VERIFYING CONCEPTS FOR COMPLEX PRODUCT-SERVICE SYSTEM (COPSS) DESIGN

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ABSTRACT

With many complex product/system manufacturers facing intensified global competition, stricter environmental regulation, increased non-conformity risks and demand shifts towards customised life cycle solutions, product bundling with additional services is viewed as a way to support company growth and societal compliance. However, Product-Service Systems (PSS) inherit design complexity because of extended product life cycle, global service operation and modular customisation aspects. This is especially true for Complex Products and Systems (CoPS), facing significant challenges as regards concurrent engineering, system architecture, portfolio management or design collaboration. While some researchers advocate modifying New Product Development (NPD) approaches to include services, others propose PSS specific frameworks. This paper systematically investigates 119 design frameworks concerning CoPS applicability and covering idea-to-launch integrated design. For this purpose, all frameworks are analysed by matching CoPS design characteristics and process scope completeness with nine conceptual frameworks fulfilling both criteria. Moreover, cross framework comparison was completed in light of related topics derived from literature. Findings indicate that 63% of the frameworks are applicable for CoPS also regularly adopting integrated product-service design approaches. However, frameworks often fall short of product/service modularity, portfolio management and network collaboration considerations. Differences between hardware, software and service solution characteristics are further neglected. In addition, most frameworks concentrate on particular tasks, phases or service designs, but do not provide a holistic approach. Although it may be possible to combine frameworks, this is problematic as the research studies investigated represent distinct perspectives, with unique focus points and industry assumptions. Having obtained deeper insights into CoPS peculiarities and PSS development, an advanced conceptual CoPSS design framework is proposed.

Keywords: Complex Products and Systems (CoPS); Product-Service Systems (PSS); New Product Development (NPD); Design Concept; Modular Development; Portfolio Management
INTRODUCTION

*Product-Service System (PSS)* design and its underlying processes play a significant role in the success of both individual projects and long-term company performance. KPMG’s *Global Manufacturing Outlook* (2016) and PWC’s *Global Innovation 1000* (2017) studies outline significant innovation investments as well as high attention to design efficiency and effectiveness. In fact, *Research and Development (R&D)* expenditures of the top global companies have soared to $US 700bn in 2017, with GE, as a leading manufacturer alone spending $US 4.8bn or 4.0% of its revenues. To support the pursuit of engineering excellence and technological advancement, the EU has initiated the €77bn *Horizon 2020* programme, which also funds PSS projects. Current initiatives focus on product-service manufacturing intelligence, life cycle optimisation mechanisms and integrated design collaboration platforms (European Commission, 2017). Baines & Lightfoot (2013A+B) argue that PSS motivation especially arises when manufacturers face fierce competition in saturated markets; adding services is viewed as an effective growth strategy. However, product-service bundling requires substantial design considerations as evidenced by a rapid growth in publications. While *Scopus* (Elsevier, 2017) lists four relevant articles up to 2004, this figure increased to 82 in 2010 and 346 in 2016.

A great deal of research focused on PSS characteristics and business concepts being associated with organisational requirements, such as service and network capabilities, to create integrated delivery systems for competitive advantage (Mont, 2002; Baines et al., 2009A+B). Efficient and effective PSS designs thereby call for concurrent product and service engineering approaches with consideration of organisational constraints (Pawar et al., 2009; Vasantha et al., 2012). This is particularly important for *Complex Products and Systems (CoPS)* manufacturers who face extended non-conformity risks or variety of service expectations (Raddats et al., 2016). Design contribution from customers and supply partners is further recommended to align product/service modules, service delivery processes and communication networks (Johnson & Mena, 2008; Meier et al., 2010). To tackle increased design complexity, much attention was therefore given to methodology frameworks like MEPSS (Van Halen et al., 2005; Vasantha et al., 2012).

Within PSS research, it can be argued, that there are few comprehensive design frameworks which can be practically applied. While some approaches cover integrated product-service design from idea generation to market launch and improvement phase, others are limited to particular tasks or phases (Dehn &2, 2016). For example, Sakao et al.’s (2009B) *Service Explorer* is an add-on module to *Computer-Aided Design (CAD)*, whereas Berkovich et al. (2011) address *Requirements Engineering* only. However, by focusing on specific aspects, critical considerations such as product complexity, customer orientation and network collaboration are regularly ignored (Hobday, 1998; Vasantha et al., 2012; Dehn & Chicksand, 2016). Additionally, research demonstrates distinct terminologies and viewpoints from engineering, informatics or management disciplines (Boehm & Thomas, 2013), and Swejczewski et al. (2015) argue that there is little linkage with *New Product Development (NPD)*.

This paper reviews and evaluates the comprehensiveness and appropriateness for CoPS of 119 PSS design frameworks selected through a systematic literature search using *Scopus* (Tranfield et al., 2003; Chicksand et al., 2012). The analysis also addresses related design integration, modularisation, portfolio, network and sustainability factors. The research questions are:

1) How applicable are identified PSS design approaches for new CoPS development?

2) How should design processes be aligned to more effectively develop related PSS?
BACKGROUND

Complex Products & Systems (CoPS)

CoPS research dates back to the late 1980s with examples of aircraft, ships, air-/seaports, IT networks, transport systems or urban utilities. Davies et al. (2011, P.8) define CoPS as “high value capital goods systems, networks and infrastructural components, designed and produced by firms as one-offs or in small tailored batches to meet the requirements of large business or government customers”. Further characteristics of CoPS are long economic life with investment decisions and solution lead times in months or years (Hobday, 1998+2000; Ren & Yeo, 2006). Complexity arises from the large number of sub-systems and components being hierarchically organised as modules in the system architecture. This modularisation requires consideration of technical interfaces or design interdependencies, along with interdisciplinary system knowledge and management capabilities. Of particular concern are embedded IT and software developments, demanding precautions for future compatibility to prolong product life through later upgrade options (Ren & Yeo, 2006; Sosa et al., 2007). However, customisation might jeopardise standardisation efforts causing technological unpredictability (Ghosh et al., 2006). Davies et al. (2011) add technical norms, safety standards and emission limits as regulatory variance factors. Due to its large scope and social implications, multi-firm coalitions consisting of contractors, authorities, customers, suppliers and service providers are often necessary to achieve CoPS realisation. Such networks are usually managed in projects allowing for flexible concurrent design and production reconfiguration in case of network, technology or market changes (Hansen & Rush, 1998; Hobday et al., 2000).

Besides technology and service collaborations, CoPS design performance regularly depends on the company’s development structures and contribution from business functions. Eppinger & Chitkara (2006) thereby identified local outsourcing and captive offshoring trends globalising development as an important factor. The reasons for these trends are a focus on design cost reduction, development acceleration, information access and facilitated technology integration. However, localisation takes time often starting with simple design tasks before creating modules or entire products. Fostering specialisation, CoPS design organisations are also regularly broken down into component or sub-system teams (Sosa et al., 2004). This requires system architecture competence with standardised processes, transparent design and advanced communication being coordinated by the engineering headquarters (Tripathy & Eppinger, 2011). Observed CoPS design structures are thereby matrix organisations, competence centres or virtual enterprises with project-based approaches (Hobday, 2000; Zhang et al., 2008). To optimise the outcome, Gann & Salter (2000) call for strong engineering linkages and function interactions to effectively harness technological and operational capabilities. For example, Sales might provide insights into customer applications, whereas Procurement assists in partner selection. By following life cycle strategies, Service aspects of time between overhaul, equipment maintainability, retrofit/upgrade options and remote control must also be considered (Baines & Lightfoot, 2013B; Szwejczewski et al., 2015).

Product-Service Systems (PSS)

The concept of PSS was introduced by Goedkoop et al. (1999) and implies the creation of product-service combinations as enhanced value proposition. Separate product and service provision means dealing with several providers, and is considered less attractive to customers who prefer to reduce
operational risk and increase overall efficiency (Mont, 2002). Boehm & Thomas (2013, P.252) define PSS as “an integrated bundle of products and services, which aims at creating customer utility and generating value”. Base, intermediate or advanced services thereby extend the manufacturer’s offering. Product-related activities like consultancy, delivery, installation, training and warranty are understood as base services. Whereas intermediate services such as monitoring, helpdesk, overhaul or repair rather attempt to keep the product in condition. Advanced services are concerned with availability or performance measures, while ownership often remains with the manufacturer. Examples of advanced services include product leasing, pay-per-use concept, support agreement or bonus-malus system that potentially reduces resource waste by enhancing utilisation (Tukker, 2004; Baines & Lightfoot, 2013B). Variety in service demand might be explained by divergent operation capabilities, in-/outsourcing preferences, cultural peculiarities, governmental regulations or other geographic circumstances. Flexible service offerings based on modular mass customisation principles are therefore essential, but also increase design complexity (Hatfield, 2010; Yurtkulu et al., 2014).

How PSS requirements are fulfilled is a function of manufacturer organisation, corporate capabilities, service network and partner collaboration. Only if customer needs are correctly understood, specific product/service modules selected and process interlinkages aligned, underlying business models can successfully be realised (Johnson & Mena, 2008). For example, when ownership remains with the manufacturer and revenue depends on CoPS utilisation, availability becomes critical, requiring real-time communication and responsiveness in case of breakdowns. Advanced service design therefore often includes ICT concepts optimising inter-firm collaboration (Baines & Lightfoot, 2013A+B; Boehm & Thomas, 2013). To establish value networks, however, co-creation involving customers, suppliers or service providers is indispensable (Aurich et al., 2009; Harrington & Srai, 2012). Contributions from internal business functions are rated equally important. For example, Fischer et al. (2012) and Szweczyewski et al. (2015) emphasise Service input to application/logistics peculiarities, equipment maintainability, component evaluations or spare part solutions. Baxter et al. (2009) hence developed service knowledge management software facilitating PSS design. A central part of our research is to consider the effective coordination of such design projects, with various contributors, and attention to design frameworks and process tools (Vasantha et al., 2012; Boehm & Thomas, 2013; Dehn & Chicksand, 2016).

**General Design Frameworks**

Systematic approaches are required for the efficient and effective development of complex solutions coordinating various network contributors and concurrent design tasks. Taking market/technology uncertainties and varying customer preferences again into account, modularisation concepts not only enable work division and risk reduction among design partners but also enhance flexibility in service provision (Hatfield, 2010; Meier & Uhlmann, 2012). This becomes particularly relevant in the case of mechanics, electronics and software interdependencies, where life cycle and obsolescence variance affects service delivery and portfolio management (Berkovich et al., 2011; Kernschmidt et al., 2013). Compatibility and interconnectivity are crucial aspects, as shorter product life cycles are widely observed, leading to higher development frequency and exerting pressure on time-to-market efficiency. However, to coordinate network design, established processes are needed providing fundamental project rules, transparency and guidance (Cooper, 2008; Edgett, 2011). Sturm & Bading (2008) assert the need for operations to embrace simultaneous and aligned product-service development to generate intertwining PSS solutions. Although substantial PSS design research has
been conducted, factors of integrated design, concurrent engineering, life cycle orientation, mass customisation and network collaboration are only partially covered (Tukker, 2013; Szwejczewski et al., 2015).

To adequately manage project resources, time-to-market and solution costs, Royce (1970) and Pahl & Beitz (1977) were among the first to highlight the relevance of systematic design. Based on their principles, delineated in Figure 1, numerous frameworks and guidelines have been devised to suit different product and industry settings (Booz Allen Hamilton, 1982; Cooper 1983+2008+2013; Boehm, 1988; VDI 1993+2004; Van Halen et al., 2005; IABG, 2006; Unger & Eppinger, 2011; Pezotta et al., 2012; Marques et al., 2013). The Stage Gate Model, as depicted in Figure 2, appears to be most commonly applied within B2B manufacturing (Edgett, 2011; Cooper, 2013; Roland Berger, 2013; Szwejczewski et al., 2015). Concerning PSS design, authors such as Meier et al. (2010) and Szwejczewski et al. (2015) recommend NPD framework extensions, whereas Kim et al. (2015) propose New Service Development (NSD) based approaches for service providers transforming to system integrators. Recognised service modelling tools such as ServQual, Service Blueprinting and Service Explorer facilitate PSS design (Cavalieri & Pezotta, 2012). However, caution is required when integrating design tools or combining frameworks as each inherit distinct focus points, assumptions and shortcomings, which might ignore relevant PSS business aspects or mislead product-service design (Vasantha et al., 2012; Dehn & Chicksand, 2016). For CoPS design, solution costs play another significant factor with 80% of product-related costs being fixed during initial design, requiring regular project reviews and sufficient cost control (Hobday, 2000; Roland Berger, 2013+2017).

![Figure 1 - Systematic Product Development Approach](source)

![Figure 2 - Stage Gate Model for Product Development](source)
METHODOLOGY

Research Strategy & Design

Given the research questions, evaluating PSS development frameworks and their suitability for CoPS, an extensive systematic literature review strategy was chosen. With the PSS field maturing, the purpose was to review, critique and potentially reconceptualise the multi-disciplinary knowledge base on PSS and CoPS design (Torraco, 2005; vom Brocke et al., 2009). In following predefined stages and applying techniques, as suggested by Tranfield et al. (2003), bias and errors were significantly reduced. A panel consisting of three researchers from different disciplines, with further practitioner verification, was established. In contrast, a traditional review was rejected because of its selective approach and lack of transparency. Additional decisions had to be made on article analysis and data synthesis methods. A Narrative Review was considered to be short-sighted and not sufficient to reach the full research potential. Meta-Analysis, even when supported by Realist Synthesis to classify process concerns and design themes for reliable net effect measurement, was equally rated inappropriate as being primarily concerned with statistical analysis and quantitative findings (Cronin et al., 2008). Instead, dealing with qualitative management studies, interpretive and inductive Meta-Synthesis based on grounded theory principles of open coding and category identification was deemed to be the most appropriate approach to investigate design frameworks. To provide a holistic account of CoPSS design, ethnographic techniques of Lines of Argument Synthesis and Reciprocal Translations addressing discipline orientations, journal interests and author motives were partly applied (Tranfield et al., 2003). Figure 3 illustrates the research design.

![Figure 3 - Literature Review Approach Overview](image)

Literature Review Approach

This review builds on Dehn & Chicksand’s (2016) literature analysis which encompassed the search terms product-service systems, hybrid products, servitisation, advanced services, service design and new service development returning 712 journal articles published between 01/2000 and 12/2015. Subsequent shortlisting to 166 articles was achieved through abstract reading, with a further eight articles added from the reference lists of Boehm & Thomas (2013) and Tukker (2013). Strategy formulations, project prioritisations, procedure adjustments, standard design techniques and general knowledge tools were not considered. Also excluded were software products or web services as well as specific articles about non-industrial goods sectors like consumer textile, food & dairy, health care or public services. Analysis was performed using a template within an Excel spreadsheet extracting article purpose, author motives, industry application, research approach,
framework scope and study findings (Tranfield et al., 2003; Bazeley, 2009). Whereas the first review examined theory foundations, framework themes, design contributors and interaction levels, this review sheds light specifically upon the applicability for CoPS and targets comprehensive framework design. A revaluation of Dehn & Chicksand’s (2016) framework list revealed minor corrections only, replacing Aifaoui et al. (2006) by Aurich et al. (2006) and reducing Resta et al.’s (2015) design scope to PSS implementation and continuous improvement.

**Design Model Categorisation**

For CoPSS framework determination, a matrix overview was elaborated as recommended by Abbott (2014). The frameworks were categorised as concerns their appropriateness to general CoPS characteristics, and inherent process stages compared with systematic design approaches (Figure 1). This categorisation enhanced cross-framework analysis, ensuring that only frameworks relevant to CoPS were included and raising our awareness about process specific factors. Additionally, a text and model screening was performed to confirm previous scope assessments, distinguishing between NPD, NSD or PSS frameworks (Cottrell, 2011; Altheide & Schneider, 2013). Froehle & Roth (2007), for example, focused purely on service design, not creating a PSS framework. Referring back, CoPS appropriateness was confirmed where frameworks were tested through equivalent industry cases (Hobday, 1998+2000; Ren & Yeo, 2006; Davies et al., 2011). Proposals providing mere illustrations or studying less complex products were also accepted unless the frameworks violated customer involvement principles or CoPS characteristics of B2B investment goods, extensive product life and small batch manufacturing. Comprehensiveness was acknowledged if the framework covered phases of idea generation, project planning, design conduct, market preparation and post launch upgrade. This approach was chosen as the frameworks reflect study summaries from various disciplines following their own agendas, which further depend on individual writing skills or journal policies. Potential variance in interpretation prevented a stricter framework matrix categorisation (Bryman & Bell, 2007; Altheide & Schneider, 2013).

**Design Model Assessments**

From analysing the frameworks, it was evident that only few satisfied both criteria. These were investigated in more detail as regards to model purpose, research perspective, underlying concept, design concerns, and whether they applied tools or design techniques. Besides outlining key aspects of the framework, application usefulness was also rated based upon the author’s shortcomings and concerns. In addition, differences between the selected frameworks with varying contexts were investigated (see dark green box Table 1), with further insights gained from focused frameworks (see light green box Table 1). Particular attention was thereby paid to integrated design, modularisation, system architecture, portfolio management, technology integration and network collaboration stated as CoPS relevant. Sustainability aspects of resource efficiency, solution replicability or optimal consumption were also considered (Ghosh et al., 2006; Meier & Uhlmann, 2012). The purpose was to obtain sufficient understanding and research evidence before initiating abductive inference (Schurz, 2008; Thornberg, 2012). Synthesis has therefore been achieved through recasting and completing design or process elements which led to the design of a new conceptual CoPSS development framework for verification within industry and academia. By outlining concerns and gaps neglected to date, this contribution moreover attempts to stimulate the PSS design debate, signpost CoPS research and foster inter-disciplinary collaboration (Hart, 1998; Bryman & Bell, 2007).
RESULTS & DISCUSSION

Out of the 119 frameworks investigated, 38 cover NSD or NPD as a potential supplement for PSS. From the remaining 81 frameworks, 75 apply integrated product-service design. Only six frameworks address separate product and service approaches. Thus, the actual divide between integrated PSS design and separate product-service design might be 63% to 37%. The reason for this split might be the selection of service-oriented keywords within Dehn & Chicksand’s (2016) initial review. Their review further refers to Meier et al. (2010) and Szwiejczewski et al. (2015) who consider NSD as add-on to extant NPD processes to develop PSS. Acknowledging the manufacturers’ heritage, we agree to this view of advancing NPD approaches but advocate integrated and concurrent product-service development to avoid inefficiencies during design or later operations. Thus, CAD software might be complemented by Service Blueprinting modules covering product life cycle, customer expectation or service delivery evaluations (Komoto & Tomiyama, 2008; Sakao et al., 2009B). However, such modules must be interconnected to directly reflect change implications on product-service design, business model and value generation (Kernschmidt et al., 2013; Windahl, 2015). Baxter et al. (2009) and Vasantha et al. (2012) also demand formal design software ontology for mutual understanding between hardware, software and service fractions.

Such considerations similarly apply to task/phase focused design versus comprehensive frameworks. Only 17 idea-to-launch design frameworks were identified. Decomposing our preceding example, Sakao et al. (2009B) focused on the creation of a service modelling tool allowing for product-service conceptualisation and business model verification. Yet doubts are prevalent as concerns the following questions: Which risks are associated with each business model and how are these to be evaluated? What product or service changes are necessary to enable alternative business models? Which technology/market changes might cause network disruptions? Additional input could clarify module cost versus business value preferences, product life extension potentials, 3D printing and after sales concepts or data/process technology advancements (Davies et al., 2011; Yurtkulu et al., 2014; Roland Berger, 2017). As propagated in the Stage Gate Model literature, cross-functional teams acting in inter-firm collaboration networks and following systematic design processes with defined deliverables and work packages generally address such questions (Cooper, 2008; Edgett, 2011). Zhang et al.’s (2012) framework therefore bundles several knowledge reuse models of Design Structure Matrix (DSM), Computer-Aided Design (CAD) and Product Data Management (PDM) to cover the entire product life from early design until its disposal. Sakao et al. (2009B) equally admit design procedure embedment weaknesses.

How applicable are identified PSS design approaches for new CoPS development?

Besides content and scope related concerns, the applicability for CoPS design was research focus. Evaluations based on CoPS examples and characteristics rated 33 frameworks as directly associated and another 42 frameworks suitable for CoPS industries (Hobday, 1998). For example, while Hew et al.’s (2001) airport construction process framework clearly belongs into the former category, Sakao et al.’s (2009B) blueprinting module being applied to washing machine services was also considered applicable for airport or defence industries and therefore counted as suitable for CoPS. Contrarily, 44 frameworks were rejected for violating CoPS characteristics by either focusing on B2C concepts such as car rental services or dealing with mass solutions like machinery tools (Yoon et al., 2012; Chen, 2015). Table 1 separates CoPS applicable frameworks (green boxes) from rejected ones (yellow
Also distinguishing between phase focused and idea-to-launch approaches. As a result, the elaborated matrix confirms Boehm & Thomas (2013), stating PSS opportunities from simple products to complex systems in both B2B and B2C sectors. However, mass PSS design approaches had to be excluded from further analysis, restricting the knowledge pool to 75 frameworks. This is because first, customer behaviour and decision-making differs in B2B and B2C settings with consumers often valuing fashion trends, life style or artefact control over long term costs and resource incentives (Tukker, 2013), second, there are general differences in product distribution, customer interaction or network collaboration with CoPS representing highly customised solutions (Hobday, 1998), and third because of CoPS inherent technological or structural complexity consisting of numerous sub-systems from various disciplines (Berkovich et al., 2011; Davies et al., 2011).
propose a spiral model which indicates competence increases through continuous development but lack detailed information about later life phases concerning improvements or generation designs. Equally following a systematic design, Clayton et al.’s (2012) framework is salient in the way of integrating the Input-Process-Output Model and Song et al.’s (2015) as regards the organisation level oriented setup. Contrasting, Harrington & Srai (2012) and Zhang et al. (2012) apply another perspective with the former coordinating global engineering networks while the latter managing life cycle design knowledge. However, both appear to pay little attention to environmental aspects such as language and culture, organisation structures or political interests (Tripathy & Eppinger, 2011). Examining management structures, a central entity seems to be responsible in most frameworks but Wang et al. (2011A+B) exclude Requirements Engineering as prepared input for conceptual design. It is only Aurich et al. (2006) who reflect separate service design entities, and Song et al. (2015) split into actual design process and business model elaboration.

CoPS related design factors are further differently covered in the frameworks investigated. While Song et al. (2015) convince in business contexts, the authors state modularisation weaknesses which are crucial for CoPS design. This is instead the focus of Wang et al. (2011A+B) with Maltzman et al. (2005) and Aurich et al. (2006) serving as additional references. Cost influence factors of portfolio management, system architecture and product/service standardisation are further addressed by the authors. Alonso-Rasgado & Thompson (2006) similarly seem to combine such pre-designed modules to create customised PSS. However, only Wang et al. (2011A+B) refer to family design as an integral part enabling upfront variance planning. Conversely, PSS co-creation, network collaboration and life cycle design with deviations in intensity are present in every framework. Most design approaches are nevertheless unspecific in the degree of customer co-creation - some let assume permanent involvement whereas others value phase-oriented contributions (Aurich et al., 2009; Meroni & Sangiorgi, 2011). By dealing with high complexity, regular exchange with lead customers might be most appropriate to ensure market acceptance (Hobday et al., 2000; Davies et al., 2011). As regards design networks, disagreeing with Johnson & Mena (2008) and confirming Maltzman et al. (2005), close collaboration should solely encompass direct PSS related integrator, manufacturer, service provider and customer exchange processes to avoid coordination overload. The manufacturer nevertheless needs to deal with critical sub-suppliers accordingly. Referring to life cycle design, all frameworks comprise initial post-launch PSS improvements, whereas Harrington & Srai (2012), Pezzotta et al. (2012) and Zhang et al. (2012) further include upgrades and product disposal. Considering stricter environmental regulations, this aspect could gain additional relevance in future (Davies et al., 2011; Roland Berger, 2017).
### Table 2 – Overview of holistic CoPSS Design Frameworks from PSS Literature

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<tr>
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<tbody>
<tr>
<td>Integrated hardware/software and service support design methodology for total care product creation</td>
<td>Modular life cycle service design being linked to the product engineering and acting in PSS networks</td>
<td>Phase based framework determining task inputs, process activities and expected deliverables</td>
</tr>
<tr>
<td><strong>Perspective:</strong> Business + Engineering</td>
<td><strong>Perspective:</strong> Technical Service Engineering</td>
<td><strong>Perspective:</strong> Process Management</td>
</tr>
<tr>
<td><strong>Concept:</strong> Systematic Product-Service Combination</td>
<td><strong>Concept:</strong> Classic Stage Gate Model</td>
<td><strong>Concept:</strong> Phase Model including Feedback Loops</td>
</tr>
<tr>
<td><strong>Concerns:</strong> Service Delivery, Resources &amp; B2B ICT</td>
<td><strong>Concerns:</strong> Modularisation, Network &amp; Processes</td>
<td><strong>Concerns:</strong> Design Phase Input-Output Activities</td>
</tr>
<tr>
<td><strong>Techniques:</strong> Quality Function Deployment (QFD)</td>
<td><strong>Techniques:</strong> Process Linking and Modularisation</td>
<td><strong>Techniques:</strong> Input-Process-Output Model (IPO)</td>
</tr>
<tr>
<td><strong>Design Tools:</strong> Service Modelling and Blueprinting</td>
<td><strong>Design Tools:</strong> Service Modelling and Blueprinting</td>
<td><strong>Design Tools:</strong> Process Mapping</td>
</tr>
<tr>
<td><strong>Comments:</strong> NPD Projects trigger Services Design</td>
<td><strong>Comments:</strong> Integrated Approaches of PSS Design</td>
<td><strong>Comments:</strong> Integrated Approaches of PSS Design</td>
</tr>
</tbody>
</table>

#### Global PSS Engineering Network Configuration

<table>
<thead>
<tr>
<th>Phase</th>
<th>Manager/Lead</th>
<th>Core Skills</th>
<th>Support Skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>Engineering, Management</td>
<td>Engineering, Management</td>
<td>Support, Management</td>
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<tr>
<td>Planning</td>
<td>Engineering, Management</td>
<td>Engineering, Management</td>
<td>Support, Management</td>
</tr>
<tr>
<td>Development</td>
<td>Engineering, Management</td>
<td>Engineering, Management</td>
<td>Support, Management</td>
</tr>
<tr>
<td>Integration</td>
<td>Engineering, Management</td>
<td>Engineering, Management</td>
<td>Support, Management</td>
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#### Design for Network Solutions

<table>
<thead>
<tr>
<th>Network Product Planning</th>
<th>PSS Engineering Network Configuration</th>
</tr>
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<tbody>
<tr>
<td>Design</td>
<td>Element 1</td>
</tr>
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<td>Element 2</td>
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<td></td>
<td>Element 3</td>
</tr>
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#### Design Tool Process-Task Layer

- **Product Modulisation**: Knowledge Modelling, Upgrading & Disposal, Needs Prioritization, Product Functions, Function List
- **Functional Modulisation**: Modelling, Knowledge Modelling, Needs Prioritization, Product Functions, Function List
- **Service Modulisation**: Knowledge Modelling, Upgrading & Disposal, Needs Prioritization, Product Functions, Function List
How should design processes be aligned to more effectively develop related PSS?

Adjusted systematic approaches to Pahl et al. (2007) or Cooper (2008) provide top level guidance throughout design. Developing from scratch thereby means to accomplish idea generation, project planning, concept design, detailed design, product/service validation, business preparation, market implementation and global roll-out. Continuous improvement and next generation development should be further considered especially for CoPS. In this paper, we propose that frameworks should include all these stages (Aurich et al., 2006; Pezzotta et al., 2012). The advantage is their general applicability, which allows for variation on subjacent levels, assigning company-specific procedures (Pahl et al., 2007). However, conventional NPD approaches often representing *Stage Gate Models* are familiar but insufficient for CoPS manufacturers transforming to service providers and require adjustments towards PSS including service design (Meier et al., 2010; Szwejczewski et al., 2015). Fischer et al. (2012) even proclaim integrated product-service design to generate more efficient or effective value packages avoiding waste and optimising consumption. In fact, through constant alignment, positive effects on technical compositions and operations interfaces can be expected (Sturm & Bading, 2008; Kernschmidt et al., 2013). This view is shared by the panel. Alternatively proposed spiral, V- or W-models contain similar design phases but rather highlight PSS competence extension, top-down decomposition or planning-realisation aspects (Wang et al., 2011A+B, Pezzotta et al., 2012). Yet over-complex structures impede practitioner ascertainability and perceptiveness, which led to the panel decision of adopting acknowledged linear approaches (Pahl et al., 2007; Van de Ven, 2007; Edgett, 2011). Aurich et al. (2006) represent such a format but fail in fulfilling the integrated design requirements. However, we agree there is a need to divide product and service design responsibility, which regularly lie within different organisations (Fischer et al., 2012).

It is evident that framework network aspects and family concepts appear underrepresented. While Maltzman et al. (2005), Aurich et al. (2006) and Wang et al. (2011A+B) provide network indicating support graphics, Harrington & Srai (2012) created a role matrix coordinating multi-organisational design tasks. However, the importance of value chain collaboration is not instantaneously obvious. CoPS development usually requires concurrent engineering, i.e. the simultaneous generation of sub-systems or components by several design teams (Hansen & Rush, 1998; Gann & Salter, 2000). Associated activities thereby belong to lower level coordination, and multi-organisational design illustration might be achieved through layers representing the integrated PSS design process within the manufacturer organisation and industry network environment. Figure 4 depicts our CoPSS design framework suggestion that is based primarily on Aurich et al. (2006). Concerning identified themes of system architecture, modularisation, standardisation and family design, Wang et al. (2011A+B) deliver the most advanced framework. However, the apparently technical design related framework potentially disregards business model and corporate strategy reflections calling for conceptual abstractness. Nevertheless, the approach is valid in lower level design as shown in Figure 5. Thus, after conducting *Requirements Engineering* with definition of business model and solution variants, CoPSS family planning might be initiated during conceptual design based on a lead development followed by derivate projects. At this stage, portfolio management plays a crucial role in suggesting standard modules and services for family design integration. Considerations also include hardware, software and service long term compatibility factors (Du et al., 2001; Jose & Tollenaere, 2005). To increase design efficiency, implying certain familiarity, Cooper (2008) recommends process and deliverable downsizing for derivate developments, module modifications or design improvements.
Product and Service Innovation Process Framework

Source: adapted from Aurich et al. (2006) and Marques et al. (2013) including Meier et al. (2010) & Johnson et al. (2008)

Figure 4 - CoPSS Network Design Process Framework

Example Product-Service Family Design Concept

Source: based on Du et al. (2001), Jose & Tollenaere (2005), Aurich et al. (2006+2009), Wang et al. (2011A+B), Marques et al. (2013)

Figure 5 - CoPSS Modular Family Roadmap Concept
CONCLUSION

The concept of PSS is gaining significant traction in different disciplines with recent research focusing on design approaches. However, PSS solutions vary according to product peculiarities, technological advancements, market conditions and customer preferences. CoPS, described as long-lasting high cost capital goods produced in one-off projects or small batches, are distinguished from mass products. In fact, CoPS solutions are usually customised, causing variance through application modifications, technology integrations, technical norms and authority regulations that impede modularisation and standardisation efforts. Design is further challenged by the complex system architecture comprising of several hierarchy levels of sub-systems, modules and components. Besides dealing with product mechanics, electronics and software elements, service design also needs to be integrated for optimised sustainable CoPSS development, enhancing product life cycle availability and performance. To obtain the best outcome on development cost, time-to-market and non-conformity risk, network collaborations should involve the manufacturer, integrator, service provider and customer. Family approaches divided into lead and time-shifted derivate projects might be chosen to realise portfolio synergies and to create economies of scale. Variation in underlying CoPSS business models and service package offerings is considered essential in the value proposition development, seeking the right balance of internal functions and external partner involvement.

Based on these design requirements, the research investigated 119 frameworks concerning their development scope, phase completeness and CoPS applicability. For this purpose, a matrix was created identifying nine comprehensive frameworks whereas numerous other frameworks solely focused on service design complementing NPD or addressed specific development tasks/ phases. Findings suggest that 63% of frameworks represent integrated product-service design. Although service design supplement is per se justifiable, significant combination challenges prevail. Similarly, task/phase-oriented approaches often neglect the overall picture and further implications. In addition, CoPS design applicability was also 63%, with nearly half directly referring to CoPS cases. Besides the in-depth analysis and comparison of shortlisted frameworks, identified themes were highlighted with reference to phase-oriented frameworks and additional design related literature. In conclusion, most selected frameworks reflect concurrent engineering at least in regards to the simultaneous product and service design. Life cycle orientation also seems to be an integral part but frameworks often lack substance in product/service modularity, portfolio management or network collaboration, with little attention paid to differences in hardware, software and service features. Finally no framework examined succeeded in all relevant themes and topics recognised. Since journal articles represent secondary data regularly based on individual case studies with underlying assumptions and perspectives, the ability to combine frameworks was considered questionable. The panel alternatively decided to develop a stage gate based holistic top-level CoPSS design framework, as introduced in the Figures 4+5. However, this framework requires validation in practice. Lower level task concept development with potential application of various design methods or support tools was out of scope of this study but definitely needs to be addressed in the future. Research should also be intensified towards product-service design integration, network collaboration, system architecture, modularisation design, portfolio management and family design.
REFERENCES


