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PSS design through Design for Supply Chain: State of the art review

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Abstract

Design for X (DfX) approaches are very important for designing products with a focus on whole lifecycle, to achieve cost reduction and product quality. The move to achieve competitiveness and unique offerings have resulted in the switch from a product to a Product Service Systems (PSS) business model. DfX concept is insufficient to address the complexity of PSS, therefore, additional concepts such as Design for Product Service Supportability (DfPSSu) are emerging. Existing research argued the role of support in ensuring customer satisfaction, revenue generation etc., which strengthens the motivation for PSS and servitization. The integration of support services into PSS has initiated the focus on DfPSSu, aiming at the synergic use of the different DfX approaches to concurrently support the services with the product features according their own heterogeneity. PSS complexity necessitates collaboration within the Supply Chain (SC) to deliver value to the customer, yet existing research focuses on individual firms. This highlights the importance of value creation in Design for SC (DfSC) in order to achieve competitiveness. This research would explore DfX from a value creation perspective while investigating the place of DfSC into the DfPSSu concept. This because DfSC encourages innovation in linking product design, process design and SC design together, according to the Concurrent Engineering paradigm. While there is need to DfSC, this idea is under-researched in literature. This paper would share the findings from a state of the art review of DfSC in relation to DfPSSu, identifying the evolution of the concept while identifying much research gap in understanding and application of this concept in theoretical and empirical research.

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1. Introduction

Nowadays the intensity of competition demands that companies must continuously innovate in order to remain competitive. For instance, changing customers need now requires traditional product manufacturers to adapt gradually to the Product Service System (PSS) model [1]. Yet the transition is laden with many challenges requiring the development of new capabilities and knowledge while establishing new collaborations to successfully deliver to the customer [2]. Indeed, PSSs are bundles of tangible products and intangible services systematically integrated with supporting infrastructures and networks. These are more complex than traditional products, necessitating different approaches in the design phase [3] in order to achieve customer satisfaction, organizational competitiveness and long-term sustainability [4]. PSS development requires designers and engineers to consider different functions and create a trade-off among them while considering both customers expectation and the firm's technical constraints [5] as well as external limitations from connected industries [6].

In this context, there are insufficient methodologies and tools to support companies and enable them avoid the servitization paradox in their attempt to move towards the integrated design of PSS components [7]–[9]. This is due to need for much interaction and decision-making between different organizational functions (e.g. product engineering and sales and marketing); and external actors within the Supply Chain (SC) which must be coordinated in order to deliver the PSS.

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Indeed, several stakeholders intervene along the entire lifecycle of the PSSs, starting from the concept phase (where the role of the customer is strategic), the design phase, (where different suppliers perspectives are harmonized to arrange the manufacturing and the ramp up), use, delivery and disposal stages. At the latter phases, major interaction with the customers requires more support by other actors such as the service providers and the spare parts suppliers. Based on the Design for Product Service Supportability (DfPSSu) approach [5], only [10] and [11] introduced a practical methodology, aimed at generating new PSS design knowledge and sharing this with relevant SC actors to foster the systematic integration of product and service components. This paper investigates the state of the art regarding the role of the SC in the PSS Design research context. By conducting a systematic review, it captures the theoretical corroboration for the Design for Supply Chain (DfSC) approach and its role in achieving DfPSSu in PSS context. Therefore, the paper is structured as follows: Section 2 provides the research context while section 3 explains the research methodology adopted. Section 4 presents the results derived from the analysis while section 5 provides detailed discussion to conclude in section 6 with areas for further research.

2. Research Context

New Product Development (NPD) employs traditional Design for X (DfX) approaches for Concurrent Engineering (CE) so that the design team can manage complexity that have an impact on the different “X contexts” [12].

DfX is an integrated approach to design products and processes for cost-effective, high-quality operations from design and manufacture (including fabrication, assembly and test) to disposal. More specifically, Design (or D) in DfX is interpreted as concurrent design of products and associated processes and systems. It means making decisions in product development related to products and processes while, ‘X’ in ‘DfX’ stands for *x+bility,* i.e. *life cycle process/certain product characteristics (x) + performance measures (bility)* [13].

In the product context, DfX approaches were aimed at enhancing the artefact according to a wide range of different functions to achieve a high degree of practical adoption and obtain important results [14]. In the last two decades, complexity has surged since traditional product manufacturers feel compelled to gradually move towards servitization, to deliver PSS their customers. In 1999, Goedkoop [15] gave the first definition of PSS as ‘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’. DfX methods support the PSS design process [16] to redesign or enhancing products in certain X dimensions, particularly those related to “service supportability”. Indeed, DfPSSu was introduced and defined as a synergic use of several criteria to enhance the design of the product features that could better support the delivery of connected services [5]. Its twofold aim is to maximize the customer value of the solution provided and minimize the cost of providing the solution during the whole lifecycle phases of the PSS.

Even when different stakeholders are involved in product design, its delivery is usually conducted without considering the SC impact of the decisions made, thereby resulting in loss of anticipated savings caused by high distribution and inventory costs [17]. This is even more important in the PSS context since the supporting network is a major component. The investment in innovative design and development processes provides a potential opportunity to deliver value to the customer but this opportunity may not be fully realized without proper coordination of the SC actors. Lack of SC coordination may result in higher procurement or logistics costs and higher delivery lead time. Therefore, the DfSC approach was developed and introduced in literature to take account of the role of the SC during the design phase in terms of coordination, collaboration and integration to deliver value to the customer [17].

Some authors [18], [19] stated that while product design requires the development process to be defined at early stages, the service design follows an iterative pattern adopting continuous improvement method to achieve the design solution: this is due to the nature of service development and delivery which includes supportability, information procurement etc. However, as suggested by Lean Product Development [20], [21], product needs a cyclical continuous improvement process during the entire development phase which considers its entire lifecycle. Compared to products, services are usually under-designed and unproductively developed in the early stages [22]; resulting in higher uncertainty from customer interaction during their delivery phase. As a result, this would require further design.

However, to develop PSS, product design and engineering methods are not suitable [23] and service has to be designed from the beginning of the PSS lifecycle to be able to adequately integrate these different components. If compared to physical products, services are generally under-designed and inefficiently developed [24] and traditional product design and engineering methods are not enough to develop PSS [3].

PSS combines both product and service elements in a single systematized bundle, hence the challenge associated with PSS design requires close collaboration among the SC. [18] developed a framework providing guidelines for PSS design, which highlighted the importance of stakeholders collaboration within the actor network. Traditionally, SC collaboration aims to deliver products to customers in order to optimize long-term profit for all SC partners and achieve competitive advantage [25]. Though SC coordination and integration is crucial to the success of the PSS [26], [27] the challenges of information sharing and knowledge management must be overcome by PSS stakeholders [26]. Supporting this issue, DfSC approach has much potential as its applicability by a computer production firm resulted in $1 billion cost saving [28], yet the approach is largely under researched in literature.

This study explores the relationship between SC and PSS design through the help of DfSC (a DfX approach), to understand its contribution to the DfPSSu approach. As stated earlier, the motivation for employing DfSC as a DfX approach is in order to improve competitiveness of the PSS offering for the provider firm and deliver value to the customer. DfPSSu has been built on this twofold perspective of provider and customer along the entire lifecycle of the PSS. This research wants to clarify how DfSC can extend the DfPSSu approach to better design the PSS while considering its supporting network.

The next section explains the approach employed in carrying out this research.

3. Research Methodology

This study employed a systematic literature review process for the investigation of the PSS design. The digital database used to select the papers has been Science Direct and the queries have been applied to all years and to all the types of publications available in order to maximize the results to the entire time-lapse and to the whole research context.

Since the paper is aimed at investigating the relationship existing between SC and PSS design through the help of DfX approaches, a twofold investigation has been performed: the first research was used to have a first glimpse of this context, trying to understand how SC has been considered in the PSS context and in its design so far. The second step was aimed at understanding the typical characteristics of the DfSC approach from the product context and discover its interaction with DfPSSu in the PSS design context. In addition, to understand how it can contribute to the extension of DfPSSu from a SC perspective.

In particular, the study was performed on all those papers using the first query ("PSS" OR "Product Service System" AND "Supply Chain"), which gave 32 results. The analysis of their abstracts led authors to consider only 6 of them as relevant for the paper purpose.

The second query instead led the authors to study the 35 results answering to DfSC context, discovering its characteristics and its typical guidelines. In addition, in this case, gauging the relevance of the papers by their abstracts, only 12 were considered for the study. In order to perform a comprehensive review, the 12 papers were analyzed along with their references. [29] echoed the lack of empirical research in this area of research, therefore, the authors identified other papers which were relevant from SCOPUS, Web of Science and EBSCO databases and included them in the review. The papers were analyzed based on number of citations and the findings are presented in Figure (1), making 18, which were reviewed, and analyzed in investigating the DfSC concept.

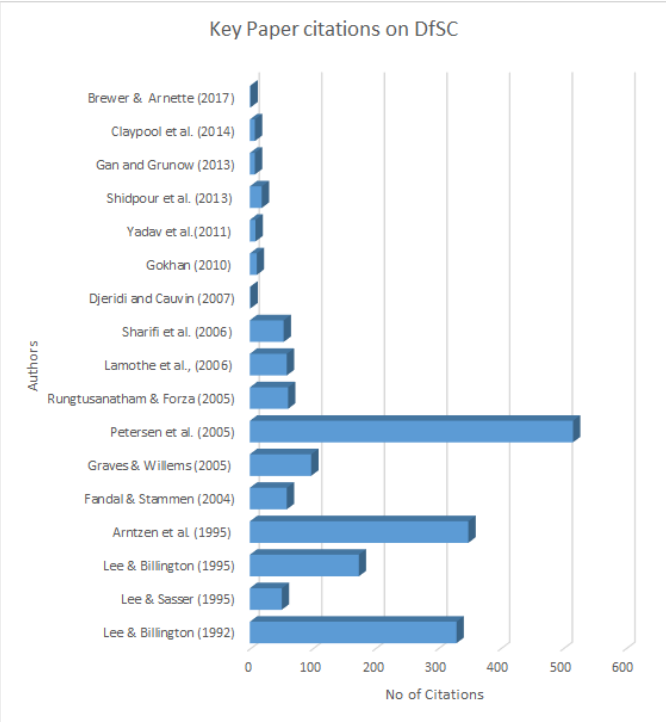

Fig. 1. Key paper citations in DfSC

Though all the papers presented in Figure (1) considered the DfSC approach, some of them did not make it a major area of focus. Most of the papers presented in Figure (1) have less than 100 citations despite the introduction of the concept in 1992 by [1]. The paper with the highest level of citation [27] has attracted that level of citation due to its focus on supplier involvement in NPD. While it touches on DfSC, this was not a major focus of the paper. This goes a long way to show there is limited research conducted on this approach. The other two papers with higher levels of citation do focus on DfSC, hence they have been employed in the review of this study and the findings are presented in Table (1) and in the following section. Generally, the more recent papers have lower levels of citations because they have yet to be widely read, while the older papers have higher levels of citations. All the papers with the higher levels of citation have been included in this review, which is discussed in the next section.

The investigation of the DfSC approach through this review is presented in the next section in order to understand its role and contribution to DfPSSu approach in supporting PSS design.

4. Value creation through DfSC in PSS Design

The evolution of the DfSC concept was adapted from the review of the papers shown in Figure (1). [28] was of particular interest in capturing the evolution. The findings are provided in Table (1) below and discussed.

The first authors [17] introduced the concept within product design process, but model development started with the following studies [44]. The following studies adopted different approaches to model development, which are listed in the Legend above. Latest research focusses on incorporating SC risks within model development.

DfSC Definition

Table (1) shows that after the introduction of the concept in 1992 by [17], modelling tools for DfSC were not developed until 1995. DfSC was explained as an approach to product and process design, which evaluates not only functionality and performance, but also cost and service implication for the supply chain [17]. [30] explained it as a concurrent redesign of a product and its production processes capturing logistics and distribution activities. [31] explained it as a collection of activities beyond internal operations which have an impact on product design and other SC tasks.

When DfSC efforts are focused on the supply side of the SC, rather than the entire SC, then [31] described it as 'Design for Procurement' (DfP). [29] believed that DfP is employed to

Table 1. Evolution of the DfSC

Author &Year	Context	Approach
Lee & Billington (1992)	Product design	N
Lee & Sasser (1995)	Concurrent product and process design including SC costs	St
Lee & Billington (1995)	Concurrent product and process design	Opt
Brewer & Arnette (1995)	Modelling NPD process with procurement as a key driver	MILP
Fandal & Stammen (2004)	Product life cycle perspective of strategic supply chain management	MILP
Graves & Willems (2005)	SC Decision model aimed at minimizing total SC costs	Opt
Lamothe et al (2006)	SC Cost Optimization model for choosing the variants for whole product family	MILP
Sharifi at al. (2006)	Concurrent Product design and SC design	Con
Gokhan et al (2010)	SC Decision model focused on minimizing SC costs over the product lifecycle	Int
Yadav et al (2011)	Process optimization in a DfSC environment	GA
Shidpour et al (2013)	Process optimization in a DfSC environment	MOLP & TOPSIS
Claypool *et al* (2014)	DfSC model for decision-making which incorporated Risks	MILP

Legend
N = None
Con = Conceptual framework
St = Stochastic DfSC model
Opt = Process Optimization model
Int = DfSC Integrated model
MILP = Mixed-Integer Linear Programming
GA = Genetic Algorithm
MOLP, FAHP & TOPSIS = Multi-objective linear programming and Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS).

enhance procurement activities in NPD to improve product performance in the long-term in sustainable way. The authors stated that DfP falls under the DfSC umbrella [31], also emphasizing the impact of product design on packaging, transportation, distribution and reverse logistics, calling it 'Design for Logistics' (DfL); as the recent emphasis on environmental sustainability has made reverse logistics a very important aspect of SCM. [32] differentiated DfL from DfSC by stating that DfSC is concerned with the management of the SC and its ability to react to changes e.g. demand fluctuation, customer service, production costs etc. On the other hand, DfL is concerned with the designers' functional requirements as well as logisticians' requirements such as availability, supportability, cost, quality and delivery time'. While DfSC focuses on the coordination of the different functions both upstream and downstream the supply chain, DfL focuses on industrial logistics, production logistics, distribution logistics and logistics support.

It is also related to Design For Reliability or the Design For Maintainability. It is interesting that researchers in DfP area believe this concept falls under the DfSC umbrella while researchers in DfL believe DfL is quite different from DfSC. [30]'s explanation of DfSC includes distribution and logistics activities, while [32] believes that DfL is separate from DfSC. The SC is defined as the network of organizations involved, through upstream and downstream linkages, in the different processes and activities that produce value in form of products and services in the hands of the ultimate consumer [33]. Procurement usually occurs upstream including early supplier involvement [28], [29] while logistics could occur both up and down the value stream. It appears DfL researchers believe that logistics activities involve more depth and complexity which is not apparent to other researchers, given the fact that most of this is usually outsourced. Clearly, there is need for further investigation of these ideas in future research activities. the findings also suggest that there is a need for a clearer and holistic definition of DfSC. The general idea of DfSC focuses on product design which takes account of impact on performance and SC success (cost, service and customer satisfaction) [31], [34]. This might have been sufficient in the past, but in order to move this research area forward and attract a higher level of interest from the research community there is need for a better definition of DfSC. This would help to clarify its alignment with DfP, DfL and DfPSSu.

DfSC Techniques

Table (1) showed that DfSC models were not always present in every publication. [29] designed an analytical model which was later redesigned to aid inventory and service management. [35] designed a mixed-integer multiproduct model to represent the extended SC network with the objective of maximising the 'sum over the time periods of the global after-tax profit in a standardized currency'. [36] developed and validated an inventory optimization model for extended SCs based on lead-time and added cost. [37] proposed a design approach that defines a product family and its supply chain simultaneously while facing a very diverse customer demand. [38]'s model was more comprehensive than the previous ones as it included manufacturing costs, customer satisfaction, demand generation, in-bound SC operation, and maximized profitability over the entire lifecycle of the product. [39] designed a conceptual framework termed the Concurrent Design Attribute Trade-Off Pyramid (CDA-TOP) to reflect a 3-layer hierarchy (tactical, operational and strategic levels) of product design and supply chain with design trade-off asymmetry. [28] improved the work started by [38] by incorporating a risk element into the model.
The literature review shows that the previous models were focused on inventory management or optimization with many of them assuming that demand data is static. The model developed by [37] improved on previous models by attempting to deal with demand variability. [28], on the other hand, focused on risk management as this is becoming more increasingly important in the current business environment.
The variety of models employed by different researchers explains why [31] described DfSC as having a very broad design concept for which no explicit considerations have been

developed. Though the authors cited above have employed different models for implementation, these have aimed at solving different SC problems like cost reduction, lead-time reduction etc. These problems are associated with efficiency, which was the focus of SCM in the past. Current competitive pressures and other emerging issues like risk and uncertainty, technological evolution, sustainability etc. require more than efficiency for the success of PSS [28], [29], [31]. The success of PSS lies in the ability to create value for the customer. Value creation has its own challenges particularly in PSS context, therefore innovation is crucial. There is need for a better definition or standardization of models, tools or guidelines for the implementation of DfSC approach. These tools should also embrace important aspects of innovation and value creation alongside efficiency. The idea of value creation is discussed in the next section.

5. Discussion

CE methodologies have been long established the need for product design activities to interact with supply chain management. and one of these approaches is DfSC. Although it was introduced since 1992, the literature review has shown the level of limited research around the subject and the under-adoption of the methodology in practice which is shown by very limited industrial case studies [29]. The question then arises as to why is the academic and industrial community reluctant to fully embrace these principles in comparison with other DfX approaches? [39] explained that it could be due to perceived complexity of cross-disciplinary research or simply due to unexhausted monodisciplinary research potentials. Also, it could be due to uncertain of the complexity and effort of concurrent design that industry is slow to adopt the methodology. However, the reality of emerging customer concern regarding the total cost of ownership, through life support and environmental impact [29], necessitates that PSS providers can no longer ignore the role of SC to achieve DfPSSu in PSS context

The importance of value creation in the delivery of PSS through DfSC could be explained by drawing a parallel from the evolution of quality management. In the past, quality was viewed as a characteristic or feature of a product with an inspection-based approach [40]. However, the recent focus on quality management views it as a strategic agenda, which embraces a Total Quality Management (TQM) approach from an organization-wide perspective [40], [41]. Likewise, in the past the emphasis was on SC efficiency, but as [33] stated, value added contributes to the competitiveness of entire SCs, because SCM should aim at the achievement of a more profitable outcome for all SC partners [33]. [41] called SCs value-added chains while [42] states that SCM involves the 1management of inter-organizational relationships including integration and coordination in order to build value for participating actors. The emphasis is not just the ability to deliver products or services with efficiency, rather ability to create value for the customer and strengthen the competitive position of the focal firm as well as other value chain actors. Value creation requires an understanding of customer requirement (which is dynamic) and a commitment to continuous improvement, which embraces innovation [29]. Innovation is defined as a 'process that begins with an invention, proceeds with the development of the inventions, and results in the introduction of a new product, process or service to the market-place' [43]. Clearly, innovation is key to employ DfSC approach like for value creation achieving DfPSSu in PSS context. Previous research by [5] identified different DfX approaches some from the provider's perspective and others from the customer perspective. DfSC is an approach which requires interaction between customer and supplier continuously.

6. Conclusions and Further Research

This paper has reviewed the state of the art regarding the role of the SC in the PSS Design research context. By conducting a systematic review, it captures the current understanding of DfSC. It examines various explanations of the DfSC concept to identify a gap in a formal definition of DfSC. The review of various models and methodologies employed in the DfSC environment showed that no explicit definition of model or tools have been developed. Therefore, there is need for a better definition or standardization of models, tools or guidelines for the implementation of DfSC approach, which embrace important aspects of innovation and value creation alongside efficiency. The limited publications in this area shows that the area has not attracted much interest in comparison with other DfX approaches, despite its importance in achieving DfPSSu in PSS context. The findings from this review should sound as a call for PSS researcher and NPD engineers to pay closer attention to the alignment between design activities and SC activities.

The research identifies many areas for further research especially the following:

- Formal definition of DfSC along with guidelines for the implementation of the approach
- Need for more empirical cases to validate the DfSC to help achieve DfPSSu in PSS context
- Further investigation of DfSC with DfPSSu in different PSS context such as use oriented , result oriented etc.
- Further investigation of DfSC with DfPSSu in different PSS context such as B2B or B2C examples.

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