Value Co-creation in Developing Sustainable Cyber-Physical Product Service Systems: Applying Design Science Research Method

Current market trends show that customers no longer perceive value in a product but in the solution it provides. Consequently, businesses are realigning their value proposition to provide solutions than just selling products. Such offerings combined with the advancement in smart capabilities have given rise to cyber-physical product-service systems (CPPSS), which enable customised solution through value co-creation between customers and providers. Among other benefits, CPPSS could support Sustainable Development Goals 9, 12 and 17 by creating partnerships to transform industry towards responsible production and consumption. Therefore, industry and academia are looking for a holistic design method to build CPPSSs catering to evolving customer needs. This research used the design science research method to propose a service-centric CPPSS design model and demonstrated its application using multiple case studies. This study has implications for project management practice as using the Design Science Research process explains how CPPSS projects are managed.

Keywords: value co-creation; cyber-physical product-service system; service-dominant logic; actor-network theory; design science research; case study.

Introduction

Technological advancements since the industrial revolution enabled producers to design and mass produce products. However, while facilitating extended reach and cheaper commodities, it also resulted in lower customer involvement, customisation and sustainability. As the information age emerged, customers started to value solutions, experience and utility rather than just the product itself (X. Yang et al., 2009). So, manufacturers started adding services to their products, using the phenomenon referred to as *servitisation* (Vandermerwe & Rada, 1988). Service has then evolved into a strategic tool for competitive edge that keeps customers satisfied and loyal (Pawar et al., 2009; Tan et al., 2010). Hence, modern businesses are shifting from product-centric model of product delivery to service-centric model of solution delivery (Annarelli et al., 2016). Solution design involves *co-creation,* where customers and providers collaborate in creating the solution ensuring higher customer satisfaction. Providers ask not “what we can do for you?” but “what can you do with us?” (Wind & Rangaswamy, 2001, p.

21). As a result, value co-creation (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).

Servitisation and VCC have given rise to product-service systems, which integrates product and service in such a way that it gives the customer a more sustainable, customised and efficient solution (Baines et al., 2009; Mont, 2002; Rizvi & Chew, 2018b). New product-service systems (PSS) are being integrated with smart capabilities to form smart or cyber-physical PSS (CPPSS), which are making life easier for us by inevitably penetrating into our daily lives (Marilungo et al., 2017; Zheng et al., 2016; Abramovici et al., 2015; Bohn et al., 2005). CPPSS form a valuable system that is superior in terms of business model and technological capabilities to provide enhanced monitoring, demand analysis, decision-making, customisation and solution delivery (Marilungo et al., 2017; Scholze et al., 2016; Wiesner et al., 2017). The optimal use of resources in CPPSS provides additional benefits like waste reduction and environmental sustainability (Minguez et al., 2012). CPPSS could also potentially enable businesses to develop sustainable solutions in conjunction with the Sustainable Development Goals (SDGs). The literature review on CPPSS shows that their design methods are still in their infancy and does not cater to the dynamic need along its lifecycle. So, this research developed a CPPSS design method that adopts a VCC and lifecycle approach.

Methodology

A comprehensive strategy is needed to operationalise a study (Creswell & Creswell, 2017; Crotty, 1998). Accordingly, the strategy involved exploring the PSS and CPPSS design methods (CPPSSDMs), identifying the knowledge gaps, developing the research questions, determining appropriate research method, discovering artefacts, synthesising definitions and constructing the design methods. Since this research is concerned with developing a design model, the design science research method (DSRM) was chosen. DSRM enables design method construction, evaluation and refinement resulting to a theory- and practice-induced CPPSSDM reference model for business-to-business (B2B) context. It was first developed conceptually and then refined using an interpretivist case study approach. The reference model assists providers, customers, designers and end-users to design a service-centric CPPSS capable of catering to changing customer demands through VCC. As shown in Figure 1 and discussed below, DSRM provides a six-step procedure to develop artefacts in the form of construct, model, method and instantiation in order to serve humans (Peffers et al., 2006; Peffers et al., 2007). In this research, steps 3, 4 and 5 were iteratively implemented to achieve the goals.

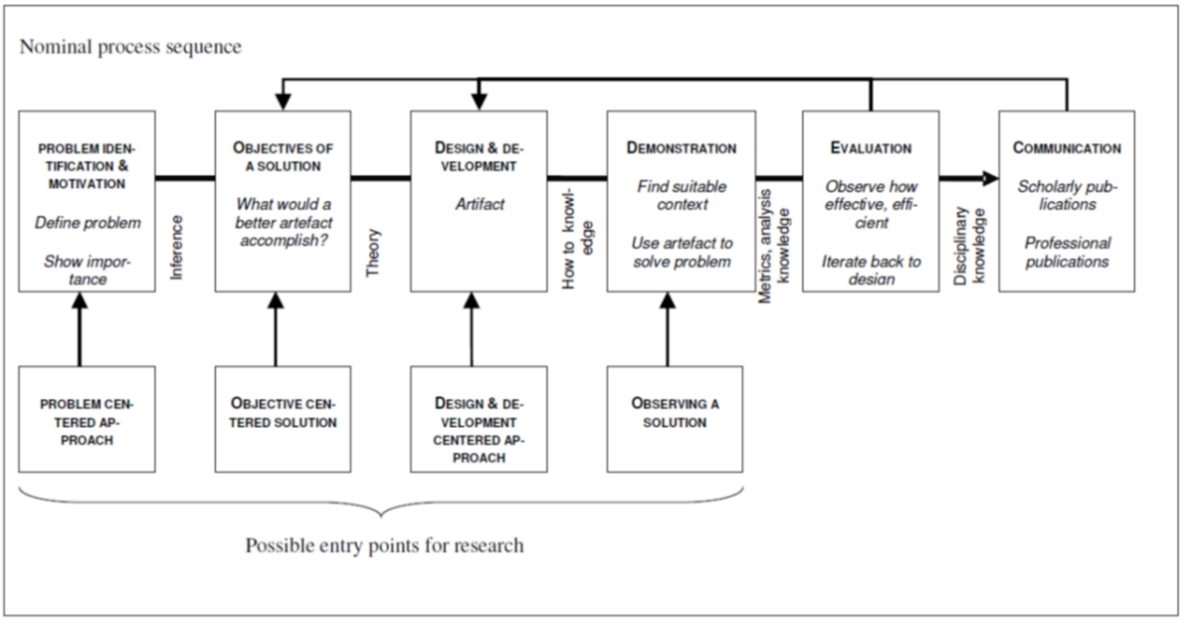

Figure 1: Design Science Research Method (Peffers et al., 2006; Peffers et al., 2007)

Step 1 – Identification. A systematic literature review (SLR) was conducted to understand the related concepts. Gaps and opportunities in PSS and CPPSS design were identified.

Step 2 – Objectives. The knowledge gaps identified from SLR provided the research motivation to develop the CPPSSDM reference model.

Step 3 – Development. The SLR facilitated the development of new PSS and CPPSS definition and conceptual design method using actor-network theory and service-dominant logic.

Step 4 – Demonstration. Case study research was implemented using semi-structured interviews to demonstrate the usability of the proposed design method and to understand CPPSS design practices in a business-to-business industry context.

Step 5 – Evaluation. The individual and cross-case analysis insights were used to evaluate the proposed reference model. The CPPSSDM reference model was refine using the inferences.

Step 6 – Communication. The findings were communicated at various stages of this research through five conference papers and a doctoral thesis. These publications helped obtain critical reviews and feedback to enhance the research outcomes.

Literature Review

A systematic literature on the concerned topics helped identify the knowledge and gaps (Rizvi & Chew, 2018a, 2018b). The following sections discuss the findings about PSS, lifecycle, VCC, CPS and CPPSS from the reviewed literature.

Product-Service Systems

The concept of a product-service system was introduced in the late 1990s, and research into the subject became prominent in the early 2000s (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).

Definition of PSS. 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). The definitions of PSS vary due to a variety of perspectives, usage and focus. Initial PSSs were mainly focused upon achieving sustainable and environmentally friendly operations by extending product life cycles through services to improve availability, efficiency and performance (Baines et al., 2007). Over the years, PSS was termed as product service, full service, service package, integrated solution and functional sales (Park et al., 2012). However, the most popular explanation is that PSS is a *system*, since a system comprehensively covers all PSS's elements and their relationships (Goedkoop et al., 1999; McKay & Kundu, 2014; Tukker, 2004; Baines et al. 2007). The extant literature on PSS yielded 21 different terms used in 35 different definitions for PSS (Rizvi & Chew, 2018a).

Types of PSS. PSS applications were found in both, business-business (B2B) and business-consumer (B2C) contexts. The B2B examples are 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. As shown in Table 1, PSS business model is classified according to three types: product-oriented, use-oriented and result-oriented (Reim et al., 2015). The extent of the PSS application shows that it can have a significant impact on achieving the UN SDGs.

Table 1: Three types of PSS (adapted from Reim et al., 2015; Tran & Park, 2014; Tukker, 2004)

	Product-oriented PSS	**Use-oriented PSS**	**Result-oriented PSS**
Focus	Tasks and payments	Availability	Characteristics of the results
Offering	Additional service(s)	Availability of a product	Result or capability
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

Design methods. Service engineering and methodology development and evaluation of PSS (MEPSS) are overarching methodologies used to design PSS (Qu et al., 2016; Tran & Park, 2014). Service engineering systematically designs PSS using suitable models, methods and tools (Pezzotta et al., 2015), that enhance 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).

PSS design methods were developed based on PSS problem, context and application. Some researchers have used a sequential or waterfall procedure (Hussain et al., 2012; Maussang et al., 2009; Sutanto et al., 2015) while others used simultaneous development of products and services (Sakao & Shimomura, 2007; Tomiyama, 2001) similar to concurrent engineering. More recently, an integrated PSS design method was proposed using the concept of the functional block diagram (Maussang et al., 2009; Trevisan & Brissaud, 2016). These blocks were reusable and replaceable sub-systems (or modules) to allow flexibility and customisation (Li et al., 2012; Wang et al., 2011). Service modelling (Phumbua & Tjahjono, 2012) and visualisation (Lim et al., 2012) are two other methods to design PSS. However, the design methods discussed so far do not provide a holistic PSS solution. Furthermore, limited application of VCC was observed in PSS design. This research proposes that holistic PSS design is could be achieved through the implementation of a VCC based PSS lifecycle.

Design tools. Two kinds of design tools were identified. First type was used to prioritise stakeholders' needs prior to design and the second was used to support the design process. The first type includes the theory of inventive problem-solving (TRIZ) (Kim & Park, 2012), quality function deployment (QFD) (Akao, 1990; Peruzzini et al., 2015), analytical hierarchy/network process (AHP/ANP) (Geng et al., 2010; Saaty, 2008; C.-L. Yang et al., 2009), Kansei engineering (Carreira et al., 2013; Nagamachi, 1995) and Kano model (Sauerwein et al., 1996). The second type includes service CAD (Akasaka et al., 2012), lifecycle simulator (Garetti et al., 2012), interaction map (Morelli, 2009), service blueprint (Shimomura et al., 2009; Shostack, 1982), PSS board (Lim et al., 2012) and PSS characterisation approach (PSSCA)

(Yip et al., 2015). Among these tools, only the PSSCA is built upon the integrated theoretical basis of actor-network theory (ANT) and service-dominant logic (SDL) (Yip et al., 2015; Yip et al., 2019).

Lifecycle

Lifecycle management is an approach implemented to improve performance in three lifecycle phases, namely, beginning of life (BOL), middle of life (MOL) and end of life (EOL) (Power, 2009; Terzi et al., 2010). Though it initially helped target, analyse and manage product-related activities, later extensions also helped improve the sustainability performance of both products and services (Remmen, 2007; Sonnemann et al., 2015). In PSS, lifecycle management was initially separated into product lifecycle management (PLM) and service lifecycle management (SLM) and later combined to form PSS lifecycle management (Wiesner et al., 2015). Reviewed PSS design literature reveal that most design methods can be mapped to one or more of the lifecycle stages (Cavalieri & Pezzotta, 2012; Tran & Park, 2014).

Value Co-creation

Value has different meanings and perspectives. Value can be the trade-off between benefits and sacrifices for a product or service (Payne & Holt, 2001) or the utility of that product or service (Tellis & Gaeth, 1990). The provider perceives value as economic gains and business success (Tukker, 2004). The customer perceives value as an affordable and reliable solution that improves her/his well-being (Dodds, 1999; Frow et al., 2014; Rese et al., 2009). On a larger scale, sustainable consumption and production are valuable for the environment, society and government (Durugbo, 2014). Overall, value is a criterion that is employed by an individual to make a judgement based on own preference (Sánchez-Fernández & Iniesta-Bonillo, 2007).

Co-creation is the activity of joint creation of an entity by the customer, provider and other stakeholders (Prahalad & Ramaswamy, 2004a, 2004b). In co-creation, providers build the opportunity to create value with customers to fulfill customers' needs (Durugbo & Pawar, 2014; Grönroos, 2008). Co-creation has shown to reduce errors, engender happier employees, produce more satisfied customers and lower costs (Kennedy & Guzmán, 2016; Lee & Kim, 2018; Ranjan & Read, 2016; Verleye, 2013). The joint creation of value through mutual collaboration and resource integration is termed as *value co-creation* (VCC).

VCC is dynamic as it involves resources, people, organisations, languages, laws, technologies and service systems (Spohrer et al., 2008). In VCC, all *actor*s are *resource integrators* who do not compete against each other but collaborate in co-producing value to improve mutual performance (Saarijärvi et al., 2013). VCC consists of two dimensions; co-production and value-in-use (Ranjan & Read, 2016). Co-production covers the *actor* activities towards developing the value proposition (Vargo & Lusch, 2008). Value-in-use covers the *actor'*s activities that help customers assess the offering and generate value through its consumption (Vargo & Lusch, 2004). VCC requires trust, inclusiveness and openness among *actor*s (Pera et al., 2016) to ensure customised and personalised solution (Zine et al., 2014), sustainability (Li & Found, 2017), achieve competitive advantage (Barquet et al., 2013) and prototype testing (Tran & Park, 2015). Thus, VCC is essential in PSS design as it helps satisfy stakeholder needs effectively (Müller & Stark, 2010). According to SDL, VCC considers the role of multiple *actor*s that always include the beneficiary (Vargo & Lusch, 2004, 2008, 2016). These *actor*s form the *value-network*, which is comparable to the *actor-network* of ANT.

Cyber-Physical Systems

The term *cyber-physical systems* was coined by Helen Gill of the National Science Foundation in 2006 (Gunes et al., 2014). CPS is a technology for managing interconnected systems of physical assets, computational capabilities and networking processes to provide customer solutions (Khaitan & McCalley, 2015; Lee et al., 2015; Wiesner et al., 2017). CPS is "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). CPS actualises a ubiquitous system that adapts to the context by learning, reconfiguring and co-operating (Broy et al., 2012). CPS is applicable in engineering, business, economics, finance, management, information systems, environmental science and social sciences.

Cyber-Physical Product-Service Systems

Integrating CPS into PSS is a new trend among researchers and industries alike (Wiesner et al., 2017). The terms used for this integrated system 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 et al., 2016) and CPPSSs (Wiesner et al., 2017; Mikusz, 2014; Rizvi and Chew 2018b). CPPSS offers enhanced equipment engineering, higher automation, optimised operations, remote control/diagnosis and information-driven service (Herterich et al., 2015; Scholze et al., 2016). Reviewed literature shows that the industry needs a design method for CPPSS that describes the procedures, starting with customer requirements to solution delivery (Dutra & Silva, 2016; Zheng et al., 2016). Some proposed CPPSS design methods consider CPS solely as a software component (Mikusz, 2014), treat PSS only as a product-service bundle (Wiesner et al., 2017), use CPS approach to develop PSS (Marilungo et al., 2017), and design PSS with CP features (Scholze et al., 2016). These variations show the existence of an inconsistency in designing CPPSS and thus this research aims to address it by developing a holistic and organised CPPSS design method.

Conceptual Design Method

The conceptual cyber-physical product-service system design method (CPPSSDM) model was developed using inspiration from service-dominant logic (SDL), actor-network theory (ANT) and the reviewed literature. Reviewed literature shows that PSS and CPPSS are socio-technical systems (Annarelli et al., 2016; Joore & Brezet, 2015; Rizvi & Chew, 2018a; Roy, 2000). ANT helps study *actor* interactions in these socio-technical systems while SDL helps understand and implement VCC in them. The congruence between SDL and ANT was also acknowledged in the literature (Vargo & Lusch, 2016).

Foundational Theories

Service-Dominant Logic. SDL was theorised by examining the ways in which businesses need to co-create value with their stakeholders and argued that service is the fundamental basis of exchange (Reim et al., 2015; Vargo & Lusch, 2004, 2016). Service is exchanged for service since it is the process of integrating competencies to solve problems. SDL brings about a paradigm shift from value-in-exchange to value co-creation. VCC takes into account the interactions between multiple *actor*s as an *actor*-to-*actor* orientation, which could also be explained by ANT (Vargo & Lusch, 2016). SDL has been used in PSS design to enable VCC between *actor*s by various researchers (Kowalkowski, 2010; Smith et al., 2014).

Actor-Network Theory. ANT was developed to understand the processes of knowledge and innovation creation by exploring how things are structured and organised based on social effects (Cressman, 2009; Law, 1992; Wickramasinghe et al., 2012). *Actor*s are all humans and non-humans that change truth with time by constantly make webs of relationships by forming connections and reconnections among them (Cressman, 2009; Law, 2009; Montenegro & Bulgacov, 2014). This perception of trust helps study how a system is dynamically maintained and what socio-technical *actor*s define this system's success or failure (Latour, 2005; Law 2009; Tatnall, 2005).

ANT-SDL inspired Value Co-creation

ANT-SDL inspired actor. In SDL, *actor* represents the entities or parties that are involved in VCC through resource integration and service exchange (Lusch & Vargo, 2006, 2014; Vargo

& Lusch, 2008). Human entities such as customers and providers are SDL *actor*s, but the influence and involvement of the non-human entities such as machines/technologies, organisations and humans-machines/technologies combination are neglected here (Storbacka et al., 2016). This limitation could be addressed by ANT as it considers human as well as non-human *actor*s in any social-technical system. For ANT, *actor* (or *actant*) is an entity that influences the space around itself, makes other entities dependent upon it and translates their will into a language of its own (Callon & Latour, 1981). This research takes inspiration from ANT and SDL by defining *actor* as an entity that is directly or indirectly involved and influences service exchange relationships in VCC. This *actor* can be a human entity (e.g., customer, provider, manager, designer or operator) or a non-human entity (e.g., technology/machine). In a business-to-business context, the customer may consist of end-users who operate the CPPSS while managers and designers interact with them to develop that CPPSS. These designers and managers form a subset of both the provider and the customer.

*ANT-SDL-inspired translation. Actor*s in a socio-technical network adapt to changes through a translation process where they take their identities by negotiating their interaction and navigating margins of manoeuvre to align their interests with that of the focal *actor* (Callon, 1986; Cressman, 2009; Walsham, 1997). Since the focal *actor* initiates the translation process, it is called the *initiator* (Andrade & Urquhart 2010). As explained in Table 2, the translation process consists of four stages: *Problematisation*, *Interessement*, *Enrolment* and *Mobilisation*.

Table 2: ANT translation (adapted from Bengtsson and Lundström (2013); Andrade & Urquhart (2010))

Translation	**Functions**
Problematisation	The initiator identifies the problem, assesses initial requirements, and gauges the *actor*s who can contribute towards the solution.
Interessement	The initiator works towards building the network by propagating the problem information and convincing other *actor*s about the benefits of joining the solution network.
Enrolment	All interested *actor*s, old and new, accept the negotiated roles assigned to them forming an *actor* network that works towards solving the problem.

Mobilisation	All *actor*s engage in fulfilling the promised roles towards implementing the solution.

ANT-SDL-inspired VCC. Comparing ANT's view of changing truth with SDL, VCC involves dynamic capabilities to address changes in environments (Preikschas et al., 2017; Osborne, 2018). A combined translation process could provide a framework that facilitates VCC among *actor*s by addressing dynamic needs of customer with matching CPPSS solution design. The ANT-SDL inspired VCC model is demonstrated in Figure 2.

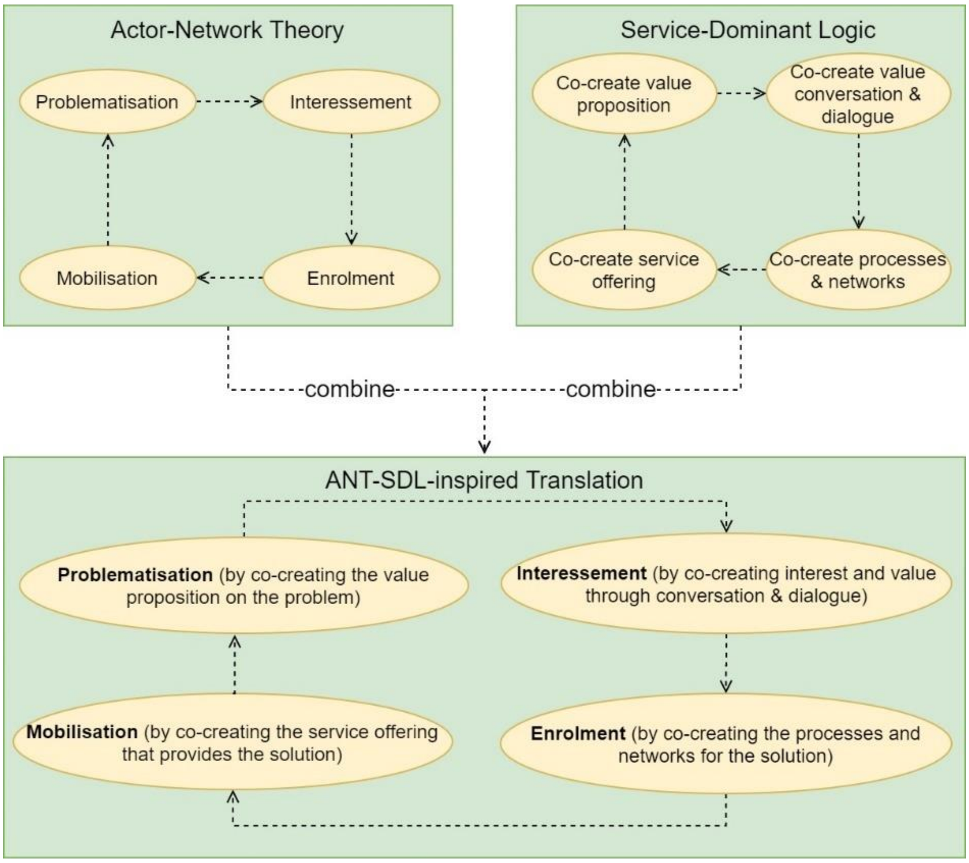

Figure 2: ANT-SDL inspired translation

Product-Service System Design Method (PSSDM)

Service, beneficiary (customer), provider and product are the *actor*s in a service-centric PSS. These actors influence, collaborate and integrate resources with each other to functionalise the service that co-create value to deliver the desired solution. Each translation stages of PSSDM, as shown in Figure 3, follows SDL by applying co-creation activities between the beneficiary, who determines the value, and all other multiple *actor*s. The *initiator* can be the customer who is facing a new problem, or the provider who proactively identifies the new problem. The other *actor*s become the *followers* by following the *initiator*'s problem definition and co-creating the solution. PSSDM is reinitiated every time the customer dynamics and demands changes to form a new customer problem. The proposed PSSDM is in congruence with the PSS lifecycle and Table 3 maps the intended outcomes of PSSDM form BOL, MOL and EOL.

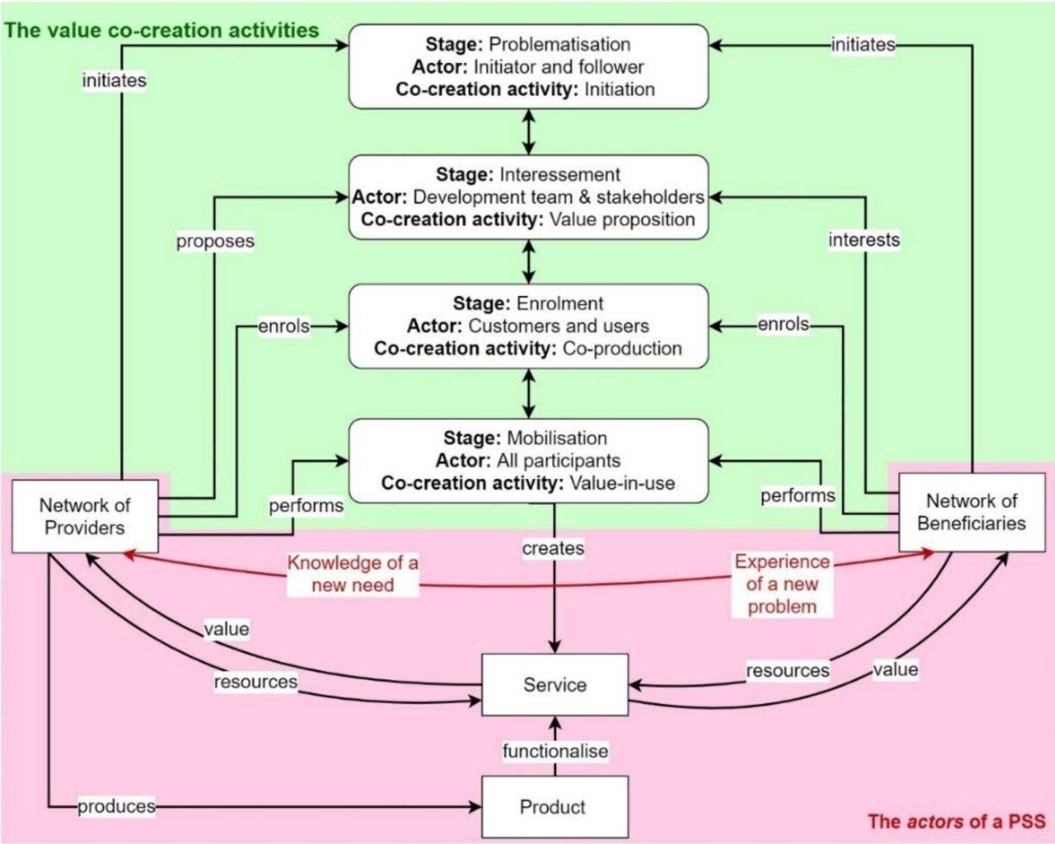

Figure 3: ANT-SDL-inspired PSSDM Reference Model with co-creation activities (Rizvi et al., 2019)

Table 3: PSSDM congruence with PSS Lifecycle (Yip et al., 2019)

Lifecycle	The intended PSSDM outcomes
BOL	• Understand the *actor*s' problems/demands and identify *actor*s' resources • Create a value proposition and develop a solution
MOL	• Obtain continuous customer response/feedback and improve 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

Cyber-Physical Product-Service System Design Method (CPPSSDM)

In the service-centric CPPSS shown in Figure 4, service, in addition to its PSS functionalities, is also continuously analysed and managed by the cyber part in response to the changing needs detected by the sensors and actuators in the physical part of CPPSS.

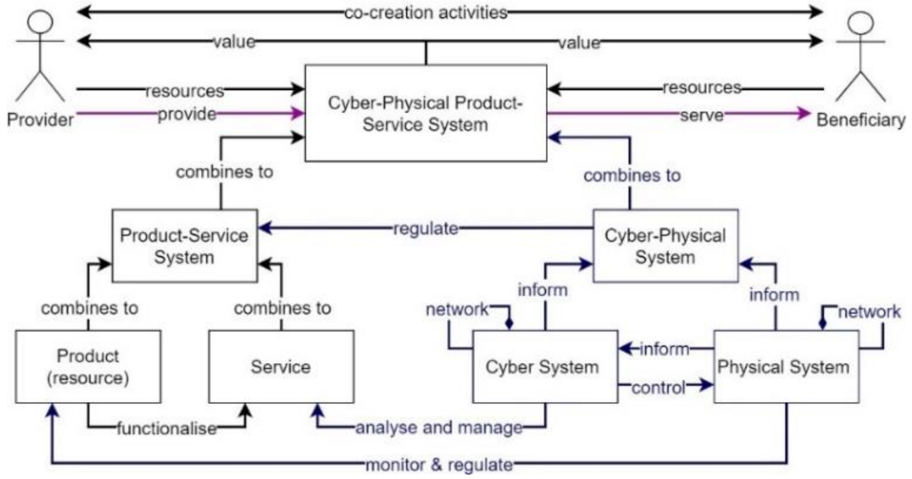

Figure 4: CPPSS actor-network model

CPPSS Design Method. In the proposed ANT-SDL-inspired CPPSSDM, the cyber-physical capabilities help monitor, analyse and manage the services. The information, like usage, feedback and experiences, enable customer-centricity by VCC and continuous improvement (Dutra & Silva, 2016; Marilungo et al., 2016; Scholze et al., 2016; Wiesner et al., 2016; Zheng et al., 2016). In the simplified CPPSSDM reference model, illustrated in Figure 5, a central theme is assigned (in brackets) to each translation stage to signify their focus.

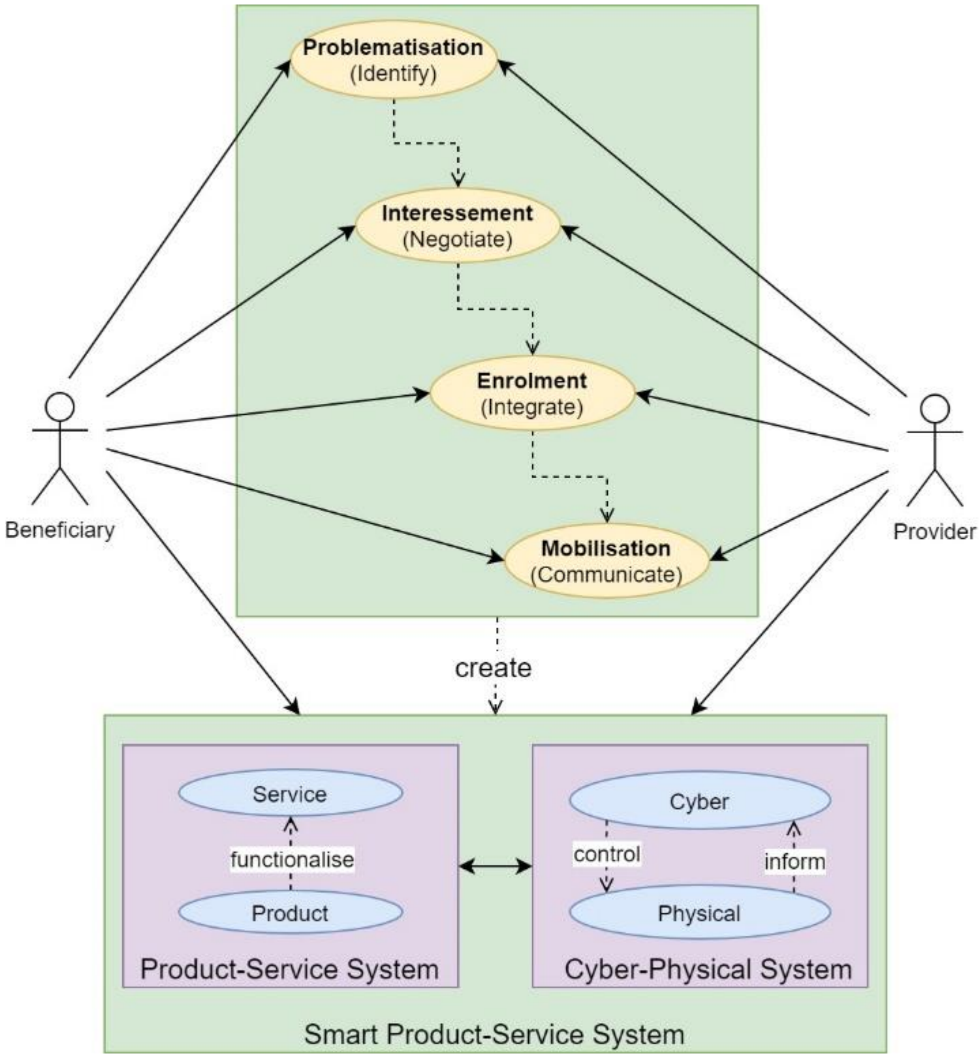

Figure 5: CPPSSDM Reference Model

Demonstration of the Design Method

Usability of the conceptual CPPSSDM reference model was demonstrated using case studies on four organisations codenamed DairyCo, PoolCo, HealthCo and VRCo, which were involved in dairy manufacturing, pool management, health informatics and virtual reality technology, respectively. These organisations were involved in co-creating a CPPSS, either as a customer or a provider in a business-to-business context. The case studies were conducted using a semi-structured interview approach. The study also helped understand real-world CPPSS design processes and identify the underlying mechanisms of VCC in form roles and responsibilities of the providers, designers, managers and operators.

Case Study 1 – DairyCo

DairyCo is a major dairy manufacturing business that owns some of Australia's most iconic brands of milk-based products. The case study was conducted on a DairyCo facility that was implementing CPPSS for processing and packaging flavoured milk. This CPPSS comprised of equipment, tools and software that enabled smart sensing and actuating of dairy manufacturing. The interview participants consisted of eight experts of DairyCo's CPPSS.

DairyCo's CPPSS. On observing a growing demand in the flavoured milk market, DairyCo decided to build new manufacturing systems capable of handling the expected metrics like the bottles per minute and silo volume capacities. As the *initiator*, DairyCo floated tenders to potential providers and co-designed the CPPSS with the selected providers. Value-in-use was generated by gathering demand, usage, performance and waste data to enable continuous improvement. As shown in Figure 6 and signified using blue text, the proposed CPPSSDM was able to explain DairyCo's CPPSS design processes.

Findings from DairyCo. DairyCo *actor*s valued continuous improvement and competitive difference. *Problematisation* was dependent not only on the current customer demand but also on the future expectations of the business. *Interessement* was governed by such factors as quality, brand image and international standards compliance. During *Enrolment*, selection of collaborators depended on the goodwill, customer loyalty, commonality of goals and *actors*' geographical distribution. *Mobilisation* was the most complex step as it involved integration of multiple modules built by different providers to form a single CPPSS.

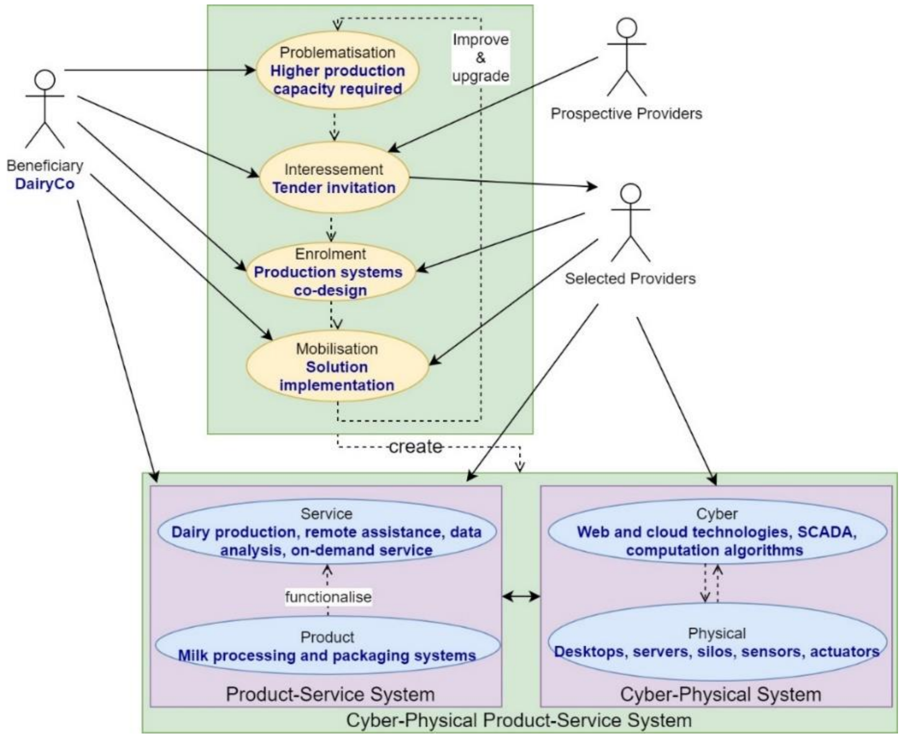

Figure 6: DairyCo CPPSSDM

Case Study 2 – PoolCo

PoolCo, a pioneer in providing pool management solutions, has one of the largest provider networks in Australia in addition to a global reach covering North America, Europe and Asia. The case study was conducted on a CPPSS implemented to serve customers with varied needs. This CPPSS consisted of the software application, related hardware and pool management services. The interview participants consisted of four experts of PoolCo's CPPSS.

PoolCo's CPPSS. To cater to the growing demand, PoolCo decided to take the proactive step of developing a pool management CPPSS. The CPPSS would enhance VCC through quality management, customer feedback, remote monitoring, task scheduling and status tracking. As the *initiator*, PoolCo first gauged its customers' expectations, profiles and needs by collaborating with a university research team. Then, PoolCo used the inferences to develop the software application by in collaborating with another university. Value-in-use was generated through remote assistance, scheduling customer-support, diagnosing water conditions and implementing corrective measures. As shown in Figure 7 and signified using blue text, the proposed CPPSSDM was able to explain PoolCo's CPPSS design processes.

Findings from PoolCo. PoolCo *actor*s valued competitive difference, solution holisticness, cost-effectiveness and long-term relationship. *Problematisation* focussed on PoolCo's business objectives, franchisees' expertise, customers' localisation and needs. *Interessement* involved PoolCo understanding the solution factors like ease of control, level of privacy and time commitment by consulting with the pool owners, franchisees and software developers. The software application was co-designed during *Enrolment* through regular communication and sharing of resources. Implementing the CPPSS in monitoring pool status, usage, and problems to provide appropriate solutions throughout all seasons marked the *Mobilisation*.

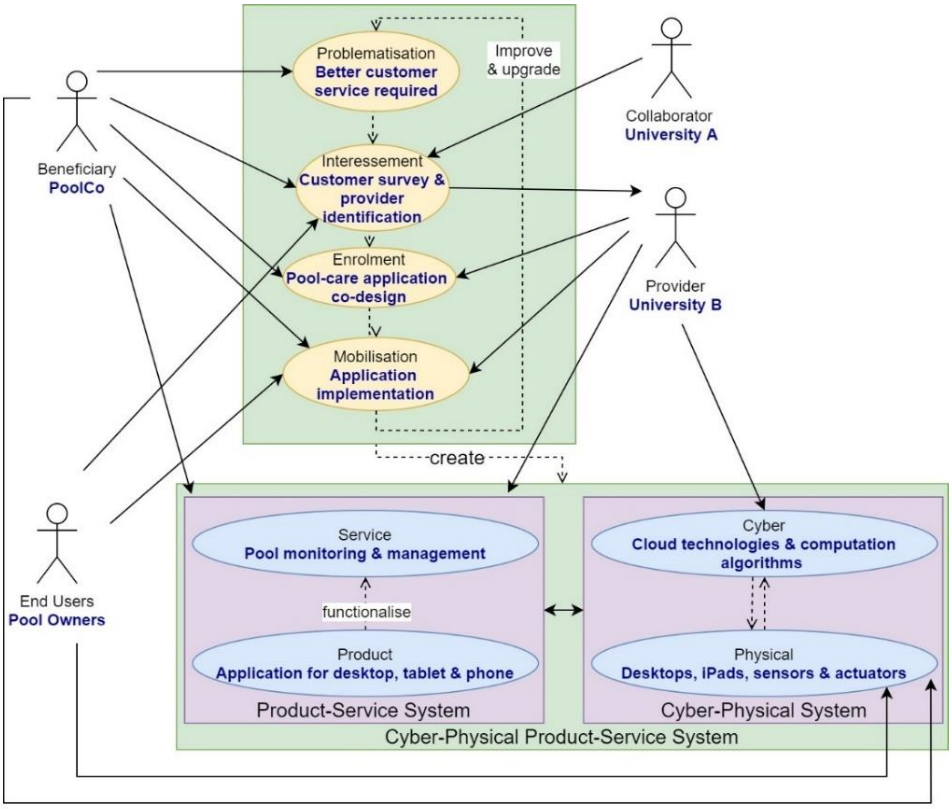

Figure 7: PoolCo CPPSSDM

Case Study 3 – HealthCo

HealthCo is a health informatics company that provides policy and procedure management solutions in Europe and Australasia. The case study was the easy-to-use application providing safe and efficient mobile bedside solution for hospitals. HealthCo continuously improves this offering through regular interactions with customers. This CPPSS comprised of the web-based application, hospital policies and customised services. The interview participants consisted of two experts of HealthCo's CPPSS.

HealthCo's CPPSS. The CPPSS under study was developed as a response to a tender floated by the Nation Health Service (NHS), United Kingdom, to improve hospital patient outcomes through paperwork reduction and workflow streamlining. The solution would provide nurses with real-time patient status to take appropriate actions as and when required. Collaborating with the *initiator* (hospital), HealthCo co-designed a CPPSS that assigned health score to each patient based on their health information and scheduled fitting patient care. Value-in-use was being generated by gathering patient care patterns to continuously improve hospital policies and procedures. As shown in Figure 8 and signified using blue text, the proposed CPPSSDM was able to explain HealthCo's CPPSS design processes.

Findings from HealthCo. In addition to the safety, risk and privacy factors, the hospitals highly valued the improved bed management through reduction in patient stay and waiting times. *Problematisation* mainly involved HealthCo taking proactive approaches to help hospitals identify problems in the current system. *Interessement* of new customers was obtained either through responding to tenders or by introducing the offerings to new hospitals. On *Enrolment*, CPPSS design and modification process always involved the end-users (nurses) to obtain a customised solution. *Mobilisation* involved sharing available health procedure information among the hospitals, enabling them to select the best patient care solution.

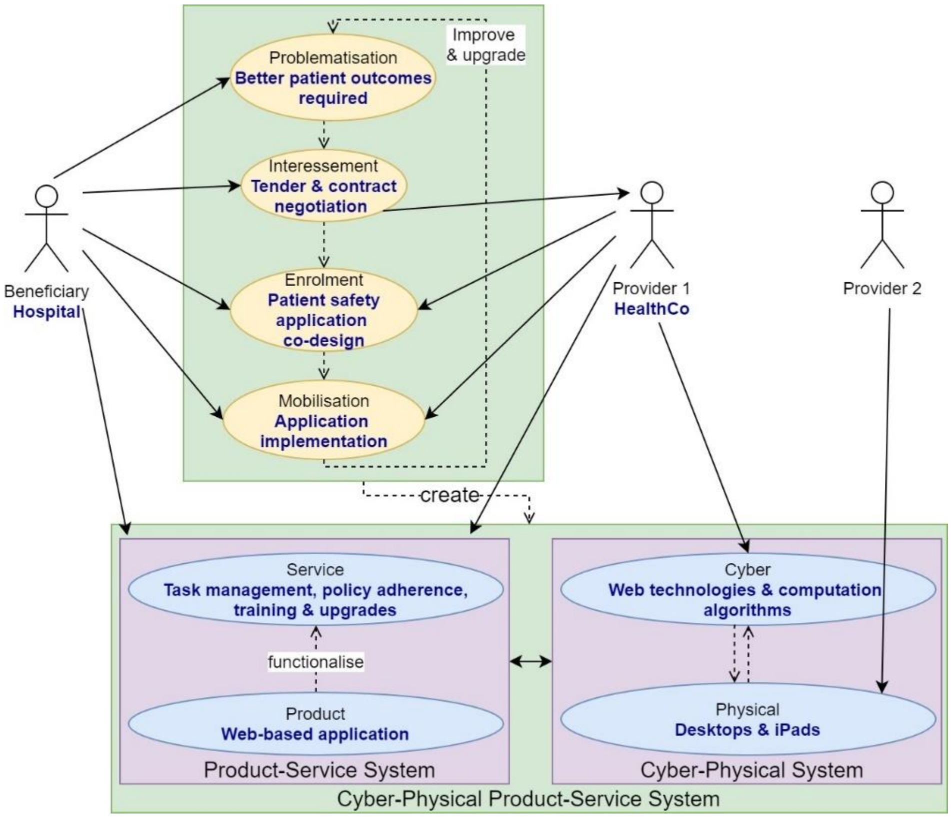

Figure 8: HealthCo CPPSSDM

Case Study 4 – VRCo

VRCo is a start-up company that designed human-computer interface solutions through virtual reality technology. The case study was a virtual-reality based locomotive board customised to various applications like entertainment, gaming, rehabilitation and real estate. The components in this CPPSS comprised the VR locomotion board, software and customisation. The interview participants were the two founders and an operator of VRCo.

VRCo's CPPSS. The co-founders conceived the CPPSS idea when they noticed a business opportunity due to the lack of real-feel locomotion in virtual reality technology. As an *initiator* VRCo developed the idea into a prototype and communicated with potential customers to gain their interest. Once customers were enrolled, VRCo co-designed customised locomotion boards using their field-specific requirements. As shown in Figure 9 and signified using blue text, the proposed CPPSSDM was able to explain VRCo's CPPSS design processes.

Findings from VRCo. In comparison to the previous three cases this company was a unique one since the provider was the *initiator*. *Problematisation* involved the co-founders identifying the VR problem using their skills and expertise. *Interessement* was achieved by communicating the ideas, building the prototype and attracting potential customers. During *Enrolment*, customer requirements were communicated to co-design customised CPPSSs. *Mobilisation* was accomplished through mutual collaboration and clear communication while operating the CPPSS. Value-in-use is generated through obtaining the device usage information and identifying opportunities to improve.

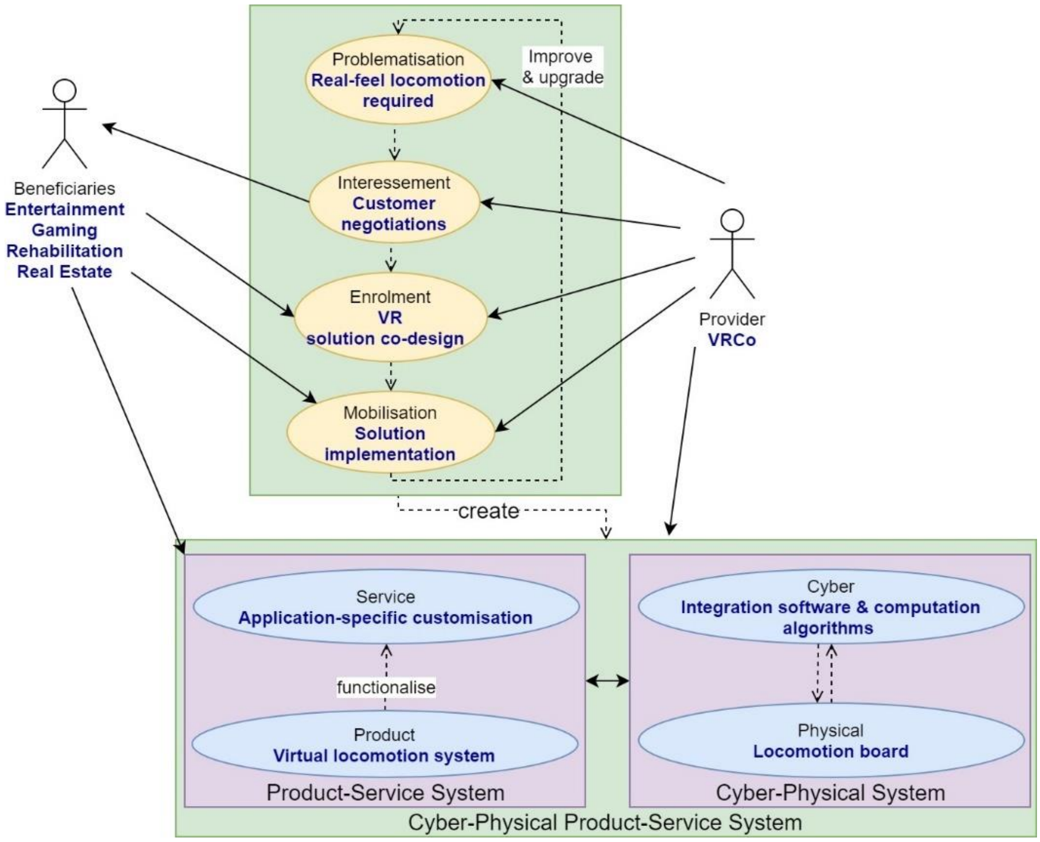

Figure 9: VRCo CPPSSDM

Cross-case Analysis

The four case-study organisations differed in terms of their industry sector, organisation size and business model. However, as summarised in Table 4, they were all involved in the design and implementation of CPPSS, either as a provider or a customer.

Table 4: CPPSS offering by each organisation

Case	*Actors*	Offering	Role	Business Model	Strength	Weakness
DairyCo	• DairyCo (designers, maintenance, managers, operators) • Providers (designers)	Processing and packaging solution	Customer & *Initiator*	Product-oriented	A large pool of *actor*s to collaborate	A high degree of complexity, leading to several issues after *Mobilisation*
PoolCo	• PoolCo (managers, engineers) • Collaborators (researchers, developers) • Customers (pool owners) • Franchisees (maintenance, service providers)	Mobile application	Customer, Provider & *Initiator*	Product and result-oriented	Close monitoring of customers	No direct contact with the end-users
HealthCo	• HealthCo (designers, service providers) • Customers (hospitals) • Operators (nurses)	Web-based application	Provider & *Follower*	Product-oriented	Direct interaction with the end-users	Difficulty communication due to geographically diverse customers
VRCo	• VRCo (designers, managers, service providers) • Customers (managers, operators) • Investors	Virtual locomotion device	Provider & *Initiator*	Product and use-oriented	Highly flexible in meeting users' needs	Lack of recognition of the CPPSS among public

The comparison between the case-study design processes and the CPPSSDM reference model helped identify each organisation's challenges and appropriate action for each of the four translation stages, as listed in Table 5.

Table 5: 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 VR	Develop prototype	Find buyers and investors	Marketing	Customisation	Collaborate	Evolving demands	Flexible customisation

Discussion

The case studies helped demonstrate the proposed reference model while providing an insight of the practices involved in CPPSS design and implementation. Information on the intricacies of VCC among *actor*s in the practitioner's world were also gathered. The comparison between their design processes and the reference model confirmed that the activities aligned with the organised and comprehensive four translation stages. *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; *Mobilisation* depended on communicating solutions. Four fundamental themes emerged from the case analysis that informed the design method further by making it more elaborate and instructive in each stage. The combined knowledge gained through the case studies helped refine the CPPSSDM reference model and define tasks and goals performed by the *actor*s in each of the four stages as illustrated in Figure 10. The themes are discussed below.

Value Co-creation and Communication

Communication was identified as a vital part of the design process in all the four stages as it facilitated VCC by revealing and addressing the dynamic needs of customers. As summarised in Table 6, communication was observed to be of two types: active and passive. Active communication took place during *Interessement* and *Enrolment*, where the *actor*s actively communicated with each other to attract interest of solving a problem. VCC was attained through negotiations, tenders, feedback, co-design and integration of resources. For example, DairyCo negotiated a higher level of customisation, PoolCo determined customer needs and franchisee opinions, HealthCo identified customer pain points and VRCo created awareness among potential customers. Passive communication occurred during the *Problematisation* and *Mobilisation* when the *actor*s passively communicated while operating the existing system and detecting new problems. VCC was achieved through analysing usage, market trends, system performance, shortfalls, waste excesses and customer behaviour to identify new customer problems and improvement opportunities. 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 tracked customer eye movements to develop customer behaviour profiles.

Table 6: Activities in each design method stage based on the four stages of CPPSSDM reference model

Stage	**Activity**	**Communication**	**Tasks**	**Techniques**
Problematisation	Identify & Set	Passive	Identify the requirements to set the priorities of the problems	Predictions, customer profiles and goal analysis.
Interessement	Convey & Negotiate	Active	Convey concerns and negotiate relationships and actor roles	Survey, tenders, contracts and agreements.
Enrolment	Integrate & Develop	Active	Integrate knowledge and resources to co-design solution	Contribute experiences, expertise and skill in the co-design process.
Mobilisation	Share & Study	Passive	Share the changes and study the value-in-use to detect a new problem or opportunities	Workshops, emails, training to share changes. Market trends and usage patterns to identify opportunities.

Initiation

The design process was triggered based on the *actor*s' value perception in solving a specific problem. Value perception helped develop the problem priority list and the worth for solutions. *Actor*s, provider or customer, could initiate the design process by actively negotiating requirements, targets, expectations, contractual terms, conditions and monetary relationships based on the priorities. DairyCo's end-users (CPPSS operator) were the *initiator* of most communication, VRCo (provider) itself was *initiator* to create awareness, PoolCo was both *initiator* and *follower* based on the context and HealthCo (provider) itself and its customers (the hospitals) were *initiators* at different instances.

Actor Roles

The customer's role was to list its requirements and to share its knowledge while the provider's role was to provide solutions, training and technical expertise. 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 VCC process. The customer was assured of continued support while the provider enjoyed a regular income with access to valuable system operation information.

Iterative Nature

The case studies showed that the design process was highly iterative. The iterations ensured a comprehensive co-creation of value and co-design of the solution through the collaboration between 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 stage. The loop then fed the customer problems detected during the value-in-use in *Mobilisation* into *Problematisation* to start a new iteration of the CPPSS design.

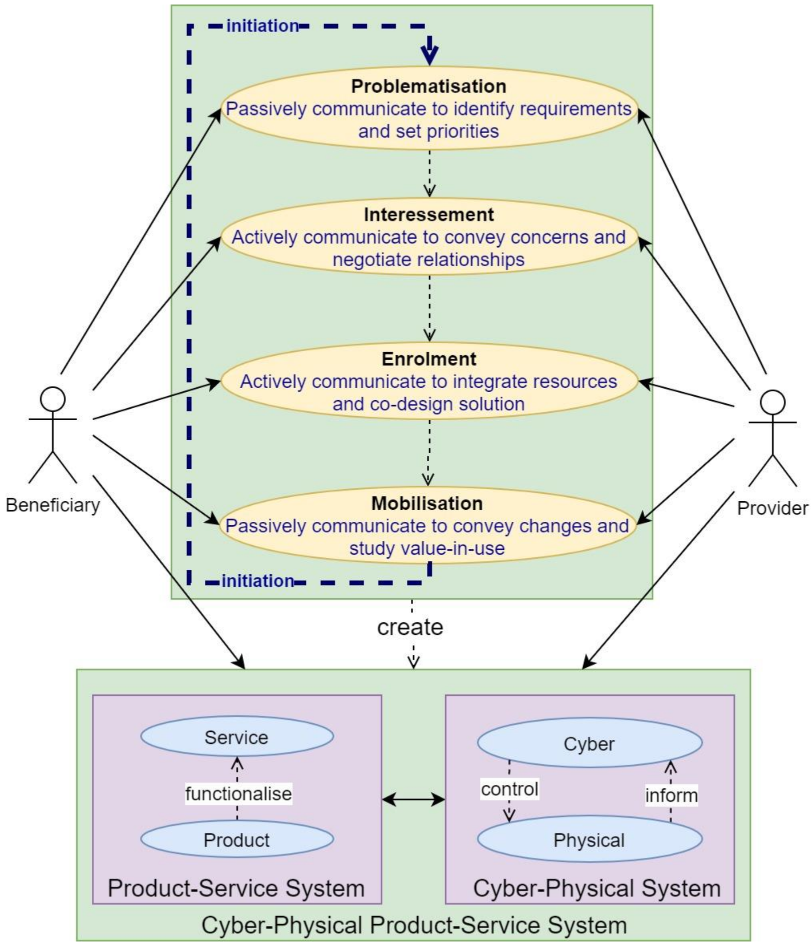

Figure 10: Refined CPPSSDM (refinements shown in blue text)

Conclusion

This research employed design science and case study research methods to develop a Cyber-physical product-service system design method. The literature has shown a link between service-dominant logic and actor-network theory. Accordingly, this paper developed a novel integrated CPPSSDM that adhered to PSS lifecycle. Where earlier design methods have contributed to either actor-dynamics or service science, this study integrates the two concepts into a single methodological approach. The proposed design method was evaluated using four case studies which showed that the proposed design method could provide a holistic design solution to providers, designers, manager and operators of CPPSS. The paper contributes a new definition, design method and research direction to PSS and CPPSS design literature by applying SDL-ANT inspired approach. The four-stage design process could be beneficial in project management practices by providing a structured approach towards executing projects involving CPPSS.

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