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THEORETICAL ARTICLE

Product-service systems evolution in the era of Industry 4.0

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Abstract
Recent economic transformations have forced companies to redefine their value propositions, increasing traditional product offerings with supplementary services—the so-called Product-Service System (PSS). Among them, the adoption of Industry 4.0 technologies is very common. However, the directions that companies are undertaking to offer new value to their customers in the Industry 4.0 have not yet been investigated in detail. Based on a focus group, this paper contributes to this understanding by identifying the main trajectories that would shape a future scenario in which PSS and Industry 4.0 would merge. In addition, future research directions addressing (a) the transformation of the PSS value chain into a PSS ecosystem, (b) the transformation inside a single company towards becoming a PSS provider, and (c) the digital transformation of the traditional PSS business model are identified.

Keywords Product-service systems · Servitization · Service transformation · Industry 4.0 · Digitalisation · Research agenda

1 Introduction

In recent years, manufacturing companies have been strongly pushed by saturated and commoditised global competitive environments to significantly transform the nature of their businesses, from being owners of competencies and resources to becoming integrators of skills, resources and technologies able to realise complex value creation processes (Cáceres and Guzmán 2015; Marilungo et al. 2017; Lindhult et al. 2018). This evolution, often referred to as *servitization* (Vandermerwe and Rada 1988) or *service transformation* (Cavalieri et al. 2017), implies a complete change of the traditional product-based business model towards a new approach

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more focused on the fulfilment of customer expectations, which promotes the sale of the performance associated with its use. This change foresees the provision of the so-called product-service system (PSS): 'A system of products, services, networks of players and supporting infrastructure that continuously strives to be competitive, satisfies customer needs and has a lower environmental impact than traditional business models' (Goedkoop et al. 1999). Hence, by its nature, PSS-oriented value creation needs to cope with conditions of high complexity, dynamics and ambiguity (Kuhlenkötter et al. 2017).

Due to multidisciplinary characteristics of PSSs, different schools of thought, related to information systems (IS), business management (BM) and design and engineering (D&E) (Boehm and Thomas 2013), have sought to explore their different angles and facets, often adopting various origins, motivations and methodological approaches. Recently, growing interest in the digital transformation of manufacturing firms, particularly in those technologies that are leading the so-called Fourth Industrial Revolution (or Industry 4.0), has fostered research on PSS to incorporate tech-based research into traditional areas of investigation (Thoben et al. 2017; Lee and Lee 2019; Pirola et al. 2020).

As underlined by theoretical and practical contributions (Dinges et al. 2015; Ardolino et al. 2017; Grubic and Jennions 2017), the literature agrees that the emergence of technologies such as the Internet of Things (IoT), cloud computing (CC) and big data analytics (BDA) may enhance the adoption of innovative services by manufacturers at both the business and engineering levels. The digitalisation of business processes and services, together with the advent of new ICT tools and facilitated by CC infrastructures and platforms, are considered trends relevant for PSS business model development, enabling a transformation from hard-wired value chains to adaptive product-service value creation networks (Blau et al. 2010).

The acceleration of technological innovation can facilitate the delivery of original personalised service functionalities able to satisfy new customers' needs and expectations (Huang 2014; Marilungo et al. 2017). In particular, the interconnectivity between different product-service components enables better interaction and development of PSS solutions, bringing them to a more intelligent level while influencing the intimate structure of the value chain and re-shaping industry competition. Benedettini and Neely (2018) highlight the need for manufacturing companies to expand and complement their offerings with increasingly advanced services. However, research is still far from identifying how companies can pursue new PSS value propositions by embedding and integrating digital technologies.

This paper aims to contribute to this gap by answering the following research question:

- What are the directions that companies are undertaking to offer new value to their customers in the context of Industry 4.0?

To answer this question, an overview of the literature on PSSs and their related technologies was conducted to support the opinions of 12 international experts collected through a focus group (Krueger and Casey 2014). The aim is to understand a complex new phenomenon and provide insights into the dominant dimensions according to which the evolution of PSS models in the era of Industry 4.0 can be analysed. In addition, it proposes future steps of these dimensions through which a company may tend to evolve in the future and shows, as an example, how companies can position themselves along with different drivers.

The remainder of the paper is structured as follows. After an analysis of the state of the art related to the main aspects of PSS business and operating models in the Industry 4.0 era (Sect. 2), the research methodology is described in Sect. 3. Sections 4 and 5 propose the intermediate output of the focus group phases, while Sect. 6 describes in detail the output of the experts' discussion. Section 7 proposes a research agenda in the PSS domain to be challenged in the future. Section 8 concludes the article.

2 Background: PSS in the era of Industry 4.0

Recently, a relevant wave of change has been fostered by the so-called Fourth Industrial Revolution (FIR), or Industry 4.0. Industry 4.0 has been defined as 'a new industrial maturity stage based on the connectivity provided by the Industrial Internet of Things (IIoT) and the use of several digital technologies such as cloud computing, big data and artificial intelligence' (Benitez et al. 2020). As mentioned in this definition, this change is based on the introduction of Internet of Things (IoT) concepts into manufacturing companies, leading to vertically and horizontally integrated production systems (Thoben et al. 2017). The alignment with the Industry 4.0 paradigm, characterised by 'smartness' and 'networking' (Kagermann et al. 2013), is a crucial topic for many companies that want to stay ahead in today's volatile and competitive market.

The literature has underlined possible advantages related to the introduction of the Industry 4.0 paradigm and the shift to 'intelligent manufacturing,' including cheap and ubiquitous sensors with high computational speeds (Gershwin 2018). Although most of them have been predicted a priori and not observed ex-post (Hermann et al. 2015), the opportunities, as well as the challenges, associated with such a transition are many. It has been declared that Industry 4.0 has a relevant impact on the implementation of PSS business models (Thoben et al. 2017).

Specifically, the literature explored the role of different technologies in the PSS scenario. *Digital technologies* are described as a crucial factor in assisting companies in their journey towards a service-based business (Neu and Brown 2005; Geum et al. 2011a), facilitating vertical and horizontal information sharing across the service network (Auramo and Ala-risku 2005; Martinez et al. 2010). Cavalieri et al. (2017) highlight that the advent of the *Internet of Things* can also be considered a further enabler for manufacturers to develop new services since it changes the way hardware is 'sold' to the market thanks to the opportunities offered by connected products and assets.

Hartmann et al. (2016) and Ardolino et al. (2017) study the great potential that the Internet of Things (IoT), cloud computing (CC) and predictive analytics (PA) offer to enable novel product-service offerings based on the transformation of data into information and knowledge. They stress how the digitalisation of products and services, as well as the digital connectivity between components and the combination of data from certain domains, could play a significant role in achieving the utility and performance related to product usage, the fundamental concept of PSS.

Bochmann et al. (2015) and Thoben et al. (2017) focus their attention on additive manufacturing, highlighting the benefits that can be brought to the fore by the possibility of fulfilling individual customer requirements with product variants in a very small lot size, down to one-off items. This may have a high potential for supporting PSS *customisation* and *adaptation*. For example, additive manufacturing supports the production of highly customised products in single batches with low resource waste in terms of material and energy, allowing quick and easy prototyping of the proposed solutions that favour PSS customisation. Strozzi et al. (2017) describe the possibility of customising the PSS solution through the availability of real-time information and through the reconfigurability of production, which in the Era of Industry 4.0 can be achieved at the same cost-efficiency level as mass-production. For instance, cloud platforms and data sharing are crucial for supporting co-design and the increasing demand for customised product-service solutions as well (Marilungo et al. 2017). Mourtzis et al. (2018) also stress the relevance of Industry 4.0 technologies in developing highly customised PSSs and hence increasing the overall system complexity.

Other researchers have deeply explored the advantages that new technologies can have in spurring *horizontal integration among companies*. Ben-Daya et al. (2017) highlight how the new technologies could support firms in integrating into a single supply chain to promptly respond to changes by enhancing effective internal operations and collaborations. Liu and Xu (2016) also see these technologies as the next stage of value chain organisation and management since Industry 4.0 will empower the monitoring and analysis of data across all stakeholders. For example, in-the-cloud data analytics favour the transition from a transactional to a relational approach to customers, since the interactions among stakeholders are more efficient. The supplier–customer relationship can also gain advantages in having direct supervision over the performance of the delivered product-service solutions, hence improving their offering based on the customers' use, but the documentation available in the literature is scarce.

Finally, some works report the role that technologies can play concerning the *PSS infrastructure*. The identification of proper technological infrastructure to embrace a specific evolutionary path towards 'servitization' is challenging (Ardolino et al. 2017; Grubic and Jennions 2017). As reported by Geum et al. (2011a, b), three different types of technologies can be adopted within PSS: (i) 'enabler technologies' allow the direct integration of product and services by embedding the technology into the product (e.g. sensors or actuators), (ii) 'mediator technologies' are already in a product or service and apply to servitization and (iii) 'facilitator technologies' ease the problem solving for additional servitization.

This overview of the literature highlights that a comprehensive set of research on the topic of PSS and Industry 4.0 is still lacking and that the transition from 'well-being based on the product' to 'well-being based on the access to the product' (Sakao et al. 2009) has not yet been explored and described. As a result, it can be stated that, apart from some specific work that explores certain topics of Industry

4.0 concerning the PSS concept, it is not yet clear how the introduction of Industry 4.0 technologies would impact the overall PSS scenario. In other words, 'How would the introduction of Industry 4.0 technologies influence the PSS paradigm?' 'How would the PSS business model and value proposition change?' 'What would be the main benefits? And what are the main challenges to be faced into this new scenario?' In line with this, 'What would be the main research areas to be explored to deepen this topic?' Hence, as a starting point to spur the discussion and develop a new PSS research stream, this paper relies on the expertise of international researchers to determine the main forces driving the future development of *technology-driven PSS* (Table 1).

3 Research methodology

Given the innovativeness of the topic and the scarce amount of literature regarding the holistic evolution of the changes in PSS research concerning new technologies and advancements, this study relies on an *overview of the literature* and the exploratory findings of an *international focus group* to identify the dominant dimensions playing a significant role in the evolution of PSS models in the Era of Industry 4.0.

An overview of the literature offers a summary of the studies attempting to understand an emerging research stream (Grant and Booth 2009). Such an overview is presented in Sect. 2 as the background of the research findings presented in this paper.

'A focus group is, at its simplest, an informal discussion among selected individuals about specific topics' (Wilkinson 1998). In the literature, it has been used in multiple domains to explore a subject or a phenomenon. The reasons behind its selection lay in its main feature, which is the interaction of participants (Wilkinson 1998) to constitute a common understanding of a complex new phenomenon. In fact, we need to keep in mind that the scope of the focus groups is not to infer or generalise but to understand and to provide insights about how experts perceive this new phenomenon (Krueger and Casey 2014).

From this perspective, the exploratory nature of a focus group makes it particularly feasible to explore new themes and to provide context and depth (Poels et al.

Table 1 Main industry 4.0 technologies and their implications for PSS

Industry 4.0 technology	Implication for PSS	References
IIoT and smart sensors	Smarter products	Song et al. (2014)
Big data analytics and artificial intelligence	Data-driven services	Lee et al. (2014)
Blockchain	Smarter service	Vogel et al. (2019)
Augmented reality	Smarter service design and delivery	Schwald and de Laval (2003)
Cloud computing	Elastic computing resources for digital services	Valilai and Houshmand (2013)
Additive manufacturing	Product customisation and adaptation	Zanetti et al. (2016)

2007; Thomas et al. 2015), as required by the scope of the current work. Besides, the reduced researcher control which characterises a focus group gives participants much greater opportunity to develop the themes that most important to them (Cooper et al. 1993), encouraging the production of more fully articulated accounts and offering an opportunity to observe the process of collective sense-making. The explicit use of group interaction and collaborative thinking produces data and insights that would be less accessible in single interviews with experts. A focus group generally involves creating an initial list of 20–25 experts with similar characteristics and interests and aiming for a core of at least 10–12 fully committed participants from within that group (Krueger and Casey 2014).

Since the focus group is theoretically characterised by homogeneity but with sufficient variation among participants to allow for contrasting opinions, the following selection criteria have been used to identify the experts:

- Research topics: It was necessary to guarantee homogeneity in the background and multiple expertise in research areas concerning PSS business management (BM), PSS design and engineering (D&E), and Industry 4.0 (I4.0).
- Geographical distribution: For a global perspective on the topics, the experts must come from a variety of countries.
- Experience in industry: To evaluate both theoretical and practical aspects, experts deeply involved in industry-oriented projects are required.

By these selection criteria, a list of 25 participants was created, and 12 experts responded positively to the invitation to participate in the focus group.

The current study relied on the participation of 12 different experts working in the fields of PSS and Industry 4.0, coordinated by one moderator assisted by three facilitators to keep the discussion flowing and to enable the strong involvement of each panel member.

The geographical distribution of the experts is mainly centred in European and North American universities and research centres. They have been selected due to their multiple expertise in research areas concerning PSS business management (BM), PSS design and engineering (D&E) and Industry 4.0 (I4.0). Table 2 reports the details of the experts' competences.

All experts have strong relationships with their country's manufacturing system. They participate and coordinate industrial projects related to both the implementation and design of PSS solutions and the transformation in Industry 4.0 contexts. Both the moderator and the three facilitators operate in academia and run research activities on the organisation and management of PSS with a specific interest in Industry 4.0.

Regarding the focus group structure, the work was organised into a two-session group meeting (group discussion and closing session) anticipated by an 'offline' individual analysis provided by each participant and used by the moderator and facilitators to collect interesting topics and prompts for the group discussion. The focus group phases are shown in Fig. 1 and detailed in Table 3.

Importantly, the final data of the focus group were interactive and qualitative in nature (Wilkinson 1998). They will be presented in Sects. 4 and 5 of the paper.

Table 2 Expert competences

Expert	PSS		I4.0
	BM	D&E	
1	x	x	
2		x	x
3	x		x
4	x		x
5	x	x	
6		x	x
7	x	x	x
8	x		x
9	x	x	
10	x		x
11	x		x
12	x		x

Fig. 1 Focus group phases

4 A common topic of PSS evolution into the 'Industry 4.0 scenario'

The first step towards the identification of the main development trajectories was the identification of commonalities and features among the individual ideas collected from the participants. As reported in Sect. 3, the *individual analysis* was pushed through open research questions to which participants provided multiple perspectives. Notably, concerning the most relevant question 'In your opinion, what are the main drivers that characterise the transformation of the product-service ecosystem towards Industry 4.0?', the following concepts were identified.

- One common driver identified for the evolution of PSS in the Industry 4.0 context is the shift in the *generation of solutions for customers*. The 'generation of individualised and customised solutions', 'new value proposition' and 'transformation of economic models in terms of customer relationships' were mentioned by some experts as main drivers of the change.
- The second group of commonalities collected from the individual analysis concerns the *technological advancements* that will lead the transformation. 'Additive manufacturing features', 'flexible machines', 'rapid prototyping' and the possibility to produce with 'lot size equal to 1′ characterising the Industry

Table 3 Focus group phases description

Phase	Description
Individual analysis	Before the group meeting, each participant was asked to start thinking and reflect individually about the future evolution and challenges of PSS in Industry 4.0. First, given the blurry meaning of 'Industry 4.0′, the participants were required to answer the question: 'Can you provide your definition of Industry 4.0?'. This question was set to ensure a common vision among the participants. Then, the following questions were set: - In your opinion, what are the main drivers that characterise the transformation of the product-service ecosystem towards Industry 4.0? Based on the Industry 4.0 drivers, how would you imagine the future shape (or configuration) of the manufacturing and global value chain ecosystem? (e.g. in terms of - organisation, strategy, operations, network) - In your opinion, how would the 'servitization continuum' evolve, in terms of offering and value proposition? The answers were collected remotely. Each participant provided his or her own definitions and concepts. At this step, only 8 participants out of 12 provided an answer. The moderator collected and reviewed all answers. The outcome of the individual discussion was organised into a common document which was meant to spur discussion during the group session. The main topics that emerged at this step are reported in Sect. 4. The provided definitions of Industry 4.0 are reported in Annex I
Introductory round	The preliminary results were presented by the moderator on the day of the meeting, along with a general insight into the literature on PSS. This had the scope to provide a homogeneous taxonomy constituting a starting point for all participants. To highlight the plethora of features around the topic, two experts from industry and academia were invited to present the latest advances in the domain and the main challenges associated with it
Group discussion	The group discussion constituted the most crucial part of the entire focus group activity. Participants were asked to provide their own opinions about the preliminary results (i.e. those from the individual analysis) and to discuss with each other freely. Similarly to the individual task, the discussion was clustered on the four main questions previously described. In addition, the discussion among participants was recorded and data transcribed by the facilitators. The main topics discussed are reported in Sect. 5
Closing session	In the closing session, the moderator proposed a graphical summary of the group discussion. In this session, another collection of feedback from the participants and an update to the results were performed. The moderator then closed the focus group, summarising the most relevant outcomes In the following days, the facilitators refined the discussed the outcomes using information recorded during the meeting. The data collected were analysed using the 'scissor-and-sort' technique (Stewart and Shamdasani 2014) The reviewed outcomes were then sent to each participant, who was asked to provide offline his or her feedback to finalise the results presented in Sect. 6

4.0 scenario have been identified as relevant drivers that will push the PSS towards a more intelligent level.

- The *network and supply chain integration* is the third common concept mentioned by multiple focus group participants. 'Ad hoc production network', 'collaboration' and 'integration between supply chain actors' were mentioned by the participants as main forces pushing the transformation.

- Finally, it is possible *to connect products or PSSs and collect data*. 'IoT, big data', 'ICT business infrastructure', 'smart connected products' and 'advanced control and monitoring' were mentioned as drivers that will influence the transformation.

Figure 2 summarises the four main ranges of interest, together with the associated keywords that emerged from the individual analysis of the focus group data.

5 Group discussion and collaborative thinking on the topic of PSS and Industry 4.0

The discussion phase of the focus group started with the presentation of the preliminary output of the individual discussion. The roundtable debate was mainly centred on the four common concepts summarised in Sect. 4. During the group discussion, the experts confronted each other on the four main topics that emerged during the individual round in a collaborative way. For each, they identify the past and existing features and then put their effort into proposing a possible future evolution. Here is

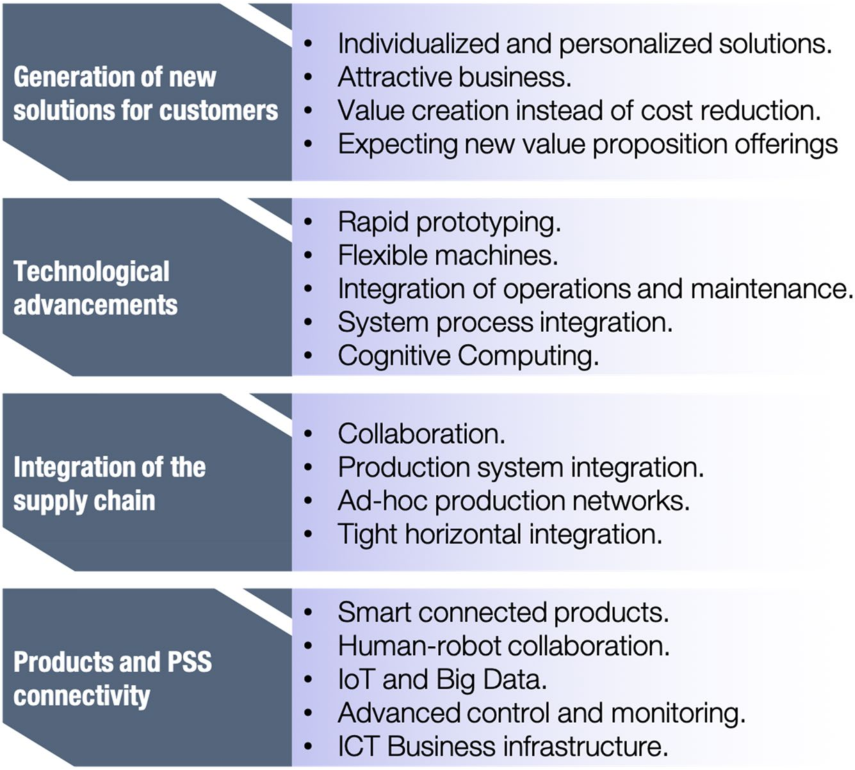

Fig. 2 The four main categories mentioned during the individual round of the focus group

a summary of the main points tackled during the conversation that led to the final output described in this work.

- First, the experts pointed out the need to clarify the concept of 'driver' or 'enabler'. According to the participants' opinion, the word 'driver' refers to something external, while in the studied topic, it is important to use a market-oriented nomenclature. The word 'dimension' seems to better suit the context. A glossary of terms was agreed upon by the experts.
- The four topics have been identified as relevant for future PSS evolution, but it is important to clarify the meaning of this phenomenon. Moreover, since they would be defined as 'dimensions', all the experts agreed in setting a proper nomenclature. The need to have a common and shared understanding of them was also highlighted.
- A consensus among the experts on the relevant role of technologies in generating new solutions for customers was obtained. This has been defined as a 'value creation mechanism' (i.e. a driving force of the PSS offering). It has been argued that 'the generation of solutions completely centred on the value for the customer will be the focal point of the PSS evolution'. One of the experts proposed the term 'full-value solution' to indicate the relevance of the value concept in the evolution. The others agreed on this concept but stressed the importance of clarifying what is meant by 'full-value solution'.
- A deep exchange of opinion focused on the concept of customisation. Although the experts recognised the high possibility of customisation and personalisation already available in the market, they all agreed on the potential of new technologies to ease and facilitate this. According to their opinions, the new technologies favour the rapid adaptability of the solutions to the customers' requirements; they can even change the level of customisation or the customisation features during the solution lifecycle. Due to this, the concept of 'evolutionist' has been mentioned.
- The other relevant topic concerning PSS evolution is value chain integration. All the participants agreed that technologies could push new partnerships and collaborations among the supply chain actors. The researchers also highlight the need to increase collaboration among actors to collect multiple sources of expertise and hence sell comprehensive solutions tackling multiple domains. It emerged that thanks to the diffusion of a pervasive interdisciplinarity and complexity, more players are involved in product-service offerings, and a value chain includes all actors that directly take part in the value creation in a star-like or network pattern. Concerning this topic, the discussion brought to the fore the concept of risk management and risk-sharing among the interactive partners.
- Finally, the role of technology and its advancements was recognised as a relevant topic to be discussed and included in the main trajectories of evolution. The development of technical capabilities was defined as a core concept in the analysed evolution.

The above summary of the discussion reports the main points discussed during the group phase of the focus group. The discussion lasted an entire day, and the full notes are available upon request. The next section includes a detailed description of the final output achieved during the focus group. It reports the four main trajectories of evolution; for each of them, it also includes the main steps that can be observed in the evolution of the specific topic.

6 PSS and technologies: trajectories of evolution

This section includes a detailed description of the outcomes of the focus group. It includes the four main drivers, or 'trajectories', which, according to the experts' opinions, would represent PSS evolution in light of the introduction of Industry 4.0 technologies.

The aim is to point out the main trajectories of the PSS ecosystem in the context of new industry trends, such as the demand for customised products, the rise of servitization, rapid technological changes combined with a highly competitive market, digitalisation of the economy, and production automation. The four main PSS evolution dimensions, with their corresponding continuum, are (1) value offerings manifestations, (2) customer value experience, (3) value creation mechanism, and (4) value creation interactions. Figure 3 reports the four dimensions and the steps that characterise their continuum. As can be observed, for each continuum, four different steps have been identified. Three of them represent previous or current configurations, whereas the last one constitutes the future step that, according to the focus group experts, can be foreseen. This 'future configuration' is the contribution of the experts and represents the starting point for defining future research topics and agendas.

According to the experts, the future configurations of the four dimensions represent the innovative concept towards which each company could evolve in the future. It represents the possible configuration enabled by the introduction of new technologies. However, all the focus group participants agreed on the fact that in a future configuration, each company can freely decide what step (or configuration) of each continuum

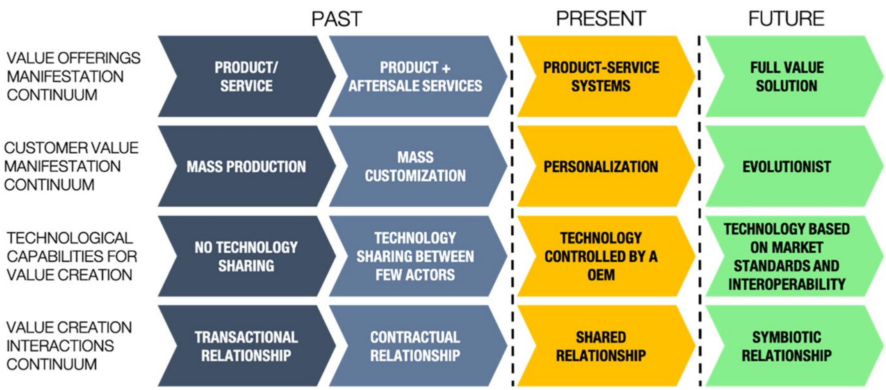

Fig. 3 Research trajectories defined by the focus group experts

to adopt. In other words, the best option for a company is not the selection of the four future configurations at the same time (i.e. 'full-value solution', 'evolutionist', 'technology based on market standards' and 'symbiotic relationship'). For example, a company can decide to establish a symbiotic relationship with other partners inside the ecosystem but decide to sell a single product or service instead of a full-value solution.

6.1 Dimension I: value offerings manifestations

As previously hinted, the group discussion of the focus group highlighted the relevance of new technologies in enabling new PSS offerings or solutions. The provision of bundles of products and services for customer satisfaction is generally referred to as the first distinguishing feature of a PSS, as reported in many definitions available in the literature (Goedkoop et al. 1999; Manzini and Vezzoli 2003; Mont 2002; Tan et al. 2009). This new solution pursues a new strategy while delivering 'value-in-use' (Baines and Lightfoot 2014) or a 'required functionality' since '…instead of the product itself, the activity, its utility and performance associated with the use of the product are considered to be of more value to the customer' (Tan et al. 2009).

In such a context, a *value offering* or *value proposition* is a promise of value to be delivered, communicated and acknowledged by the customer, while the *value of an offering or proposition* is defined as the measure of the satisfaction and benefits received by a customer from acquiring or consuming (i.e. value-in-exchange) and experiencing (i.e. value-in-use) a product, a service or a bundle of both. *Value-added creation* is the process of creating a positive difference or gain for the customer between his or her current solution for a need and the new value proposition offered by a company, which better responds to such need.

The focus group shed light on the changes in the *value-added creation systems* and therefore identified the *value-offerings manifestation continuum* through which manufacturing companies would evolve: from (a) being pure manufacturers of product or services, to (b) offering complementary services for their products (i.e. after-sale services), to (c) offering product-service bundles (i.e. product-service systems), to (d) aiming to deliver full-value solutions. The role of technology in supporting this shift is of utmost relevance. The focus group agreed that digital technologies such as the Internet of Things (IoT), Cloud computing (CC), and predictive analytics (PA) offer great potential to enable novel product-service offerings based on the transformation of data into information and knowledge (Hartmann et al. 2016; Ardolino et al. 2017). Moreover, the digitalisation of products and services as the digital connectivity between components and the combination of data from certain domains plays a significant role in achieving the utility and performance related to product usage, the PSS fundamental concept. Table 4 reports the phases of the value-offering manifestation continuum and their descriptions.

6.2 Dimension II: customer value experience

Consistent with recent literature that has emphasised how the PSS value offering can be designed to allow an increased level of quality (Vezzoli et al. 2017; Song and

Table 4 PSS value offerings possibilities

Value offering	Value orientation
Product or service	The value offering is based on a transaction, the trade, between the customer and the manufacturer, or the retailer, of a tangible artefact (the good), which concludes with the customer ownership of the product
	The value offering is based on a transaction, the trade, between the customer and the service provider, of an intangible and perishable artefact (the service), which concludes with the temporal customer accessibility to the (service) benefit
Product + after sales services	The value offering is based on an initial transaction of a good and its ownership by the customer, followed up by value-added complimentary service benefits (e.g. product warranty)
Product-service systems	The value offering is designed and delivered as a product-service bundle composed of tangible products and intangible services that, combined, fulfil specific customer needs that include a wide range from ownership to accessibility to result-oriented benefits
Full-value solution	The value offering is completely oriented to the satisfaction of the customer's needs through a mix of product and service elements that appear indistinguishable in their ability to deliver value from the customer/user view. The customer/user only perceives the final value (result) associated with experiencing the solution

Sakao 2017), personalisation of solutions is another relevant dimension of the PSS evolution identified by the focus group. In particular, discussion among focus group participants has underlined how much, as shown by Aurich et al. (2006), the little capital-intensive character of services offers high customisation potentials, supporting flexible adaptation according to individual product usage. The service component, being flexible, can deliver new functionality to suit customer needs (Baines et al. 2007). Moreover, the combination of products and services can be appropriately matched to satisfy specific necessities (Long et al. 2016), though this topic is still under debate, as a systematic approach to properly combine products and services remains missing (Song and Sakao 2017).

After agreeing that from a value creation tailoring customer perspective, *customer value experience* can be seen as the degree to which a value offering has been particularised for a specific customer need(s), participants in the focus group converged towards the *customer-value experience continuum* reported in Table 5. It starts with 'mass-production', where goods and services are standardised commodities produced or offered through large-scale manufacturing or service systems. It then continues with mass-customised value propositions (i.e. modularisation), which represents the first advancement, since a limited number of variants are proposed to customers. The third step is constituted by personalised value propositions (i.e. individualisation). It represents the latest advancement in place and is currently available. It consists of a complete restructuring of the solution to make it completely aligned with the customer's features and requirements.

Here, Industry 4.0 technologies and concepts may have great potential in supporting PSS customisation and adaptation, fulfilling individual customer requirements with product variants in a very small lot size, down to one-off items (Bochmann

Table 5 PSS value offerings possibilities

Customer value	Value orientation
Mass-production	Uniform value propositions of products or services (i.e. mass-production)—where goods and services are standardised commodities produced or offered through large-scale manufacturing or service systems
Mass-customisation	Products and services are customised with a predefined solution space (a product/service architecture) to enable different but limited variants and options in an effort to satisfy specific preferred customer value configurations
Personalisation	Products and services are tailored to customers' needs through the voice of the customer or other co-design approaches
Evolutionist	Products and services become intelligent proactive entities (Wuest et al. 2018) capable of anticipating different needed value-added product upgrades and complementary value-added services

et al. 2015; Thoben et al. 2017). For example, additive manufacturing supports the production of highly customised products in single batches with low resource waste in terms of material and energy, allowing quick and easy prototyping of the proposed solutions that favour PSS customisation. Moreover, the possibility for customising the PSS solution can be further enabled by the availability of real-time information and by the reconfigurability of production, which in the era of Industry 4.0 can be achieved at the same cost-efficiency level as mass-production (Strozzi et al. 2017). In line with this, many companies are offering co-design or participatory approaches that help them in developing flexible innovative solutions that could match multiple customer requirements. In particular, cloud platforms and data sharing are crucial for supporting co-design and the increasing demand for customised product-service solutions as well.

According to the focus group experts, the introduction of the new technologies can further exacerbate the customer-value experience continuum. More than being completely tailored to customer requirements, new solutions (or PSS) could be designed to adapt during their use and to accommodate evolving customer needs. According to the experts' opinions, products and services could become intelligent, proactive entities (Wuest et al. 2018) that monitor customers' changing needs and usage and modify themselves to comply with them.

6.3 Dimension III: technological capabilities for value creation

Recent studies have stressed the relevance of technology in supporting the integration of products and services and guiding the evolution towards 'system management' (Park et al. 2012). By definition, PSS infrastructure is the area where technologies and digitalisation can have the most impact. Indeed, as underlined by some studies, the identification of proper technological infrastructure to embrace a specific evolutionary path towards servitization is challenging (Ardolino et al. 2017; Grubic and Jennions 2017). In particular, one key element that could influence how PSS evolves is the way new Industry 4.0 technologies can be appropriately incorporated into PSS infrastructure as a positive means to improve and differentiate a company's offerings. However, how technology can support the integration of products and services into unique PSS business models is still under analysis (Bertoni and Larsson 2017), and the further potential enabled by Industry 4.0 needs to be studied.

From this perspective, according to the focus group participants, to create and deliver value for the customer, manifested as products, services and product-service bundles, the *value provider* (e.g. the Original Equipment Manufacturer—OEM) should develop and implement new capabilities related to the adoption, use and management of key technologies in any stage of the lifecycle, as reported in Table 6. The first step analysed in this continuum is the 'basic case', in which every single actor is developing and using its own technological capabilities without sharing any kind of knowledge. A step further is the sharing of information between a few actors. In this case, one actor (usually the OEM) develops technological capabilities and invites selected and certified service providers to its value chain to use such capabilities.

Here, the adoption of technology-based infrastructures such as those based on smart devices (i.e. RFID tags, sensors, actuators), human–computer interfaces and computational models can be of relevance in supporting the relationship between the tangible product and service delivery process. In this case, the sharing of information between the OEM and service provider is meant to enhance the potentiality of products for the customers (i.e. after-sale services), as smart infrastructures enable better exchange of knowledge among the actors of the network throughout the product-service lifecycle.

Further improvement of such a model includes the case in which the technology is owned and controlled by the OEM, but any actor, by using its capabilities based on OEM's technology, can eventually develop and provide authorised services for the OEM's products to the customers after the OEM's approval (i.e. product-service bundles). The future frontier in this context is represented by the situation in which all the value chain actors can share information since they all adopt technologies

Table 6 PSS technological capabilities possibilities

	Technological capabilities
No technology sharing	Technology capabilities are developed by every single actor without sharing any kind of knowledge
Technology sharing between few actors	Technology is shared between a few actors. One actor, usually the focal product company, develops technological capabilities and invites selected and certified service providers to its value chain to use such capabilities
Technology controlled by an OEM	The technology is developed, owned and controlled by the OEM, but any actor, by using its capabilities based on OEM's technology, can eventually develop and provide authorised services for the OEM's products to the customers, after the OEM's approval
Technology-based on market standards and interoperability	All the value chain actors can use the technology developed by any of the actors involved in the value chain since they all adopt technologies based on market standards and interoperability protocols, and these develop their capabilities

based on market standards and interoperability protocols, and these develop their capabilities.

Ubiquitous and pervasive computing permits the interaction and coordination between things (objects) produced by different actors to reach computational modelling of previously disconnected systems, allowing the delivery of solutions based on an open contest of technology and interaction. Moreover, IoT enables real-time data acquisition from sensors and actuators in various manufacturing facilities and fields and subsequent analyses that facilitate the dynamic fulfilment of customer demands (Thoben et al. 2017).

The aim is to insert their new value offerings (i.e. single products or single services, or product-service bundles) into a more extensive open system (i.e. a meta-ecosystem of product-service systems) to offer the ultimate and full-value solution for a customer segment within the target market.

6.4 Dimension IV: value creation interactions

A differentiating feature of PSS stressed by many definitions refers to the concepts of a 'network of players' (Goedkoop et al. 1999) and 'network' (Mont 2002) required to pursue a 'system' integration. As companies shift from pure transactions to relational engagements, assuming operational responsibilities for customers' processes, the interactions with the customers intensify along with their engagement in value co-creation processes (Nordin et al. 2011; Benedettini et al. 2015; Baines et al. 2017). Moreover, a single organisation is rarely able to solely provide a comprehensive PSS value offering (Sakao et al. 2009), so the engagement of several partners within the upstream and downstream value chain emerges as crucial (Bikfalvi et al. 2013; Sakao et al. 2013; Selviaridis and Norrman 2014). In turn, this potentially raises the likelihood of conflicts, disagreements and opportunistic behaviour with both customers (Richter et al. 2010; Kindström 2010) and collaborating partners, mainly because they are characterised by diverse organisational features, positions in the value chain and incentive models (Meier et al. 2011; Lockett et al. 2011). Parida et al. (2013) further show that as partnering organisations are often globally distributed, additional relational issues may arise, negatively influencing the likelihood of 'win–win' collaboration between PSS providers and their global value-chain delivery organisations.

Based on these premises, *value creation interaction* can be defined as the collaborative form among the stakeholders of a product system, service system, product-service system or solution system. In other words, it represents their risk and revenue-sharing model in the context of a business model supporting determined value creation and delivery mechanisms. The experts from the focus group identified four collaborative forms that can evolve in a *value creation interactions continuum.* 'Transactional relationships' represent the basic type of relationship in which stakeholders (i.e. supplier → OEM → customer) share risks and revenues in individual transactions, as reported in Table 7. The 'contractual relationships' were also mentioned by the experts in the focus group. This kind of relationship is agreed upfront in order to provide boundaries for risk and revenue sharing between a defined hierarchy of stakeholders in a collaborative value chain, where transactions are conducted based on these agreements (i.e. contracts).

With respect to these requirements of collaboration and networking, the new technologies brought by Industry 4.0 can carry some advantages since they spur horizontal integration among the companies. They also enable firms into a single supply chain to respond promptly to changes by enhancing effective internal operations and collaborations (Ben-Daya et al. 2017; Schuh et al. 2014). The third case is the case of 'shared relationships' that takes place in non-hierarchical networks of stakeholders, where risks and revenues are eventually distributed among the stakeholders. Here, as the next stage of value chain organisation and management (Liu and Xu 2016), Industry 4.0 technologies empower the monitoring and analysis of data across all groups of stakeholders. For example, in-the-cloud data analytics favour the transition from a transactional to a relational approach to customers, since the interactions among stakeholders are eased. The suppliers can also gain advantages in having direct supervision over the performance of the delivered product-service solutions, hence improving their offering based on the customers' use.

Regarding this continuum, the 'symbiotic relationships' represents the innovative step. According to the experts, in this kind of relationship, stakeholders work in a networked value ecosystem, where all stakeholders can collaborate 'on-the-fly', through open platforms, to support the optimal configuration of the networked value ecosystem and to co-create full-value solutions.

7 PSS evolution dimensions: an example in the automotive industry

To understand the validity of identified dimensions and related steps, possible combinations defining possible configurations have been investigated, and examples from the automotive sector have been reported. The objective is not to identify predefined configurations but to understand if the various dimensions were sufficient and clear in describing the peculiarities of past, present and future configurations. In

Table 7 PSS value creation interactions possibilities

	Value creation interactions
Transactional relationship	Transactional relationships represent the basic type of relationship in which all the actors share risks and revenues in individual transactions
Contractual relationship	This kind of relationship is agreed upon upfront in order to provide boundaries for risk and revenue sharing between a defined hierarchy of stakeholders in a collaborative value chain, where transactions are conducted based on predefined agreements (i.e. contracts)
Shared relationship	This kind of relationship takes place in non-hierarchical networks, where risks and revenues are eventually distributed among the stakeholders
Symbiotic relationship	This relationship takes place in a networked value ecosystem, where all stakeholders can collaborate 'on-the-fly', utilising open platforms, to support the optimal configuration of the networked value ecosystem and to co-create full-value solutions for the customer

particular, four configurations, reported in Fig. 4, have been investigated to explain the different combinations of drivers. The four configurations are not exhaustive and are not intended to give prescriptive indications with respect to the different configurations. They are only intended to exemplify the above dimensions and report how the dimensions can be used to describe companies' positioning.

7.1 PSS configuration I

In the first configuration, the OEM is creating and delivering a value proposition (i.e. a product or a service) individually to its customers. Usually, companies do not have planned collaboration agreements, but they have a transaction-based relationship characterised by a low level of integration. For instance, in the automotive industry, cars are sold on the market, and independent service providers would decide to enter the market and provide service along the product life cycle. The car manufacturer could interact with the service supplier in a transactional way by selling spare parts directly or through its authorised service network. No partnership and long-term collaborations are put in place. The technology developed and adopted by the various actors is not shared; any data collected are used by those who collected them (OEM or service provider) independently without any kind of sharing. Nowadays, this type of configuration does not represent the core business, but it persists in all sectors to cover the demand of niche markets.

7.2 PSS configuration II

This second configuration is characterised by OEM inviting selected and certified service providers to its value chain to offer specific complementary services for its products for its customers (i.e. after-sale services). The main collaboration is focused on the exchange of relevant information along the product lifecycle

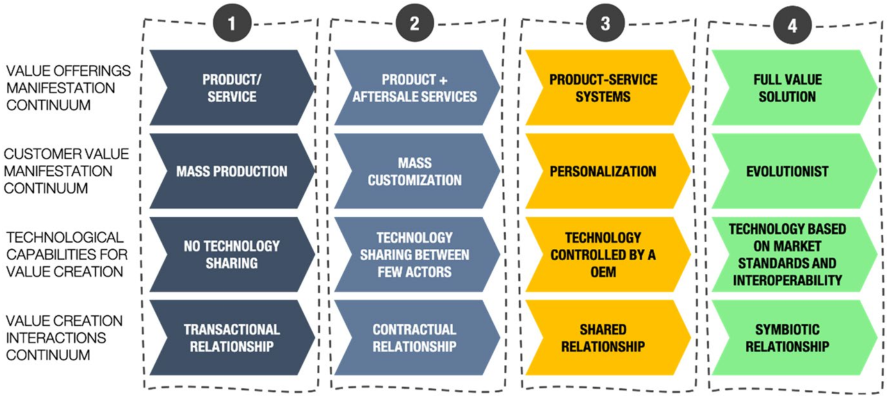

Fig. 4 Example of configuration of the automotive industry along the identified PSS business model dimensions

to reactively support customer needs. This context is mainly characterised by an OEM (dominant partner), which drives decisions both in the area of product and service and from the strategic to the operational levels. Asymmetrical distribution of information and market position characterise such a configuration. This calls for matching customer demand and product and service supply more effectively by promising mutual benefit for all involved. Strategic partnerships between provider and supplier are often created in a one-to-one collaboration approach, and the OEM provides technological capabilities to the certified service network. In this configuration, the car is sold to the customer in a transactional way. Then, the car manufacturer establishes a network of certified service providers (official workshop network) to support customers along the car lifecycle by providing after-sale services. The workshops are in charge of providing the service as designed and certified by the manufacturer. The collaboration is based on a contract defining revenues stream and risk-sharing issues and on a predefined exchange of information, usually done through a Dealer Management System, contractually enforced by the OEM. The system is designed to manage and coordinate the activities of the car dealership network, including sales of new and used vehicles and service spare parts management. This is the most common configuration currently used in the car industry by all the brands.

7.3 PSS configuration III

The third configuration can be represented by an ecosystem of actors formed and controlled by one specific OEM, which is generally the product provider. In this configuration, service providers are allowed to provide any service for the OEM's products, and therefore customers, after the OEM approval. This kind of ecosystem is characterised by vanished borders between different organisations to improve transparency. The dominant company (i.e. the OEM) acts as a decision-maker concerning both product and services features that can be delivered to the final customer. In this perspective, the solution is orchestrated by the OEM since there is always control from one party's perspective. In detail, the product acts as a platform, technologies are decided and developed by the OEM, and in the meantime, different service suppliers can develop services that are subject to the dominant company decision. This configuration is characterised by a 'one-to-many' relationship. A typical example is a car-sharing solution, where the car manufacturer designs a car and defines the mobility service for the customer. In this context, several actors develop and share technologies following the OEM standards to provide a personalised customer experience. Each service and technology implemented in the car (e.g. app reader) or for the use of the car (e.g. service repair network), or to enhance the customer experience within the car use (e.g. mobile apps for mobility), must be designed coherently with the car specifications and technology and must be approved by the car manufacturer. Examples of this type of configuration are Car2Go, the largest car-sharing worldwide service owned by Daimler, and the bike-sharing, provided by the famous Italian manufacturer Piaggio.

7.4 PSS configuration IV

As long as companies in an ecosystem start collaborating with external companies and with competitors, interactions among multiple actors and interested parties increase. Such interaction pushes all involved actors to collaborate along with various value co-creation processes within a balanced customer-centricity. In this configuration, all the actors act as in a choreography in which all are willing to collaborate and no party has the overall control. This is a 'many to many' collaboration environment. This could represent the future where the car industry will operate, in which the car will be one of the players of a wider mobility system. Car manufacturers and service providers will collaborate with other mobility product providers and service suppliers to be able to improve passenger experience by making travel easier and more comfortable even across different modes of transportation. In this context, traditional and new players must cooperate to allow a constant evolution of mobility by incorporating new services and products. The adoption of common standards and protocols is essential to allow a comprehensive collaboration among all the actors interested. Deutsche Bahn Connect is the new integrated mobility service promoted by the German rail transport giant for individuals and companies.

8 The research agenda

As argued, this paper represents explorative research on the topics of Industry 4.0 and PSS. A set of experts in the field shared their opinions in a focus group and brought to the fore possible drivers to analyse the phenomenon. Four main constituting pillars of PSS gathered high attention into the research group, which found an agreement, in accordance also with previous literature, considering the driving forces behind the 'transition to service' (Song and Sakao 2017), as well as the defining characteristics of a PSS (Pan and Nguyen 2015; Haase et al. 2017). Serving as the multifaceted aspects of a PSS embodied into the transition from a 'well-being based on the product' to a 'well-being based on the access to the product' (Sakao et al. 2009), the group of experts identified those pillars could either represent a challenge or an opportunity for PSS providers (Matschewsky et al. 2015). Also, participants studied possible steps associated with each driver, which can be defined as a 'continuum'. Although some concepts included in the four dimensions are well known, the last step of each continuum represents the vision of the focus group participants and represents the starting point for the identification of a research agenda.

The vision of a future configuration of each dimension has also been a stimulus for the experts in defining research topics that are currently under-investigated and that could be interesting for the future. The majority of the research areas identified are related to all four dimensions, but some research topics are specific to a single dimension.

Hereafter, the identified list of research areas to be investigated is reported. The research areas have been split into three different categories. First, all the research topics mainly related to the transformation of the PSS value chain into a PSS ecosystem are reported. Second, the areas concerned with the transformation inside a single company are described. Third, the research topics are related to the main technological issues.

In Fig. 5, a summary of the three main areas with the related research directions is reported.

Concerning the value chain, the future configurations of the four dimensions identified by the experts pointed out the strong changes that could take place.

- Network configuration: The last step of the technological capabilities for value creation, i.e. ‘technology based on market standards and interoperability’ and the ‘symbiotic relationship’, which is the last step of the ‘value creation interactions continuum’, highlights the necessity to create an extended and organised network that can also be defined as an ecosystem. This implies the creation of complex and intricate relationships among the different actors of the ecosystem. In line with the ‘technology based on market standards and interoperability’, experts highlighted the technological nature of such a collaboration that is not only contractual but based upon a share of technological capabilities. From a research perspective, this implies the need to further explore the value chain and network. The study of networking models and tools is required to face these future scenarios. According to the experts, methods to model and analyse complex networks will be of key relevance, as well as the development of tools to monitor and support decision-making, taking into account multiple constraints and multiple actors inside the enlarged value chain often referred to as an ecosystem.
- Risk and revenue management: While companies are rethinking the collaboration and co-creation models among the actors of the value chain and within the customers, the creation and management of risk and revenue-sharing agreements will be of utmost relevance, since they will consider delivery partners’ and customers’ interests at the same time. Hence, risk and revenue-sharing mechanisms represent a relevant future research interest. This topic becomes even more relevant considering the data sharing between the different actors of the ecosystem.
- Data management: Concerns about data privacy and security were mentioned by the experts as factors that may potentially inhibit (or spur) the relationships inside the ecosystem. Additional research will be required on understanding under which modes and conditions there can be a ‘win–win’ collabora-

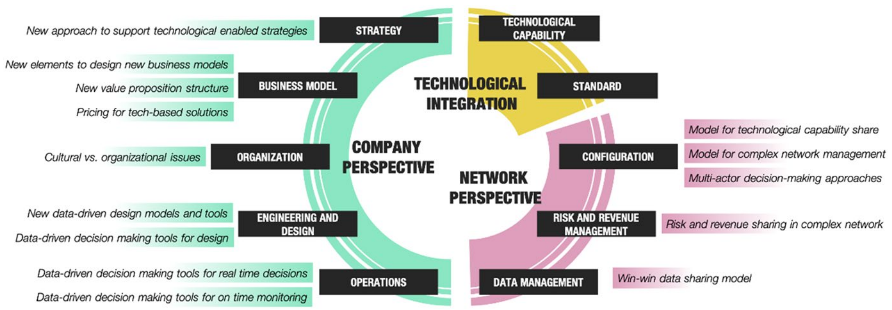

Fig. 5 Technology-driven PSS research agenda

tion with partners to deliver the best offering and to be competitive in markets featuring a high degree of uncertainty and risk. During the focus group, it emerged that it could be interesting to study the factors that motivate or inhibit the sharing of data.

At the company level, a wider variety of research topics could be explored. To provide such solutions, companies should transform themselves, fostering a tech-driven mindset across all levels of their organisations. This is likely to be a daunting undertaking, and it is expected that this process will require substantial transformation. Therefore, companies should be able to overcome technological and cultural challenges. Moreover, they should understand how they could push leadership with a clear vision and strategy to optimally use technologies and related data as essential resources to enable tech-driven innovation in the PSS scenario. From an individual perspective, the main research areas are the following:

- Strategy: The first main implication for both practice and research involves the company strategy. Since the introduction of new technologies enables the provision of new value offerings, i.e. full-value solutions, the experts highlight the need for new research from a strategic management perspective. The company needs to reshape its mission and strategy. It has been acknowledged that Industry 4.0 innovations have implications for PSS firms' strategy, development and execution such as increased profitability, being a source of innovation, or enabling new customer–firm and partner–firm interactions.
- Business model: Directly connected with the shift in the strategic vision of the company, the experts shed light on the need for further research on the topic of the business model and pricing strategy. Some questions arose during the focus group: How should PSS business models co-evolve with Industry 4.0 technologies? How is it possible to define the new forms of value propositions? How can such a business model be implemented? Hence, the business model would need to be rethought and re-shaped. From a research perspective, the experts pointed out the need to understand if the 'traditional' business model elements would still work in the new scenario. In other words, 'What could be a possible business model for a full-value solution?' 'Are the existing business model elements enough to describe a 'full-value solution?' 'How the full-value solution could be sold?' 'What are the partnerships required to manage the solution?' The issue of *solution pricing* also emerged during the discussion. Many experts pointed out the complexity of setting a price for the new solutions offered to customers. Further analyses and research can be related to the pricing mechanism to be adopted.
- Organisation: The cultural transformation taking place into a company is pervasive, and according to what emerged during the focus group, it plays a significant role in the success or the failure of a shift of a company towards the future based on PSS and technologies. To the experts' best knowledge, this is still an under-investigated topic, and it will be relevant to understand how the cultural transformation will affect the introduction of digital technologies and vice versa.

- Design and engineering: Given the expertise of the focus group and the relevance of the topic, it has been recognised that engineering and design is a key topic to be included in a future research agenda. It has been the central topic of the first 10 or 15 years of the PSS community, and the experts confirm the future relevance of the topic. Further efforts and research regarding the engineering and design of the solutions are necessary. It is of utmost relevance to define and study methods that can support companies in designing integrated solutions while simultaneously considering the product, the service and the technology integrated into the solution (Pezzotta et al. 2018). To offer the foreseen 'full-value solution', which is 'evolutionist', proper tools and integrated approaches are required. This is a fundamental issue with profound consequences on processes, methods and tools that today are taken for granted in PSS design. For example, in an extreme situation in which a PSS designer will have almost unlimited access to data, measuring every aspect of usage and performance, from the most to the least obvious, traditional and well-known techniques such as focus groups, observations, interviews and questionnaires currently adopted for need-finding will not be needed; on the other hand, we will need (big) data analysis models. Moreover, while today the 'best' design is often chosen based on an performance vs. investment equation, the availability of almost unlimited data about PSS usage will make it possible to quantify more intangible aspects of value and to use this information to perform more accurate trade-off studies for new solutions and to optimise the delivery of the already available solution in an evolutionist and holistic perspective. The transition towards a networked ecosystem perspective implies moving from a single sequential discipline to a parallel multidisciplinary evaluation and design, in which all decisions, usually made on an individual basis, are now jointly evaluated and merged in a decision environment. Finally, the experts describe the need for future research to reflect on the role of humans in engineering and designing the PSS.
- Operations: In parallel to design, experts highlighted the need for deeper research on PSS operations management. In their opinion, operations management in the PSS field has been under-investigated, but with the introduction of new technologies and the foreseen evolution of the PSS value proposition towards the so-called 'full-value solution', operations management research has become a key topic to be explored. With the introduction of new technologies and with the improvement of PSS becoming 'evolutionist', the experts shed light on the relevance of the monitoring and analysis of the solutions during the whole lifecycle. During the focus group, the fundamental role of decision-making during the operations of a PSS was pointed out. The scanning of the solution, together with its evolutions throughout the whole lifecycle, shall be properly monitored and managed. Furthermore, considering the possibility of connecting the PSS (or solution), decisions regarding data to be shared and service to be offered play a fundamental role. More than this, if in the future the new solutions would become 'intelligent' (Wuest et al. 2018), the monitoring activity would be of primary importance.

As underlined in the company and network perspectives, technology's potential has always been front and centre. It emerged in the discussion that technology is creating new value streams for customers, companies and the overall network and ecosystem. To promote a technology-enabled business integrated into the network, there are still open research issues that must be addressed, such as

- Technological capability: Technology represents the core element discussed during the focus group; hence, it is quite obvious that all the experts agreed on the necessity to explore the role of technology in the company organisation more deeply. In particular, the technological capabilities required by a company to offer a new value proposition must be studied. They are of utmost relevance in enabling companies to properly use data available on the market or in the products, to anticipate the client's requests and then create 'ad hoc' experiences.
- Standards: Last but not least, given the relevance of the technology/technical interoperability as a key topic in the analysed scenario, the need to spur additional research on the topic of standards has been pointed out. In the PSS domain, standards are poorly addressed, and the researchers highlighted the need to further explore them and propose reference standards to be adopted. Explorative research in the available ISO could be the starting point to address this issue.

9 Conclusions, limitations and further developments

A growing interest in the topic of PSS has been registered in many industries in recent years. A variety of companies recently introduced new services in relation to their products to meet new and higher customer expectations. This interest further developed with the introduction of new technologies and advancements brought to the fore by Industry 4.0. Thanks to such technologies, the availability and intensity of information increased exponentially, and this also enables the connection of products to the cloud and the supplementary collection of data regarding their usage and functioning. Hence, Industry 4.0 enables a wide variety of improvements to the existing PSS, entailing the possibility of making them digital and more connected. In this sense, it has been recognised that 'the service revolution and the information revolution are two sides of the same coin' (Rust 2004).

However, the specific impact that the new digital technologies would have on PSS and its business is not yet clear. Still, it is recognised that a complete change in the value offering will also impact the whole value chain, influencing the relationships between the company and the customers and among all the actors of the ecosystem.

This aims at defining future research directions and proposes four main directions that would influence the future evolution of PSS and technology. Notably, it presents four main dimensions that, according to the experts, are leading this transition. The four dimensions are (1) value offerings manifestations, (2) customer value experience, (3) value creation mechanism, and (4) value creation interactions. The four identified dimensions are worthy of further research to be successfully implemented in the industry. A research agenda has also been identified concerning this. In particular, it emerged that the introduction of new digital technologies will stimulate

PSS researchers to rethink the existing research concerning both business model and management, engineering and design. Among them are the changes in the design tools, the business model and the organisation, operations and standards. The cultural transformation was also mentioned together with the complexity in managing ‘win–win’ partnerships and relationships with customers.

The four main dimensions identified in this work, together with the four configurations for each dimension, represent a seminal work on the topic of PSS and digitalisation. The proposed research agenda is meant to set the basis for further developments and discussion at both the academic and practitioner levels.

Nevertheless, this work presents some limitations, in particular related to the adopted methodology. Although we believe that the composition of the focus group was adequate for the topic under exploration in terms of competences and number of involved experts, the final contribution may have been affected by the dominant role of some participants, the difficulty of sharing sensitive information from others rather than the different levels of commitment among experts. To address the problem, future research will have to consider the possibility of refining the achieved results through a survey combined with a systematic analysis of literature. Furthermore, although all participants had both theoretical and practical experience on the topic, general considerations may have been altered by the academic background of the majority of participants. Therefore, it will be necessary for the future to extend the debate by involving more practitioners and managers.

Appendix

Annex I: Workshop participants’ answers to the question ‘can you provide your definition of Industry 4.0?’

Participant	Definition
#1	Industry 4.0 (or 4IR) represents a subset concept of digitalisation, which describes the process of incorporating digital capabilities (i.e. sensors and connectivity) into objects that are primarily physical. Digitalisation can radically reshape manufacturing organisations both ‘within and beyond the factory’. Internally, concepts such as digital manufacturing and Industry 4.0 target the optimisation of the design processes, support process simulations and visualisations, and ensure fast and responsive manufacturing systems. Externally, digitalisation (i.e. IoT) can impact the wider value network, enabling the capture of greater business intelligence, underpinning the personalisation of products, and allowing innovative business models to create substantial innovation and new value creation opportunities
#2	Industry 4.0 is ‘real-time, high data volume, multilateral communication and interconnectedness between cyber-physical systems and people’. The term Industry 4.0 has been used since 2011 to describe the widespread integration of information and communication technology in industrial manufacturing. The main economic potential of Industrie 4.0 lies in its ability to accelerate corporate decision-making and adaptation processes. The ultimate goal is to become a learning, agile company capable of continuous, agile adaptation to a changing environment

Participant	Definition
#3	Industry 4.0 represents the movement towards a fully digital, automated manufacturing plant using IoT, cloud analytics, simulation-driven design, etc. The Swedish government defines Industry 4.0 as 'the ability to take advantage of the potential of digitization'. Under these premises, Industry 4.0 aims at: - Stimulating the development, dissemination and use of digital technology that has the highest potential to lead the industry's transformation - Taking advantage of the potential of digitisation regardless of industry, company size and geographic location - Encouraging new business and organisational models to accommodate the potential of new technology - Meeting new knowledge needs that digital development entails - Customising frame conditions and infrastructure for the digital era
#4	Industry 4.0 depicts the expected transformation/revolution of supply chains and manufacturing systems (i.e. production facilities, processes, and paradigms), due to the enablement and integration of automation, mechatronics and advanced digital technologies (e.g. IoT, cloud, cognitive computing, mixed reality, additive manufacturing, advanced manufacturing systems a.k.a. CPS, predictive models and analytics, etc.). These enablements create what has been called 'Smart Factory' ('Factory of the Future', FoF), a modular and structured manufacturing context in which interconnected cyber-physical systems are aware of environmental and context-specific situations, can autonomously communicate and negotiate, and thus decide and configure the production processes to achieve optimal performances with few or no human control/needs
#5	Industry 4.0 is a shift from automated to intelligent manufacturing. It is based on the introduction of 'Internet of Things' and 'servitization' concepts into manufacturing companies, leading to vertically and horizontally integrated production systems. The resulting smart factories are able to fulfil dynamic customer demands with high variability in small lot sizes while integrating human ingenuity and automation. Cyber-physical systems (CPS) equipped with sensors and actuators collect data about themselves and their environment in real-time, enabling manufacturing systems to meet customer requirements through dynamic business and engineering processes. This enables new services that can replace traditional business models based solely on product sales
#6	Industry 4.0 represents the paradigm of the manufacturing industry that takes advantage of information communication technologies mostly involving cyber-physical systems and connecting multiple actors in a value chain. In this paradigm, new technologies, such as the Internet of things (IoT), big data analytics, cloud computing, etc., are used, and more and more smart devices are utilised to achieve higher degrees of automation and even autonomous production and operation. Through this, product-service innovation is highly facilitated
#7	Industry 4.0 represents a broad set of different paradigms: - New consumption modes, customer relationships, user involvement to increase individualism of customer requirements - A full-integrated lifecycle engineering and management vision, covering the whole value creation chain of products and services from the idea to the end-of-life - Strong real-time information exchanges and interconnectivity among processes, objects and persons mediated by new big data capabilities for real-time data treatment - A collective and adaptive intelligence emerging from the dynamic interconnection among systems, objects and human beings, requiring new organisational abilities

Participant	Definition
#8	The Fourth Industrial Revolution, or Industry 4.0, represents the 'convergence' of the progress of the industrial production technologies revolutions, such as advanced materials, manufacturing processes and production equipment, and the developments of the digital technologies revolutions, like the internet, wireless networks and enterprise information systems

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