

A Methodology for Architecting Collaborative Product Service System of Systems

Andreas M. Hein

Laboratoire Genie Industriel, CentraleSupélec, Université
Paris-Saclay
Gif-sur-Yvette, France
Andreas-makoto.hein@centralesupelec.fr

Yann Chazal

Renault SA
France
yann.chazal@renault.com

Samuel Boutin

Knowledge Inside
Versailles, France
sbo@k-inside.com

Marija Jankovic

Laboratoire Genie Industriel, CentraleSupélec, Université
Paris-Saclay
Gif-sur-Yvette, France
Marija.jankovic@centralesupelec.fr

Abstract—Product service systems (PSS) can be understood as an innovation / business strategy that includes a set of products and services that are realized by an actor network. More recently, PSS that comprise System of Systems (SoS) have been of increasing interest, notably in the transportation (autonomous vehicle infrastructures, multi-modal transportation) and energy sector (smart grids). Architecting such PSS-SoS goes beyond classic SoS engineering, as they are often driven by new technology, without an a priori client and actor network, and thus, a much larger number of potential architectures. However, it seems that neither the existing PSS nor SoS literature provides solutions to how to architect such PSS. This paper presents a methodology for architecting PSS-SoS that are driven by technological innovation. The objective is to design PSS-SoS architectures together with their value proposition and business model from an initial technology impact assessment. For this purpose, we adapt approaches from the strategic management, business modeling, PSS and SoS architecting literature. We illustrate the methodology by applying it to the case of an automobile PSS.

Keywords—PSS, system of systems, system architecture, collaborative services, service engineering, business model, value proposition

I. INTRODUCTION

Classic system of systems (SoS) engineering in a defense and aerospace context is typically characterized by a governmental agency that defines the capabilities of the system of systems (see for example [1]–[4]). The main task of engineering the system of systems then consists of how these capabilities can be implemented by a (often given) set of actors and (existing or new) systems [3], [5]–[10]. More recently, systems of systems engineering has extended to areas such as transportation [10], [11] and energy [12] that have different characteristics than classic system of systems: There is no clear client a priori who sets the desired capabilities and

the actors that participate in the system of systems are not yet identified. In addition, these actors have not collaborated with each other before. The challenge from a systems of systems engineering perspective is that this situation vastly increases the number of SoS alternatives. Furthermore, proper incentive structures and value propositions need to be in place for encouraging actors to participate in the SoS. The existing SoS literature which deals with this type of SoS rather deals with an already given architecture or a predefined design space. For example, [13]–[15] analyze the resilience of an existing energy infrastructure architecture. [16] and [10] focus on the analysis of SoS transportation architectures, where the architecture alternatives are already given. Hence, the design of the SoS architecture itself does not seem to be sufficiently addressed, with a few exceptions [7], [17], [18].

Apart from the SoS domain, a distinct stream of literature deals with systems that consist of a set of product(s) and services, realized by a network of actors and a supporting infrastructure [19]–[22]. Such systems are called product service systems (PSS). More precisely, a PSS is 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.” [23] PSS can be understood as an element of an innovation / business strategy that aims at tapping new revenue streams from existing markets and delivering environmentally sustainable solutions [21], [24], [20]. Although a few publications have pointed at the obvious connection between PSS and SoS [25], [26], neither the PSS nor the SoS literature seems to have dealt in depth with PSS-SoS. Hein et al. [19] define a PSS-SoS as “a set of products, services, infrastructures, and networks where its constituent elements exhibit operational and managerial independence”, referring to the two key characteristics of SoS of operational and managerial independence in Maier [27]. Real-world PSS-

SoS usually have some of the following characteristics, as presented in [19] and as illustrated in Figure 1:

- Multiple actors providing lower-level services that are combined into a higher-level service via collaborations.
- Collaboration between actors from industries that have no track-record of collaborating becomes important, for example, the collaboration between car manufacturers and energy suppliers in vehicle-to-grid applications [28]–[30].
- Addressing societal concerns such as pollution reduction, quality of life, and job creation become crucial for getting approval from public stakeholders.
- Governance and management of the combined service and physical products becomes a key issue, e.g. one central actor has oversight vs. no single actor is responsible for the overall system, which is a typical topic in the SoS literature [31].
- New technologies often trigger its development such as autonomous driving, electric vehicles, and smart grid [28]–[30].

Such PSS-SoS have the potential to address some of society's most pressing challenges, but little is known about how to design them. Neither the existing PSS literature nor the existing SoS literature seems to provide sufficient guidance on designing PSS SoS [19].

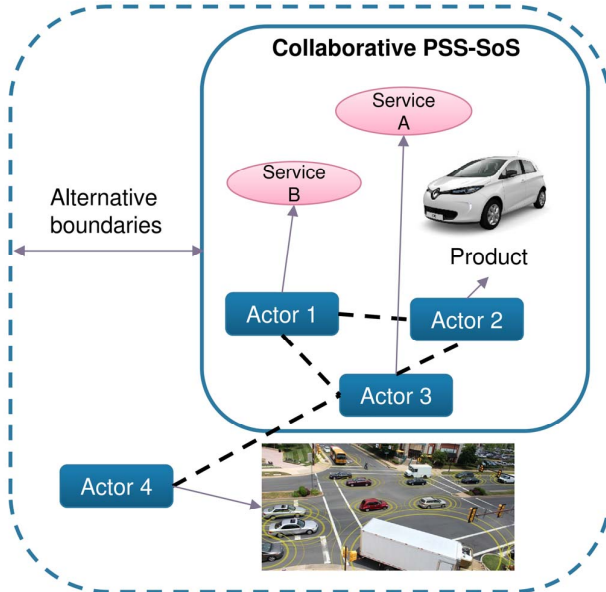


Figure 1: Collaborative product service system

In the following, we propose a methodology for architecting PSS-SoS at an early stage, focusing on SoS that are, according to Maier's SoS taxonomy [27] directed or collaborative, and are technology innovation-driven (technology push) [32].

II. A METHODOLOGY FOR ARCHITECTING COLLABORATIVE PSS

This research was conducted in the context of the French automotive company Renault, in an effort to systematize the development of PSS-SoS. For simplicity, we abbreviate PSS-SoS by PSS in the following.

A. Methodology Requirements

In order to understand the requirements of a PSS architecting approach at Renault, the authors have engaged in discussions and collaborations with different internal stakeholders (R&D, product, service, business). These interactions took place in regular workshops for developing PSS concepts, team meetings, outreach meetings, and one-to-one conversations during a period of one year (2017-2018). From these interactions, a set of requirements for a PSS engineering methodology were elicited:

- Support the identification of potential impact of the PSS on societal factors,
- Support the exploration of different PSS concepts with regards to business development objectives,
- Support the identification of potential collaborations,
- Support the identification of value propositions (pains and gains / pain relievers and gain creators),
- Support the development of a business model canvas-like representation around a PSS concept, and,
- Support the development of PSS architectures that provide sufficient detail for the technical domain for deriving high-level requirements.

B. Methodology Process Steps, Inputs and Outputs

The principal objective of the methodology is to derive PSS architectures together with their value propositions and business models. The focus is on technologies, which are expected to have a large societal impact. The main inputs and outputs of the methodology are shown in Figure 2. As inputs, the technology under consideration is required. A technology is understood as a combination of an artifact and its underlying competencies that allow for its development, production, and operation as defined in the technology maturity literature [33]–[35]. In addition, the field of interest is a set of domains such as an area of economic activity (e.g. energy, insurance) for which the potential impact of the technology is of interest. The outputs address the previously defined requirements. The PSS architecture provides a starting point for stakeholders in the technical domain refine the architecture. Stakeholders from the business domain are mainly interested in the resulting value proposition and business model.

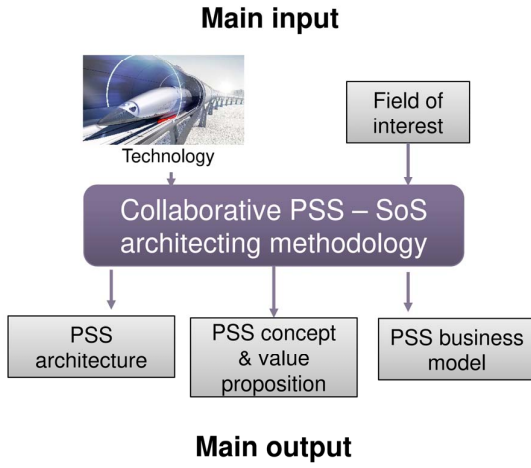


Figure 2: Methodology inputs and outputs

The methodology comprises two main steps, as shown in Figure 3. The first step essentially addresses the technology push case where the impact of a set of technologies on specific domains are assessed. This step was introduced, as we observed that technology push seems to be a common mode in the Renault context and the automotive industry in general. The main question in the technology push case is, what potential impact the technology has on its context and how adequate PSS value propositions and PSS concepts can be developed that use the technology.

In the second step, starting from the outputs of the first step (PSS stakeholder network, PSS concept and value proposition alternatives), the PSS architecture and PSS business model alternatives are developed. The rationale behind the second step is to provide system architects with a sufficiently detailed description of the PSS architecture that allows them to start working on their specific product or service architecture. Analogously, the resulting business model intends to provide business developers with a sufficient description to start working on a more detailed description of the business model.

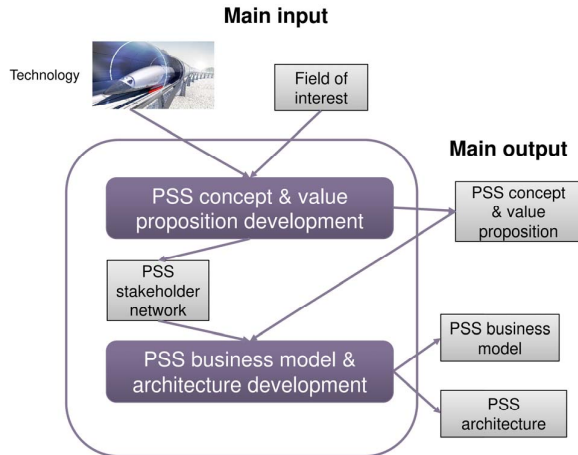


Figure 3: Main methodology steps

C. Collaborative PSS concept and Value Proposition Development

The main purpose of this step is to generate alternatives for PSS concepts and value propositions starting from a technology and fields of interest, as shown in Figure 4.

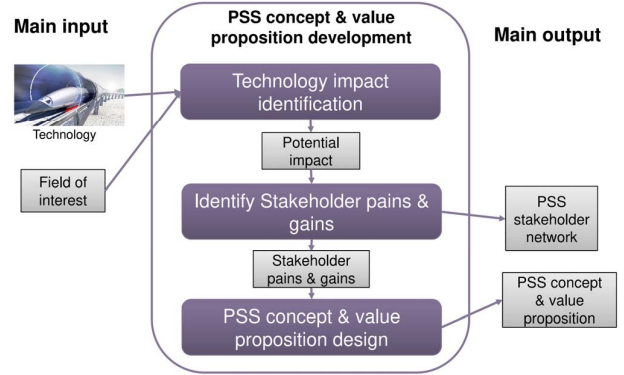


Figure 4: PSS concept and value proposition development step

It starts with the elicitation of potential impacts of a technology on one or more fields of interest, as shown in Figure 5. The technology and fields of interest can stay generic and little detail is required. For example, artificial intelligence could impact the field of logistics, medicine etc. Autonomous driving can impact urban areas, transportation, and energy. However, it is often difficult to articulate the impact on a field of interest, as technologies at low maturity levels lack sufficient detail to relate them to impacts. Two concepts are introduced to support impact identification. First, we introduce capabilities, i.e. what the technology allows for. For example, autonomous driving can lead to the capabilities of driver-less operation of a vehicle in all conditions. For artificial intelligence, a capability could be image recognition or automated translation.

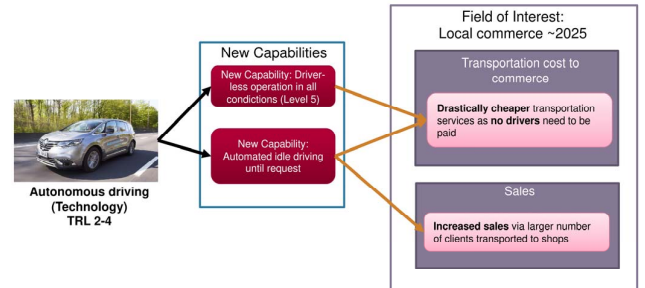


Figure 5: Technology impact assessment

Second, each field of interest contains key performance indicators. These are indicators that are of general concern for various stakeholders in a field of interest. For example, within the field of interest “energy”, energy price is a key indicator among others. For transportation, availability, cost, and reliability are important indicators. The reason we introduce key performance indicators is that it is often easier to identify technology impacts with respect to a key performance

indicator. For example, autonomous driving could lead to a decrease in transportation cost, as no driver is required. Once a potential impact has been identified, it is documented, including the rationale why this impact is expected, e.g. transportation cost decrease due to omission of a driver.

Furthermore, as is common for scenario analysis and strategic forecasting, time horizons for the field of interest need to be defined. This is particularly important with regards to the technology under evaluation. For example, we can look at the field of interest of transportation in 2025, when level 5 autonomous driving is expected to exist.

This helps to prioritize the potential impacts, not only in terms of the importance of the impact, but also in terms of the associated uncertainties. These prioritized potential impacts are used in the next step.

Although technology impacts have been identified in the previous step, it is still unclear how specific stakeholders perceive these impacts. Hence, in the second step, stakeholder pains and gains with respect to the potential impacts are identified. We draw from the business model literature and adapt the notion of “pains” and “gains”, as used in Osterwalder et al. [36] to express pains and gains of a stakeholder with respect to a technology impact. As the autonomous driving example shows, the potential impact on a key performance indicator comes without a value judgement. Autonomous driving has the potential to decrease transportation cost. However, this potential impact will be perceived very differently by different stakeholders. For example, professional drivers are likely to oppose transportation cost reduction, in case their salary diminishes. On the other hand, passengers are likely to welcome a decrease in transportation cost. Figure 6 shows the pains and gains for two autonomous driving impacts on the domain of transportation.

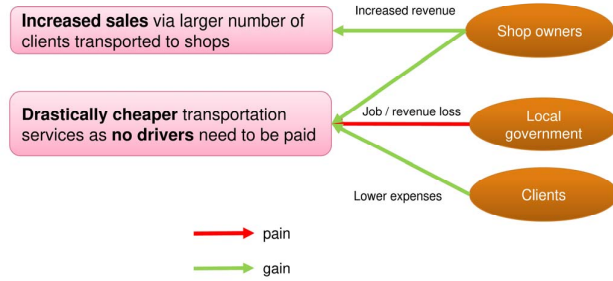


Figure 6: Sample stakeholder pains and gains for an autonomous driving case

Once the pains and gains of stakeholders have been identified, they are used for developing the PSS concept and value proposition. For this purpose, we adapt the value proposition design from Osterwalder et al. [36]. They introduce a representation of value proposition which is based on a customer segment’s pains and gains on the one hand and pain relievers and gain creators associated with a set of products and services on the other. The task of the value proposition designer is to find adequate matches between the pain relievers and gain creators and the pains and gains.

As collaborative PSSs involve a network of actors, value proposition from Osterwalder et al. needs to be adapted. First, we replace *customer* by *stakeholder*, as the notion of customer would be too narrow in the case of collaborative PSSs. Furthermore, we do not only consider pains and gains of stakeholders with respect to their activities but we also take pains and gains with respect to the technology under consideration into account. In Figure 7, the technology impact along with the pain relievers / gain creators to clients, shop owners, and the local government are shown. As in Osterwalder et al.’s value proposition design [36], the left hand side consists of the products and services. The products and services are not limited to those products and services that are based on the technology under consideration. Here, autonomous driving is infused into a vehicle, resulting in a robo vehicle. In addition to the robo vehicle, the service of a contextualized advertisement feed is added. It takes advertisements from local shops and feeds them to passengers. The capability of this service is added to the “capabilities” box and supports the “increased sales” gain creator for shops. The set of products and services along with their capabilities are called “PSS concept”. The notion of “concept” in this context has been borrowed from [37], where a concept comprises a system or product, eventually its components, along with its main function.

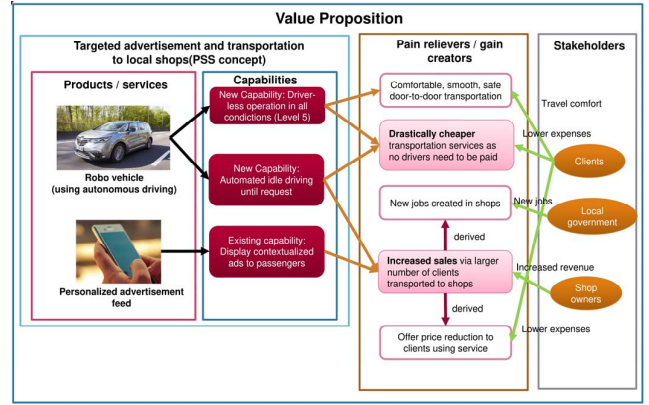


Figure 7: PSS value proposition

This adapted value proposition representation allows for a systematic reasoning over PSS alternatives and how they impact stakeholders. Note that at this point only the capabilities that generate / support pain relievers and gain creators are considered. Furthermore, contributors to the PSS such as service providers are not represented. A more detailed description of the PSS that includes these elements is developed in the subsequent step.

D. Collaborative PSS Business Model and Architecture Development

In order to evaluate the feasibility of the PSS concept and value proposition, two additional steps performed: One with respect to business model development and the second with respect to the development of the PSS architecture. In the first step, the business model for the value proposition is developed, including *key partners*, *activities*, *resources*, *sources of revenue*, and *costs*. Based on the business model, the PSS

architecture is developed, where actors are linked to the products and services. The two steps are shown in Figure 8.

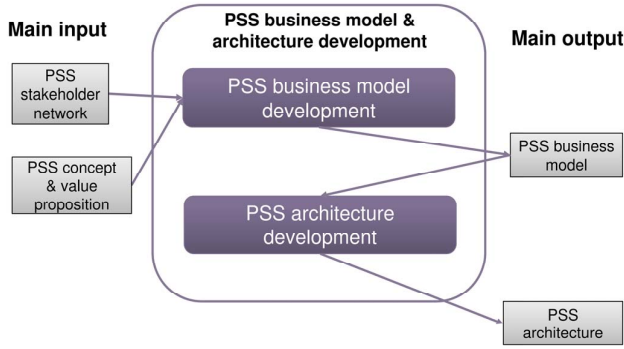


Figure 8: PSS business model and architecture development step

The business model is developed around the PSS value proposition, shown in Figure 7. The pain relievers and gain creators are directly adopted, together with the stakeholders. However, the business model canvas from [38] provides the possibility to display more elements that comprise a business model, as shown in Figure 9. We use the canvas, as it is well-known in the business domain and provides a shared vocabulary that translates between the technical and business domain.

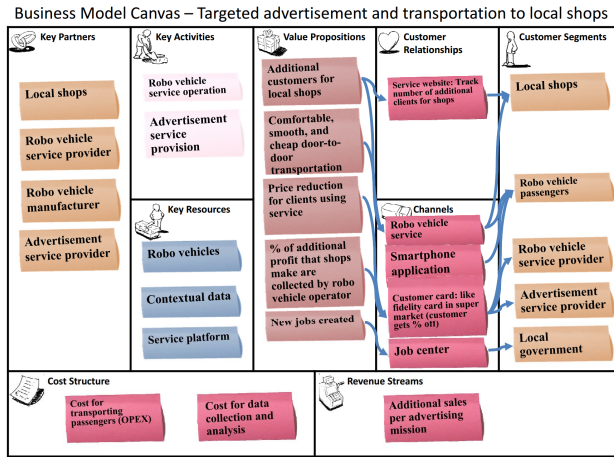


Figure 9: Targeted advertisement and transportation PSS business model canvas

First, for delivering the value propositions, certain key activities and key resources are required. In this case, the robo vehicle and advertisement service need to be operated. Furthermore, these activities require resources such as robo vehicles, contextual data, and a service platform. These activities and resources are provided by a set of stakeholders called *key partners*. For collaborative PSS, some of the stakeholders can be at the same time customers and partners, such as local shops. Contrary to the classic business model canvas, the canvas developed here is not from a specific organization's perspective. It rather displays how a set of stakeholders provides activities and resources to support value

propositions. It has therefore similarities with the RCOV framework from [39]. Finally, cost structure and revenue streams are identified such as the cost of transporting passengers, cost of data collection and analysis, and the revenues generated by the service via additional sales.

The business model canvas provides important information for the subsequent architecture generation step, such as the underlying resources and the set of partners that contribute to the PSS. Figure 10 shows a sample PSS architecture which includes the key partners from the business model canvas and some of the key resources. In addition, the constituent services of the PSS are defined. For example, for realizing the value proposition "Price reduction for clients using service", some form of traceability is required, in order to verify that customers have actually used the robo vehicle service. The constituent service "customer tracing" is based on a customer card. Of course, alternatives exist. Furthermore, a key resource is the service platform that allows for exchanging data between resources used in the services. In addition, the contribution of key partners to the constituent services and products / resources are explicitly defined. Collaborating actors are shown at the bottom of the figure, where the ad service provider and the robo vehicle service operator jointly operate the service platform.

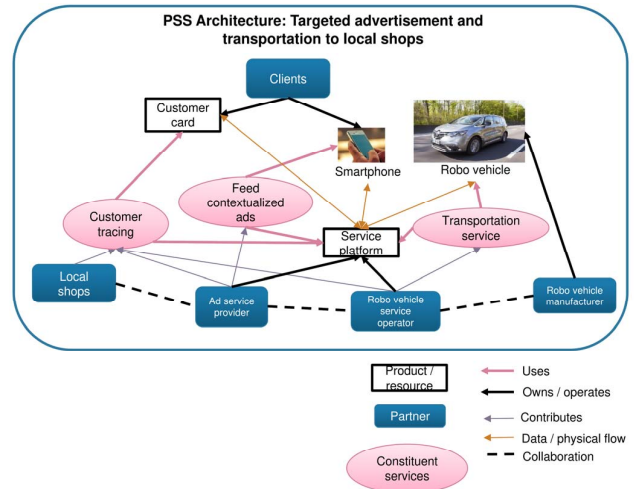


Figure 10: Targeted advertisement and transportation PSS architecture

Using the PSS architecture description, a first architecture specification is provided to system architects who are working on the architecture of a constituent product or service. For example, the definition of the service platform in Figure 10 specifies that it will be used for running three services and it is developed and / or operated in collaboration with the advertisement service provider and the robo vehicle service operator. It is easy to imagine alternatives to this constellation, e.g. the services are operated on different platforms. This PSS architecture description addresses the gaps of existing PSS and SoS approaches for representing PSS-SoS architectures as described in [19]: different service / product configurations, actor / stakeholder collaborations, supporting networks and infrastructure, and roles of actors (ownership, operation).

III. CONCLUSIONS

This paper presents an approach that is currently under development at Renault focusing on architecting product service systems (PSS) that comprise of a system of systems and one or more new technologies that may trigger its development. The basic steps of the methodology are shown, using a running example of a service based on autonomous vehicles. Starting from the autonomous driving technology, its impact on the field of local commerce, the value proposition, business model, and PSS architecture are developed. The technology impact assessment and PSS concept development have so far been applied to several PSS projects at Renault.

For future work, the methodology needs to be further matured via its application to industry case studies. For this purpose, the methodology is going to be implemented in the arKItect™ tool. In addition, a promising area of future work is the representation of the value network that forms the basis for collaborations between actors.

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