DISTRIBUTED MANUFACTURING APPLIED TO PRODUCT-SERVICE SYSTEMS: A SET OF NEAR-FUTURE SCENARIOS

Aine Petrulaityte
Brunel University London, College of Engineering, Design and Physical Sciences, Department of Design, Uxbridge, United Kingdom. E-mail: aine.petrulaityte@brunel.ac.uk
Fabrizio Ceschin
Brunel University London, College of Engineering, Design and Physical Sciences, Department of Design, Uxbridge, United Kingdom. E-mail: fabrizio.ceschin@brunel.ac.uk
Eujin Pei
Brunel University London, College of Engineering, Design and Physical Sciences, Department of Design, Uxbridge, United Kingdom. E-mail: eujin.pei@brunel.ac.uk
David Harrison
Brunel University London, College of Engineering, Design and Physical Sciences, Department of Design, Uxbridge, United Kingdom. E-mail: david.harrison@brunel.ac.uk

ABSTRACT

Product-Service Systems (PSS), if properly designed and implemented, represent a promising approach to sustainability. However, there is a number of organisational, cultural and regulatory barriers that hinder the widespread PSS implementation. In this paper, we address this problem by applying Distributed Manufacturing (DM) to tackle some of PSS implementation barriers. We systematically analyse favourable DM features and their potential application for PSS and put forward a set of near-future scenarios. 40 scenarios created to initiate strategic discussion about DM and PSS combination are presented along PSS life cycle stages illustrating the potential of DM features to address PSS implementation. These scenarios can be used by educators, designers and businesses to identify future opportunities to design sustainable PSS solutions.

Key Words: Product-Service Systems; Distributed Manufacturing; Scenarios; PSS lifecycle

1. INTRODUCTION

Modern societies face a number of global environmental challenges, such as resource depletion, excessive waste production, climate change, etc. caused by the patterns of production and consumption of goods (UN, 1992). Attempts to solve these challenges by improving design of products can only partly address existing issues, since these improvements are more than offset by increasing consumption levels (Binswanger, 2001). There is a need to redesign not only products but also services to influence people behaviour towards choosing more environmentally-aware consumption patterns (Cherry and Pidgeon, 2018).

A promising way to address environmental challenges is through the implementation of Product-Service Systems (PSS), defined as "a mix of tangible products and intangible services designed and combined so that they are jointly capable of fulfilling final customer needs" (Tukker and Tischner, 2006). An appropriately designed PSS has the potential to improve production processes and consumption patterns towards environmental sustainability, provide companies with competitive advantage and build strong relationship with their customers (Cooper & Evans, 2000; Mont, 2002). However, PSS implementation requires companies to redesign their business processes as well as acquire different competences, thus creating a number of obstacles for companies to overcome (Besch, 2005). In this paper, authors investigate Distributed Manufacturing (DM) as a promising production model which can be applied to PSS to address some of its implementation barriers. DM is defined as "a network of small-scale production units equipped with advanced manufacturing technologies, which facilitate localised and individualised production" (Petrulaityte et al., 2017). Initial attempts to apply DM principles to PSS development can be found in the existing literature (Suominen et al. 2009; Arup, 2015; Moreno & Charnley, 2016; Ford & Despeisse, 2016). However, these attempts are still fragmented and illustrate a need for a systematic in-depth analysis of DM application for improved PSS development.

Aiming to explore and illustrate DM and PSS combination, authors put forward a set of DM applied to PSS near-future scenarios developed within the LeNSin research project (EU-funded, 2015-2019). Scenarios can be described as "narratives of alternative environments in which today's decisions may be played out." (Ogilvy and Schwartz, 2004). Scenarios are used to stimulate strategic conversation (Ogilvy, 2006) and facilitate decision-making process in the present (Lelah et al., 2014). Near-future scenarios introduced in this paper were developed to illustrate the potential of DM to address existing PSS implementation barriers. Furthermore, the aim of the developed scenarios was to encourage educators, designers and businesses to discuss DM and PSS combination and consider DM application to PSS development.

This paper is structured in three sections. Section 2 presents scenario development process, including adopted methodology, examples and a complete list of developed scenarios. It also discusses classification of near-future scenarios and their sustainability implications. Section 3 concludes the paper briefly outlining future development opportunities.

2. DEVELOPMENT OF DM APPLIED TO PSS NEAR-FUTURE SCENARIOS

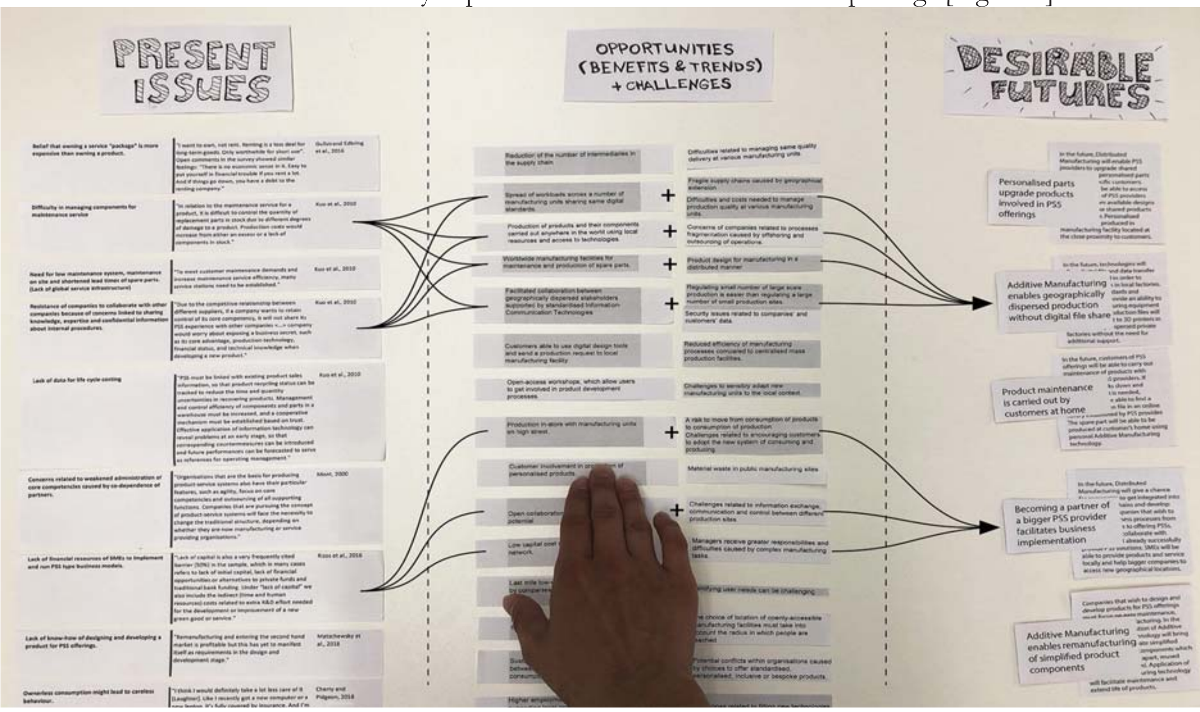
This section introduces scenario development process, provides one example of DM applied to PSS near-future scenarios and summarises a list of scenario titles. Furthermore, it outlines scenario classification to illustrate areas in which scenarios can be applied.

2.1. Methodology

DM applied to PSS near-future scenarios aim at illustrating how DM can be applied to foster and support PSS implementation. For this reason, the research started with in-depth literature review aiming to collect existing PSS implementation barriers. Later, DM benefits, challenges and near-future trends were gathered through the literature review, semi-structured expert interviews and research seminar. All collected DM benefits and near-future trends were listed as DM opportunities with their corresponding challenges. In total, 50 PSS implementation barriers and 68 DM opportunities with 39 challenges were gathered to develop DM applied to PSS near-future scenarios. Initial data collection and analysis are described in Petrulaityte et al. (2017), Petrulaityte et al. (2018).

In order to arrange a large amount of the collected data in a meaningful way, a theory building approach has been applied (Meredith, 1993). The aim of the theory building is to define relationships between events and studies, reasons for which these relationships exist and their potential influences (Meredith, 1993; Wacker, 2008). Therefore, relationships between collected PSS implementation barriers and DM opportunities and challenges have been defined to develop new insights. This has been done by matching all PSS implementation barriers with DM opportunities and challenges in all possible combinations: each identified PSS barrier was systematically coupled with each individual DM opportunity to understand if the latter could tackle the former. Logical pairings were described in short scenarios narrating specific DM features and their application for PSS implementation, with multiple scenarios addressing individual barriers as well as multiple barriers being addressed in individual scenarios.

In order to control the scenario building process (in total 3,876 DM and PSS pairings can be made from the collected data) a cognitive mapping method was applied (Goodier and Soetanto, 2013). According to this method, opportunities, trends, challenges and other collected data have to be mapped in an empty space between present issues and desirable futures. PSS implementation barriers were identified as undesirable situation that needs to be addressed. Desirable futures – actual DM applied PSS near-future scenarios – represented improved PSS implementation. Collected DM opportunities (and challenges) were named as a link between present issues and desirable futures. Each of PSS barriers, DM opportunities and challenges were printed on individual pieces of paper to facilitate physical interaction with data and visually express links between DM and PSS pairings [Figure 1].



[Figure 1] DM applied to PSS near-future scenario development using cognitive mapping method

The following text describes three of DM applied to PSS near-future scenarios, including a brief narrative, PSS implementation barriers each scenario addresses and DM challenges to take into consideration.

Collaboration between PSS providers and customers in makerspaces

Open access makerspaces help people to learn skills needed to design and develop new products and services. PSS companies use public makerspaces for the development of new PSS solutions. PSS providers invite customers to co-design sessions in order to co-create products and services.

This scenario addresses PSS implementation barrier of PSS companies finding it challenging to define customers' needs and service acceptance behaviour. Moreover, direct collaboration with PSS providers may help customers to build trust required for PSS acceptance. Finally, possible misunderstandings which can appear between PSS providers and customers can be solved during co-design sessions.

However, PSS companies that wish to collaborate with their customers in public makerspaces have to consider limited independence caused by rules and regulations of public makerspaces. Moreover, it may be challenging for companies to encourage customers to spare their time and get involved in PSS design.

Remote control of manufacturing equipment

Digital production files are sent directly to Additive Manufacturing equipment based in geographically dispersed manufacturing facility in order to produce products at or close to the point of need. Same digital standards (i.e. file formats required for AM operations) provide an ability to remotely control manufacturing equipment. Remote control of manufacturing equipment enables production or products or their components without digital file share with third parties.

This scenario addresses the PSS implementation barrier related to resistance of PSS delivering companies to collaborate with other companies because of concerns linked to sharing confidential information. Moreover, such localised production has the potential to improve global service infrastructure, with maintenance delivered on site and reduced lead times of spare parts. This way of manufacturing allows PSS providers to avoid shipping products via long distances, reduces the number of partners in the supply chain (including distribution and warehousing) and, at the same time, protects intellectual property rights.

Regarding challenges linked to such geographically dispersed production, products and their components have to be specifically designed to be produced in a distributed manner using AM equipment. PSS providers can potentially face challenges related to managing quality of products produced in various manufacturing facilities. Finally, geographical extension can cause fragile supply chains.

Monitoring of hygiene level of PSS products carried out by customers

Sensors are applied to leased and rented products to inform customers about the level of cleanliness of a used product and advise whether the product is safe to use. Data from sensors can be accessed directly by customers using a smartphone, without the need for involvement of PSS provider.

This scenario tackles the barrier, related to customer concerns about the hygiene of used or shared products. Product monitoring through the application of sensor technology also has the potential to improve customers trust in PSS provider, caused by transparency and provision of real-time information.

However, adoption of sensor technologies and their integration in existing company's business processes requires high initial investment from PSS providers. Moreover, data available from sensors can cause issues related to company's and customer's data.

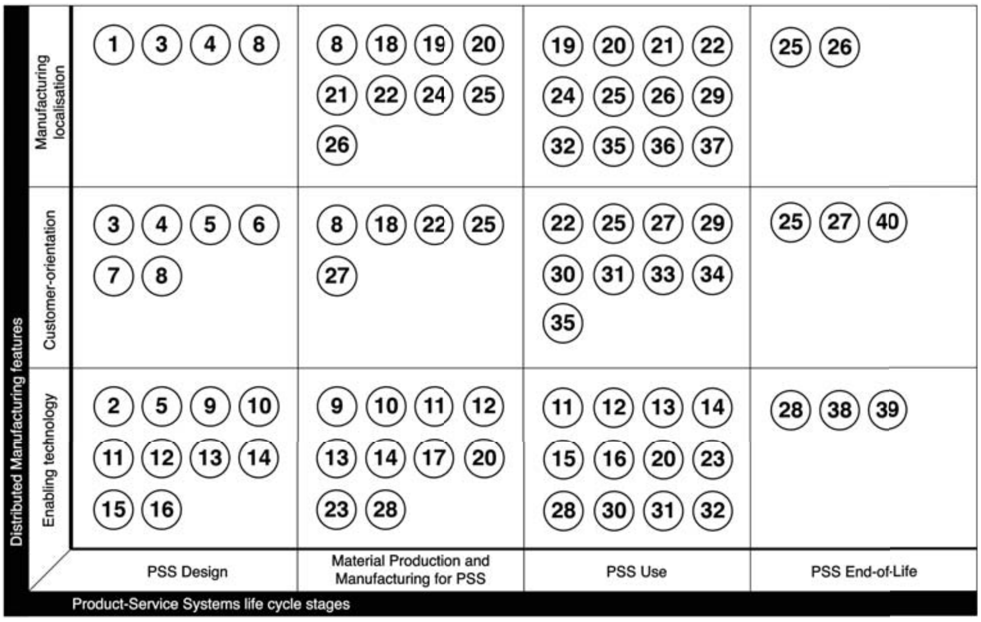
In total, 40 DM applied to PSS near-future scenarios have been developed. A complete list of scenario titles is presented in Table 2.1.

[Table 2.1] A complete set of DM applied to PSS near-future scenarios

No	Scenario title
1	Facilitated implementation of PSS businesses
2	Comparison between PSS and traditional product-based solutions
3	PSS solutions created by customers in makerspaces owned by PSS providers
4	Collaboration between PSS providers and customers in makerspaces
5	Customisation of existing PSS solutions carried out by customers
6	Personalised PSS solutions designed by customers themselves
7	Entirely bespoke PSS solutions created for each customer
8	PSS solutions available on a high street
9	Complex geometries of PSS products and reduced material usage
10	Reduced number of materials needed to produce PSS products
11	Design of self-(dis)assembling PSS products
12	Design of self-repairing PSS products
13	Design of lightweight PSS products
14	Simplified components for remanufacturing of PSS products
15	Improved development of future PSS solutions through user monitoring
16	Maintenance of PSS products predicted through product specifications and historical trends
17	Reduced waste production
18	Home manufacturing of personalised parts of PSS products
19	Outsourced manufacturing services for localised production of PSS solutions
20	Remote control of manufacturing equipment
21	Manufacturing kit for local production of PSS solutions
22	Blueprints of PSS products available in makerspaces
23	Simplified upgrade of PSS products
24	Production and support of PSS solutions carried out by local artisans
25	Reduced number of supply chain actors
26	Simplified transportation through local manufacturing
27	Manufacturing ran by customers, service provision carried out by PSS providers
28	Reverse engineering for remanufacturing of components of PSS products
29	Educated customers with knowledge about PSS benefits and maintenance
30	Monitoring of PSS products carried out by PSS providers and/or customers
31	Monitoring of hygiene level of PSS products carried out by customers
32	Identification of manufacturing facility located closest to the customer
33	Upgrade of PSS products with personalised parts
34	Home assemble and maintenance of PSS products using DIY kits
35	Maintenance of PSS products carried out by customers at home
36	Maintenance of PSS products carried out by PSS providers in makerspaces
37	Production of spare parts of PSS products carried out in a mobile factory
38	Monitoring of PSS products for their End-of-Life
39	Simplified collection of PSS products at their End-of-Life
40	Transformation of obsolete PSS products into personalised solutions

2.2. Classification of DM applied to PSS near-future scenarios and their sustainability implications

In order to illustrate areas is which scenarios can be applied, all DM applied to PSS near-future scenarios have been classified according to PSS and DM attributes. For this reason, scenarios were categorised according to four PSS life cycle stages: Design, Material Production and Manufacturing, Use and End-of-Life with some scenarios addressing more than one life cycle stage. Later, scenarios were classified according to three DM features scenarios contain: Manufacturing localisation, Customer-orientation and Enabling technologies. These DM features based on Srai et al. (2016) defines key components of distribution of manufacturing. PSS and DM attributes with mapped numbers representing near-future scenarios (from Table 2.1) are presented in Figure 2.



[Figure 2] Classification of DM applied to PSS near-future scenarios

According to Vasantha et al. (2012), sustainable value adding PSS can only be created taking into account every life cycle stage of products and services. Figure 2 illustrates that DM applied to PSS near-future scenarios address each PSS life cycle stage. PSS Design stage predominantly benefits from collaboration between PSS provider and customer, enabled by connectivity through digital channels and physical interaction in local manufacturing facilities. Application of Additive Manufacturing technology helps to optimise design of PSS products to simplify their production and extend their lifespan. Material Production and Manufacturing for PSS stage benefits from distribution of manufacturing facilities, equipped with digitally connected manufacturing technology. An ability to send digital production files to remote locations allows PSS companies to produce products at the close proximity to customers and/or resources. Use of PSS stage is supported with the largest number of near-future scenarios tackling on-site and on-time provision of maintenance services. PSS End-of-Life phase is facilitated by the application of sensor technology, which helps to indicate products' end-of-life by alerting PSS providers and customers. Even though recycling is considered as the last chance to retrieve materials and energy embedded in PSS products, a distributed network of localised recycling facilities eases product collection, recycling and re-manufacturing.

3. CONCLUSSION

Implementation of Product-Service Systems shows the potential to improve business processes and consumption patterns towards environmental sustainability at the same time providing companies with competitive advantage and an ability to better satisfy customer demands. However, PSS implementation is still limited by a number of barriers, linked to organisational mind-set, lack of customer acceptance and absence of appropriate regulations. This paper has introduced a set of near-future scenarios developed to illustrate the potential of Distributed Manufacturing to address some of PSS implementation obstacles.

50 PSS implementation barriers and 68 DM opportunities with corresponding challenges were used to describe 40 DM applied to PSS near-future scenarios. Later these scenarios were classified according to PSS and DM attributes to illustrate potential application areas. These 40 near-future scenarios provide an overview of the sustainability potentials and practical implications of applying DM throughout the whole PSS life cycle. These scenarios can be used by educators, designers and businesses to identify future opportunities to support sustainable PSS implementation.

The developed near-future scenarios have been integrated into a design toolkit aiming to support various user groups in PSS solution development (Petrulaityte et al., 2019).

BIBLIOGRAPHY

1. Arup (2015). *Rethinking the factory*. Report. Retrieved from https://www.arup.com/publications/research/section/rethinking-the-factory (Accessed on: 16Dec 2018)
2. Besch, K., (2005). *Product-service systems for office furniture: barriers and opportunities on the European market*. Journal of Cleaner Production, 13, 1083-1094
3. Binswanger, M. (2001) Technological progress and sustainable development: what about the rebound effect? *Ecological Economics,* 36(1): 119-132.
4. Cooper, T., Evans, S. (2000). *Products to Services*. A report for Friends of the Earth produced by the Centre for Sustainable Consumption. Sheffield, UK: Sheffield Hallam University
5. Cherry, C. and Pidgeon, N. F. (2018). *Why is ownership an issue? Exploring factors that determine public acceptance of product-service*

systems. Sustainability 10(7), 2289

6. Ford, S., and Despeisse, M. (2016). *Additive manufacturing and sustainability: an exploratory study of the advantages and challenges*. Journal of Cleaner Production, 137, 1573-1587
7. Lelah, A., Boucher, X., Moreau, V., Zwolinski, P., (2014). *Product-Service Systems Scenarios as a Tool for Transition towards Sustainable PSS. Product Services Systems and Value Creation*. Proceedings of the 6th CIRP Conference on Industrial, IPSS 2014. Windsor, Canada.
8. Meredith, J., (1993). *Theory Building through Conceptual Methods*, International Journal of Operations & Production Management, 13(5), 3–11
9. Mont, O. (2002). *Clarifying the concept of product-service system*. Journal of Cleaner Production, 10(3), 237-245
10. Moreno, M., and Charnley, F. (2016). *Can Re-distributed Manufacturing and Digital Intelligence Enable a Regenerative Economy? An Integrative Literature Review*. Sustainable Design and Manufacturing, 52, 563-575
11. Ogilvy, J. and Schwartz, P., (2004). *Plotting your scenarios*, Global Business Network.
12. Ogilvy, J., (2006). *Education in the information age: scenarios, equity and equality*. In Think Scenarios, Rethink Education. OECD
13. Petrulaityte, A., Ceschin, F., Pei, E., Harrison, D. (2017). *Supporting Sustainable Product-Service System Implementation through Distributed Manufacturing*. The 9th CIRP Industrial Product-Service System Conference: Circular Perspectives on Product/Service-Systems. Denmark.
14. Petrulaityte, A., Ceschin, F., Pei, E. and Harrison, D. (2018). *A Design Tool to Apply Distributed Manufacturing Principles to Sustainable Product-Service System Development*. Design Research Society (DRS) 2018. Limerick, Ireland. 25 - 28 July
15. Petrulaityte, A., Ceschin, F., Pei, E. and Harrison, D. (2019). *A Design Toolkit to Integrate Distributed Manufacturing into Product-Service System Development*. Designing Sustainability for All: The LeNS World Distributed Conference 2019. Milan, Italy. 3-5 April
16. Srai, J. S., Kumar, M., Graham, G., Phillips, W., Tooze, J., Tiwari, A., Ford, S., Beecher, P., Raj, B., Gregory, M., Tiwari, M., Ravi, B., Neely, A., and Shankar, R. (2016). *Distributed manufacturing: Scope, challenges and opportunities*. International Journal of Production Research, 54(23), 6917- 6935
17. Suominen, J., Piller, F., Ruohonen, M., Tseng, M., and Jacobson, S. (2009). *Mass Matching - Customization, Configuration & Creativity*. Proceedings of the 5th International Conference on Mass Customization & Personalization MCPC 2009. Aalto University School of Art and Design Publication Series B 102. Helsinki
18. Tukker, A. and Tischner, U. (2006). *New business for old Europe: product–service development, competitiveness and sustainability*. Sheffield: Greenleaf Publishing
19. United Nations. (1992). *Agenda 21*. In Proceedings of the United Nations Conference on Environment and Development, Rio de Janerio, Brazil.
20. Vasantha G., Roy R., Lelah A., Brissaud D. (2012). *A review of product-service systems design methodologies*. Journal of Engineering Design, 23(9), 635-659
21. Vezzoli, C., Ceschin, F., Diehl, J.C., and Kohtala, C. (2015). *New Design Challenges to widely implement 'Sustainable Product-Service Systems'*, Journal of Cleaner Production, 97, 1-12.
22. Wacker, J. G., (2008). *A conceptual understanding of requirements for theory-building research: Guidelines for scientific theory building*. Journal of Supply Chain Management, 44(3), 5–15.