solutions. *IEEE Communications Magazine, 52*(8), 106-113. https://doi.org/10.1109/MCOM.2014.6871677

Wang, J., Abid, H., Lee, S., Shu, L., & Xia, F. (2011). A Secured Health Care Application Architecture for Cyber-Physical Systems. *Control Engineering and Applied Informatics, 13*(3),101-108.

Wang, L., Törngren, M., & Onori, M. (2015). Current status and advancement of cyber-physical systems in manufacturing. *Journal of Manufacturing Systems, 37*(Part 2), 517-527. https://doi.org/10.1016/j.jmsy.2015.04.008

Wang, P., Xiang, Y., & Zhang, S. H. (2012, September 9-11). *Cyber-Physical System Components Composition Analysis and Formal Verification Based on Service-Oriented*

Architecture [Paper presentation]. 2012 IEEE Ninth International Conference on e-Business Engineering, Hangzhou, China. https://doi.org/10.1109/ICEBE.2012.60

Wang, P. P., Ming, X. G., Li, D., Kong, F. B., Wang, L., & Wu, Z. Y. (2011). Modular Development of Product Service Systems. *Concurrent Engineering, 19*(1), 85-96. https://doi.org/10.1177/1063293X11403508

Wang, Y., Liu, M., Zheng, P., Yang, H., & Zou, J. (2020). A smart surface inspection system using faster R-CNN in cloud-edge computing environment. *Advanced Engineering Informatics, 43*, 101037. https://doi.org/10.1016/j.aei.2020.101037

Wang, Z., Chen, C.-H., Zheng, P., Li, X., & Khoo, L. P. (2019). A novel data-driven graph-based requirement elicitation framework in the smart product-service system context. *Advanced Engineering Informatics, 42*, 100983. https://doi.org/10.1016/j.aei.2019.100983

Webster, J., & Watson, R. T. (2002). Analyzing the Past to Prepare for the Future: Writing a Literature Review. *MIS Quarterly*, *26*(2), xiii-xxiii. http://www.jstor.org/stable/4132319

Wickramasinghe, N., Tatnall, A., & Bali, R. K. (2010). Using Actor-Network Theory to Facilitate a Superior Understanding of Knowledge Creation and Knowledge Transfer. *International Journal of Actor-Network Theory and Technological Innovation, 2*(4), 30-42. https://doi.org/10.4018/jantti.2010100104

Wieland, H., Koskela-Huotari, K. & Vargo, S.L. (2016). Extending actor participation in value creation: an institutional view. *Journal of Strategic Marketing, 24*(3-4), 210-226. http://dx.doi.org/10.1080/0965254X.2015.1095225

Wiesner, S., Freitag, M., Westphal, I., & Thoben, K.-D. (2015). Interactions between Service and Product Lifecycle Management. *Procedia CIRP, 30*, 36-41. https://doi.org/10.1016/j.procir.2015.02.018

Wiesner, S., Hauge, J. B., Haase, F., & Thoben, K.-D. (2016). Supporting the Requirements Elicitation Process for Cyber-Physical Product-Service Systems Through a Gamified Approach. In I. Nääs et al. (Eds.), *Advances in Production Management Systems. Initiatives for a Sustainable World: APMS 2016. IFIP Advances in Information and Communication Technology, 488* (pp. 687-694). Springer. https://doi.org/10.1007/978-3-319-51133-7_81

Wiesner, S., Hauge, J. B., Sonntag, P., & Thoben, K.-D. (2019). Applicability of Agile Methods for Dynamic Requirements in Smart PSS Development. In F. Ameri, K. Stecke, G. von Cieminski & D. Kiritsis (Eds.), *Advances in Production Management Systems. Production Management for the Factory of the Future: APMS 2019. IFIP Advances in Information and Communication Technology, 566* (pp. 666-673). Springer. https://doi.org/10.1007/978-3-030-30000-5_81

Wiesner, S., Marilungo, E., & Thoben, K.-D. (2017). Cyber-Physical Product-Service Systems – Challenges for Requirements Engineering. *International Journal of Automation Technology, 11*(1), 17-28. https://doi.org/10.20965/ijat.2017.p0017

Wind, J., & Rangaswamy, A. (2001). Customerization: The next revolution in mass customization. *Journal of Interactive Marketing, 15*(1), 13-32. https://doi.org/10.1002/1520-6653(200124)15:1<13::AID-DIR1001>3.0.CO;2-%23

Woodruff, R. B. (1997). Customer value: The next source for competitive advantage. *Journal of the Academy of Marketing Science, 25*, 139-153. https://doi.org/10.1007/BF02894350

Xiong, G., Zhu, F., Liu, X., Dong, X., Huang, W., Chen, S., & Zhao, K. (2015). Cyber-physical-social system in intelligent transportation. *IEEE/CAA Journal of Automatica Sinica, 2*(3), 320-333. https://doi.org/10.1109/JAS.2015.7152667

Xu, Z., Ming, X., Song, W., Li, M., He, L., & Li, X. (2014). Towards a new framework: Understanding and managing the supply chain for product-service systems. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 228*(12), 1642-1652. https://doi.org/10.1177/0954405414521189

Yang, C.-L., Chuang, S.-P., & Huang, R.-H. (2009). Manufacturing evaluation system based on AHP/ANP approach for wafer fabricating industry. *Expert Systems with Applications, 36*(8), 11369-11377. https://doi.org/10.1016/j.eswa.2009.03.023

Yang, X., Moore, P., Pu, J.-S., & Wong, C.-B. (2009). A practical methodology for realizing product service systems for consumer products. *Computers & Industrial Engineering, 56*(1), 224-235. https://doi.org/10.1016/j.cie.2008.05.008

Yi, Y., & Gong, T. (2013). Customer value co-creation behavior: Scale development and validation. *Journal of Business Research, 66*(9), 1279-1284. https://doi.org/10.1016/j.jbusres.2012.02.026

Yin, R. K. (2009). How to do Better Case Studies: (With Illustrations from 20 Exemplary Case Studies). In L. Bickman & D.J. Rog (Eds.), *The SAGE handbook of applied social research methods* (2nd ed., pp. 254-282). SAGE Publications.

Yin, R.K. (2003). *Case Study Research: Design and Methods* (3rd ed.). SAGE Publications

Yin, R. K. (2014). *Case Study Research Design and Methods* (5th ed.). SAGE Publications.

Yin, R. K. (2015). *Qualitative Research from Start to Finish* (2nd ed.). Guilford Publications.

Yin, R. K. (2017). *Case Study Research and Applications: Design and Methods* (6th ed.). SAGE Publications.

Yip, M. H., Phaal, R., & Probert, D. R. (2013, February 8-10). *Value co-creation in early stage new product-service system development* [Paper presentation]. In P. J. Tossavainen, M. Harjula & S. Holmlid (Eds.) Proceedings of 3rd Service Design and Service Innovation conference, ServDes.2012, Espoo, Finland. Linköping Electronic Conference Proceedings, 67. Linköping, Sweden: Linköping University Electronic Press. https://www.repository.cam.ac.uk/handle/1810/248556

Yip, M. H., Phaal, R., & Probert, D. R. (2015). Characterising product-service systems in the healthcare industry. *Technology in Society, 43*, 129-143. https://doi.org/10.1016/j.techsoc.2015.05.014

Yip, M. H., Rizvi, M. A. K., & Chew, E. (2019, August 25-29). *Managing Value Co-Creation: An Integrated Design Framework for Service-Centric Product-Service Systems* [Paper presentation]. 2019 Portland International Conference on Management of Engineering and Technology (PICMET) - Technology Management in the World of Intelligent Systems, Portland, OR, USA. https://doi.org/10.23919/PICMET.2019.8893876

Yoon, B., Kim, S., & Rhee, J. (2012). An evaluation method for designing a new product-service system. *Expert Systems with Applications, 39*(3), 3100-3108. https://doi.org/10.1016/j.eswa.2011.08.173

Yu, C., Jing, S., & Li, X. (2012, August 11-13). *An Architecture of Cyber Physical System Based on Service* [Paper presentation]. 2012 International Conference on Computer Science and Service System, Nanjing, China. https://doi.org/10.1109/CSSS.2012.355

Zeng, J., Yang, L. T., & Ma, J. (2016). A System-Level Modeling and Design for Cyber-Physical-Social Systems. *ACM Transactions on Embedded Computing Systems (TECS), 15*(2), Article 35. https://doi.org/10.1145/2834119

Zhang, D., Hu, D., Xu, Y., & Zhang, H. (2012). A framework for design knowledge management and reuse for Product-Service Systems in construction machinery industry. *Computers in Industry, 63*(4), 328-337. https://doi.org/10.1016/j.compind.2012.02.008

Zhang, K., Wan, M., Qu, T., Jiang, H., Li, P., Chen, Z., Xiang, J., He, X., Li, C., & Huang, G. Q. (2019). Production service system enabled by cloud-based smart resource hierarchy for a highly dynamic synchronized production process. *Advanced Engineering Informatics, 42*, 100995. https://doi.org/10.1016/j.aei.2019.100995

Zhang, L.-J., Zhang, J., & Cai, H. (2007). Service-oriented architecture. In *Services Computing* (pp. 89-113). Springer. https://doi.org/10.1007/978-3-540-38284-3_5

Zhang, P., Nie, Z., Dong, Y., Zhang, Z., Yu, F., & Tan, R. (2020). Smart concept design based on recessive inheritance in complex electromechanical system. *Advanced Engineering Informatics, 43*, 101010. https://doi.org/10.1016/j.aei.2019.101010

Zhang, X., & Chen, R. (2008). Examining the mechanism of the value co-creation with customers. *International Journal of Production Economics, 116*(2), 242-250. https://doi.org/10.1016/j.ijpe.2008.09.004

Zhang, Z., & Chu, X. (2010). A new approach for conceptual design of product and maintenance. *International Journal of Computer Integrated Manufacturing, 23*(7), 603-618. https://doi.org/10.1080/09511921003736766

Zheng, C., Le Duigou, J., Hehenberger, P., Bricogne, M., & Eynard, B. (2016, May 16-19). *Multidisciplinary Integration During Conceptual Design Process: A Survey on Design Methods of Cyber-Physical Systems* [Paper presentation]. In D. Marjanović, M. Štorga, N. Pavković, N. Bojčetić & S. Škec (Eds.), DS 84: Proceedings of the DESIGN 2016 14th International Design Conference (pp. 1625-1634), Dubrovnik, Croatia.

Zheng, M., Song, W., & Ming, X. (2016). A Framework for Integrating Industrial Product-Service Systems and Cyber-Physical Systems. In Rau P.-L.P. (Ed.), *Cross-Cultural Design: CCD 2016. Lecture Notes in Computer Science, 9741*, pp. 628-637. Springer. https://doi.org/10.1007/978-3-319-40093-8_62

Zheng, P., Xu, X., Trappey, A., & Zhong, R. Y. (2020). Editorial Notes: Design innovation of Smart PSS. *Advanced Engineering Informatics, 44*, 101069. https://doi.org/10.1016/j.aei.2020.101069

Zhu, H., Gao, J., & Cai, Q. (2015). A product-service system using requirement analysis and knowledge management technologies. *Kybernetes, 44*(5), 823-842. https://doi.org/10.1108/K-11-2014-0244

Zhu, Q., Jiang, P., Huang, G., & Qu, T. (2011). Implementing an industrial product-service system for CNC machine tool. *The International Journal of Advanced Manufacturing Technology, 52*, 1133-1147. https://doi.org/10.1007/s00170-010-2761-9

Zine, P. U., Kulkarni, M. S., Chawla, R., & Ray, A. K. (2014). A Framework for Value Co-creation through Customization and Personalization in the Context of Machine Tool PSS. *Procedia CIRP, 16*, 32-37. https://doi.org/10.1016/j.procir.2014.01.005

Glossary

1. *Actor*: Taking inspiration from the concepts of ANT and SDL, the actor is defined as something or someone that is directly or indirectly involved in exchange relationships and influences other actors towards value co-creation. The actor consists of humans, machines/technologies and their combinations (Storbacka et al., 2016).
2. *Beneficiary (Customer):* The beneficiary is the recipient of the benefits of the service in response to demands or problems. According to SDL, the beneficiary determines the value in use. In a PSS, the beneficiary is the customer, who is looking to enhance his or her output by combining resources with the service provided by the provider. According to ANT, the customer/beneficiary is not a single actor, but a network of actors (i.e. the customer and their ecosystem of partners and potentially other suppliers) that directly or indirectly find value in the service provided.
3. *Co-creation*: Co-creation is the activity of joint creation of an entity by the customer, provider and possibly other stakeholders in a PSS (Prahalad & Ramaswamy, 2004b). The co-creation process may involve joint problem definition, problem-solving, offering construction of services, creation of experiences and benefits. Here, the provider does not develop the solution autonomously but engages the customer and considers its perspective during the design and implementation. This process helps ensure higher customer satisfaction. firm is not trying to please the customer but involve the customer in every possible step of the solution. As Frow et al. (2015) suggest, the co-creation framework consists of six dimensions: co-creation motive, co-creation form, engaging actors, engagement platform, level of engagement and duration of participation.

4. *Communication Network:* The entity that connects the cyber and physical using the mobile network (Wang et al., 2012), converters (Gunes et al., 2014b) and wireless sensor/actuator network (Cheng et al., 2016) to facilitate communication and feedback. However, the internet may not necessarily be part of it (Wang et al., 2015).
5. *Customer-centric*: This refers to a system where the customers are at the heart of the providers' marketing efforts and strategies and helps to satisfy the needs, wants and resources of individual customers rather than those of mass markets.
6. *Cyber system*: This is a system that combines computation resources (Cardenas et al., 2008; Gunes et al., 2014b), control algorithms (Cheng et al., 2016), data storage (Sanislav & Miclea, 2012), networks (Wang et al., 2015) and decision-making capabilities (Horvath & Gerritsen, 2012) to create the virtual world of a multitude of interconnected actors and stakeholders. It is an essential part of the CPS and uses sensors to obtain information and actuators to execute control actions.
7. *Cyber-physical product-service system (CPPSS):* A product-service system equipped with cyber-physical capabilities to enable value co-creation using its technology and intelligence to deliver greater efficiency, usability and appeal.
8. *Cyber-physical system (CPS)*: A system formed by the integration of computation with physical processes, whose behaviour is dependent on both the cyber and physical parts of the system (Lee & Seshia, 2017, p. 1).
9. *Enrolment:* The ANT translation stage that involves recruiting suitable and interested actors in the problem-solving process. The beneficiary/customer succeeds in convincing all other actors/stakeholders to accept the problem definition put forth by it and allocates the roles to be performed by each of them.
10. *Follower:* The actor who follows the initiator's definition of the problem and works towards co-creating the solution.

11. *Initiator:* The actor who observes a problem in the actor network (or system) and initiates the CPPSS solution design process.
12. *Interessement:* The ANT translation stage that involves propagating the information about the identified problem to other concerned actors. The beneficiary/customer executes various strategies to convince other actors to accept its definition of the problem and work towards solving it.
13. *Method*: In accordance with DSRM, '*method*' is a set of steps used to perform a task based on the underlying constructs/entities and their models/relationships (March & Smith, 1995).
14. *Mobilisation*: The ANT translation stage that involves establishing the actor network and actuating the solution. The beneficiary/customer ensures that all actors/stakeholders are engaged in fulfilling the agreed roles, practices and relationships in the system.
15. *Offering*: The total value or the benefits offered by the provider to the customer in form of a product-service system or a cyber-physical product-service system solution.
16. *Physical system*: The system consisting of the natural entities, sensors and actuators that relate to the real world (Lee & Seshia, 2017). Natural entities include temperature, light intensity, motion, energy, heartbeat, size, weight etc. Sensors are deployed to measure these variables and transmit the information to the central system. The actuators follow the central system to make necessary changes to maintain the stability of the system performance.
17. *Problematisation*: The ANT translation stage that involves identifying a problem in the service ecosystem by at least one actor. The beneficiary/customer defines the problem and aligns the stakeholder's interests so as to develop the required solution.

18. *Product*: The product is the physical and tangible gadget that functionalises the service that solves the customer problem.
19. *Product-service system (PSS)*: A socio-technical system consisting a network of actors who integrate their resources in terms of product and service offering to co-create value-in-use for mutual benefit aligned with the customer needs while improving the socio-economic and environmental impact on all actors throughout its lifecycle.
20. *Provider:* The actor that dedicates its resources towards the provision of service to the beneficiary. The primary resource is the product that functionalises the service. Other resources are the provider's knowledge, information and skills used to perform the service. The provider is also a network of actors that includes manufacturers, service providers, suppliers and other stakeholders.
21. *Reference Model*: It is an abstract framework of the relationships among the actors in an environment (MacKenzie et al., 2006). It's a conceptual model that represents an industry problem and captures the domain knowledge (Cherdantseva & Hilton, 2013). The framework explains the artifacts, their attributes and relationships in the network (Gunter et al., 2000).
22. *Service:* Following SDL, the application of the resources and skills of one actor for the benefit of the other.
23. *Service-oriented*: The ability to anticipate, recognise and deliver the needs of other actors in a system. It involves proactively engaging in service-giving practices, processes and procedures to create superior value, customer satisfaction, competitive advantage, growth, and profitability.
24. *Value co-creation:* The joint creation of value. The value, which can be value-in-exchange, value-in-use or value-in-context, is jointly created by the participation and collaboration of concerned actors.

25. *Value*: The result of an activity that is executed as a combination of the product and service functionalities. Value is the term used to denote the gains received by an entity in exchange for certain costs in a given context. According to SDL, value can be value-in-exchange, value-in-use and value-in-context (Lusch & Vargo, 2006a). The value captured as the price at the point of exchange between actors is the value-in-exchange. The value-in-use is when the value is captured during the consumption (in use) process by the user. The value-in-context is where the value is captured in use based on the context of the exchange, service and resources from the perspective of each user actor in the system (Chandler & Vargo, 2011).

Appendix

I. Terminology

- *Actor*: The entity that is directly or indirectly involved in exchange relationships and influences other entities towards value co-creation. The actor consists of humans, machines/technologies and their combinations (Storbacka et al., 2016).
- *Artefact*: It is something that is created by humans for a practical or valuable purpose (Geerts, 2011). Artefacts can be physical (e.g., consumer products and vehicles) or virtual (e.g., value-added services and music streaming) materials that are created to provide beneficial functionality to humans (Herterich & Mikusz, 2016). In this thesis, the artefact is the reference model for cyber-physical product-service system design method that can be implemented by operators, designers and mangers of CPPSS to design the solution.
- *Co-creation:* The activity of joint creation of an entity by the customer, provider and possibly other stakeholders in a product-service system (PSS) (Prahalad & Ramaswamy, 2004b).
- *Customer*: The customer or beneficiary is the recipient of the benefits of the service in response to their demands or problems.
- *Cyber-physical product-service system (CPPSS)*: A product-service system equipped with cyber-physical capabilities to enable value co-creation by using its technology and intelligence to yield higher efficiency, usability and appeal.
- *Cyber-physical system (CPS):* An integration of computation with physical processes whose behaviour is defined by both cyber and physical parts of the system' (Lee & Seshia 2017, p. 1).

- *Cyber system*: A system that combines computation resources (Cardenas et al., 2008; Gunes et al., 2014), control algorithm (Cheng et al., 2016), data storage (Sanislav & Miclea, 2012), network (Wang et al., 2015) and decision-making capabilities (Horvath & Gerritsen, 2012) to create the virtual structure of a multitude of interconnected actors and stakeholders.
- *Enrolment:* The third of the four actor-network theory translation stages. It involves the *initiator* recruiting suitable and interested actors in the design process to form a solid actor network consisting of old and new actors (Callon, 1986; Bengtsson & Lundström, 2013; Andrade & Urquhart, 2010).
- *Follower:* The actor who follows the initiator's definition of the problem and works towards co-creating the solution.
- *Initiator:* The actor who observes a problem in the actor network (or system) and initiates the CPPSS solution design process.
- *Interessement:* The second of the four actor-network theory translation stages. It involves the *initiator* propagating the information about the identified problem to other actors and convincing them that the initiator's interests align with their own (Callon, 1986; Bengtsson & Lundström, 2013; Andrade & Urquhart, 2010).
- *Mobilisation:* The last of the four actor-network theory translation stages. It involves the *initiator* establishing the actor network and actuating the solution by ensuring that all actors are engaged in fulfilling their agreed roles in the network (Callon, 1986; Bengtsson & Lundström, 2013; Andrade & Urquhart, 2010).
- *Offering*: The total value or the benefits offered by the provider to the customer in the form of a product-service system or a cyber-physical product-service system solution.
- *Physical system*: The system consisting of the natural entities, sensors and actuators that relate to the real world (Lee & Seshia, 2017). These include such factors as temperature, light intensity, motion, energy, heartbeat, size and weight.

- *Problematisation*: The first of the four actor-network theory translation stages. It involves the *initiator* identifying a problem in the existing actor network (or system), defining the problem and aligning all the other actors' interests to develop the required solution (Callon, 1986; Bengtsson & Lundström, 2013; Andrade & Urquhart, 2010).
- *Product*: The physical and tangible tool or device that functionalises the service that then solves the customer's problem.
- *Product-service system (PSS)*: A socio-technical system, consisting of a network of actors who integrate their resources in terms of product and service to co-create value-in-use for mutual benefit aligned with customer needs, while improving the socio-economic and environmental impact on all actors throughout its lifecycle.
- *Provider*: The actor that dedicates its resources towards the provision of service to the beneficiary. The provider is also the network of actors that contain manufacturers, service providers, and suppliers.
- *Reference Model*: It is an abstract framework of the relationships among the actors in an environment (Gunter et al., 2000; MacKenzie et al., 2006). It's a conceptual model that represents an industry problem and captures the domain knowledge (Cherdantseva & Hilton, 2013). In this thesis, the reference model provides the actors, their roles, responsibilities and design steps towards developing a CPPSS.
- *Service*: The application of the resources and skills of one actor for the benefit of the other. The service is facilitated by physical tools that enable that service to solve the customer's problem.
- *Service-oriented:* The ability to anticipate, recognise and deliver the needs of other actors in a system. It involves proactively engaging in service-giving practices, processes and procedures to create superior value, customer satisfaction, competitive advantage, growth and profitability.

- *Servitisation*: A phenomenon where services are bundled together with goods to create a holistic solution to customer problems and gain a competitive edge (Vandermerwe & Rada, 1988).
- *Smart*: Technologies that include a combination of sensors, microprocessors and actuators to enable the collecting, processing, storing, and communicating information.
- *Value*: The result of the activity that is executed as a combination of the product and service functionalities. Value is the term used to denote the gains received by an entity in exchange for a specific cost in each context.
- *Value co-creation*: The joint creation of value by the concerned stakeholders in a system. This value can be value-in-exchange, value-in-use or value-in-context.
- *Value-in-use*: Value generated during the use or consumption process of the solution jointly created by multiple actors, involving providers and beneficiaries.

II. Keywords for SLR

Table 52: Keywords used for the three topics - PSS, CPS and CPPSS

Topic	Keywords	
Product-service system	• Product service system • product service • full service • service package • integrated solution	• functional sales • PSS • Servitisation • Productisation
Cyber-physical system	• Cyber physical system • CPS • Internet of things	• IoT • Cyber-physical • Smart system
Cyber-physical product-service system	• Cyber physical product service system • Smart product service system • Intelligent product service system • Cyber product service system	• Smart PSS • Cyber physical system AND Product service system • CPPSS • CPSS

III. Articles on PSS Design

Table 53: Articles on PSS Design

	Methodology	Article	Business Model	Perspective	Application	PSS Stage	Research Method
	Scopus sourced articles						
1	Service CAD and Lifecycle	Komoto and Tomiyama, 2008	Product	Upgradation	Computer Embedded products	End-of-Life	Theoretical
2	Service CAD	Sakao et al., 2009	Use	Service modelling	Washing Service	Relationships	Theoretical
3	Service CAD and Blueprinting	Hara et al., 2009	Use	Customer Value, Stakeholder collaboration	Elevator posters	Service Implementation	Theoretical
4	Service CAD	Akasaka et al., 2012	Use	Knowledge	Coffee-shop, Accommodation Service	Design (Using knowledge base)	Example
5	Service Engineering, Service CAD, DEVS	Pezzotta et al., 2015	General	Customer value, Internal performance	Truck Company (Repair)	BOL and MOL	Case Study, Action research
6	Modelling (Framework), Service CAD	Nemoto et al., 2015	General	Design knowledge management	Agriculture	Idea generation (Conceptual design)	Example
7	Lifecycle	Manzini and Vezzoli, 2003	All	Resource optimisation	Textile flooring, Lubricant supply, Detergent supply & Solar heat	Stakeholders reconfiguration	Case Study

8	Lifecycle	Aurich et al., 2006	Product	Process modularisation	Investment goods industry	Technical service design	Case Study
9	Lifecycle	Yang et al., 2009	Product and Use	Smart product	Consumer products (PS2)	Service Delivery	Field Trial
10	Lifecycle	Schweitzer and Aurich, 2010	All	Continuous improvement (Kaizen), performance measurement	Agricultural machines	Feedback and updatation	Case study
11	Lifecycle	Zhang et al., 2012	Product	Knowledge Management	Construction machinery industry (Large Crane)	PSS reuse and improvement	Case Study and Interview
12	Lifecycle	Garetti et al., 2012	All	Modularity, behaviour, cost and socio-environmental impacts	NA	Simulation	Theoretical
13	Lifecycle	Tran and Park, 2014	All	Stakeholder involvement	Pay & download, social service	Beginning of Life	Example
14	Lifecycle	Peruzzini and Germani, 2014	Product	Design for Sustainability, Concurrent engineering	Hot water as a service	Sustainability assessment	Industrial case study
15	Lifecycle (product)	Igba et al., 2015	General	In service Knowledge and Information Management (KIM)	Gearbox	Feedback and Reuse	Case Study, action research
16	Modelling (waterfall)	Sundin et al., 2009	Product	Remanufacturing (product design)	Forklifts, soil compactor and household electronics.	End of Life	Interview and Lab Analysis

17	Modelling (Conceptual)	Becker et al., 2009	NA	Reference models and modelling languages	Logistics	Design and deliver value bundle	Case study, workshop, interview
18	Modelling (IDEF0)	Kimita and Shimomura, 2009	Result	Customer Satisfaction	Domestic in-flight services	Evaluation and Conceptual	Questionnaire Survey
19	Modelling	Baxter et al., 2009	NA	Knowledge management and reuse	Electro-mechanical products	Ontological knowledge framework	Case Study
20	Modelling (Meta)	Rexfelt and Ornas, 2009	All	User-centred design, consumer acceptance	B2C (car, TV shows, energy for heating system, clothing, broker, helping hand, recruitment,)	Requirement elicitation (consumer acceptance)	Focus group and individual interviews
21	Modelling (IDEF0, DFD)	Durugbo et al., 2011	All	Information flow	Selective laser melting	Value proposition	Case study
22	Modelling (Service Blueprint)	Geum and Park, 2011	Use	Product-service relationships (Line of X)	Car sharing and Water purifier	Division of area (Product, Service, Support)	Case Example
23	Modelling	Yoon et al., 2012	Use	Service innovation, customer-provider perspectives	Car sharing	Evaluation	Questionnaire survey (customer), Feasibility (provider)
24	Modelling (feedback loop)	Clayton et al., 2012	All	Input, output, feedback.	Railway sector	Design and Implementation	Case study, unstructured interview

25	Modelling (Line of visibility and interaction)	Hussain et al., 2012	General	System-in-use (instead of just product-in-use) data, capability	Maintenance (Aerospace, Naval, Land vehicle, and trains)	Feedback (for new conceptual design)	Case study (HVAC, laser and sensor trucks), Interview (maintenance)
26	Modelling (Statistical)	Geng and Chu, 2012	General/NA?	Customer satisfaction (importance-performance analysis)	Metering pump	Evaluation	Case Study
27	Modelling (waterfall and lifecycle)	Vasantha et al., 2013	General	Capability requirements, feedback	Laser system for cutting operations	Solution development	Case Study (interviews)
28	Modelling (framework)	Durugbo, 2014	General	Industrial value	Micro electro-mechanical system companies	IPS2 Co-design	Case study (Semi-structured interviews)
29	Modelling, Service blueprinting	Stacey and Tether, 2015	General	Emotions (creating positive emotional chain reactions)	Healthcare (Maggie - Cancer care PSS)	Service design/blueprinting	Case Study (interpretivist, semi-structured interviews)
30	Modelling (framework), QFD, ANP	Zhu, Gao and Cai, 2015	General	Ontology, Requirement Analysis and Knowledge management, (RdPSS)	Aerospace manufacturing (engine)	Solution selection	Case Study
31	Modelling (Waterfall, rating)	Sutanto et al., 2015	Product	Customer requirements rating	Mobile phones	Design requirements (identification and validation)	Case Study (Quantitative Questionnaire survey)

32	Modelling (3 phase methodological framework)	Liedtke et al., 2015	Result	Sustainability (Sustainable Living Labs)	Heater service	Insight, Prototyping, Field testing	Action and transdisciplinary
33	Modelling (QFD, fuzzy etc.)	Chen et al., 2015	Use, Product	Sustainability criteria, Uncertainties	Car rental, crane machine	Solution Evaluation	Case Study
34	Modelling (MEPSS)	Chou et al., 2015	Product	Value perception and sustainability impacts	Kitchen appliances manufacturer (Two scenarios)	Assessment (value and sustainability)	Questionnaire survey
35	Modelling (Maturity)	Pigosso and McAloone, 2016	General	Best practices (PSS design (30) and eco-design(62)), maturity	Not Applicable	Product-environment integration	Literature Review
36	Modelling, Visualisation	Santamaria et al., 2016	General	Cultural codes (cultural values, user's utilitarian and socio-psychological needs)	Not Applicable	Customer/user-specific sustainable design	Theoretical
37	Modelling (framework), IDEF0	Trevisan and Brissaud, 2016	Result	Multi-views (communication between product and service engineers)	Pneumatic energy delivery	Product-service design and integration	Case Study
38	Modelling (Relationship)	MacDonald et al., 2016	General	Value in use, solution quality (and their relationship)	Medical devices, printing, pharmaceuticals and building products	Solution Design	Interviews

39	Modelling (Modular), Service blueprint	Song and Sakao, 2017	Product	Customisation, sustainability	Elevator Manufacturing	PSS concept generation/selection	Case Study
40	Modelling, Visualization	Thomas et al., 2008	General	Customer requirements (determines the characteristics of product-service components)	Machine and plant construction (Heating, Air Conditioning and sanitary)	PSS development (BOL)	Case Study
41	Visualization and IDEF0	Morelli 2006	Use	Scenarios and Interaction	Bike and Car sharing	Actor interactions	Example
42	Visualization	Krucken and Meroni, 2006	Result	A platform for Communication materials/strategies	Food Solutions	Stakeholder Partnerships for new PSS	Case Study
43	Visualization	Evans et al., 2007	Result	Sustainability, Platform by producer	Catering Provider	Solution Co-creation	Case Study, Action Research
44	Visualization	Pawar et al., 2009	Result	Organisation	Aircraft engines and military aircrafts	Networking of firms	Grounded theory, Case study
45	Visualization (Scenario mapping)	Morelli, 2009	General	Service as value co-production (Active customer participation)	Meal Service	Implementation	Case Study
46	Visualization	Rese et al., 2009	General	Customer preference changes (nine drivers)	Insulin pump (example)	Evaluation	Theoretical
47	Visualization (3D)	Roy and Cheruvu, 2009	All	Competitiveness	Business to business	PSS framework	Literature review

48	Visualization	Tan et al., 2010	Product	DfX – Serviceability, Supportability and Service	Refrigeration and office furniture	Customer Activity/Experience	Case Study
49	Visualization (value), CAD (3D colour coded)	Bertoni et al., 2013	Product	Value contribution	Aerospace Industry (Engines)	Early design concept	Questionnaire survey
50	Visualization, AHP	Dewberry et al., 2013	Result	Relationships between people, resources and the environment. (demand side - supply side)	Housing Development in the UK (including home lifecycle)	PSS selection and evaluation	Project
51	Visualization	Sakao and Mizuyama, 2014	Product	PSS dimension (nine), micro-strategies (seven) and macro-strategies (five)	Drilling Equipment for the construction industry	Value cycle, Remanufacturing	Quantitative
52	Visualization (Multilevel Design method - Cyclic and Hierarchical)	Joore and Brezet, 2015	General	Innovation (Reflection, Analysis, Synthesis, Experience)	Sustainable transportation	Continuous Improvement (Societal, socio-technical, product-service, product-technology)	Case Example
53	Visualization	Wallin et al., 2015	Product	PSS innovation capabilities, customer interaction	Aerospace (engines)	PSS development (BOL)	Explorative and unstructured interviews
54	Visualization	Yip, Phaal and Probert, 2015		Contextual factors	Healthcare (3 cases – IT, fitness and psychology counselling)	PSS characterisation (for new PSS development)	Case Study (Action research)

55	TRIZ and QFD	Kim and Yoon, 2012	Use	PS contradictions and interference	Car Sharing, (Fortune 500)	Customer requirements and sub-services	Case study
56	TRIZ	Song and Sakao, 2016	Product	Linguistic judgements (scale), constraints	Elevator Service	Service/design conflict identification and resolution	Case Study
57	QFD, DEA	Geng et al., 2010	Product and Use	Rating engineering characteristics (derived from customer requirements)	Horizontal directional drilling	Customer and manufacturer requirements (PSS Planning)	Case Study, Questionnaire survey
58	QFD, FMEA	Zhang and Chu,2010	Product	Integrated product-service design, maintenance	Horizontal directional drilling machine	Conceptual Design	Case Study
59	QFD, DEA, Fuzzy logic	Geng et al., 2011	General	Engineering characteristics (derived from customer requirements)	Metering pump	Decision making (PSS planning)	Case Study, Questionnaire
60	QFD, Correlation	Sakao and Lindahl, 2012	General/NA	Customer value and budget	Investment machine manufacturer	Evaluation	Case study
61	QFD	Geng et al., 2012	General	Conversion of customer requirements to design requirements & module characteristics, knowledge/rule reuse and updating	Metering pump	Conceptual design	Case Study

62	QFD	Peruzzini et al., 2015	Product	Customer needs, PSS functionalities, Ecosystem requirements	White goods (household appliances), machine tools, textile industry	Requirements Elicitation for new PSSs	Case Study
63	QFD, AHP	Kim et al., 2015	General	Service-oriented/service-centric PSS (productization)	Telecom (Education services)	BOL (service provider and manufacturer partnership)	Case Study (interviews)
64	Modularization, QFD	Li et al., 2012	General	Product-service relationship	Electric power transformer	Module partition	Case Study
65	Modularization	Wang et al., 2011	General	A collaboration of service, functional and product modules	Civil aircraft manufacturer	Product-service modularization	Case Study
66	Service Engineering	Pezzotta et al., 2016	Product and Use	Decision-making process, service requirement tree	Automation Solutions (ABB)	PSS offering, service delivery process	Case Study
67	Service Engineering	Bertoni et al., 2016	General	Value-driven design	Aerospace (engines) and Road construction equipment	Value assessment (Decision making on design)	Case Study
68	G-DEVS/HLA	Alix and Zacharewicz, 2012	Product, Use	Service scenarios	Toy Industry	PSS phases and operational activities	Case Study
69	Kansei Engineering	Carreira et al., 2013		Customer Experience, multidisciplinary inter-	Bus Service	New PSS development	Design Science, Action research

				company design collaboration			
70	Ontology	Akmal et al., 2014	All	Solution similarities	General PSSs	Solution design	Case study
71	S-D logic	Liu et al., 2014	All	Sustainability	Examples of Aircraft engines (Rolls-Royce), the computer system (IBM). Platform (Yahoo, eBay)	Stakeholder relationships (flow of data, materials and value/money)	Literature Review
72	Scoring (Rating)	Tran and Park, 2016	All	Design approach (eight)	Education (Leasing of manuals, books and supporting services)	Design Methodology selection	Example
	Articles through citation analysis						
73	Lifecycle	Alonso-Rasgado et al., 2004	Product	Customer-supplier relationship, total care	Not Applicable	Define and design service systems	Theoretical
74	Lifecycle	Alonso-Rasgado and Thompson, 2006	Product	Hardware-service integration, fast design, total care	Not Applicable	Business solution and risk assessment	Theoretical
75	Visualization	Maussang et al., 2009	Result	Function-oriented description (Product specification for interaction between product and service).	Helium-based refrigeration	Implementation	Case Study
76	Modularization	Shikata et al., 2013	Product, Use	Product development, competitive advantage	Orthotics (product-oriented), electric care bed (use-oriented)	Performance improvement	Case Study (interviews, quantitative data

							from customers, manuals)
77	Requirements Engineering	Berkovich et al., 2014	All	Requirements (customers and other stakeholders, domain-specific, traceability, conflicts, validation)	Not Applicable	Requirements data model (at goal, system, feature, function and domain levels)	Case study (interviews with two experts)

IV. Articles on CPS Design

Table 54: Articles on CPS Design

	Article	Phase	Application	Contribution
1	(Lee et al., 2015)	I	Industry 4.0	5 level architecture – Smart connection, data-to-information conversion, cyber, cognition, configuration
2	(Bagheri et al., 2015)			
3	(Jin et al., 2014)	I	Smart city	Three domain infrastructure – Network, Cloud and Data
4	(Wan et al., 2014)	I	Park vehicles	Context-awareness logic
5	(Hu et al., 2013)	I	Crowdsensing	Two platform architecture - mobile and cloud (knowledge base)
6	(Dillon et al., 2011)	I	Web of things	Three-layer framework – Physical environment, cyber-physical interface and WoT (Device, Kernel, Overlay, Context and API)
7	(Lai et al., 2011)	I	Digital home	Three-layer architecture – Physical, Service and Application.
8	(Hu et al., 2016)	I	Healthcare	6 level framework – sensing, processing, modelling, decision fusion, human and actuator
9	(Xiong et al., 2015)	I	Social systems (Transport)	CP social system architecture – ACP, parallel control & management, application
10	(Liu et al., 2017)	I	Review	Three-layer architecture – physical, information and user.
11	(Wan et al., 2013)	I	UAV platform	Architecture – IoT (sensing, processing, application, access) and Decision-control (processing, decision-making, real-time control)
12	(Cao et al., 2013)	I	HVAC system	Optimizing errors, delays, constraints and capabilities in cyber (including user), physical and wireless network.
13	(Sampigethaya & Poovendran, 2013)	I	Aviation	Bridge (integration) and interaction between cyberspace and physical world using sensor, actuator and controller

14	(Leitão et al., 2016)	I	Manufacturing industry	Cloud-based service-oriented multi-agent system for real-time responsiveness, intelligence and adaptiveness in manufacturing
15	(J. Wang et al., 2011)	I	Healthcare	Three core system – Communication and sensing core, computation and security core, scheduling and resource management core.
16	(Sangiovanni-Vincentelli et al., 2012)	D	Aeroplane braking	V model – design and integration phases are parallel (merge contract-based and platform-based design)
17	(Sztipanovits et al., 2012)	D	UAV	3-layer design method – computation/communication, platform & physical
18	(Eyisi et al., 2013)	D	Control	
19	(Banerjee et al., 2012)	D	Body Area Network	Seven steps – model (requirements, parser, variants), compute (cyber-physical interactions, variation), requirements verification, results
20	(Hehenberger et al., 2016)	D	Production systems	Two phases design process – conceptual and system modelling. Three disciplines – physical, computation and integration
21	(Zeng et al., 2016)	D	CP social systems	4 step Design framework – functional specification, intermediate representation model, architecture platform and design solutions.
22	(Kumar et al., 2015)	D	UAV	3 stage framework for design and validation of systems – concept design, detailed design and recursive refinement.

I: Implementation Phase; D: Design Phase

V. Articles on CPPSS

Table 55: Articles on CPPSS

	Article	Perspective	Application	Contribution
1	(Wiesner et al., 2017b)	Requirements Engineering	Whitegoods, plastic extrusion	CPPSS consists of intelligent product that provides diverse services. It connects the customers, providers, suppliers, and other third parties
2	(Wiesner et al., 2016)		Video Surveillance	The game approach considers stakeholders, environments, innovative ideas and visualises the consequences of the defined requirements
3	(Kuhlenkötter, Wilkens, et al., 2017)	Value creation Lifecycle	Creation of research centre named ZESS	Different engineering perspectives for the design of smart PSS (systems, a system of system, PSS, smart object, product and service)
4	(Kuhlenkötter, Bender, et al., 2017)	Customer integration		Engineering lifecycle development, planning (manufacturing, product use, service provision, reconfiguration/end of life)
5	(Uhlmann et al., 2017)	Value creation	Manufacturing Industry	Onion architecture of CPS, IPS2 business model, lifecycle monitoring system structure, industry cockpit, modular factory control
6	(Marilungo et al., 2017)	CPS design for PSS	Plastic extrusion pipes	Five-step method – analyse scenario, map tangible & intangible assets, model ICT infrastructure, define a new process and analyse CPS benefit
7	(Scholze, Correia, & Stokic, 2016)	Context/scenario sensitivity	automation equipment	Two-platform product extension service – development (product) and deployment (services). Design method for PSS having CP features
8	(Scholze, Correia, Stokic, et al., 2016)	Feedback for new PSS	Machine industry	The collaborative development environment and context-sensitivity using stakeholders, supply chain and product network
9	(M. Zheng et al., 2016)	Intellectualization of industrial PSS	Manufacturing Industry	7-module PSS framework – customer need centred product lifecycle, stakeholders, service abilities, business model, CPS and resources. A 5-layer CPS supported intellectualised PSS – physical resource, virtual resource, management platform, service and interface.

10	(Valencia et al., 2015)	Value of Smart PSS & design	General	Seven characteristics of smart PSS – consumer empowerment, service individualisation, community feeling, service involvement, product ownership, individual/shared experience and continuous growth
11	(Herterich et al., 2015)	Service innovation	Manufacturing industry	It identified seven affordances for the service business and its impact on manufacturers, operators and service organisations.
12	(Mikusz, 2014)	Business-oriented CPS	Manufacturing industry	The conceptualisation of industrial software PSS with three perspectives – solution, value chain and software part.
13	(Mehrsai et al., 2014)	Lifecycle, cloud, flexibility.	Manufacturing Industry	Make-to-X grade and avatar concept for the manufacturing industry at product, manufacturing, service and user cycles. Discusses the interaction between the products, manufacturers and end-users.
14	(Lee & Kao, 2014b)	Innovation	Manufacturing Industry	Proposed the dominant innovation design approach for smart PSS using innovation matrix, application space map and QFD

VI. Definitions of PSS

Table 56: Definitions of PSS

		Citation	Definition	Infrastructure	Collaboration	Performance	System	Competition	Network	Customer	Environment	Economic	Social Aspect	Strategy	Value in use	Innovation	Sustainability	Business	Value	Solution	Lifecycle	Integration	Functionality	Offering
1	Frambach et al., (1997)	205	“The set of all potential additional services a supplier can supplement his product offering with, in order to differentiate his offering relative to the competitors’ as perceived by (potential) customers and distributors.”					x																x
2	Goedkoop et al. (1999)	1023	“A product-service-system is a system of products, services, networks of players and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models."				x	x	x	x	x													
3	Manzini et al. (2001)	24	“A business innovation strategy offering a marketable mix of products and services jointly capable of fulfilling clients' needs and/or wants - with higher added value and a smaller environmental impact as compared to an existing system or product."							x	x			x	x	x						x		x
4	Mont (2002)	1542	“A system of products, services, supporting networks and infrastructure that is designed to be: competitive, satisfy customer				x	x	x	x	x													

			needs and have a lower environmental impact than traditional business models."																					
5	Brandstotter et al. (2003)	69	“A product-service system consists of tangible products and intangible services, designed and combined so that they jointly are capable of fulfilling specific customer needs. It tries to reach the goals of a sustainable development, which means improved economic, environmental and social aspects.”							x	x	x	x				x					x		
6	Manzini and Vezzoli (2003)	592	"An innovation strategy, shifting the business focus from designing (and selling) physical products only, to designing (and selling) a system of products and services which are jointly capable of fulfilling specific client demands."				x			x						x								
7	Wong, (2004)	100	Product-service systems (PSS) may be defined as a solution offered for sale that involves both product and service elements, to deliver the required functionality																	x			x	x
8	Tukker, (2004)	1231	A system consisting of tangible products and intangible services designed and combined so that they jointly are capable of fulfilling specific customer needs							x												x		
9	Halme et al., (2006)	58	Product and services which can simultaneously fulfil people’s needs and considerably reduce the use of materials and energy							x	x													

10	Krucken., Meroni, (2006)	77	An advanced industrialised solution based on collaboration between social players, which gives rise to both effective and efficient, highly contextualised services.		x	x							x							x				
11	Morelli, (2006)	425	A social construction, based on "attraction forces" (such as goals, expected results and problem-solving criteria) which catalyse the participation of several partners. A PSS is a result of a value co-production process within such a partnership. Its effectiveness is based on a shared vision of possible and desirable scenarios.		x	x							x											
12	Tukker and Tischner, (2006)	635	"Product-service (PS): a value proposition that consists of a mix of tangible products and intangible service designed and combined so that they jointly are capable of fulfilling final customer needs." "Product-service system (PSS): the product-service including the (value) network, (technological) infrastructure and governance structure (or revenue model) that 'produces' a product-service."	x					x	x									x			x		
13	Baines et al., (2007)	1527	"PSS is an integrated product and service offering that delivers value in use. A PSS offers the opportunity to decouple economic success from material consumption and hence reduce the environmental impact of economic activity. The PSS logic is premised on utilizing the knowledge of the designer-			x					x	x			x							x		

			manufacturer to both increase value as output and decrease material and other costs as an input to a system."																					
14	Evans et al., (2007)	130	An attempt to use existing industrial and commercial structures to create radically environmentally improved products by treating them as services.		x						x													
15	Botta, (2007)	37	an ordered set of products and services developed and manufactured as a solution to the problem and can be a subset of a superior socio-technical system.				x						x							x		x		
16	Sakao et al., (2008)	29	"a functional solution that fulfils a defined customer need. The focus is, with reference to the customer value, to optimize the functional solution from a life-cycle perspective."			x				x									x	x	x			
17	Leimeister and Glauner, (2008)	120	The intelligent interlocking of physical products and services that are already in the design and development phase closely linked. Their individual components can be decoupled from each other, only with difficulty.																			x		
18	Azarenko et al., (2009)	74	Technical Product-Service System emphasises the physical product core enhanced and customised by a mainly non-physical service shell the investment character of all PSS components, the relatively greater importance of the physical core of PSS and the relation between PSS manufacturers and customers.		x																	x		

19	Neely, (2008)	868	A Product-Service System is an integrated product and service offering that delivers value in use												x							x		x
20	Muller et al., (2009)	68	“a concept that integrates products and services in one scope for planning, development and delivery, thus for the whole life-cycle.”																		x	x		
21	Jiang and Fu, (2009)	10	Industrial PSS can be defined as a systematic package in which intangible services are attached to tangible products to finish various industrial activities in the whole product lifecycle.																		x		x	
22	Meier et al., (2010)	702	An Industrial Product-Service System is characterised by the integrated and mutually determining planning, development, provision and use of product and service shares, including its immanent software components in Business-to-Business applications and represents a knowledge-intensive socio-technical system.										x									x		
23	Tan et al. (2010)	132	“PSS is in effect an approach to designing integrated products and services with a dual focus on both product lifecycle and customer activity considerations.”							x											x	x		
24	Schrödl and Turowski, (2011)	5	“Offerings that provide both tangible goods as well as services and intangible assets in an integrated manner.”																			x		x

25	Zhu et al., (2011)	32	“PSS is defined as a solution for optimal resource operations in the product life cycle by integrating tangible products with intangible services here."			x														x	x	x		
26	Cavalieri and Pezzotta, (2012)	19	"It (PSS) ensues from an innovative strategy shifting the business focus from the design and sales of physical products to the design and sales of a system consisting of products, services, supporting networks and infrastructures, which are jointly capable of fulfilling specific client demands."	x					x		x	x		x		x								
27	Park et al., (2012)	78	“Integrated product-service is any offering in which product and services are integrated, regardless of its type(s), objective(s) and feature(s)”																			x		x
28	Boehm and Thomas, (2013)	118	“A Product-Service System (PSS) is an integrated bundle of product and services which aims at creating customer utility and generating value.”							x					x							x		
29	Centenera and Hasan, (2014)	4	A product-service system (PSS) is an integrated combination of products and services for optimal consumption.			x																x		
30	McKay & Kundu, (2014)	6	A PSS is a system composed of a physical product and associated services that support the product through-life.				x														x	x		

31	Reim et al., (2015)	159	“PSS is defined as a marketable set of products and services that are capable of jointly fulfilling customers’ need in an economical and sustainable manner.”							x		x					x					x		
32	Tran and Park, (2016)	6	“PSS is defined as a marketable set of products and services capable of jointly fulfilling user’s need. The product/service ratio in this set can vary either in terms of function fulfilment or economic value.”							x		x										x	x	
33	Annarelli et al., (2016)	14	“PSS is a business model focused towards the provision of a marketable set of products and services, designed to be economically, socially and environmentally sustainable, with the final aim of fulfilling customer's needs."							x	x	x	x				x	x						
34	Qu et al., (2016)	29	“It’s core idea is to provide solutions to customers by integration of products and services, meeting customers’ requirements while reducing consumption and environmental impact at the same time.”			x				x	x									x		x		
35	Kuijken et al., (2017)	5	"PSS involve offerings that include one or more product functionality and one or more service functionality."																				x	x
	Total number of publications			2	4	7	5	3	4	15	10	6	6	2	4	3	3	1	2	6	6	21	4	7
	Total number of citations			654	706	2123	3200	2770	3219	5661	4435	1794	1324	43	2537	635	242	14	664	304	277	5062	121	1363

VII. Semi-Structured Interview

i. Ethics Approval

Mohd Ahsan Kabir Rizvi

From:	research.ethics@uts.edu.au
Sent:	Tuesday, 6 November 2018 11:48 AM
To:	Mohd Ahsan Kabir Rizvi; Eng Chew
Cc:	Ann-Marie Hopps; Ann Hobson; Bronwyn Clark-Coolee
Subject:	Your ethics application has been approved as low risk - ETH18-2445

Dear Applicant

Your local research office has reviewed your application titled, "Towards Cyber-Physical Product Service Systems Design", and agreed that this application now meets the requirements of the National Statement on Ethical Conduct in Human Research (2007) and has been approved on that basis. You are therefore authorised to commence activities as outlined in your application, subject to any conditions detailed in this document.

You are reminded that this letter constitutes ethics approval only. This research project must also be undertaken in accordance with all UTS policies and guidelines including the Research Management Policy (http://www.gsu.uts.edu.au/policies/research-management-policy.html).

Your approval number is UTS HREC REF NO. ETH18-2445.

Approval will be for a period of five (5) years from the date of this correspondence subject to the submission of annual progress reports.

The following standard conditions apply to your approval:

- Your approval number must be included in all participant material and advertisements. Any advertisements on Staff Connect without an approval number will be removed.

- The Principal Investigator will immediately report anything that might warrant review of ethical approval of the project to the Ethics Secretariat (Research.Ethics@uts.edu.au).

- The Principal Investigator will notify the UTS HREC of any event that requires a modification to the protocol or other project documents, and submit any required amendments prior to implementation. Instructions can be found at https://staff.uts.edu.au/topichub/Pages/Researching/Research%20Ethics%20and%20Integrity/Human%20research%20ethics/Post-approval/post-approval.aspx#tab2.

- The Principal Investigator will promptly report adverse events to the Ethics Secretariat (Research.Ethics@uts.edu.au). An adverse event is any event (anticipated or otherwise) that has a negative impact on participants, researchers or the reputation of the University. Adverse events can also include privacy breaches, loss of data and damage to property.

- The Principal Investigator will report to the UTS HREC annually and notify the HREC when the project is completed at all sites. The Principal Investigator will notify the UTS HREC of any plan to extend the duration of the project past the approval period listed above through the progress report.

- The Principal Investigator will obtain any additional approvals or authorisations as required (e.g. from other ethics committees, collaborating institutions, supporting organisations).

- The Principal Investigator will notify the UTS HREC of his or her inability to continue as Principal Investigator including the name of and contact information for a replacement.

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We also refer you to the AVCC guidelines relating to the storage of data, which require that data be kept for a minimum of 5 years after publication of research. However, in NSW, longer retention requirements are required for research on human subjects with potential long-term effects, research with long-term environmental effects, or research considered of national or international significance, importance, or controversy. If the data from this research project falls into one of these categories, contact University Records for advice on long-term retention.

You should consider this your official letter of approval.

If you have any queries about this approval, or require any amendments to your approval in future, please do not hesitate to contact your local research office or Research.Ethics@uts.edu.au.

REF: 12a

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ii. Invitation Letter

Invitation letter to Participating Organizations

Dear Sir/Madame,

This invitation is soliciting your and/or your firm's interest in participating in a research on **"designing service-oriented '*smart*[1]' products"** that I am conducting as part of my Doctoral study at the University of Technology Sydney (UTS) under the supervision of Prof. Eng Chew. Below is a brief explanation about this research and what your involvement would entail if you decide to proceed.

From an extensive literature review and using the theoretical lenses of the multi-disciplines of marketing, service and management sciences, I have developed *a new **theoretical** method of how to design* such service-oriented and *customer-centric* '*smart*' products and associated business models *to adapt with the evolving customer requirements*.

I am now seeking practitioners' participation, from *disparate industries*[2] operating in a business-to-business (B2B) context, to *evaluate* and modify/refine my design method to make it practical and useful for designer and product end-users alike. The target disparate organisations include logistic, automation, medical and construction solution providers.

The research will involve conducting semi-structured interviews with practitioners experienced in designing product and service solutions, to explicate their *practical design experiences*. The practitioners may include design engineer, managing director, general manager, marketing manager and chief people officer. The *experiences* of the practitioners will be kept *anonymous* and aggregated into *thematic practice-based design principles* to evaluate and to refine my above-mentioned theoretical design method.

Participation in this study is voluntary. The interviews of selected practitioners will last approximately one hour per informant at an agreed upon location. The interview questions will be related to the informants' practical design-related experiences. You may decline to answer any of the interview questions. Further, you may decide to withdraw from this study at any time. With your permission, the interview will be tape-recorded and later transcribed anonymously for analysis. Shortly after the interview, I will send you a copy of the transcript to confirm its accuracy and clarify any points that you wish. All information you provide will be treated with strict confidentiality and stored securely. Your name will not appear in any thesis or report resulting from this study, however, with your permission anonymous quotations may be used.

There are no known or anticipated risks to you as a participant in this study. As this study is expected to surface the differences in opinion among your organisation's team members, it may help them to improve their performance through resolution. Your design team may also benefit from the study's key outcome in the form of an integrated method for designing service-oriented 'smart' products.

I would like to assure you that this study has received ethics clearance by the UTS Research Ethics Review Board. I look forward to hearing from you and thank you in advance for your assistance in this project.

Sincerely,

Mohd Ahsan Kabir Rizvi
PhD Candidate, School of Built Environment, University of Technology Sydney

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[1] Smartness comes from leveraging a mixture of multiple technologies, such as social, mobility, analytics, cloud, and internet-of-things technologies
[2] Purposely sampled from disparate industries *to avoid involving competing organizations* from the same industry.

iii. Participant Information Sheet

UTS UNIVERSITY OF TECHNOLOGY SYDNEY

PARTICIPANT INFORMATION SHEET
DESIGNING CYBER-PHYSICAL PRODUCT SERVICE SYSTEMS
UTS HREC REF NO. ETH18-2445

WHO IS DOING THE RESEARCH?
My name is Mohd Ahsan Kabir Rizvi, and I am a doctoral candidate at UTS. My supervisors are Prof. Eng K Chew and Dr. Phillippa K Carnemolla, both from the School of Built Environment, UTS,

WHAT IS THIS RESEARCH ABOUT?
As customer demands are evolving, businesses have grown beyond products to become more and more dependent on service. Customers are more interested in the solutions, experiential outcomes and benefits rather than products alone. As a result, businesses are providing customer-specific solutions by servitizing their offerings and co-creating value with the customer at the centre of the strategy. Additionally, these solutions are expected to combine customer orientation with real-time sensing, data processing and decision-making capabilities from IoT to evolve into "smart" solutions. Thus, practitioners and researchers alike are seeking to answer the question: "How to design a service-oriented smart solution adaptable to customers' dynamic needs through customer value co-creation?"

WHY HAVE I BEEN ASKED?
You have been invited to participate in this study because you are involved in designing product and service solutions in your field of business

IF I SAY YES, WHAT WILL IT INVOLVE?
If you decide to participate, I will invite you to be interviewed in person or online according to your convenience. The interview is expected to last for about an hour.

The interview questions will be related to your practical design-related experiences and will be guided by my desire to understand their view on value co-creation in a smart solution environment.

With your permission, the interview will be tape-recorded and later transcribed anonymously for analysis. Shortly after the interview, I will send you a copy of the transcript to confirm its accuracy and clarify any points that you wish.

ARE THERE ANY RISKS/INCONVENIENCE?
Apart from some inconvenience caused by your time commitments, there are no known or anticipated risks to you as a participant in this study.

DO I HAVE TO SAY YES?
Participation in this study is voluntary. It is completely up to you whether or not you decide to take part.

WHAT WILL HAPPEN IF I SAY NO?
If you decide not to participate, it will not affect your relationship with the researchers or the University of Technology Sydney.

Once the study has started, you may decline to answer any of the interview questions. Furthermore, if you wish to withdraw from the study, you can do so at any time without having to give a reason, by contacting Mohd Ahsan Kabir Rizvi.

If you withdraw from the study, all your identifiable data will be destroyed. However, it may not be possible to withdraw your data from the study results if these have already had your identifying details removed.

CONFIDENTIALITY
By signing the consent form, you consent to the research team collecting and using information about your design experience for the research project. All this information will be treated confidentially and will be used

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solely for this research. Your name will not appear in any thesis or report resulting from this study, however, with your permission anonymous quotations may be used. Only the three nominated researchers mentioned above will have access to the material provided by participants in this study. Confidentiality will be preserved by using subject numbers for each participant while recording the data. We plan to publish the results in journals and conferences. However, in any publication, information will be provided in such a way that you cannot be identified.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?

If you have concerns about the research that you think my supervisor or I can help you with, please feel free to contact us on.

Investigator: Mohd Ahsan Kabir Rizvi
Email: mohdahsankabir.rizvi@student.uts.edu.au

Principal Investigator/Supervisor: Prof. Eng Chew
Email: eng.chew@uts.edu.au

Co-supervisor: Dr. Phillippa Carnemolla
Email: phillippa.carnemolla@uts.edu.au

You will be given a copy of this form to keep.

NOTE:
This study has been approved by the University of Technology Sydney Human Research Ethics Committee [UTS HREC]. If you have any concerns or complaints about any aspect of the conduct of this research, please contact the Ethics Secretariat on ph.: +61 2 9514 2478 or email: Research.Ethics@uts.edu.au] and quote the UTS HREC reference number. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

UNIVERSITY OF TECHNOLOGY SYDNEY

CONSENT FORM
DESIGNING CYBER-PHYSICAL PRODUCT SERVICE SYSTEMS
UTS HREC REF NO. ETH18-2445

I ____________________ agree to participate in the research project DESIGNING CYBER-PHYSICAL PRODUCT SERVICE SYSTEMS (UTS HREC REF NO. ETH18-2445) being conducted by Mohd Ahsan Kabir Rizvi, PhD Candidate, School of Built Environment, UTS, Phone: +61[redacted].

I have read the Participant Information Sheet, or someone has read it to me in a language that I understand.

I understand the purposes, procedures and risks of the research as described in the Participant Information Sheet.

I have had an opportunity to ask questions, and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time without affecting my relationship with the researchers or the University of Technology Sydney.

I understand that I will be given a signed copy of this document to keep.

I agree to be audio recorded.

I agree that the research data gathered from this project may be published in a form that does not identify me in any way.

I am aware that I can contact Mohd Ahsan Kabir Rizvi if I have any concerns about the research.

____ ____/____/____
Name and Signature [participant] Date

____ ____/____/____
Name and Signature [researcher or delegate] Date

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iv. Main Questions

a. Introduction

I am interested in finding a design method to support the design of smart solutions using product and service systems. For this purpose, I would like to know about your knowledge, experience, views and expectations from product and service design. I am also interested to know the customer involvement in the design and development of such smart systems. We will also talk about the overall process of value co-creation through the collaboration between various stakeholders of the smart system.

This interview will be semi-structured to give you maximum freedom and flexibility to express your views and ideas.

b. Introductory Questions

What's your position and duties in this organisation?

PROBES: design engineer? Customer relation? Manage a team? Propose design, obtain customer inputs, cover reliability, feasibility analysis.

You have been involved in designing CPPSS, how has it been??

PROBES: Challenges, accomplishments, innovation.

What do you like about your work?

PROBES: Challenging? Meet people? Understand customer demands and needs?

What have the main challenges for you and the company? How have you coped those challenges?

PROBES: Challenging? Meet people? Understand customer demands and needs?

c. Doman Based Questions

Table 57: Domain based Interview Questions

#	Domain	Questions and Probes
1	Perceived Value	• How did you manage to connect with the customers and understand their demands? • What does the term 'value' mean to you, your company and the customers? • What do you think is missing in the value perception among the stakeholders?
2	Value Co-creation (Co-design)	• How do you interact with other actors in the network? • How do you integrate the customers into the design and development process? • What are your views on the level of customer involvement in such processes?
3	Smart Product and Service Design	• What procedures do you follow in the design and development of the smart system? • What factors govern the process? • What are the shortcomings in this process which you wish to eliminate?
4	Value Co-Creation (Value-In-Use)	• How do you extract value during the use of your offering? • How do you bring in changes to the existing product and service system delivery? • How do you cater to the changing needs of the customers? • How do you think the ViU process can be improved?

v. Extra Questions

1) The latest literature shows that customer is no longer a consumer of commodities but is a co-creator of value.
   a. How have you involved your customers in co-creating value during the implementation and usage of Assessment Pack? (What were the procedures/mechanisms?)
   b. In your opinion, how would you describe as the customer value-creating processes and supplier value-creating processes? (examples: relationship experience, customer learning, co-creation opportunities, planning, implementation and organisational learning)
   c. After various co-creation activities between the actors, do you see any emergence of routines the value co-creation activities? If so, how and why?

2) We find it more and more apparent that value is embedded in customer experiences rather than in the goods and services.
   a. How did you support the customers in generating valuable experiences, including the aspects of functional and emotional value? (This could be interactions and communications you have with the customers, or the act of using Assessment Pack and getting the services you provide with it, which lead customers to think, feel or act in specific ways.)
   b. How about other stakeholders? How do you develop a healthy relationship? (Resource integration, service exchange, communicative interactions and relational development)
   c. How do you share knowledge? How does it shape your value proposition?
   d. Do you negotiate the rules, regulations and agreements with your stakeholders towards delivering the solutions? (If so, how and why?)

3) As we know, human lives and demands are dynamic and change with time. This fact asks for changes in their problem solutions and renewal of knowledge to adapt to those changes. Appropriately, the value proposition is a dynamic and adjusting mechanism.
   a. Do you still face new customer demands and challenges with regards to the problem that Assessment Pack was designed to address? (If so, have you come up with a procedure or technique to cater to those new demands?)
   b. How did you upgrade the value of Assessment Pack? What are the strategies and techniques you have used? Did you involve customers and other stakeholders? (If so, how were they involved?)

VIII. Survey

i. Ethics Approval

Mohd Ahsan Kabir Rizvi

From:	research.ethics@uts.edu.au
Sent:	Friday, 7 February 2020 4:11 PM
To:	Research Ethics; Mohd Ahsan Kabir Rizvi; Phillippa Carnemolla
Cc:	Divya Priya Dakshinamurthy; Gemma Vallance; Kanwal Baluch; Mikhaela Rodwell
Subject:	Your ethics application has been approved as low risk - ETH19-4287
Attachments:	Ethics Application.pdf

Dear Applicant

Re: UTS HREC Ref. No. ETH19-4287 - "Towards Cyber-Physical Product Service Systems Design"

Your local research office has reviewed the amendment application for your above-named project and agreed that the amendments meet the requirements of the National Statement on Ethical Conduct In Human Research (2007). I am pleased to inform you that your amendment has been approved as follows:

The original ethics application was based on qualitative data collection using semi-structured interviews. The data helped refine the CPPSS design methods. We now seek to obtain expert reactions on the research method using the survey approach.

This amendment is subject to the standard conditions outlined in your original letter of approval.

You are reminded that this letter constitutes ethics approval only. This research project must also be undertaken in accordance with all UTS policies and guidelines including the Research Management Policy.

You should consider this your official letter of approval. If you require a hardcopy please contact your local research office.

To access this application, please click here. A copy of your application has also been attached to this email.

If you have any queries about this approval, or require any amendments to your approval in the future, please do not hesitate to contact your local research office or the Ethics Secretariat (Research.Ethics@uts.edu.au).

Ref: 12e

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ii. Invitation Letters

a. Case-study Participants

Invitation letter to Participating Organizations

Dear Sir/Madame,

This invitation is soliciting your and/or your firm's interest in participating in a research on **"designing service-oriented '*smart*[1]' products"** that we are conducting as part a doctoral study at the University of Technology Sydney (UTS). Below is a brief explanation about this research and what your involvement would entail if you decide to proceed.

From an extensive literature review and using the theoretical lenses of the multi-disciplines of marketing, service and management sciences, we have developed *a new* ***theoretical*** *method of how to design* such service-oriented and *customer-centric 'smart'* products and associated business models *to adapt with the evolving customer requirements*.

We are now seeking practitioners' participation, from *disparate industries*[2] operating in a business-to-business (B2B) context, to *evaluate* and modify/refine my design method to make it practical and useful for designer and product end-users alike. The target disparate organisations include logistic, automation, medical and construction solution providers.

The research will involve conducting semi-structured interviews with practitioners experienced in designing product and service solutions, to explicate their *practical design experiences*. The practitioners may include design engineer, managing director, general manager, marketing manager and chief people officer. The *experiences* of the practitioners will be kept *anonymous* and aggregated into *thematic practice-based design principles* to evaluate and to refine my above-mentioned theoretical design method.

Participation in this study is voluntary. The interviews of selected practitioners will last approximately one hour per informant at an agreed upon location. The interview questions will be related to the informants' practical design-related experiences. You may decline to answer any of the interview questions. Further, you may decide to withdraw from this study at any time. With your permission, the interview will be digitally audio recorded and later transcribed anonymously for analysis. Shortly after the interview, we will send you a copy of the transcript to confirm its accuracy and clarify any points that you wish. All information you provide will be treated with strict confidentiality and stored securely. Your name will not appear in any thesis or report resulting from this study, however, with your permission anonymous quotations may be used. **Following the data analysis, we will present to you the developed design method. We will then send you a link to an online survey. This survey will seek your opinion on the design method. This survey information will be deidentified, your provided answers will not be attributed to you.**

There are no known or anticipated risks to you as a participant in this study. As this study is expected to surface the differences in opinion among your organisation's team members, it may help them to improve their performance through resolution. Your design team may also benefit from the study's key outcome in the form of an integrated method for designing service-oriented 'smart' products.

We would like to assure you that this study has received ethics clearance by the UTS Research Ethics Review Board. We look forward to hearing from you and thank you in advance for your assistance in this project.

Sincerely,

Dr. Phillippa Carnemolla, Principal Investigator
Prof Shankar Sankaran, Co-Investigator
Mohd Ahsan Kabir Rizvi, Co-Investigator

School of Built Environment, University of Technology Sydney

[1] Smartness comes from leveraging a mixture of multiple technologies, such as social, mobility, analytics, cloud, and internet-of-things technologies
[2] Purposely sampled from disparate industries *to avoid involving competing organizations* from the same industry.

b. Other Practitioners

Invitation letter to Participants

Dear Sir/Madam,

This invitation is soliciting your and/or your firm's interest in participating in a research on **"designing service-oriented '*smart*[1]' products"** that we are conducting as part a doctoral study at the University of Technology Sydney (UTS). Below is a brief explanation about this research and what your involvement would entail if you decide to proceed.

As customer demands are evolving, businesses have come to realise that customers see more value in the outcomes of using a product than in the product itself. Consequently, they are re-modelling their business strategies from selling products to provisioning services through servitisation. Smart products are one of the systems that implement servitisation, has shown to provide a multitude of benefits to all its *actors*[2] value co-creation and *value-in-use*[3]. This research seeks to harness value co-creation by developing a design method that answers the question: "How to design a service-oriented smart system adaptable to customers' dynamic needs through customer value co-creation?".

From an extensive literature review on the disciplines of marketing, service and management sciences, we have developed a design method of how to build 'smart' products and services that can adapt with the evolving customer requirements. We have refined this design method using practitioners' participation from *disparate industries*[4] operating in a business-to-business (B2B). The research involved conducting semi-structured interviews with practitioners experienced in designing product and service solutions to illustrate their practical design experiences.

We now plan to re-evaluate and validate the refined design method using the participation of practitioners involved in the design and innovation of smart products and services. This step is expected to make the design method practical and useful for designers and end-users alike. Thus, we would like to present our proposed design method to suitable experts, like yourself and receive the feedback. This presentation will enable a two-way knowledge-sharing process. The audience will benefit by gathering awareness of a theory and practice backed design method while we expect to obtain valuable feedback from the experts.

We would like to assure you that this study has received ethics clearance by the UTS Research Ethics Review Board. We look forward to hearing from you and thank you in advance for your assistance in this project.

Sincerely,

Dr. Phillippa Carnemolla, Principal Investigator
Prof Shankar Sankaran, Co-Investigator
Mohd Ahsan Kabir Rizvi, Co-Investigator

PhD Candidate, School of Built Environment, University of Technology Sydney

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[1] Smartness comes from leveraging a mixture of multiple technologies, such as social, mobility, analytics, cloud, and internet-of-things technologies
[2] Entities involved in the creation of value through mutual collaboration
[3] Value evolved during the use or consumption process of the solution jointly created by multiple actors involving providers and beneficiaries
[4] Purposely sampled from disparate industries *to avoid involving competing organizations* from the same industry.

iii. Participant Information Sheet

a. Case-study Participants

UTS UNIVERSITY OF TECHNOLOGY SYDNEY

PARTICIPANT INFORMATION SHEET
DESIGNING CYBER-PHYSICAL PRODUCT SERVICE SYSTEMS
UTS HREC REF NO. ETH18-2445 and ETH19-4287

WHO IS DOING THE RESEARCH?

The principal investigator of this research is Dr. Phillippa K Carnemolla and the co-investigators are Mohd Ahsan Kabir Rizvi and Prof. Shankar Sankaran, all from the School of Built Environment, UTS. This research is a part of the doctoral study conducted by Mohd Ahsan Kabir Rizvi.

WHAT IS THIS RESEARCH ABOUT?

As customer demands are evolving, businesses have grown beyond products to become more and more dependent on service. Customers are more interested in the solutions, experiential outcomes and benefits rather than products alone. As a result, businesses are providing customer-specific solutions by servitizing their offerings and co-creating value with the customer at the centre of the strategy. Additionally, these solutions are expected to combine customer orientation with real-time sensing, data processing and decision-making capabilities from IoT to evolve into "smart" solutions. Thus, practitioners and researchers alike are seeking to answer the question: "How to design a service-oriented smart solution adaptable to customers' dynamic needs through customer value co-creation?"

WHY HAVE I BEEN ASKED?

You have been invited to participate in this study because you are involved in designing product and service solutions in your field of business

IF I SAY YES, WHAT WILL IT INVOLVE?

If you decide to participate, we will invite you to be interviewed in person or online according to your convenience. The interview is expected to last for about an hour.

The interview questions will be related to your practical design-related experiences and will be guided by our desire to understand their view on value co-creation in a smart solution environment.

With your permission, the interview will be tape-recorded and later transcribed anonymously for analysis. Shortly after the interview, we will send you a copy of the transcript to confirm its accuracy and clarify any points that you wish.

The transcript will then be deidentified and analysed to improve the proposed design method. The refined design method will be presented to you and you will be invited to participate in an online survey. The link to the survey will be emailed to you. This survey will seek your opinion on design methods. All survey information will be deidentified.

ARE THERE ANY RISKS/INCONVENIENCE?

Apart from some inconvenience caused by your time commitments, there are no known or anticipated risks to you as a participant in this study.

DO I HAVE TO SAY YES?

Participation in this study is voluntary. It is completely up to you whether or not you decide to take part.

WHAT WILL HAPPEN IF I SAY NO?

If you decide not to participate, it will not affect your relationship with us or the University of Technology Sydney.

Once the study has started, you may decline to answer any of the interview questions. Furthermore, if you wish to withdraw from the study, you can do so at any time without having to give a reason, by contacting any one of the three researchers.

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UTS UNIVERSITY OF TECHNOLOGY SYDNEY

If you withdraw from the study, all your identifiable data will be destroyed. However, it may not be possible to withdraw your data from the study results if these have already had your identifying details removed.

CONFIDENTIALITY

By signing the consent form, you consent to the research team collecting and using information about your design experience for the research project. All this information will be treated confidentially and will be used solely for this research. Your name will not appear in any thesis or report resulting from this study, however, with your permission anonymous quotations may be used. Only the three nominated researchers mentioned above will have access to the material provided by participants in this study. Confidentiality will be preserved by using subject numbers for each participant while recording the data. We plan to publish the results in journals and conferences. However, in any publication, information will be provided in such a way that you cannot be identified.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?

If you have concerns about the research that you think my supervisor or I can help you with, please feel free to contact us on.

Principal Investigator: Dr. Phillippa Carnemolla
Email: Phillippa.Carnemolla@uts.edu.au

Co-Investigator: Mohd Ahsan Kabir Rizvi
Email: MohdAhsanKabir.Rizvi@student.uts.edu.au

Co-Investigator: Prof Shankar Sankaran
Email: Shankar.Sankaran@uts.edu.au

You will be given a copy of this form to keep.

NOTE:
This study has been approved by the University of Technology Sydney Human Research Ethics Committee [UTS HREC]. If you have any concerns or complaints about any aspect of the conduct of this research, please contact the Ethics Secretariat on ph.: +61 2 9514 2478 or email: Research.Ethics@uts.edu.au] and quote the UTS HREC reference number. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

CONSENT FORM
DESIGNING CYBER-PHYSICAL PRODUCT SERVICE SYSTEMS
UTS HREC REF NO. ETH18-2445 and ETH*19-4287*

I ____________________ agree to participate in the research project DESIGNING CYBER-PHYSICAL PRODUCT SERVICE SYSTEMS (UTS HREC REF NO. ETH18-2445 and ETH19-4287) being conducted by Dr. Phillippa Carnemolla and her team from the School of Built Environment, UTS, Phone: +61 [redacted].

I have read the Participant Information Sheet, or someone has read it to me in a language that I understand.

I understand the purposes, procedures and risks of the research as described in the Participant Information Sheet.

I have had an opportunity to ask questions, and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time without affecting my relationship with the researchers or the University of Technology Sydney.

I understand that I will be given a signed copy of this document to keep.

I agree to be audio recorded.

I agree that the research data gathered from this project may be published in a form that does not identify me in any way.

I am aware that I can contact any of the members of the team if I have any concerns about the research.

____ ____/____/____
Name and Signature [participant] Date

____ ____/____/____
Name and Signature [researcher or delegate] Date

b. Other Practitioner

UTS UNIVERSITY OF TECHNOLOGY SYDNEY

PARTICIPANT INFORMATION SHEET
DESIGNING CYBER-PHYSICAL PRODUCT SERVICE SYSTEMS
UTS HREC REF NO. ETH19-4287

WHO IS DOING THE RESEARCH?

The principal investigator of this research is Dr. Phillippa K Carnemolla and the co-investigators are Mohd Ahsan Kabir Rizvi and Prof. Shankar Sankaran, all from the School of Built Environment, UTS. This research is a part of the doctoral study conducted by Mohd Ahsan Kabir Rizvi.

WHAT IS THIS RESEARCH ABOUT?

As customer demands are evolving, businesses have grown beyond products to become more and more dependent on service. Customers are more interested in the solutions, experiential outcomes and benefits rather than products alone. As a result, businesses are providing customer-specific solutions by servitizing their offerings and co-creating value with the customer at the centre of the strategy. Additionally, these solutions are expected to combine customer orientation with real-time sensing, data processing and decision-making capabilities from IoT to evolve into "smart" solutions. Thus, practitioners and researchers alike are seeking to answer the question: "How to design a service-oriented smart solution adaptable to customers' dynamic needs through customer value co-creation?"

WHY HAVE I BEEN ASKED?

You have been invited to participate in this study because you are involved in designing product and service solutions in your field of business

IF I SAY YES, WHAT WILL IT INVOLVE?

If you decide to participate, we will invite you to a presentation of the design method developed in our research. You will then be invited to participate in an online survey. The link to the survey will be emailed to you. This survey will seek your opinion on design methods. All survey information will be deidentified.

ARE THERE ANY RISKS/INCONVENIENCE?

Apart from some inconvenience caused by your time commitments, there are no known or anticipated risks to you as a participant in this study.

DO I HAVE TO SAY YES?

Participation in this study is voluntary. It is completely up to you whether or not you decide to take part.

WHAT WILL HAPPEN IF I SAY NO?

If you decide not to participate, it will not affect your relationship with the researchers or the University of Technology Sydney.

Once the study has started, you may decline to answer any of the interview questions. Furthermore, if you wish to withdraw from the study, you can do so at any time without having to give a reason, by contacting the research team.

If you withdraw from the study, all your identifiable data will be destroyed. However, it may not be possible to withdraw your data from the study results if these have already had your identifying details removed.

CONFIDENTIALITY

By signing the consent form, you consent to the research team collecting and using information about your design experience for the research project. All this information will be treated confidentially and will be used solely for this research. Your name will not appear in any thesis or report resulting from this study, however, with your permission anonymous quotations may be used. Only the three nominated researchers mentioned above will have access to the material provided by participants in this study. Confidentiality will be preserved by using subject numbers for each participant while recording the data. We plan to publish

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the results in journals and conferences. However, in any publication, information will be provided in such a way that you cannot be identified.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?

If you have concerns about the research that you think my supervisor or I can help you with, please feel free to contact us on.

Email: Phillippa.Carnemolla@uts.edu.au

Co-Investigator: Mohd Ahsan Kabir Rizvi
Email: MohdAhsanKabir.Rizvi@student.uts.edu.au

Co-Investigator: Prof Shankar Sankaran
Email: Shankar.Sankaran@uts.edu.au

You will be given a copy of this form to keep..

NOTE:
This study has been approved by the University of Technology Sydney Human Research Ethics Committee [UTS HREC]. If you have any concerns or complaints about any aspect of the conduct of this research, please contact the Ethics Secretariat on ph.: +61 2 9514 2478 or email: Research.Ethics@uts.edu.au] and quote the UTS HREC reference number. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

CONSENT FORM
DESIGNING CYBER-PHYSICAL PRODUCT SERVICE SYSTEMS
UTS HREC REF NO. ETH*19-4287*

I ____________________ agree to participate in the research project DESIGNING CYBER-PHYSICAL PRODUCT SERVICE SYSTEMS (UTS HREC REF NO. ETH19-4287) being conducted by Dr. Phillippa Carnemolla and her team from the School of Built Environment, UTS, Phone: +61[redacted].

I have read the Participant Information Sheet, or someone has read it to me in a language that I understand.

I understand the purposes, procedures and risks of the research as described in the Participant Information Sheet.

I have had an opportunity to ask questions, and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time without affecting my relationship with the researchers or the University of Technology Sydney.

I understand that I will be given a signed copy of this document to keep.

I agree that the research data gathered from this project may be published in a form that does not identify me in any way.

I am aware that I can contact any of the members of the team if I have any concerns about the research.

____ ____/____/____
Name and Signature [participant] Date

____ ____/____/____
Name and Signature [researcher or delegate] Date

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iv. Survey Questionnaire

Feedback Form

Thank you for participating the presentation. The information you provide in this feedback form will be treated anonymously and will be aggregated with other data collected for on-going PhD research work.

Presentation date(s): ________________

Which of the following best describes your level of responsibility in the company? **check all hat apply*

☐ End user/Operator ☐ Designer/Engineer ☐ Manager/Leader

If *Others*, please specify ____________________

Industry: ___________________________

Company size	☐ Start-up	☐ Local Level	☐ National Level	☐ Multi-national level

About you

How long have you been working in this company? ___________________

Total lifetime experience in the industry: ________

Which of the following functions do you have one or more year(s) of experience? **check all that apply*

☐ Design - product ☐ Design – service ☐ Design - system / process
☐ Engineering ☐ Information technology (IT) ☐ Management / Finance
☐ Marketing ☐ Operations ☐ Product life-cycle management
☐ Quality assurance / Regulatory ☐ Sales / commercial ☐ Service delivery / support
☐ Others ____

Your feedback and comments

1. Problematisation (Identify requirements/goals/targets)

a. Please rate the stage based on this presentation experience using the scale of **1** to **5**

	Low ⟷				High
Clarity of using the Problematisation step	1	2	3	4	5
Utility of the Problematisation in my field of work	1	2	3	4	5

b. What have I learnt from the Problematisation step that could be implemented in my field of work?

c. What changes would improve the Problematisation step?

2. Interessement (Negotiate rules, regulations and procedures)

a. Please rate the stage based on this presentation experience using the scale of **1** to **5**

	Low ⟷				High
Clarity of using the Interessement step	1	2	3	4	5
Utility of the Interessement in my field of work	1	2	3	4	5

b. What have I learnt from the Interessement step that could be implemented in my field of work?

c. What changes would improve the Interessement step?

This document is part of the on-going work of Mohd Ahsan Kabir Rizvi's PhD research project
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Mohdahsankabir.rizvi@student.uts.edu.au

3. Enrolment (Integrate knowledge, skills and resources)

a. Please rate the stage based on this presentation experience using the scale of **1** to **5**

	Low ⟵			⟶	High
Clarity of using the Enrolment step	1	2	3	4	5
Utility of the Enrolment in my field of work	1	2	3	4	5

b. What have I learnt from the Enrolment step that could be implemented in my field of work?

c. What changes would improve the Enrolment step?

4. Mobilisation (Communicate solutions and improvements)

a. Please rate the stage based on this presentation experience using the scale of **1** to **5**

	Low ⟵			⟶	High
Clarity of using the Mobilisation step	1	2	3	4	5
Utility of the Mobilisation in my field of work	1	2	3	4	5

b. What have I learnt from the Mobilisation step that could be implemented in my field of work?

c. What changes would improve the Mobilisation step?

5. Any further comments?
