TOWARDS AN UNCERTAINTY FRAMEWORK FOR PRODUCT SERVICE SYSTEMS OF SYSTEMS

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ABSTRACT

Product Service Systems (PSS) are increasingly complex and collaborative. For instance, manufacturing companies, service providers, and other companies collaborate and jointly develop and operate a PSS (ex: smart grid), where its constituent elements are managed and operated independently. Managerial independence and operational independence are commonly considered key characteristics of a System of Systems (SoS). Hence, a collaborative PSS exhibits System of Systems (SoSs) characteristics. These systems have previously been introduced as Product Service Systems of Systems (PSSoSs). In this paper, we propose to identify relevant uncertainties in the PSSoS design process. For this purpose, we go beyond the PSSoS concept definition and propose a comprehensive framework for PSS and PSSoS characterization. Moreover, based on both a literature review and an industrial diagnosis, we identify PSSoSs-specific design uncertainties.

Keywords: Product-Service Systems (PSS), System of Systems, Uncertainty, Complexity

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1 INTRODUCTION

Different domains propose a variety of definitions for Product Service Systems (PSS) (Haase *et al*., 2017; Park *et al*., 2012; Tukker, 2015). In engineering design, a Product Service System (PSS) is commonly defined by its constituent elements: Products, Services, Supporting networks and Infrastructure (Mont, 2002). A collaborative PSS is a bundle of interoperable systems developed and managed by different actors each one aiming at more competitiveness and sustainability (Mont, 2002). Collaborative PSS features can be seen as similar to Systems of Systems (SoSs) features (Estrada and Romero, 2016; Hein, Poulain, *et al*., 2018b). Hence, based on Maier's (1996) definition of a SoS, Hein *et al*. (2018a) introduce the concept of a Product Service System of Systems (PSSoSs) defined as "a set of products, services, infrastructures, and networks where its constituent elements exhibit operational and managerial independence".

PSSoSs are already being developed and deployed by industry. For instance, a large automotive company, an energy provider and an infrastructure manager collaborate and jointly develop and operate PSSs (EV2G) (Chazal, 2018). These PSSs involve different and heterogeneous systems jointly capable of fulfilling customer needs, each of them operated and managed by independent companies. More generally, in the context of PSSoS, each actor can develop, manage and/or operate product(s), service(s), PSS(s) and/or infrastructure(s). Actors can also share the development, management and/or operation of Product(s), Service(s), PSS(s) and/or infrastructure(s) (Hein, Poulain, *et al*., 2018b).

The multitude of possible Product Service combinations and allocation of roles among actors increases PSSoS complexity compared to "classic" PSS. Thus, PSSoS introduce the new challenge of defining the collaborative value proposition (Hein, Chazal, *et al*., 2018a). Design for interoperability between the PSSoS' constituent elements is another challenge. In the following, we present an example for a design challenge related to interoperability in PSSoS. While a service provider develops intangible services able to interoperate with tangible products throughout their lifecycle, the responsibility of a company in the manufacturing industry for its product extends to its use phase and disposal and covers its whole lifecycle. Moreover, product lifecycles are usually longer than services lifecycles. The fact that service lifecycle is more rapidly evolving introduces additional difficulties and uncertainties in the PSSoS development.

In this paper, we propose to identify relevant uncertainties in the PSSoS design process. For this purpose, we propose a comprehensive framework allowing for PSS and PSSoS characterization, from which these uncertainties can be derived. The aim is to identify uncertainties in order to support overall PSSoS development. The structure of the paper is as following. In section 2, we consider the literature pertaining to both PSS and SoS as few research addresses the PSSoS concept. Moreover, we also address different PSSs and SoSs specific uncertainty definitions and modelling. In Section 3, we describe the adopted research approach. Section 4 details the proposed characterisation of PSS and PSSoS. In section 5, identification of PSSoS uncertainties is discussed with regard to existing literature as well as identified industrial needs. We finally conclude by providing future research avenues in section 6.

2 LITERATURE REVIEW

PSS and SoS have been traditionally discussed separately in literature. Hence, we propose to discuss both PSS and SoS characteristics in order to identify PSSoS characteristics. Moreover, uncertainties related to PSS and SoS development might be different with regard to their different characteristics. In this section, we propose to discuss different types of uncertainties pertaining to PSSoS characteristics.

2.1 PSS SoS characterizations

The PSS typology presented in (Tukker, 2004) is one of the most used in the literature. In this typology, a PSS is defined as a business model. A distinction is made between product-oriented PSSs, use-oriented PSSs, and result-oriented PSSs. The differentiating criteria between these three PSS types are mainly the ownership of the product and the payment method (Aurich *et al*., 2010). Tukker's typology gives a business perspective on PSSs but lacks insight on engineering difficulties related to PSSs development. Meier *et al*. (Meier *et al*., 2010) suggest a systems engineering oriented typology for PSSs. The authors distinguish "Service Products", "Extended Products" and "Industrial Product Service Systems". The differentiation between the three types of PSSs is based upon the engineering

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development methods (Independent product and service engineering, Machine/ Product oriented engineering and simultaneous service and systems' engineering respectively). Both typologies describe the decreasing product-centricity of the PSS or as one can define it's increasing heterogeneity. Product-oriented PSS, use-oriented PSS, and result-oriented PSS could be equivalent to "Service Products", "Extended products", and "Industrial Product Service Systems" respectively.

Most of the literature underlines these three PSS characteristics: customer orientation (Manzini and Vezzoli, 2003), sustainability (Pieroni *et al*., 2017), and heterogeneity (Meier *et al*., 2010; Sassanelli *et al*., 2016; Song and Sakao, 2017). Heterogeneity features can further be refined and related to products and services bundles (Song and Sakao, 2017), the diversity in service types (Sassanelli *et al*., 2016) and the variety of stakeholders expectations (Meier *et al*., 2010).

Other characteristics are more specifically relevant for user-oriented PSSs and result-oriented PSSs. In use-oriented and result-oriented PSSs, there is a continuous delivery of a service that needs to be supported through the entire life-cycle. As customer needs evolve, (Sakao *et al*., 2009; Song, 2017) there is a need to be able to dynamically adapt PSS to satisfy these evolutions. This is linked to the notion of evolvability in the literature (Maleki *et al*., 2017).

As for the SoS characteristics, several research underlined the following characteristics: independence (managerial & operational) of their elements, their evolutionary nature, emergent behaviours, geographic distribution, interoperability, complementarity and holism (Keating and Katina, 2011; Maier, 1996). Baldwin *et al*. (2011), focuses on the taxonomy with regard to increasing complexity. Authors distinguish between a simple system, a complicated system, a complex system, an adaptative system, a System of Systems, a collaborative System of Systems and, a complex adaptative system. The taxonomy is based upon 7 characteristics or attributes: Autonomy, Connectivity, Belonging, Emergence, Diversity, Self-organization, and Adaptability (Sauser *et al*., 2009).

2.2 PSS SoS related uncertainties

One can identify several research streams that identify and tackle the notion of development related uncertainties: engineering design, PSS literature, Innovation management and System of Systems literature. In this paper, we consider uncertainty as «a potential deficiency in any phase or activity of the process, which can be characterized as not definite, not known or not reliable» (Kreye, 2011).

In the design engineering literature, one of the most used classification in product design is the one proposed by De Weck *et al*. (2007) suggesting a classification of sources of uncertainties for early design. The classification includes product, use, corporate, market, and political and cultural contexts as sources of uncertainty.

In the PSS literature, several research proposes PSS related uncertainties (Hernandez *et al*., 2018; Herzog *et al*., 2014; Kumar *et al*., 2013, p. 91,96).

In (Hernandez *et al*., 2018), the PSS specific uncertainty classification covers Environmental , Organizational, Relational, Technical and Resource uncertainty. This classification is interesting with regard to PSSSoS as authors propose under Technical uncertainty type: uncertainties related to hard/software combination, service definition, forecasting timing and scale of service, Systemic integration (Service + Product). As for Relational uncertainty, it covers uncertainties related to customer and collaboration partners. Reim *et al*. (2014) in particular address behavioural uncertainties related to PSSs. The increased service content of a PSS leads to more value co-creation with the customer but also increases the risks of customers' opportunistic behaviour. Herzog *et al*. (2014) classify PSS uncertainties according to three main classes constraints/Requirements, system context, and development processes. This classification is relevant for PSSoSs development as it covers the whole PSS lifecycle and integrates the PSS evolvability through changing customers' needs. The uncertainty classification presented in (Kumar *et al*., 2013) appears to be the most comprehensive and includes: Market uncertainty, Company uncertainty, Environment uncertainty, Uncertainty of product functioning, Product function uncertainty, Uncertainty of innovative services, PSS integration uncertainty, Supplier coordination uncertainty, communication uncertainty and Uncertainty with remanufacturing. These uncertainties apply to PSSoSs development. More specifically, Product function uncertainty points out the risk of changing product's function over time through upgrades. Obsolescence appears as a cause for this uncertainty. Uncertainty of innovative services leads to technology changes. PSS integration uncertainty highlights the complexity and difficulty of adjustment when the degree of (Product and Service) integration is high. PSSs can also be seen as an "innovation strategy shifting the business focus from designing (and selling) physical products only, to

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designing (and selling) a system of products and services which are jointly capable of fulfilling specific client demands'" (Manzini and Vezzoli, 2003). Looking at uncertainty in the innovation management can then be relevant for PSSoS development. O'Connor and Rice (2013) suggest 4 categories of uncertainty, Market, Organizational and Resource uncertainties. Market uncertainties include features of customer/ Product interactions. Organizational uncertainty underlines the fundamental conflict between the mainstream organization the unit engaged into radical innovation. Resource uncertainty points out the competency gap in innovation projects. These uncertainties are also interesting with regard to PSSoS development as manufacturing industry address new markets by offering services apart from their core business.

O'Connor and Rice (2013) also add latency and criticality classes to uncertainty. "Latency refers to the degree to which the uncertainty can be perceived or anticipated". Criticality is the "the degree to which resolution of the uncertainty must occur immediately or the project's survival will be at risk".

In the SoS literature review, uncertainty is considered from a SoS enterprise engineering perspective. The uncertainties are mainly business partnership organization and partners role allocation (Carlock and Fenton, 2001).

Previously discussed literature underlines the need to identify PSSoS specific uncertainties as they are not addressed by current literature to our knowledge. Therefore, we propose to address this gap, firstly by identifying relevant PSSoS characteristics that are afterward used as a basis for uncertainty identification.

3 RESEARCH METHODOLOGY

The aim of this paper is to identify relevant uncertainties in the PSSoSs design process. The adopted approach Figure 1 is inspired by both the Design Research Methodology and the Action Research Method (Blessing L.T.M. and Chakrabarti, 2002; Brydon-Miller *et al*., 2015; Ferris, 2009; Järvinen, 2007). A literature survey has been conducted to characterise increasingly complex PSSs, including PSSoSs. Design uncertainties related to different PSSs types are assessed. Concomitantly, the research has been conducted within a large automotive industry. The field study is based upon data gathered from documents, observations, and interviews. This descriptive study allows to identify PSSs and PSSoSs programs' features and pertaining design uncertainties. The assessment of theoretical research along with the investigation of the field permits to build a PSSs and PSSoSs characterization map and a to identify related design uncertainties. The theoretical output aims at responding to the automotive industry needs and in a larger context, the manufacturing industry needs.

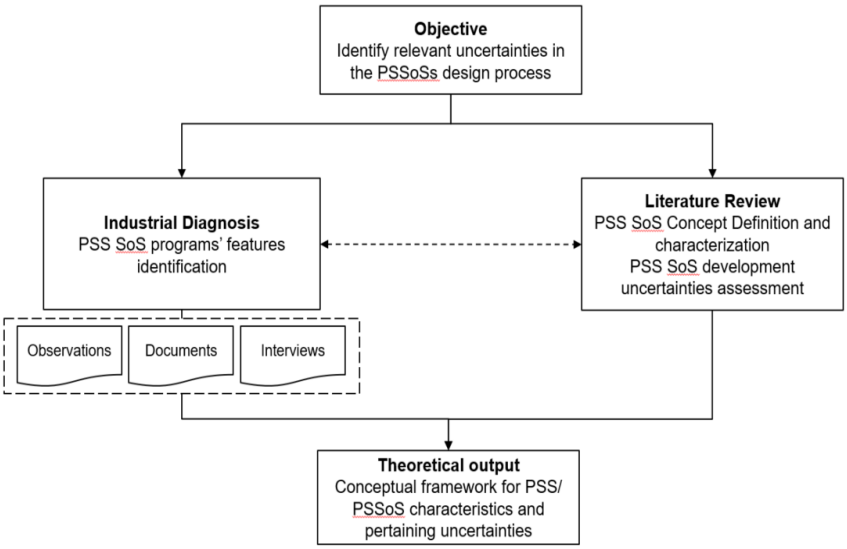

Figure 1: Research approach

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4 PROPOSITION OF A PSS/PSSOS CHARACTERIZATION

Previously discussed literature underlines different aspects of PSS and SoS. In the following, we go beyond the PSSoS definition in (Hein, Poulain, *et al*., 2018b) by mapping PSS-types to a system taxonomy by (Baldwin *et al*., 2011), including SoS.

In order to characterise PSSoSs, we base ourselves on the possible evolution of the PSS systems (product oriented, use-oriented, result-oriented) (Tukker, 2004; Wang *et al*., 2011) and the characterisation of types of systems (Baldwin *et al*., 2011; Baldwin and Sauser, 2009). The proposed PSSoS characterization map is two dimensional: PSS taxonomy dimension and system taxonomy dimension (Figure 2).

The PSS dimension describes how product-centric a PSS is or it's increasing heterogeneity. Along the Y-axis, the product centricity of PSSs decreases. PSSs characteristics add up moving from Product Oriented PSSs to Result-Oriented PSSs (Tukker, 2004).

While product-oriented PSSs (maintenance, reuse…) are customer oriented and sustainable, they only represent few features of heterogeneity. In use-oriented PSS, services, and usages diversify. The ownership of the product moves from the customer to the PSS providers which intensify the dynamic system/ customer interactions. The evolvability applies to Result oriented PSSs. In fact, the absence of a predefined product frees the PSS up to evolve throughout its lifecycle, according to customers' needs and stakeholder network configuration.

Using the systems taxonomy proposed in (Baldwin *et al*., 2011), we distinguish between PSSs and PSSoSs through the system dimension.

The system dimension describes the increase of systems complexity moving from simple systems to Systems of systems. Systems are characterized by their autonomy, connectivity, emergence, belonging, diversity and self-organization defined in (Baldwin *et al*., 2011).

According to this characterization authors distinguish between a simple system (Autonomy), a complicated system (Autonomy, Connectivity), a complex system (Autonomy, Connectivity, Belonging, Emergence), a system of system (Autonomy, Connectivity, Belonging, Emergence, Diversity) and a collaborative system (Autonomy, Connectivity, Belonging, Emergence, Diversity, Self-organization).

In (Baldwin *et al*., 2011), authors also introduce Adaptative systems and Complex Adaptative systems. Both systems share the adaptation characteristic. Adaption describes the ability of a system to "modify itself for the sake of its goals". The adaptive system also "has an awareness of itself in its environment and updates its behaviour based on this information". As no examples of human-made adaptative systems are given in (Baldwin *et al*., 2011), we consider adaptability out of the scope of this paper. The used characteristics help distinguish between simple systems and systems of systems.

In the literature, PSSs are usually studied as simple to complex systems. PSSs are little studied as SoSs or Collaborative SoSs. Yet, studied industrial examples show PSSoSs features.

In Figure 2, examples of mobility PSSs or PSSoSs developed by an automotive company (Renault) (except for Bike sharing) are presented (Chazal, 2018; Williams, 2007). Features of the mobility PSSs represented by black stars (Figure 2) have already been addressed in the Engineering Design and Systems Engineering literature (Herrmann *et al*., 2010; Pezzotta *et al*., 2011; Sakao *et al*., 2009; Shimomura *et al*., 2009; Zhang and Banerji, 2017). However, collaboration and evolutivity features of "On-demand Robot Vehicle", "Electric Vehicle to Grid (EV2G)" and "Battery as a Service" (Red Stars Figure 2) are rarely covered in the Engineering Design literature but rather in the Transportation Research Field (Bischoff and Maciejewski, 2016; Chen *et al*., 2016).

Figure 1 allows us to go beyond the uncertainties mentioned in the PSS literature, which mainly pertain to simple to complex systems. At this point, we can systematically identify PSSoS-related uncertainties that are not treated explicitly in the literature. The results are presented in the following section 5.

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Figure 2: PSSs/ PSSoSs characterization map - Examples of mobility PSSs/ PSSoSs

5 IDENTIFICATION OF PSSOS UNCERTAINTIES

PSSoSs specific uncertainties could be deduced from both PSS literature and SoS literature (2.2). However, identified uncertainties do not cover exhaustively PSSoSs specific characteristics (Section 4). Based on the proposed PSSoS characterization section 3 and through an industrial diagnosis within an automotive company, we extend identified PSSs/ PSSoSs uncertainties and attempt to map PSSoSs characteristics and PSSoSs specific uncertainties.

The industrial diagnosis has been conducted as part of the new mobility solutions and services development team and in close contact to systems engineering experts in a large automotive company. Existing and future PSSoSs development programs have been assessed. Structured and semi-structured interviews have been conducted with both systems engineering experts and project managers to comprehend PSSoSs development difficulties.

Just like any other system, PSSoS development takes place under market uncertainties, environmental (political and cultural) uncertainties, company or corporate uncertainties and, product uncertainties (Kumar *et al*., 2013; De Weck *et al*., 2007).

Besides these uncertainties, the following uncertainties both from the literature and from the industrial context have been identified and seem to be specific PSSoSs uncertainties:

- Heterogeneous and independent systems interface uncertainties:

The heterogeneity of PSSs constituent elements is studied in the literature (Hernandez *et al*., 2018). However, the autonomy and independence (managerial and operational) of each system within a PSSoS are not considered. As heterogeneous systems are independent, systems interfaces are harder to design, manage and control by different stakeholders.

- Heterogeneous systems interoperability related uncertainties:

Heterogeneous systems integrations are extensively studied in the PSS literature (Geum and Park, 2011). However, in a PSSoS context, integrations and interoperability are even more challenging as they involve stakeholders' collaborations.

- Lifecycle offsets uncertainties:

Products and services lifecycles and development strategies are different (Cavalieri and Pezzotta, 2012). In the PSS literature, authors tend to suggest integrated PSS lifecycles models or more precisely integrated PSS development processes (Aurich *et al*., 2006; Hänsch *et al*., 2016; Hepperle *et al*., 2010; Kim *et al*., 2011; Shimomura *et al*., 2009; Wang *et al*., 2011). However, as Products and services in a PSSoS context could be independent systems, their lifecycles remain independent. Thus, lifecycle offsets are PSSoSs-specific uncertainties.

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- Uncertainty of innovative services/ products:

"Innovation often leads to technology changes, and, consequently, can be a source of uncertainties." (Kumar *et al*., 2013). Innovative services uncertainties lead to innovative products uncertainties as Products and Services are interoperable. This poses challenges for the manufacturing industry because their products need to keep pace with innovative services.

- Obsolescence uncertainties:

Within a PSSoS, products and services are interoperable, yet independent. Lifecycle offsets or fast evolutions of service technologies compared to product development could compromise products and services interoperability leading to systems' obsolescence.

- Usage uncertainties:

PSS development is seen as a mass customization strategy (Song and Sakao, 2017). Authors develop a PSS design framework able to support a variety of customers' needs and usages. However, in a PSSoS context, usages are not only diverse but also time dependent. Customers' needs, and perception of the service offer evolve and change throughout the PSSoS lifecycle.

- Collaboration uncertainties:

In a PSSoS context, systems contributions and stakeholders' roles allocation are not necessarily defined a priori. Systems/ actors could integrate and exit the PSSoS throughout its Lifecycle. Thus, in a PSSoS context, systems capabilities might need enhancement and changes to ensure interoperability and PSSoS functioning. This requires the right technical training, knowledge, and skills (Carlock and Fenton, 2001), a stakeholder/ company might lack. These issues are usually studied in the SoS Enterprise Engineering (SoSEE) or the SoS management literature (Carlock and Fenton, 2001; Sauser *et al*., 2009; Sauser and Boardman, 2008). Hence, Competency Gaps (O'Connor and Rice, 2013) are an additional PSSoS-specific uncertainty.

Uncertainties find their roots in either PSS characteristics or SoS characteristics (Figure 3). PSS Customer orientation, sustainability, heterogeneity, complexity, and evolutivity account for Heterogeneous and independent systems interface uncertainties, Heterogeneous systems interoperability related uncertainties, Lifecycle offsets uncertainties, Uncertainty of innovative services/ products, Obsolescence uncertainties and Usage uncertainties (Blue Rectangles Figure 3). However, the autonomy of each system and the diversity within a SoS make these uncertainties even more critical. Diversity and Self-organization explain the Collaboration uncertainties (Grey Rectangle Figure 3). Yet, competency gaps, for example, are particularly challenging as systems exhibit features of heterogeneity.

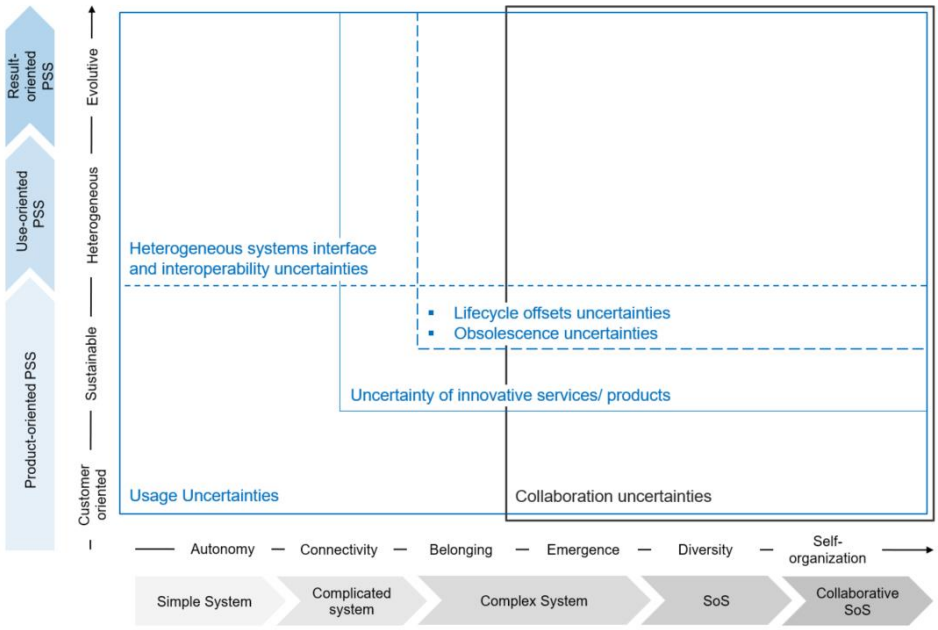

Figure 3: Mapping PSSs/ PSSoSs characteristics and PSSs/ PSSoSs specific uncertainties

The uncertainties described above, represent development challenges we need to specifically pay attention to, especially in the context of PSSoS and for the automotive industry. A generalization and a validation of PSSoSs-specific uncertainties are yet to be made. A PSSoS uncertainty model is needed.

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PSSoS uncertainty propagation methods are also to be developed. These models and methods should allow for the development of PSSoS uncertainty management strategies in design.

6 CONCLUSION

Product Service Systems (PSS) and Systems of Systems (SoS) are rarely linked in the literature. We call systems that exhibit both, PSS and SoS characteristics, Product Service System of Systems (PSSoS). For instance, the automotive industry develops increasingly complex PSSs (such as EV2G) that could be seen as PSSoSs. However, PSSoSs characterization and PSSoSs development difficulties need further discussion.

In this paper, by assessing PSS and system types, including SoS in the existing literature, we proposed a PSSoS characterization map. PSSoS features of heterogeneity, evolutivity, and complexity on one hand, managerial and operational independence of PSSoS constituent systems, on the other hand, raised uncertainty related issues for PSSoS development. The PSS and SoS literature mention some PSSoS-specific uncertainties such as customers changing needs, Products and Services lifecycles offsets and obsolescence issues. Besides, some PSSoS specific uncertainties could be identified through automotive industry examples analysis. However, an exhaustive study of PSSoS-specific uncertainties is still required.

For future work, a PSSoS-specific uncertainty model is needed. PSSoS uncertainties propagation methods could also be developed. Uncertainty models and propagation methods could help assess uncertainty management strategies in design.

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