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Product-Service Systems across Life Cycle

A Literature Review of Life Cycle Costing in the Product-Service System Context

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Abstract

A transition from a product-selling to a Product-Service Systems (PSS) business model incurs a transition in costs from customer to provider. Due to this shift in cost ownership, Life Cycle Costing (LCC) is used by providers and customers to better understand the PSS costs spanning from design to end-of-life. Through a literature review the paper determines that there are similarities in the approach to LCC for specific types of PSS e.g. availability type, but further research needs to be undertaken to identify commonalities between different types of PSS.
The review also discerned that the terminology for LCC is not consistent and sometimes it is used to identify only the costs incurred by a specific actor. Furthermore, the end-of-life stage and the implications of a second life for a remanufactured PSS in LCC are also yet to be fully understood. A number of challenges associated with obtaining quality data for costing within PSS were identified. These include the lack of availability, the relevancy due to use of pre-PSS data that does not reflect the redesign of products and services to fit in PSS and challenges associated with the design paradox. Finally, a lack of empirical studies is noted.

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1. Introduction

1.1. Background

A Product-Service System (PSS) is a system of tangible products and intangible services designed and combined so that they are jointly capable of fulfilling specific needs of customers [1]. A number of terms have been used to describe this type of business model, one of which is Integrated Product Service Offering (IPSO) [2] and another is Industrial Product Service Systems (IPS^2) [3]. All three are often used interchangeably and in this paper the term PSS is used.

One of the most compelling reasons for transitioning to PSS is the possibility of simultaneous cost minimization and environmental impact mitigation [1]. Studies have shown that this is true under certain circumstances [4] and therefore PSS is considered a key solution in the shift towards a more circular and relatively more sustainable economy.

The widely accepted narrative is that when transitioning from product to PSS oriented business models, a firm's focus shifts from maximizing products sold to maximizing output e.g. focus moves from the number of buses sold but on the number of people transported. Therefore, the products and their associated costs become costs for the provider and not for the customer [5]. In the previous example the shifted costs are those of the bus, petrol, driver, servicing, breakdown etc. The firm is then highly motivated to reduce these costs e.g. petrol consumption, which will indirectly impact positively on the environment [6].

This means that a provider transitioning towards PSS has to broaden his costing to include other life cycle stages. Therefore, many authors discuss the use of Life Cycle Costing (LCC) in the context of PSS, see e.g. Lindahl *et al.* [4], Erkoyuncu *et al.* [7], Aurich *et al.* [8], Sakao and Lindahl [9], and Datta and Roy [10]. Costing within the realms of PSS is also perceived to differ from traditional costing [10,11] because as products and services become more integrated and hence

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more complex so do their interrelational costs. This affects the cost model, the cost objects or elements included and the ways of monitoring them. The situation is made worse by the fact that services are co-created with the customer [12,13] and therefore the provider does not have complete control over the costs. Also costing often takes place during the design or bidding stage of a contract and therefore there is a lot of uncertainty attached to the costing process.

1.2. Objective and Research Questions

Costing is a recurring and important feature in PSS, a scientific field that is booming [14], and therefore *the objective of this study is to examine how authors use and describe LCC in the PSS context.* Based on the overall objective, three research questions (RQ) have been formulated:

- RQ1. *Is there a clear and common approach to conducting LCC in the context of PSS literature?* When taking into consideration the shift of costs between actors, then the following question also becomes relevant:
- RQ2. *What parameters of LCC are included in the context of PSS literature, both from a life cycle stage and actor perspective?*
- RQ3. *What data challenges are faced when conducting LCC in the context of PSS?*

Furthermore, the implications that the findings from RQs have on future research are presented.

1.3. Structure of the Paper

The rest of the paper is organized as follows. In Sections 2 the methodology is described respectfully. This is followed by Section 3 that presents findings, and Section 4 that describes conclusions. Section 5 presents future research.

2. Research Methodology

The first step was to find the pool from which to pull relevant literature. As Boehm and Thomas [5] point out, PSS is a multidisciplinary field, so for this study the following data sources: Scopus, ScienceDirect* and Web of Science, were used in order to cover the disciplines of engineering, environmental sciences, social sciences and economics. Emerald Insight and Business Source Premier were also used in order to broaden the research to include business management.

Initial database results included journal articles, conference papers and industry reports in order to get a strong overview. The deeper analysis however focused predominantly on peer-reviewed articles because conference papers only had abstracts available and industry reports were not found to be relevant. Finally, the search was limited to English language literature.

Deciding on search terms was also key to conducting the review. The first term concerns PSS, which goes under many names [5]. In their two reviews of the field Tukker [14] exclusively uses the term 'PSS' whether as Boehm and Thomas [5] use a number of different terms. Because this paper's focus lies within costing in PSS, the search is limited to the term "Product-Service System", thereby capturing researchers consciously exploring PSS. But, in order to get a broader view, the search engines were set to look within all text fields. Meaning that results came back even of documents that had only referenced PSS articles.

The second search term had to do with costing. The study focuses on LCC, but because LCC has many names and because it was important to place LCC within the broader costing context, the stem of the word "costing" was used i.e. "cost*". In this way all derivational suffixes and inflectional suffixes e.g. *–s:* costs, would be included. Because the word cost and its derivatives is widely used in the English language the search, where possible, was limited to the title, abstract and keywords in order to ensure that cost estimation would be a real component in the article.

The outcome of the search is presented in Table 1. The search yielded 699 articles. In the next step, duplicates were simultaneously removed and abstracts read in order to filter out non relevant articles. Unique hits were approximately 550. Out of those 166 were deemed to be relevant to costing within PSS after reading their abstracts titles and keywords. This included 36 conference proceedings for which only abstracts and titles were available. These were therefore only taken into consideration in the general findings.

Table 1 Search details and results

Databases	"PSS"	cost*	Results	Unique	Use
Scopus	all fields	ti-abs-key	424		
ScienceDirect	all fields	ti-abs-key	129		
Web of Science	Topic	Topic	49	Ca 550	166
Emerald Insight	all fields	all fields	68		
Business Source	all fields	all fields	29		

3. Findings

Findings from the literature review are described. It is done with a funnel approach, starting with the presentation of general findings about costing in the context of PSS. The second part discusses the LCC approach and the third LCC from the perspectives of the two main actors: the provider and the customer. In the fourth, issues concerning data quality and availability are presented.

3.1. General Findings

A cost is a monetary value of goods and services that producers and consumers purchase [9]. Costing or cost estimation is used in PSS literature to address a broad set of questions and provide information to a variety of stakeholders. Apart from comparing the costs of a traditional versus a PSS

* Although articles found via ScienceDirect should be included in the findings from Scopus, I found a couple of mismatches so I searched in both.

business model [2], costing is used as part of sustainability assessments [15], as a metric of customer value [16], affordability [7,17], for assessing the financial consequences of transition to PSS for a firm [18], provider pricing mechanisms for PSS [19], as input to PSS design, etc.

One of the most common challenges dealt with in literature is how to manage uncertainty impacts on cost estimation calculated during the design or bidding stage [10] often in the defense industry [17,20,21]. Most of the uncertainty is centered around the use stage [8,20,22,23] and has to do with service, maintenance and repairs. Less emphasis is put on the uncertainty of the disposal costs, despite the fact that large inherent uncertainties exist, e.g. the quality of returned products, costs of dismantling and profits. This resonates with Xu *et al.*'s [23] findings in 2008 about the future trends of cost engineering. Uncertainty is dealt with through a variety of qualitative and quantitative models such as complex probabilistic models and artificial intelligence [10,22–24].

Many of the studies are theoretical and discuss cost models, methods, frameworks, managing risks and uncertainties. In this review very few empirical studies or cases were identified. This is in line with Doualle *et al.*'s [15] and Lindahl *et al.*'s [2] findings.

By setting quite broad parameters in the literature, a substantial amount of relevant literature outside of the strict confines of PSS was identified i.e. articles that do not clearly identify themselves as PSS in the title, abstract or keywords but are relevant to costing to PSS. This could mean that because of the nature of costing a lot of research questions can be answered by piecing together information from different research areas. To illustrate this, the most comprehensive review of costing in PSS by Settanni *et al.* [11] uses a mixture of PSS and non PSS focused articles and seamlessly shifts between them in the argumentation. This is an indication that there is merit in conducting a more structured search into non PSS costing literature, not necessarily for finding a theoretical base, but for identifying relevant empirical or case studies.

3.2. Life Cycle Approach

In his definition of LCC almost 20 years ago Woodward [25] refers to the sum of *"all the cost factors relating to the asset during its operational life"*, whereas Asiedu and Gu [26] expand the object of the study from asset to product. In PSS literature Sakao and Lindahl [9] have the PSS as the object of study which is more in line with Settanni *et al.*'s [11] proposition not to focus on any single cost object but rather on cost objects that interact simultaneously. Practically, this might be quite a challenge for practitioners trying to calculate costs.

From a practical point of view, LCC is always tailored to fulfill the requirements of its intended use [26]. It is also a reflection of its cost object, the scope and boundaries, etc. [27]. Effectively that means that two different studies described as an LCC within PSS literature can vary very dramatically. The first research question is concerned with identifying a common approach to LCC within PSS. However rather than finding a common approach to LCC in PSS literature, it seems that there are common approaches within different types of PSS or PSS narratives. What is meant by different types of PSS is product- or use- or result- oriented [1] or function-, availability- or result-oriented business models [3]. Most researchers within costing actually limit their research to a specific type of contract [10,28,29] while others have the word PSS in the title but already from the abstract limit themselves to a specific type e.g. function oriented business models [30] or availability type contracts [11,17]. This proposition needs to be further investigated. Firstly, by searching for common themes within each PSS type and then between types to identify similarities. Secondly, by searching for the respective authors' motivations for the limits they place on their studies.

One perspective which is common in PSS literature, is the argument for using a life cycle perspective when assessing PSS [2,10,15]. In the costing section of their keynote article on PSS, Meier *et al.* [3] state, that through a deep understanding of the true costs of a contract i.e. life cycle costs, the firm has the potential to earn higher profit. Indeed, out of the relevant articles for costing found in the literature review, approximately three quarters make reference to some synonym of LCC e.g. Whole Life Cycle Costing (WLCC) [10], Whole Life Costing (WLC), Through-life Costing (TLC) [11,23].

A life cycle approach is important because in many types of PSS the product remains exclusively in the possession of the provider so a broader perspective is needed when focusing on costs [8]. Even if the product does not remain in the possession of the provider it is important to take on a life cycle costing approach because cost savings for other members may bring about a competitive advantage and add value. For example, Lindahl *et al.* [15] demonstrated that the costs savings from PSS, in comparison to traditional sales, were distributed to different members of the supply chain e.g. customer, provider or intermediary. As Doualle *et al.* [15] points out though, it is not clear in the study at least which member each costing saving is attributed to.

As discussed in section 3.1, there is a lack of research on the end-of-life stage [23]. The disposal or end-of-life stage may also lead to a potential second life for the product though refurbishment or remanufacturing [31]. It is not frequently discussed in literature if the second life should be included or not in an LCC. In one of the three LCC in PSS studies that Lindahl *et al.* [2] conducted, extended life through reuse was included in their estimations. According to PSS literature the possibility of cost-benefits from a second life is a strong driver for PSS and therefore omitting it from LCC calculations could in some cases have a strong impact on the results. In fact the inclusion of the second life is dependent on the definition of the PSS' life expectancy [23,25] (see Woodard [25] for a more detailed explanation), the functional unit [2,11] or if the life cycle costing is based on the physical product or the offering. The reasons for including or omitting the second life of a PSS, as well as the implications this choice has on the LCC results are interesting potential future research topics.

3.3. Actors

According to Asiedu and Gu [26] LCC comprises costs to the manufacturer, user, and society. The dominant position in literature is that life cycle costs are only those directly covered by actors in a product's life cycle [32] thereby excluding

various costs or externalities [27] such as indirect societal costs which are covered in environmental life cycle costing [32].

Sometimes a study may focus on the costs from one specific actor in the supply chain. This is most commonly known as Total Cost of Ownership (TCO) and usually the actor is the customer [33] although some authors use this term interchangeably with LCC thus creating an etymological confusion. Baines *et al.* [34] for example uses each term in a different way; customer TCO is the customer's criteria for selection of a PSS and life cycle costs is a value metric for the internal delivery system, although he does not define or elaborate on what is included in each. Sakao and Lindahl [9] also differentiate between provider and customer life cycle costs and conduct two different calculations to not only to optimize minimum overall costs but also to find good distribution of cost savings.

Bankole *et al.* [17] states that WLCC should be compared with the total customer budget to determined affordability of the offering whereas provider costs should be compared to provider revenue to determine the profitability from the providers perspective. For Colen and Lambrecht [35] transitioning to PSS should only be undertaken when reducing the total cost of servicing below the do-it-yourself costs of the customer.

That there should be different actor perspectives to the LCC and different uses for them in natural and expected. The challenge that arises is that when an author proposes LCC as a tool or metric the reader has to be alert to understanding what the author includes or more precisely whose view point is taken e.g. see research limitations in Erkoyuncu *et al* [7] where the authors categorize uncertainties from the manufacturers' life cycle perspective. In summary, there is not a clear and consistent terminology for LCC. Furthermore, the perspectives and the parameters in a study change according to its intended use and a reader seeking to use a study should be aware of this.

3.4. Data

Three main issues concerning the quality of data used in the costing and LCC of PSS was identified, namely availability, relevance and the challenges associated with the design paradox.

3.4.1. Availability

All cost estimations are a reflection of the quality of the input data [3]. The necessary life cycle information is often not gathered systematically or not available [8]. This can be attributed to how the predominant manufacturer's or provider's business model of selling products has been set up. In these business models, the customer traditionally covered the operational and end-of-life costs and the manufacturer accordingly only collected information on and tried to minimize the production costs [36]. From a customer perspective, however, this focus is in general negative. LCC studies and life cycle assessments have shown that the major costs and environmental impacts of many products occur during the use phase as this is usually the longest phase of a product's life and involves most actors [4,37].

When developing a PSS though, the basic principle is to design the product and the service in parallel, so that they are integrated, simultaneously taking into consideration all life cycle phases in order to optimize the offering from a life cycle perspective[3]. This principle demonstrates that there is a need for good quality data from all considered life cycle phases in order to define the initial PSS specification. But because this type of data wasn't useful within the traditional business model the data available for the operational and end-of-life costs is limited or it is belongs to a different part of the company [35,38] so it is not shared or it is not shared in an effective way.

So for designing a PSS or calculating the LCC, data may need to come from the customer or other supply chain members and there may be a number of challenges obtaining it. These challenges could be associated with trust [10] i.e. the customer not trusting the provider and vice versa or competence [13,21] i.e. the customer does not have the data or communication i.e. it is not clear what data is needed. For example, in a study of TCO as a measure of customer value, Sandin [16] points out the futility of the metric because the customers have difficulty in calculating their TCO.

3.4.2. Relevance

The second challenge has to do with the relevancy of the data. In traditional product selling business models, the initial focus is on first developing the product; once that is done, a possible service is developed, but the service design is hindered by the limitations set up from the product. Furthermore, this service is generally designed to be a source of income, so it is managed and optimized differently to how it should be in the context of a PSS [13] (see also 3.4.1).

In contrast, when service, maintenance, refurbishment etc. becomes part of a PSS the products and services should be designed to fit each other [2,39]. If the PSS is optimally designed so that the product and service are integrated, then the PSS costs should be less than the sum of product and service costs from the pre PSS business model (equation 1).

$$PSS\ costs < service\ costs + product\ costs \qquad (1)$$

Although this is not a data challenge per se, it is worth also mentioning that the old service data may be correct and relevant for conduction LCC if the product and service have not been redesigned to fit each other. When designing a new PSS, this often can be a real challenge because organizations have been set up with focus on minimization of production costs so as to have the lowest price [36]. In either case the PSS is not functioning optimally and cost estimations are not the lowest they could be for fulfilling the same level of functionality. In the first case because the wrong data is used and in the second case because the transition to PSS has not been optimized.

3.4.3. The Design Paradox

When designing a PSS, the initial PSS specification sets up boundaries for potential actions in the later phases of the PSS's life cycle. Therefore, it is important to consider the PSS specifications thoroughly in order to avoid unwanted lock-in effects. This boundary effect in the design process is often referred to as the "design paradox" [40]. When the PSS design

project starts, little is known about the final PSS, especially if it is a new PSS. As one goes further into the design, knowledge is increased but simultaneously the possibility of making changes (also known as freedom of action) decreases because each decision rules out some options. Subsequently, change also means higher costs because it implies that earlier work has to be redone see e.g. Ullman [40], Andreasen and Hein [41] and Bergman and Klefsjö [42]. The later the changes take place, the higher the cost since more work must be redone [43].

The design paradox affects the data quality from the different life cycle phases. Even though, during PSS design the products and services are developed in a parallel and integrated way, nevertheless the production of products will still occur before the service is performed. Therefore, a partial lock-in effect of the product attributes on the service will still occur and affecting the performance of the PSS, and subsequently the generated and collected data.

The time perspective also affects the quality of data. The use phase, where the service is performed, often is the predominant life cycle phase and moreover PSS in many cases prolongs the life of an offering [10]. In some cases, the life can span a few decades. Therefore, some data which is useful for making further developments to the PSS will not be collected until very late in the PSS' life cycle therefore this data won't be available to drive the continuous development, implementation and even redesign of a PSS.

4. Conclusions

Based on the original research questions, the main findings and opportunities for future research are summarized here.

4.1. Approaches to Conducting LCC in the Context of PSS

This research highlighted the importance and widespread use of LCC costing in PSS as a tool to provide decision makers, designers and stakeholders with relevant financial information. Researchers, either explicitly or inexplicitly, classify their approaches to LCC based on PSS type, e.g. product- or use- or result- oriented and there are similarities between these approaches. Further research, is needed to see if there are similarities between different types that is to say overarching common approaches.

4.2. LCC Parameters Included in the Context of PSS

A main problem is that the terminology used to describe LCC is not consistent. Indeed, the term "LCC" is even used to describe the LCC for a specific actor e.g. provider or customer without clearly making the distinction. Also because LCC often is not the main object of study, time is not spent to define what exactly the author includes. This means that readers need to be alert to understanding what is meant by LCC or its synonyms in each study.

Concerning LCC stages, there is a lack of focus on the end-of-life stage and it is not clear how to approach the costing of refurbished or remanufactured products that get a prolonged life.

4.3. Data Challenges in the LCC of PSS

In this study three main challenges concerning data used in LCC of PSS were identified. Firstly, data from all life cycle stages has not traditionally been collected by providers or customers so it is not available; also their organizational setup is not geared towards utilizing this data.

Secondly, it is a challenge to obtain data which is relevant to the PSS because a PSS means redesigning the products and services to fit. This renders the data from when the product and service were offered separately irrelevant, although this fact is often not immediately clear to the practitioners carrying out cost estimations.

Thirdly, the design paradox is applicable to PSS because the data needed for optimal design may be available late in the life cycle when the costs of redesign and optimization are large. This is amplified by the partial lock-in effect the product has over the service because it is produced before the service.

5. Future Research

There is an abundance of theoretical literature available but it is clear that more empirical LCC studies that put PSS theory into practice are needed, see e.g. Tukker [1]. These studies need to be applied on different types of PSS as well as different industries as there is a one sided focus on the defense industries [7,11,17,20,44].

Since a lot of relevant literature that wasn't immediately identifiable as PSS was found to be relevant, the shortage of empirical studies might also be partly solved by looking into non PSS literature. A more structured literature review would be needed for that. This literature review could also include a bottom up investigation to determine whether a common approach to LCC in PSS really exists. This would involve finding the common approaches within PSS types and then identifying the similarities in approaches between these types.

Improvements in costing the end-of-life and a unified way of dealing with a possible second life of the PSS due to refurbishment or remanufacturing in LCC was another relevant research area. Three data challenges were also identified and further research into to finding methods for dealing with them is pertinent.

The main limitation of this research, which is also an opportunity for future research, is that it does not utilize all the available information in the relevant articles and limits itself to an overview of LCC in PSS and the life cycle and actor perspectives. There are many more subjects that could be touched upon e.g. modelling and the use of new information technologies in data management that can be brought into the discussion of LCC in the context of PSS.

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