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## Supporting Sustainable Product-Service System Implementation through Distributed Manufacturing

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### Abstract

Despite the potential of Product-Service Systems (PSS) to provide societal and economic well-being and environmental sustainability, they have not been widely implemented. The adoption of sustainable PSS is restricted by a number of implementation barriers linked to organisational, cultural and regulatory challenges. There are some initial yet still very fragmented attempts to support sustainable PSS development through the application of Distributed Manufacturing (DM). Distributed Manufacturing is a production network made of small scale manufacturing units equipped with emerging technologies, which facilitates localised customer-oriented production. This paper aims to fill the knowledge gap and identify the potential to build a systematic analysis for DM-supported PSS development. In order to understand to what extent DM can address some implementation barriers of sustainable PSS, existing PSS barriers and potential DM opportunities were collected. All DM opportunities were applied to each and every one PSS implementation barrier. Most promising pairings were described in initial scenarios. The implications from this research showed that a number of obstacles related to design, development and customer acceptance of PSS can be potentially tackled through the application of DM.

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*Keywords:* Product-Service System; Distributed Manufacturing; Additive Manufacturing; Localised Production; Customisation

### 1. Introduction

Properly designed Product-Service Systems (PSS) have the potential to fulfill the needs of customers and provide a competitive advantage for companies, and at the same time reduce resource consumption and lower the environmental impact [1,2]. However, despite all the benefits and drivers, sustainable PSS have not been widely applied [3]. Successful adoption of PSS is affected by a number of implementation barriers related to corporate structures, customer behaviour and regulatory frameworks [4]. In order to facilitate the adoption of sustainable PSS, ways to address these barriers must first be identified.

Distributed Manufacturing (DM) is introduced in this paper as a promising production model to tackle some of the implementation barriers of PSS. DM can be described as a production system where small scale local manufacturing and

personalisation of products and services are enabled by emerging technologies [5-7]. Existing attempts to combine PSS and DM can be found in the literature [7,20-24], however, a systematic analysis of how PSS barriers can be addressed by DM is missing.

In order to fill this gap, this paper offers an initial attempt to understand to what extent DM can potentially address some implementation barriers of sustainable PSS. The paper is structured as follows: Section 2 presents literature review findings regarding PSS implementation barriers and potential DM opportunities. Section 3 describes the methodology adopted in this research. Section 4 presents findings and provides initial scenarios of how DM opportunities can tackle PSS implementation barriers. The final section outlines the potential usefulness of the findings and suggests future research.

## 2. Literature review

A literature review was carried out in order to identify main implementation barriers of PSS and DM opportunities, and to summarise existing attempts to apply DM to PSS development made by other authors. Scopus was used to locate sources containing the following keywords: *Product-Service Systems, Barrier, Distributed Manufacturing* and *Localised Production*.

### 2.1. Implementation barriers of sustainable PSS

In total, 49 papers dedicated to PSS were reviewed, of which 22 contained sections about PSS implementation barriers. All of these sources were analysed in a chronological sequence in order to collect a broad range of barriers, identify the ones which are outdated and focus on those which are still relevant to modern businesses. Only barriers identified in early sources and validated in more recent studies are presented in this paper. All selected barriers can be described according to three categories: barriers for companies, barriers for customers and regulative barriers.

One of the most crucial barriers faced by companies is the adoption of a service-oriented culture within the organisation [4,8,9]. In general, companies lack of the knowledge to design, price and deliver a competent PSS [2,4]. Another set of barriers is related to collaborating with a number of partners along the value chain: co-dependence causes fears linked to reduction of core competencies and sharing of confidential information about internal organisational procedures [1,4,10]. Complicated customers' purchase and service acceptance behaviour is another obstacle that prevents companies from implementing PSS solutions [11].

For some product categories customers find it challenging to accept PSS offerings because of the lack of knowledge about the overall PSS concept and anxiety caused by not knowing what to expect [4,11,12]. Customers believe that product ownership is related to social status and achievement in life encourages them to adopt product-oriented solutions [1,4,11]. Concerns linked to independence, hygiene [11] and hidden costs [4,12] of the use of shared products also play a role in preventing customers from accepting PSS offerings.

The final group of PSS implementation barriers is related to the lack of sufficient governmental interventions to encourage environmentally aware business development [13, 14]. PSS innovations are not supported by financial institutions and often experience prolonged time to market [4,15].

The focus of this paper is set on PSS barriers for companies and customers. Regulative barriers are considered not being able to be influenced by PSS companies and not suitable to be tackled through the application of DM in this paper.

### 2.2. Characteristics and definition of DM

In order to define the characteristics and to formulate the working definition of Distributed Manufacturing (DM), 31 papers describing the concept were reviewed.

DM has been analysed since the early 90's and characterised as *downsizing*, companies' separation into smaller-size independent units and *outsourcing*, purchasing

services from external partners [6,16]. More recent sources introduced the importance of technology for manufacturing systems to become distributed: heterogeneous hardware and software, which facilitate communication within the company and with partners [17]. Communication between dispersed manufacturing units and all supply chain actors is essential for DM to operate [16,17]. Comprehensive communication and close factory proximity to the end user allows companies to develop make-to-order manufacturing models [16].

Taking into account the main characteristics of DM, the working definition of the concept has been summarised: *Distributed Manufacturing is a production system made of small scale manufacturing units equipped with physical and digital technologies, which enable localisation of manufacturing facilities and comprehensive communication between all supply chain actors in order to facilitate customer-oriented on-demand production.*

### 2.3. Opportunities of DM

According to existing literature, DM has the potential to provide opportunities for companies, customers and social and environmental sustainability.

Resilience of manufacturing companies is the principal opportunity named by a number of authors [6,16,18]. Localisation of small-scale manufacturing units enables companies to alter their production processes in case of changes in market needs [6,18]. Application of digital technologies, introduced to facilitate collaboration between manufacturing units, allows companies to monitor, control and optimise stock and material flows [6]. Combination of software and hardware enables digital file transfer and production of goods to be carried out in dispersed geographic locations using local resources [6].

One essential DM opportunity for customers is improved personalisation of products and services [6,16,18,19]. This is caused by localisation of production facilities and customer involvement into product development in person and through the internet [6]. This type of involvement brings the potential for companies to better identify the needs of customers and to produce goods on-demand [6].

DM has the potential to address some of the social and environmental issues related to mass production [5]. Using Just-in-Time strategies for small-scale manufacturing of products only when required by customers helps to avoid waste and reduce the burden of a large inventory [18]. Distribution of digital production facilities enables products and spare parts to be produced at the point of consumption which reduces transportation distances and lowers the environmental impact [6,20].

A more detailed description of DM opportunities that show the potential to address implementation barriers of PSS is provided in section 4.

### 2.4. Existing DM application for PSS development

Potential applications of DM to sustainable PSS development were identified in 6 papers. All these sources can

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