Mariusz Salwin

DESIGN OF PRODUCT-SERVICE SYSTEMS IN PRINTING INDUSTRY

ACTA UNIVERSITATIS LAPPEENRANTAENSIS 975

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Dissertation for the degree of Doctor of Science (Technology) to be presented with due permission for public examination and criticism in the Auditorium 1318 at Lappeenranta-Lahti University of Technology LUT, Lappeenranta, Finland on the 7th of October 2021, at noon.

Acta Universitatis
Lappeenrantaensis 975

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ISBN 978-952-335-700-6
ISBN 978-952-335-701-3 (PDF)
ISSN-L 1456-4491
ISSN 1456-4491

Lappeenranta-Lahti University of Technology LUT
LUT University Press 2021

Abstract

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Design of Product-Service Systems in printing industry
Lappeenranta 2021
95 pages
Acta Universitatis Lappeenrantaensis 975
Diss. Lappeenranta-Lahti University of Technology LUT
ISBN 978-952-335-700-6, ISBN 978-952-335-701-3 (PDF), ISSN-L 1456-4491, ISSN 1456-4491

Traditional manufacturing enterprises allocated all their attention, resources, and efforts to design, manufacturing, and selling their products on the market. Changes occurring in the marketplace, growing competition, and environmental measures have rendered this traditional approach insufficient. In order to keep pace with competitors and maintain the market position, manufacturing enterprises had to make changes to their business strategies. These changes consisted in offering higher customer value and assuming responsibility for manufactured products. This is how manufacturers' operations have got shifted from manufacturing and selling products to providing services.

On the other hand, customers are unwilling to invest huge amounts, possibly get indebted and be in the red so they are looking for solutions that would minimise investment outlays. What counts for them is, above all, the machinery working continuously at top speed and loss elimination. In addition, customers expect solutions that are tailored to meet their individual needs. They want to solve emerging problems swiftly and comfortably and expect the manufacturer's support.

Product-Service System (PSS) is a solution, in which products and services integrated together meet customer needs and generate higher value. To manufacturing companies it is an attractive solution allowing them to achieve economic, environmental, and social benefits. Through the integration of an offer and parties to the transaction the effectiveness of activities increases as each party focuses on its core duties. It is especially important in B2B (business-to-business) solutions. Designing new PSS for new industries is an important research area. Being able to design a PSS for industrial applications is seen as the key success factor.

The study is aimed to identify the possibilities and limitations of using a Product-Service System in printing industry. There are some research methods that are used to attain the goal. They combine practical industry-specific knowledge in printing with the synthesis and analysis of Product-Service System-related literature. A PSS increases the effectiveness and efficiency of printing house operations and its financial analysis shows that there are long-term benefits to the manufacturer and user of printing machines.

The study discusses problems faced by printing houses, services that they need, as well as how and for what periods machines can be made available under a PSS arrangement. Data were collected from 80 printing houses. Results of conducted studies indicate that

printing industry falls short of PSS-based solutions. On the other hand, it is important to know that printing houses are interested in them. The working out of a Product-Service System for printing industry expands the lifecycle of a printing machine and provides services that meet the needs and requirements of the printing house. These studies make a valid input into the development of PSS for a new industry, in this case, for the printing industry. They also suggest an innovative approach to PSS design based on practical knowledge of manufacturers and users of printing machines. Close cooperation with printing machine user is worth highlighting.

Keywords: Product-Service System (PSS), Product-Service System design, business model, printing industry, printing machines, printing houses

Acknowledgements

I would like to thank my supervisor, Professor Andrzej Kraslawski, for his support, motivation, and valuable advice and tips. Cooperation with the Professor is a fantastic time. Each meeting and conversation with him gave me strength and inspiration for further work. The help I received from the Professor is huge. He is a great person, teacher, scientist, great friend, and a great role model. Thank you for teaching and showing me what the profession of a scientist is about. Thank you for investing in me.

Many thanks to Professor Xavier Boucher and Yuriy Bilan, who agreed to review my dissertation and provide valuable comments. Your comments helped me to improve the quality of my dissertation and to eliminate any shortcomings. Professor Xavier Boucher, thank you for the very nice comments, the positive evaluation of my work, all the tips you have given me, and the quick replies. Professor Yuriy Bilan, thank you for your very nice comments, positive evaluation of my work and all the tips you gave me, and the quick answers.

I would like to express my most profound appreciation to my parents for getting me out of a long and severe illness. Thank you for all the time and effort you put into saving my health. Thank you for your support, love, faith, and my abilities. You have always been with me in the good and bad times of my life. Thank you for your attention, education, and support. You gave me everything I could wish for.

I would like to thank my sister for always supporting me and being with me. You've always been with me in the good and bad times of my life. Thank you for believing in me and for the kind words you say to me every day. I am grateful for your continued understanding and encouragement for further action.

Special thanks to Damian Gołębiewski for his help. You always help me, and you have patience with me. Thank you for sharing your time with me and listening to me. Thank you for being such a great friend. Thank you for your friendship and help in critical moments in my life. Looking at my whole life, I know there are no words to describe how much I appreciate your help and support.

Special thanks to Sebastian Gołębiewski for his help. Like your brother Damian, you have always been with me, and you have never refused to help me. You are a great friend who always listened to me and gave me directions. Thanks for your patience and understanding. The support and help I have received from you are hardly invaluable.

I would like to thank my friends Jan and Hanna Lipiak, the owners of the Etigraf printing house. Without your support and help, I wouldn't have been able to do so much. I appreciate your friendship and the fact that you have helped me a lot in this process. I am pleased to meet you and cooperate with you. Thank you for every meeting and conversation in which you emphasized that it is worth pursuing the goal.

I would like to thank Michał Andrzejewski for his support, help, and talks. I really appreciate the opportunity to meet you and work with you.

Thanks for help Manouchehr Mohammadi, Nima Alaei, Egor Fadeev, and Paul Wan. Friends I met during my studies at the Lappeenranta University of Technology and my research visit to the Technische Universität Berlin. I am grateful for the opportunity to work with the exceptional colleagues I met there.

I would also like to thank everyone who asked me when I would defend my doctorate at every meeting and on every occasion.

Mariusz Salwin
October 2021
Lappeenranta, Finland

Contents

List of publications

The dissertation is based on the following papers. The rights have been granted by publishers to include the papers in the dissertation.

I. Lipiak, J., and Salwin, M. (2019). The improvement of sustainability with reference to the printing industry – case study. Conference article. In: Hamrol, A., Grabowska, M., Maletic, D., and Woll, R. ed., *Advances in Manufacturing II, Volume 3 - Quality Engineering and Management*, pp. 254-266. Cham: Springer. (https://doi.org/10.1007/978-3-030-17269-5_19).

II. Lipiak, J., and Salwin, M. (2021). Improvement of the Warehouse Functioning: Printing Industry Case Study. Conference article. In: Tonkonogyi, V., Ivanov, V., Trojanowska, J., Oborskyi, G., Grabchenko, A., Pavlenko, I., Edl, M., Kuric, I., and Dasic, P. et al. ed., *Advanced Manufacturing Processes II. InterPartner-2020*, pp. 61-71. Cham: Springer. (https://doi.org/10.1007/978-3-030-68014-5_7).

III. Salwin, M., Kraslawski, A. and Lipiak, J. (2020). State-of-the-Art in Product-Service System Design. Conference article. In: Panuwatwanich, K., Ko, C.-H. ed., *The 10th International Conference on Engineering, Project, and Production Management*, pp. 645–658. Singapore: Springer. (https://doi.org/10.1007/978-981-15-1910-9_53).

IV. Salwin, M., and Kraslawski, A. (2020). State-of-the-Art in Product-Service System Classification. Conference article. In: Ivanov, V., Trojanowska, J., Pavlenko, I., Zajac, J., and Peraković D. ed., *Advances in Design, Simulation and Manufacturing III*. pp. 187–200. Cham: Springer. (https://doi.org/10.1007/978-3-030-50794-7_19).

V. Salwin, M., Kraslawski, A., Lipiak, J., Gołębiewski, D., and Andrzejewski, M. (2020). Product-Service System business model for printing houses. *Journal of Cleaner Production*, Vol. 274, pp. 122939. (https://doi.org/10.1016/j.jclepro.2020.122939).

VI. Salwin, M., Santarek, K., Kraslawski, A., and Lipiak, J. (2021). Product-Service System: New Opportunity for Printing Industry. Conference article. In: Tonkonogyi, V., Ivanov, V., Trojanowska, J., Oborskyi, G., Grabchenko, A., Pavlenko, I., Edl, M., Kuric, I., and Dasic, P. et al. ed., *Advanced Manufacturing Processes II. InterPartner-2020*, pp. 83-95. Cham: Springer. (https://doi.org/10.1007/978-3-030-68014-5_9).

Author's contribution

Mariusz Salwin is the principal author and researcher for works No. III-VI. The author reviewed literature, conducted questionnaire-based studies in 80 printing houses, ran workshops in a printing house, analysed data and prepared the first draft of all the works. Data for works No. I and II were provided by Dr Jan Lipiak, Eng. – President of Etigraf Printing House. Mariusz Salwin took part in studies discussed in these works, carried out data analysis, and wrote the first drafts thereof.

Nomenclature

Abbreviations

GDP	Gross Domestic Product
PSS	Product-Service System
B2B	Business-to-Business
B2C	Business-to-Consumer
B2G	Business to Government
B2A	Business-to-Administration

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1 Introduction

This chapter aims to explain importance of Product-Service Systems (PSS) in contemporary industry and economy. A brief review of knowledge on PSS and the direction of research were introduced. Finally, research gap, research aim, research questions and the dissertation structure were presented.

1.1 Background

Closing decades of the 20th century were marked with growing levels of consumption and production. They triggered significant increases in the consumption of raw materials (minerals and water) and energy but also had a huge negative environmental impact (Stahel, 2008). Soon, the subject became an issue hotly debated in many different circles. Many organisations took interest in the idea of sustainable development. People realised that positive environmental effects and reduction in consumption of resources and in production can be achieved by providing customers with solutions tailored to their needs and based on product utility or functionality (Roy, 2000; Toepfer, 2002).

Currently, we are observing changes in economic structures as a result of which manufacturing industry starts playing less prominent role. Recent decades have witnessed increasing share of the service sector in GDP. According to STATISTA.COM portal, in 2018 the sector accounted for over 65% of global GDP. In the same year in Poland service sector share in GDP amounted to 56.80% while in Finland it reached 74.3% (Statista, 2020). That is linked with the global trend known as servitisation, in which manufacturing companies are shifting from just manufacturing products and selling them as a one-off act and turn towards rendering services connected with these products (Baines *et al.*, 2007; Kryvinska *et al.*, 2014; Lay, 2014). To manufacturing enterprises, servitisation means a huge change in the perception of their business and in the vision of its future evolution. Servitisation, which also triggers changes in the business model of traditional manufacturing enterprises, consists in supplying customers with much more intangible content and services instead of tangible products (T. Baines *et al.*, 2009; Lightfoot, Baines and Smart, 2013).

Globalisation, environmental protection, competition, technological progress, and knowledge-based economy have produced dynamic changes in economy (Munier, 2006). Nowadays, manufacturing enterprises cannot rest their activities only on traditional product-centred business models. Market saturation, as well as evolving customer behaviour patterns and needs force manufacturers to come up with new solutions, strategies and offers that can generate higher added value. This is why manufacturers are looking for alternative business models and strategies (Marcus and P.T, 2014; Adrodegari, Pashou and Saccani, 2017; Pirayesh *et al.*, 2018). Under such circumstances, services integrated with the product represent the highest added value. The solution is known as a Product-Service System (PSS) (Goedkoop *et al.*, 1999; Mont, 2000). Today, manufacturers increasingly more often put such solutions in place as they help them to

stand out from their competition. They see it as a way to survive in the market, improve their competitiveness, as well as maintain the existing and attract new clients (Martinez *et al.*, 2010; Y. S. Kim *et al.*, 2015; Matschewsky, 2019).

Remarkably, services change the way manufacturing enterprises operate. In its most advanced form, a PSS completely changes the perspective of a manufacturing enterprise and makes it see things from the customer perspective. Numerous organisational changes stem mainly from the transition from being a manufacturer to becoming a service provider, which is why this shift towards the PSS is not so easy to traditional manufacturing enterprises (Margherita, Eugenia and Michele, 2015; Oliveira *et al.*, 2018). The intention to apply the PSS solution must be clearly reflected in company's strategy and in its business model. When implementing the PSS, the business model itself is a guarantee of successful transformation of an enterprise and of its offering. Therefore, manufacturers have to make significant changes to their business model or create a new business model from scratch. Transformation or developing a new business model and a new offer require support from experts in a given industry and appropriate tools (Barquet *et al.*, 2015; Cattaneo *et al.*, 2017; Lahy and Found, 2017).

PSS systems are gaining increasingly more interest amongst academic and industrial circles (Tukker, 2015; Annarelli, Battistella and Nonino, 2016). PSS is a combination of tangible components (products) and intangible services brought together and designed to jointly meet concrete customer needs and desires and to generate new useful value proposition for them (Tukker, 2004; Neely, 2008). In accordance with the PSS concept, a service is not meant to be a supplement to a tangible product but an intrinsic component of an integrated offering. These are comprehensive solutions focused on the maximising of productivity and availability of products needed by a customer at a given moment. PSS helps in expanding the product lifetime. It also enhances manufacturers' interest in considering product durability at the design stage, enables product regeneration and reuse. It is also one of the most effective proposals that support the circular economy, which facilitates transition towards resource saving and environmental protection. The system does away with consumption-based economy and shifts towards a functional economy. Functional economy optimizes the functioning or use of products and services, and thus the management of existing resources (products, knowledge and the environment). It aims to generate the highest possible functional / utility value for the longest possible period of time using the least possible amount of energy and materials (Stahel, 2008, 2010; Scott and Stahel, 2017). PSS has got a huge potential to develop competitive business models while reducing negative environmental impacts (Tukker and Tischner, 2006a; Baines *et al.*, 2007; Vezzoli *et al.*, 2014).

Although there are many PSS design methods, there are no ideal design methods addressed to each specific industry. This is mainly due to the specificity of these industries, their products and services raising the biggest customer interest. Because of gaps and challenges that PSS design is facing and considering the demand for studies in this area, works on the PSS for new industries should be continued.

The target market and relationships between a manufacturer and his customers are critical for PSS success (Mont, Dalhammar and Jacobsson, 2006; Sadek and Theiss, 2010; Nguyen *et al.*, 2014). Cooperation between companies (a manufacturer of printing machines and a printing house) is different from cooperation with an individual customer. B2B transactions often call for a much more complex business solutions than B2C relations. A PSS addressed to B2B is also intended to help entrepreneurs (customers) in running their businesses and accomplishing business goals. These may be concrete services or solutions that support business processes and other operations of an enterprise. Customers of B2B segment wish to put in place the best solutions in enterprises to generate the biggest benefits and often want to test the proposed solutions before they accept an offer. To a manufacturer it is an additional difficulty which shows that a lot of attention needs to be paid to building customer relations, to get better acquainted with customer needs, provide him with professional service and expert knowledge in a given area. Another aspect that should be considered is offering personalised solutions to customers (Sakao and Lindahl, 2009; Ebikake, Sassanelli and Terzi, 2018; Ding, Liu and Yang, 2019).

Whether a PSS can be applied and whether it is successful largely depends on the industry and situation in the marketplace. Successful PSS implementation also depends on customer requirements which are seen as a fundamental barrier to the approval of a PSS. This is why when designing a PSS one desperately needs knowledge accumulated by users, as well as an in-depth analysis of their needs and problems. The strategies that would bring to a solution range from a questionnaire-based study to the direct involvement of customers in designing a PSS through workshops. Studies help to more precisely specify services that need to accompany the product under the PSS solution. Findings from such studies will be translated into practice and deployed in developing new PSS.

Despite many research studies on PSS and models that have already been put into practice, no thorough analysis has been conducted for a concrete industry. Both literature and practice have, however, revealed a research gap, a white spot on the PSS map, i.e., the printing industry (industrial printing) for which no PSS has been proposed so far. Industrial printing includes the development of patterns (printing forms) of drawing and text originals, printing them in large quantities and refining (varnishing, laminating), mainly for the masses. It is not close to other areas of printing such as printing and copying office documents. The industry is continuously growing and will continue to grow dynamically. Printing industry is a specific branch of economy using high value and high-tech machinery to print various materials (books, posters, labels, billboards). All of them are produced in a complex printing process carried out in printing houses, users of printing machines. PSS design for such an industry should be preceded with market analysis, analysis of needs of printing machinery users, and consultations with business practitioners from the industry. This is how it could provide a model comprehensive PSS framework to be followed by enterprises from this industry.

This dissertation is motivated by the wish to provide an input into the theory and practice of PSS design in the printing industry. It focuses on printing (industrial printing) and the industrial printing machines used in it, rather than on other related areas of printing, such as office document printing and copying and the photocopiers used in it. To start with, possibilities to implement improvements and innovation in printing houses were examined. Then literature on PSS design, classification and practical deployment was reviewed. In addition, a comprehensive analysis of the Polish printing industry was carried out: printing market was examined, questionnaire-based studies were conducted together with consultations with practitioners from the printing industry and workshops at printing houses. All these exercises enabled the development of a PSS business model for the printing industry, considering real problems and needs of printing houses, as well as environmental aspects. The study has clearly deepened the insight into the customer (printing house) perspective and his involvement in the PSS development process.

1.2 Research gaps and questions

This section presents a literature gap discovered during the research. It identifies the purpose of the work and research questions of this dissertation.

1.2.1 Research gap

Analysis of literature on PSS design and its applications in industry has revealed a significant gap resulting from the absence of PSS solutions for the printing industry. This aspect has been used as a pretext to comprehensively examine the printing industry to find out about problems and needs of printing machine users. We need to learn whether the use of PSS in the printing industry is feasible and if it can have positive effects on the manufacturer of such machinery, its users (printing houses), and the environment.

1.2.2 Research questions

The aim of the research is to determine possibilities and limitations to using Product-Service System in printing industry. This dissertation focuses on the following research questions, which are answered in the corresponding publications:

RQ1. How to apply the users experience in design and implementation of PSS in printing industry? (Paper 1, 2)

RQ2. What are the peculiarities of using PSS business model in printing industry? (Paper 5, 6)

RQ3. What are the main limitations of PSS design methods presented in literature and by the practitioners? (Paper 3, 4)

RQ4. How to develop new PSS business models for printing industry? (Paper 5, 6)

RQ5. What benefits can PSS bring to machine manufacturers, customers in printing industry as well as the environment? (Paper 5, 6)

While responding to research questions, this dissertation aims to investigate the area of PSS design and development. In addition, it proposes a new PSS model for the printing industry substantiated with questionnaire-based studies and workshops in printing houses.

1.3 Outline and structure of the dissertation

This Ph.D. dissertation is composed of two principal parts. The first one consists of five chapters. The first chapter is an introduction which discusses the background of the research, motivation behind it, formulates the researched problem, goal of the research studies, research questions, core definitions, and the structure of the doctoral thesis. The second chapter is an overview of literature dealing with PSS design, classification of PSS models and PSS solutions applied in practice. It also provides characteristics of the printing industry. The third chapter focuses on the research goal and methodology of the study. It discusses approaches used in publications and research draft. Chapter No. 4 overviews and summarises results of each published paper included in this dissertation. Chapter five summarises the main findings and suggestions as to future studies. Table 1.1. presents the structure of the dissertation. The second part consists of six papers published in relation with this dissertation.

Table 1.1: Structure of the dissertation.

Chapter	Title	Input	Output
Part 1			
Chapter 1	Introduction	Background of the study Motivation of the study	Background Problem Objectives Research questions Justification of the study
Chapter 2	Theoretical framework	PSS design methods Challenges to PSS design PSS classification Printing industry as an important market for PSS	Research gap Market of PSS-based solutions Situation in the printing market
Chapter 3	Research methodology	Methodological choice Surveys Industrial workshops	Analysis of the research problem and justification of the methodological choice Data collection PSS application in printing industry

Chapter 4	Overview of the publications	Principal goal and crucial findings	Summary of individual publications and review of key results
Chapter 5	Discussion and concluding remarks	Responses to research questions Long-term analysis	Summary of the input from research Core conclusions Suggestion for future studies
Part 2 - papers			

2 Theoretical framework

This chapter briefly summarizes the current knowledge on PSS, especially in the printing industry. There were presented classification and design methods of PSS and examples of PSS use in industrial practice.

The purpose of this chapter is to provide an overview of the scientific literature on PSS. It contains also the analysis of industry reports, statistical yearbooks and specialised references related to printing industry.

2.1 Product-Service System

This dissertation is motivated by the wish to provide an input into the theory and practice of PSS design in the printing industry. To start with, possibilities to implement improvements and innovation in printing houses were examined. Then literature on PSS design, classification and practical deployment was reviewed. In addition, a comprehensive analysis of the printing industry was carried out: printing market was examined, questionnaire-based studies were conducted together with consultations with practitioners from the printing industry and workshops at printing houses. All these exercises enabled the development of a PSS business model for the printing industry, considering real problems and needs of printing houses, as well as environmental aspects. The study has clearly deepened the insight into the customer (printing house) perspective and his involvement in the PSS development process.

Over recent decades manufacturers have started to re-define their offer by shifting from the sales of products towards ensuring an integrated combination of products and services. The concept known as the Product-Service System (PSS) is a specific case of servitisation. It originates from Northern EU and brings together three pillars of sustainable development: economic, environmental, and social (Goedkoop *et al.*, 1999; Mont, 2000; Tukker, 2004; Baines *et al.*, 2007). Remarkably, PSS models are increasingly more often treated as business models that integrate products and services (Reim, Parida and Örtqvist, 2015).

Initially, discontinuation of making offerings of only products was motivated by an increasingly greater contribution of the service sector to GDP (back in 2018 the sector accounted for more than 65% of global GDP) and its share in employment, as well as the idea to strive for the sustainable development and knowledge-based economy (Bates, Bates and Johnston, 2003; Sawhney, Balasubramanian and Krishnan, 2004). Manufacturers realised that services could become a new source of revenue and the main distinguishing factor. In addition, services in combination with products could ensure higher profits than the products (Oliva and Kallenberg, 2003; Neely, 2008; T. Baines *et al.*, 2009).

Besides, this solution makes a manufacturer's offer very distinctive by which it improves his competitive position. In addition, a manufacturer retains ownership rights to products

which gives him direct access to them and a possibility to collect data on their productivity and performance. He may also check and monitor the products. All of the aforesaid translates into the improvement of product design, its parameters and uses, reliability, lower total costs, and reduced environmental impacts (Mont, 2002; Manzini and Vezzoli, 2003; T. S. Baines *et al.*, 2009).

PSS concept is seen as a market proposal that expands product functionality by adding services to it. In PSS stress is put predominantly on effects brought by the product or the possibility of using it rather than on the sale of the product. A customer does not pay for product purchase but for being able to use it and for effects that it produces. This way customers benefit from depreciation, reduce risk, obligations, and other costs resulting from being a product owner. One needs to stress, however, that often customers are not interested in the purchase and owning a product but in effects it produces (Tukker and Tischner, 2006a; Azarenko *et al.*, 2009; Annarelli and Nonino, 2016).

A PSS covers also sustainable development and environmental protection. It is an environment-friendly model mainly due to (Manzini, Vezzoli and Clark, 2001; Vezzoli *et al.*, 2014):

- more effective use of materials in production,
- reduced energy consumption,
- more effective and sustainable use of products
- extension of product life span,
- minimised number of passes of the material through the production cycle,
- waste reduction.

Importantly, offering all environment-friendly aspects, a PSS does not undermine customer satisfaction with the product. That is very important from the point of view of environmental policy and growing public awareness (Vezzoli *et al.*, 2014).

Until to date there is no single consolidated and universally approved PSS definition. In literature we can come across several dozen different PSS definitions. Their selected examples are presented in Table 2.1.

Table 2.1: Product-Service System definitions.

Author	Year	PSS Definition	Source
Goedkoop *et al.*	1999	"*A Product Service System (PSS) system is a marketable set of products and services capable of jointly fulfilling a users' need. The product/service ratio can vary, either in terms of function fulfilment or economic value*"	(Goedkoop *et al.*, 1999)
Behrendt *et al.*	2003	"*Product-service combinations (or eco-services) are those intangible service components that partially or completely substitute for tangible*	(Behrendt *et al.*, 2003)

		components, resulting in a positive effect on the environment"	
Tukker and Tischner	2006	"*A value proposition that consists of a mix of tangible products and intangible service designed and combined so that they are jointly are capable of fulfilling integrated, final customer needs...PSS: the product-service including the network and infrastructure needed to 'produce' a product-service*"	(Tukker and Tischner, 2006a)
Neely	2008	„*A Product-Service System is an integrated product and service offering that delivers value in use*"	(Neely, 2008)
Zhu *et al*.	2011	„*PSS is defined as a solution for optimal resource operations in product life cycle through integrating tangible products with intangible services*"	(Zhu *et al.*, 2011)
McKay and Kundu	2014	„*A PSS is a system composed of a physical product and associated services that support the product through-life*"	(McKay and Kundu, 2014)
Piscicelli, Cooper and Fisher	2015	„*Product-service systems (PSS) are business models that provide for cohesive delivery of products and services. PSS models are emerging as a means to enable collaborative consumption of both products and services, with the aim of pro-environmental outcomes*"	(Piscicelli, Cooper and Fisher, 2015)

The main components of a Product-Service System include: (T. Baines *et al.*, 2009; Lim *et al.*, 2012):

- a product – a tangible component of the system manufactured for sale and meeting customer needs,
- a service – an intangible component of the system, performed as commercial activity, added value to a customer,
- a system – a collection of relationships between a product and a service,
- infrastructure – a collection of artifacts necessary to deliver a product or a service to the customer (e.g. technologies or IT systems),
- a network of suppliers – producers or suppliers and partners (sellers, repair workshops).

In PSS, a product and a service are fundamental components of the solution and they are critical for customer experience and interactions with PSS. Products facilitate the rendering of services while services facilitate the using of products (Lim *et al.*, 2012).

2.1.1 Product-Service System classification

PSS classification makes an important part of research on PSS. Different services can be added to different products in different combinations. Hence, industrial practice knows a variety of PSS types in different industries (Salwin and Kraslawski, 2020).

Many classifications can be found in available literature. The most popular one is the classification proposed by a Dutch researcher A. Tukker. He distinguishes three main PSS types broken down into altogether eight categories (Fig. 2.1.) (Tukker, 2004). The first type is a product-oriented PSS, in which a product is sold traditionally and the ownership right passes on to the customer. A product, however, comes with additional services that ensure its functionality and durability and with consultancy as to how the product can be used the most effectively. There are two categories of a product-oriented PSS: product related and advice and consultancy. The second type is a use-oriented PSS in which product usefulness and availability are sold while product ownership remains with the manufacturer. Under this model, a customer pays for the use of products and services within the system. Usually, it means a product is used for a specific period of time. Use-oriented PSS solutions can be divided into three categories: product lease, product renting/sharing, and product pooling. Finally, the third type, result-oriented PSS, consists in selling the results or work productivity ensured by a product; the right of ownership to the product remains with the manufacturer. Manufacturer and the user specify the result for which the user will pay. In these systems, a manufacturer may choose the most effective products and services to attain the pre-defined result. Result-oriented PSS systems are broken down into three categories: activity management, pay per service unit and functional result (Tukker, 2004; Tukker and Tischner, 2006b).

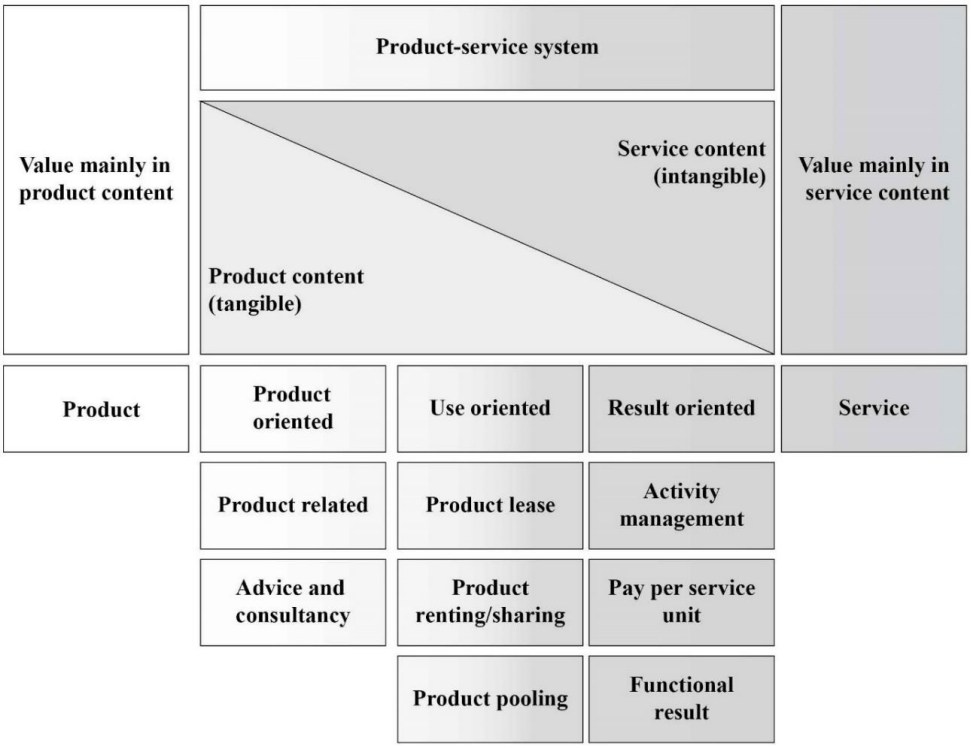

Figure 2.1: PSS classification (Tukker, 2004)

Besides the above-discussed Tukker's classification, there are some other that are worth mentioning. Mathieu describes two dimensions of PSS, i.e., Service specificity and Organizational intensity (Mathieu, 2001). In her classification, Mont focused on a wide approach to PSS and distinguished five types that can be used in PSS research and design (Mont, 2002). Oliva and Kallenberg in their two-dimensional classification focused on the transformation of a manufacturing company into a service-oriented business. The first dimension refers to changes in interactions with a customer, the second one to types of services and delivered values (Oliva and Kallenberg, 2003). In their classification, N. Uchihira and collaborators distinguished three principal types of PSS expansion, in which PSS solutions are divided into eight models of service functions. It focuses on the development of customer relations and possibilities to expand manufacturing operations (Uchihira *et al.*, 2007, 2008). V. Martinez and collaborators developed a servitisation continuum. A classification, closely linked with the PSS includes four levels of enterprise servitisation and changes implied by PSS use in an enterprise (Martinez *et al.*, 2010). Based on the Tukker's classification, A. Neely proposed a new classification. To make a more complete presentation of the scope of service strategies put in place by enterprises, Neely added on two new types of PSS (integration-oriented and service-oriented) (Neely,

2008). Classification developed by R.J. Clayton et al., was intended to help in generating new offers. Based on Tukker and Neely's classifications, Clayton made a continuum of five PSS types leading from a pure product to a pure service (Clayton, Backhouse and Dani, 2012). When developing their PSS classification, Fan and Zhang also drew from Tukker and Neely. They supplemented the already known PSS types with application-oriented PSS. Their classification highlights the relevance of market environment for the PSS (Fan and Zhang, 2010). Van Ostaeyen and collaborators distinguished four main types of PSS. They categorise PSS types according to two features (the efficiency orientation of the dominant revenue mechanism and the degree of integration between the product and services) (Van Ostaeyen *et al.*, 2013).

All the PSS classifications concur as to the high degree of innovation, high level of design, and the use of technology indispensable to reap economic but also environmental and social benefits. In addition, it is believed that each PSS leads to organisational changes in an enterprise.

2.1.2 Product-Service System design

PSS design consists in the integration of products, services, and business models to create solutions that generate new added value to customers. Designing process covers a great deal of aspects connected with technological potential, user mentality and behaviours. It considers past industrial patterns, environmental requirements, and benefits generated by using PSS solutions. To design such a system is a new and huge challenge to a manufacturing enterprise which needs to reorganise its structure and base it on new values.

A PSS can be designed from two perspectives (Baines *et al.*, 2010) (Fig. 2.2.):

- product servitisation – meaning adding services to products with a view to integrate them. A classic example can be selling contracts for the maintenance of investment goods.
- service productivisation – meaning a service is integrated with products. Transport contracts are a classic example. They can be defined so well that they become a service effectively sold as a product.

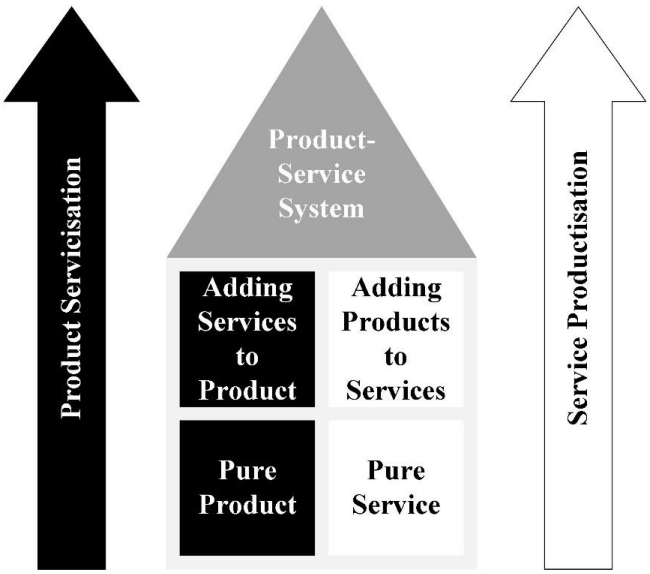

Figure 2.2: PSS development (Baines *et al.*, 2010)

There are two key parties to PSS design: an enterprise which designs the system and a customer who will be using it. The enterprise which designs the model assumes full responsibility for the delivered product over its entire useful life while the customer does not pay for the product but for the possibility of using it or for the outcomes that the product produces. The role of PSS design consists primarily in a continuous finetuning of the business, quality of offers, and company-customer relationship (Morelli, 2002; Oliva and Kallenberg, 2003; Martinez *et al.*, 2010).

As a process, PSS development draws attention to a number of components. PSS design requires taking account of elements of a product and services that need to be added to it. Features of these two components must be examined to find complementarity between them. One needs to bear in mind that a product is a means which enables rendering services. The combination of these two elements generates new value to the customer (Baines *et al.*, 2007; Geng *et al.*, 2010a; Lim *et al.*, 2012).

When designing a PSS one may not forget customer experiences, needs, and problems; they need to be identified and well understood. That is important since a PSS should respond to customer needs and problems. With regard to that, it is critical to include customer observations as they provide an input into PSS design and will also be integrated with the process. It may take place through questionnaire-based studies, workshops, think-tank, or the exchange of information about customer needs (Geng *et al.*, 2010a, 2010b; Nemoto *et al.*, 2015; Ding, Liu and Yang, 2019).

PSS design must also consider more intense interactions between a manufacturer and a customer as employees from diverse levels and departments on the manufacturer side will be interacting with customers. They will be doing so to deliver services, offer assistance in solving problems and collecting information that may contribute to generating new solutions (Mont, 2002; Manzini, Collina and Evans, 2004; Evans, Partidário and Lambert, 2007; Nemoto *et al.*, 2015).

To design an effective PSS, one needs to identify and analyse key partners. They exert impact upon the development of PSS and their collaboration is fundamental, above all, for the delivery of materials, spare parts, financial resources, knowledge, and know-how. In addition, key partners will be sharing experiences and best practices. Moreover, public institutions may help in promoting PSS solutions while suppliers may have an impact upon future design of products and services by supplying specific information (Alonso-Rasgado, Thompson and Elfström, 2004; Morelli, 2006; Evans, Partidário and Lambert, 2007).

The key aspect in PSS development is communication amongst all actors engaged in PSS design. It consists in selecting an appropriate flow of information within the design team, as well as in units involved in PSS design at the manufacturer, between a manufacturer and a client, as well as a manufacturer and key partners. During the PSS design exercise, effective communication can be ensured by eliminating all emerging barriers that hinder the flow of information. Precise communication and distribution of information amongst the participants and departments engaged in PSS design, discussions, and reporting produce benefits and have a substantial share in effective meeting customer needs, and, consequently, in developing a successful PSS (Krucken and Meroni, 2006; Yip, Phaal and Robert, 2012; Yip, Phaal and Probert, 2014; Pezzotta, Cavalieri and Romero, 2017).

A PSS design forces an enterprise to enter new markets; mainly the service market and a secondary market, in which the enterprise has usually little or no experience. This is also a step taken into a new business field which triggers changes in the business model and may change the organisational structure of the enterprise. The changes are mainly related to: the change in the way of thinking and acting of the producer; design, production and delivery to the customer of comprehensive solutions; increased product liability; significant rapprochement of relations and frequent communication between the producer and the customer (Mont, Dalhammar and Jacobsson, 2006; Martinez *et al.*, 2010). A PSS business model differs from the traditional one with respect to how value is offered. In a PSS value does not lie in a physical product but in meeting customer needs. The product becomes merely an artefact around which consumer experiences are shaped. An important role is to obtain information on the needs, requirements, experiences and wishes of the customer related to a given product. The answer to this becomes a fundamental value and plays one of the main roles in PSS. In addition, customers increasingly expect the possibility of active participation in the development of solutions through interactions with manufacturers, experts or other customers. Customer participates to value creation may receive individualized and tailored solution to it and

acquire new knowledge (Barquet *et al.*, 2013; Reim, Parida and Örtqvist, 2015; França *et al.*, 2017).

A PSS cannot be developed without adequate human resources. The attainment of goals specified in a PSS design, which are often times atypical, calls for creativity and knowledge from different fields and can be achieved only through a collaborative effort of many people. This is why in PSS design attention should be paid to people that make up the team responsible for PSS design, in particular to the designer. His task is to ensure such a combination of a product and a service that makes a new system feasible and able to meet customer needs. The designer specifies fundamental features and functions of a product which impact product functionality and outcomes of delivered solutions, and the future development of the system. He also defines criteria against which the customer will assess the effectiveness of delivered solutions (Vasantha *et al.*, 2012; Tukker, 2015; Khan and Wuest, 2018; Pereira, Kreye and Carvalho, 2019).

In literature, we can come across a number of PSS design methods addressed to different industries. The review of subject-matter literature carried out by the author revealed 60 PSS design methods (Table 2.2.). The most popular ones include: AEPSS (Austrian 'Eco-efficient PSS'), HICS (Highly Customised Solutions), INNOPSE method (Innovation Studio and Exemplary Developments for Product Service Engineering), MEPSS (Methodology for Product Service Systems), IPSE method (Integrated Product and Service Engineering), SPSD method (Sustainable Products and Services Development), PROSECCO method (Product & Service Co-design), the Kathalys method, and TraPSS (transition along the PSS continuum).

In the conducted research, it was decided to search for works using the keywords “Product-Service System design” or synonyms. The papers were searched in leading scientific databases (including Science Direct, Scopus, Web of Science). The time frame was 2001-2019. As a result, 400 scientific articles were obtained. Intensive reading of the works led to the selection of 64 articles in which 60 methods of PSS design were described. The sources of PSS design methods are presented in the Figure 2.3.

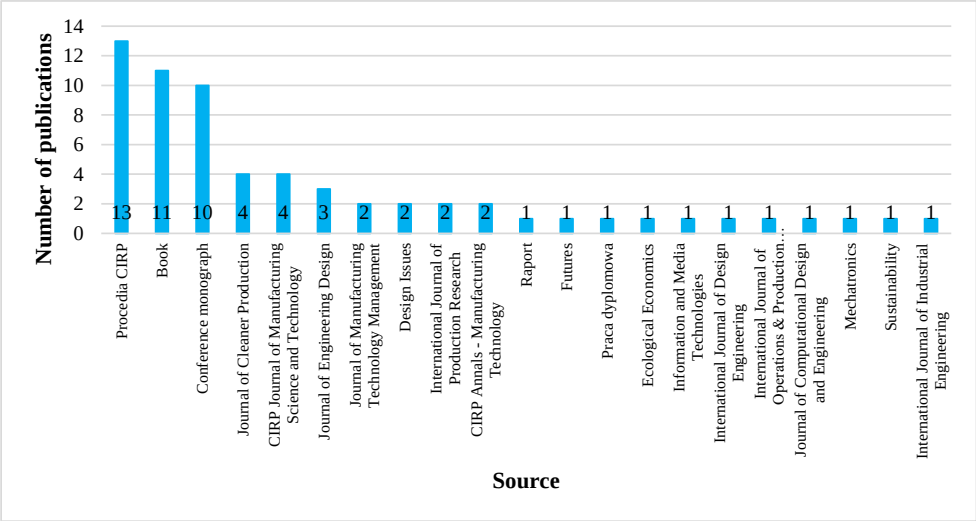

Figure 2.3. PSS design method - sources

Table 2.2: PSS design methods.

No.	Method	Year	Validated	Proposal	Framework	Aim
1.	(Brezet *et al.*, 2001)	2001	+		A PSS design framework composed of two parts: the first one dealing with product and service design and the second one concerning policy formulation and finding ideas for new PSS	To design environment-friendly PSS, to focus the design team attention on three aspects: product, infrastructure, and user practices
2.	(Engelhardt *et al.*, 2003)	2001	+		A design framework based on interaction with customers	Business plan for a new PSS offer
3.	(James, Slob and Nijhuis, 2001)	2001	+		A design framework based on responses to questions	A wide perspective on designed PSS, generating many ideas from which the best one is selected
4.	(Luiten, Knot and van der Horst, 2001)	2001	+		Five paths that should be worked on simultaneously during five design stages	Guidebook for the design of sustainable PSS

5.	(Morelli, 2002) (Morelli, 2003)	2002	+		A PSS design framework based on service development model. Two design space dimensions are distinguished: a space of problems and a space of solutions	Focused on PSS design from the designer's perspective, stresses the role of designers in creating innovative PSS
6.	(Green and Vergragt, 2002)	2002	+		Workshops, building scenarios oriented at design, environmental and consumer assessment and strategy formulation	To use social and technological innovation for the development of sustainable PSS for households
7.	(Abdalla, 2003)	2003	+		An innovation studio as a foundation of a framework for correct PSS design	To ensure useful suggestions for innovation in PSS
8.	(Maxwell and van der Vorst, 2003)	2003	+		A product lifecycle-based design framework, Triple Bottom Line (TBL) and economic, environmental, and social aspects	To develop sustainable PSS solutions, which ensure the required functionality, meet user needs and are profitable.
9.	(Tukker and Van Halen, 2003)	2003	+		Innovative scanning as a foundation of the framework for correct PSS design	Structured searching, design, and introduction of new PSS concepts and help in exploiting added value generated by them
10.	(Weber and Deubel, 2003)	2003		+	A framework based on product development, considers product characteristics and properties, structure, shape, and exploitation possibilities	To develop a PSS based on the collection and analysis, product properties and characteristics
11.	(Alonso-Rasgado, Thompson and Elfström, 2004) (Alonso-Rasgado and Thompson, 2006)	2004 2006		+	A framework covering a five-stage design process, Total Care Product architecture, business aspects, and support in decision-making	To draft Total Care Products: an innovative package composed of a product and services integrated with it to ensure full functionality to a customer

12.	(Tukker and Tischner, 2006a)	2004	+		Elimination of waste (materials, energy, or labour) potentially increases profitability	To develop a business model Sustainable PSS
13.	(Manzini, Collina and Evans, 2004)	2004	+		Design framework based on expert knowledge in a given industry	To develop an environmentally-effective product-service system throughout the entire product lifetime, in which manufacturers closely corporate with other entities
	(Evans, Partidário and Lambert, 2007)	2007				
14.	(Halme, Jasch and Scharp, 2004)	2004	+		A customer-oriented framework for PSS	A sustainable PSS design for households
15.	(Van Halen, Vezzoli and Wimmer, 2005)	2005	+		A modular design framework for innovative PSS	To effectively design and implement new PSS, which concur with manufacturers' business goals, guarantee optimum customer satisfaction, and minimise negative effects to the environment and society.
16.	(Tukker and Tischner, 2006a)	2005	+		A method based on an Internet platform through which companies may independently carry out design process	To supply small and medium-sized enterprises with methodologies and tools used to manage PSS design, to recognise market opportunities
17.	(Lindahl *et al.*, 2006)	2006		+	A framework consisting of three sub-methods (service modelling, evaluation, and design) and Service Explorer application	To support innovative thinking, technical solutions, to draw attention to environmental aspects, internal and external communication in the course of PSS design
18.	(Matzen and McAloone, 2006)	2006	+		A framework of PSS design based on identification and categorisation of development tasks	To interact with customer relationships, expand enterprise activities, and create a network with external partners

19.	(Aurich, Fuchs and Wagenknecht, 2006)	2006	+		A systematic design process based on PSS modularity through the selection, combination, and adaptation of adequate modules of the system and linking them with adequate processes	To design a technical, lifecycle-oriented PSS
20.	(Morelli, 2006)	2006		+	A PSS design framework based on a systemic approach	To identify stakeholders, requirements vis-a-vis PSS, its structure, and design
21.	(Uchihira *et al.*, 2007)	2007		+	A PSS design framework based on DFACE-SI procedure	To facilitate the understanding of potential PSS-related opportunities and difficulties to stakeholders, PSS development, risk analysis
	(Uchihira *et al.*, 2008)	2008				
22.	(Welp *et al.*, 2008)	2008		+	A design framework based on three levels of systematic development of an industrial PSS: level of function, object, and process	To design an industrial PSS, eliminate blurred borders between products and services
23.	(Komoto and Tomiyama, 2008)	2008		+	A design framework based on an Integrated Service CAD and Life cycle simulator	To supply hints and support designers in generating PSS
24.	(Müller *et al.*, 2009)	2009	+		A method based on strict, logical reasoning and conclusions; a stage-wise iterative process, enables making an orderly evidence of an existing or future PSS. It defines a metamodel of nine principal classes of PSS elements	Used mainly in early development stages, expected to assist in clear identification of tasks, analysis and synthesis of PSS design ideas
25.	(Rexfelt and Hiort af Ornäs, 2009)	2009	+		A framework based on the investigation of target group customs, problems, and values	To design PSS in cooperation with customers

26.	(Sundin, Lindahl and Ijomah, 2009)	2009	+		A design framework based on a product life cycle	To shift from product selling to making them available/renting
27.	(Maussang, Zwolinski and Brissaud, 2009)	2009		+	A design framework based on a systemic approach	To deliver technical hints to designers on PSS development.
28.	(Shimomura, Hara and Arai, 2009)	2009	+		A framework based on the integration of services and products to maximise value to customers.	To achieve complementarity of products and services within a PSS
29.	(Tan, McAloone and Hagelskjær, 2009)	2009		+	A design framework based on the Deming Cycle	To develop and improve PSS solutions
30.	(Kimita, Shimomura and Arai, 2009)	2009		+	A PSS design framework based on Service Engineering	To meet customer needs
31.	(van de Kar, 2010)	2010		+	A design framework composed of elements of process and project management	To adjust the model to the needs of a customer from the target group.
32.	(Wood and Tasker, 2011)	2011	+		A PSS design framework based on a systemic approach	To supply designers with hints on PSS design, to achieve higher level of understanding customer needs and preferences and greater customer satisfaction
33.	(Vasantha *et al.*, 2011)	2011		+	A PSS design framework based on co-creation, possibilities, responsibility, and competence	A PSS solution in which stakeholders know their duties
34.	(Geum and Park, 2011a)	2011		+	A PSS design framework based on a transformed Blueprint – extended with new areas, lines, and symbols reflecting PSS features	To support sustainable development and deliver higher value to customers
35.	(Lee *et al.*, 2011)	2011		+	A PSS design framework based on predefined components describing	To develop a PSS business model

					strategic models and components of the business model	
36.	(Kim *et al.*, 2012)	2012		+	A PSS design framework based on affordance	To design a PSS in which elements of services and products are integrated through affordance
37.	(Akasaka *et al.*, 2012)	2012		+	A PSS design framework based on analogical reasoning and view models	To assist PSS design, in particular to help in generating PSS ideas and evaluating them
38.	(Dimache and Roche, 2013)	2013		+	A systematic method, composed of a framework offering a toolkit that supports decision making	To support decision making in designing a PSS business model
39.	(Marques *et al.*, 2013)	2013	+		Implementation of product and service design processes as a parallel sequence of actions leading to a PSS	Clear understanding of processes and organisational changes to be used in PSS design and development
40.	(Tran and Park, 2014)	2014	+		Methodology proposed as a general approach to guiding practitioners and designers through an effective PSS design, also considers the engagement of users, a business model and organisational structure.	To develop a PSS together with a customer to ensure higher level of his satisfaction
41.	(Vezzoli *et al.*, 2014)	2014	+		The process consists of five activity clusters and three phases. The method is based on a network of relations, innovation, and learning	To develop a sustainable PSS
42.	(Pezzotta *et al.*, 2014)	2014		+	A PSS design framework based on Service Engineering	To focus on two main areas: a customer and a service provider
43.	(Pezzotta *et al.*, 2015)	2015		+	A Service Engineering Framework based on Service Explorer	To reorganise business, assumptions, structures, and processes, capabilities, customer and supplier relations

44.	(S. Kim *et al.*, 2015)	2015	+		A service-oriented PSS development process composed of two layers	To design a PSS that is innovative from the point of view of the service
45.	(Barquet *et al.*, 2015)	2015	+		A PSS design framework based on fuzzy front-end	To provide hints and guidelines for companies to support the development of PSS business models
46.	(Moser *et al.*, 2015)	2015	+		A design framework based on the product life cycle	To supply designers with hints concerning PSS design
47.	(Muto, Kimita and Shimomura, 2015)	2015	+		A PSS design framework based on Software Engineering Methods and Theory (SEMAT)	To ensure hints for designers in PSS design, milestones for the design process, and process management
48.	(Tran and Park, 2015)	2015	+		A strategic framework of PSS prototyping	To ensure support in generating customer value, PSS evaluation before implementation, and improvement of PSS quality
49.	(Ziout and Azab, 2015)	2015	+		A PSS design framework based on relationships between a manufacturer, a supplier, and a customer	Closer customer-manufacturer relations designed to increase customer satisfaction and improve the quality of PSS
50.	(Chiu, Kuo and Kuo, 2015)	2015		+	A PSS design framework based on internal capabilities of an enterprise and factors in the external environment	To design a PSS and support design-related decisions
51.	(K Medini and Boucher, 2016)	2016		+	A method based on a general platform for PSS configuration composed of diagnostic instruments, modelling, and simulation.	To support PSS development, decision making concerning the configuration of PSS value chain, to ensure higher value and more personalised solutions to customers
52.	(Trevisan and Brissaud, 2016)	2016		+	Multi-views modelling framework for supporting integrated PSS design	To support modelling, integration of product and services, to facilitate

						communication between engineers, to develop PSS architecture until detailed specifications are obtained
53.	(Muto *et al.*, 2016)	2016	+		A PSS design method based on an analytical tool consisting of four points of view on the design and several checklists	Optimum management of tasks involved in design
54.	(Sassanelli *et al.*, 2016)	2016		+	A PSS design framework based on Design for Excellence	To design more customer-oriented PSS, to maximise the value of solutions delivered to a customer at minimised costs
55.	(Scherer *et al.*, 2016)	2016		+	A PSS design framework based on Service Engineering Methodology (SEEM), Design Thinking, and Business Analytics	To understand customer needs and to develop innovative, profitable, and durable PSS solutions
56.	(Adrodegari, Pashou and Saccani, 2017)	2017	+		An integrated PSS design framework linking strategy with operational practices	To support managers in PSS design and in the transformation of the business model, in managing crucial PSS components and critical requirements
57.	(Campos *et al.*, 2017)	2017		+	A PSS design framework based on Diversity Platform	PSS design, to improve effectiveness, to carry out a continuous customer needs analysis and adapt to them
58.	(Chiu, Chu and Chen, 2018)	2017		+	A customer-oriented PSS framework	To identify potential customer needs
59.	(Idrissi, Boucher and Medini, 2017)	2017	+		A PSS design framework based on a general meta-model applicable to many industrial cases	To design a PSS from scratch, step by step, a model that can be applied universally
60.	(Andriankaja, Boucher and Medini, 2018)	2017	+		A PSS design framework based on extending the	To maximise stakeholder value, to integrate many aspects: product design, to

					Functional Analysis (FA) approach	identify service-related possibilities, configuration of PSS value network.

The analysis of PSS design methods enabled their classification. In the first step, the methods were classified according the industries. The mechanical engineering sector dominates here. There are also methods for which the area (industry) of application has not been indicated. It should be noticed that some methods are used in several industries. The classification is presented in the Table 2.3.

Table 2.3: PSS design methods - classification according to industry.

No.	Industry	Source PSS design methods
1.	Mechanical engineering	(Alonso-Rasgado, Thompson and Elfström, 2004; Alonso-Rasgado and Thompson, 2006; Aurich, Fuchs and Wagenknecht, 2006; Matzen and McAloone, 2006; Shimomura, Hara and Arai, 2009; Sundin, Lindahl and Ijomah, 2009; Vasantha *et al.*, 2011; Wood and Tasker, 2011; Dimache and Roche, 2013; Ziout and Azab, 2015; Adrodegari, Pashou and Saccani, 2017; Campos *et al.*, 2017)
2.	Production sector	(Green and Vergragt, 2002; Engelhardt *et al.*, 2003; Maxwell and van der Vorst, 2003; Lindahl *et al.*, 2006; Welp *et al.*, 2008; Lee *et al.*, 2011; Muto, Kimita and Shimomura, 2015; Tran and Park, 2015; Chiu, Chu and Chen, 2018)
3.	Domestic appliances, consumer electronics and other equipment sector	(Brezet *et al.*, 2001; Green and Vergragt, 2002; Halme, Jasch and Scharp, 2004; Alonso-Rasgado and Thompson, 2006, 2006; Uchihira *et al.*, 2007, 2008; Kimita, Shimomura and Arai, 2009; Sundin, Lindahl and Ijomah, 2009; Geum and Park, 2011b; Kim *et al.*, 2012; Andriankaja *et al.*, 2016; Chiu, Chu and Chen, 2018)
4.	Transport - mobility	(Brezet *et al.*, 2001; Luiten, Knot and van der Horst, 2001; Geum and Park, 2011a; Marques *et al.*, 2013; Vezzoli *et al.*, 2014; Barquet *et al.*, 2015; Moser *et al.*, 2015)
5.	Construction and environmental engineering	(Green and Vergragt, 2002; Morelli, 2002, 2003; Engelhardt *et al.*, 2003; Tran and Park, 2014; Muto *et al.*, 2016)
6.	Food sector	(Green and Vergragt, 2002; Engelhardt *et al.*, 2003; Manzini, Collina and Evans, 2004; Evans, Partidário and Lambert, 2007)

7.	Electronics sector	(James, Slob and Nijhuis, 2001; Akasaka *et al.*, 2012; Chiu, Kuo and Kuo, 2015)
8.	Energy sector	(Maussang, Zwolinski and Brissaud, 2009; Müller *et al.*, 2009; Trevisan and Brissaud, 2016)
9.	Training sector	(Tran and Park, 2014; S. Kim *et al.*, 2015)
10.	IT sector	(James, Slob and Nijhuis, 2001; Komoto and Tomiyama, 2008)
11.	Telecommunications sector	(Kar, 2010; S. Kim *et al.*, 2015)
12.	Other sectors	(Engelhardt *et al.*, 2003; Pezzotta *et al.*, 2015; Khaled Medini and Boucher, 2016)
13.	No reference - potentially arbitrary	(Abdalla, 2003; Tukker and Van Halen, 2003; Weber and Deubel, 2003; Van Halen, Vezzoli and Wimmer, 2005; Morelli, 2006; Tukker and Tischner, 2006a; Rexfelt and Hiort af Ornäs, 2009; Pezzotta *et al.*, 2014; Sassanelli *et al.*, 2016; Scherer *et al.*, 2016; Idrissi, Boucher and Medini, 2017)

The authors of the methods propose a different structure to design PSS using sets of tasks. The most popular are the standard and simple multi-step structure, modular structure and flowchart structure (Table 2.4.)

Table 2.4: PSS design methods - classification according to structure.

No.	**The structure of the method**	**Source PSS design methods**
1.	A multi-step approach	(Brezet *et al.*, 2001; Green and Vergragt, 2002; Abdalla, 2003; Engelhardt *et al.*, 2003; Maxwell and van der Vorst, 2003; Tukker and Van Halen, 2003; Halme, Jasch and Scharp, 2004; Manzini, Collina and Evans, 2004; Morelli, 2006; Tukker and Tischner, 2006a; Evans, Partidário and Lambert, 2007; Uchihira *et al.*, 2007, 2008; Rexfelt and Hiort af Ornäs, 2009; Sundin, Lindahl and Ijomah, 2009; Lee *et al.*, 2011; Wood and Tasker, 2011; Akasaka *et al.*, 2012; Dimache and Roche, 2013; Marques *et al.*, 2013; Barquet *et al.*, 2015; Moser *et al.*, 2015; Tran and Park, 2015; Ziout and Azab, 2015; Andriankaja *et al.*, 2016; Khaled Medini and Boucher, 2016; Adrodegari, Pashou and Saccani, 2017; Campos *et al.*, 2017; Chiu, Chu and Chen, 2018)
2.	Modular structure	(Weber and Deubel, 2003; Van Halen, Vezzoli and Wimmer, 2005; Aurich, Fuchs and Wagenknecht, 2006; Lindahl *et al.*, 2006; Komoto and Tomiyama, 2008; Welp *et al.*, 2008; Kimita, Shimomura and Arai, 2009; Pezzotta *et al.*, 2014, 2015; Chiu,

		Kuo and Kuo, 2015; Muto, Kimita and Shimomura, 2015; Scherer *et al.*, 2016)
3.	Block diagram	(Alonso-Rasgado, Thompson and Elfström, 2004; Alonso-Rasgado and Thompson, 2006; Maussang, Zwolinski and Brissaud, 2009; Shimomura, Hara and Arai, 2009; Tan, McAloone and Hagelskjær, 2009; Kar, 2010; Vasantha *et al.*, 2011; Kim *et al.*, 2012; Tran and Park, 2014)
4.	Other	(Luiten, Knot and van der Horst, 2001; Morelli, 2002, 2003; Matzen and McAloone, 2006; Müller *et al.*, 2009; Geum and Park, 2011a; Vezzoli *et al.*, 2014; S. Kim *et al.*, 2015; Muto *et al.*, 2016; Sassanelli *et al.*, 2016; Trevisan and Brissaud, 2016; Idrissi, Boucher and Medini, 2017)

In the next stage, the methods were classified according to the approach (the producer / service provider who has to design the PSS and the customer's perspective, where the requirements are collected, analysed and delivered to the client's specific needs). It is worth noting that some of the methods take into account both perspectives (producer / service provider and customer perspective).

Table 2.5: PSS design methods - classification by perspective.

No	Perspective	Source PSS design methods
1.	Manufacturer / service provider and client perspective	(Green and Vergragt, 2002; Maxwell and van der Vorst, 2003; Tukker and Van Halen, 2003; Alonso-Rasgado, Thompson and Elfström, 2004; Halme, Jasch and Scharp, 2004; Van Halen, Vezzoli and Wimmer, 2005; Alonso-Rasgado and Thompson, 2006; Aurich, Fuchs and Wagenknecht, 2006; Matzen and McAloone, 2006; Welp *et al.*, 2008; Müller *et al.*, 2009; Vasantha *et al.*, 2011; Akasaka *et al.*, 2012; Marques *et al.*, 2013; Pezzotta *et al.*, 2014; Tran and Park, 2014; S. Kim *et al.*, 2015; Khaled Medini and Boucher, 2016; Scherer *et al.*, 2016; Campos *et al.*, 2017; Chiu, Chu and Chen, 2018)
2.	Manufacturer / service provider perspective	(Abdalla, 2003; Engelhardt *et al.*, 2003; Tukker and Tischner, 2006a; Komoto and Tomiyama, 2008; Lee *et al.*, 2011; Dimache and Roche, 2013; Barquet *et al.*, 2015; Chiu, Kuo and Kuo, 2015)
3.	Customer perspective	(James, Slob and Nijhuis, 2001; Luiten, Knot and van der Horst, 2001; Morelli, 2002, 2003, 2006; Manzini, Collina and Evans, 2004; Evans, Partidário and Lambert, 2007; Uchihira *et al.*, 2007, 2008; Kimita, Shimomura and Arai, 2009; Maussang, Zwolinski and Brissaud, 2009; Rexfelt and Hiort af Ornäs, 2009; Shimomura, Hara and Arai, 2009; Sundin, Lindahl and Ijomah, 2009; Tan, McAloone and Hagelskjær, 2009; Kar, 2010; Geum and Park, 2011a; Wood and Tasker, 2011; Kim *et al.*, 2012; Vezzoli *et al.*, 2014; Moser *et al.*, 2015; Pezzotta *et*

		al., 2015; Tran and Park, 2015; Ziout and Azab, 2015; Andriankaja *et al.*, 2016; Sassanelli *et al.*, 2016; Trevisan and Brissaud, 2016; Adrodegari, Pashou and Saccani, 2017; Idrissi, Boucher and Medini, 2017)
4.	Lack of information	(Brezet *et al.*, 2001; Weber and Deubel, 2003; Muto *et al.*, 2016)

When designing PSS, the environment to which the developed system will be addressed should be taken into account. Design methods can be classified as targeting B2B, B2C, B2G / B2A. The authors of the methods point out that one method can be addressed to several of the above-mentioned types of transactions.

Table 2.6: PSS design methods - PSS design methods - classification by types of transactions.

No.	Environment	Source PSS design methods
1.	B2B/B2C/B2G/B2A	(Brezet *et al.*, 2001; James, Slob and Nijhuis, 2001; Luiten, Knot and van der Horst, 2001; Green and Vergragt, 2002; Abdalla, 2003; Maxwell and van der Vorst, 2003; Tukker and Van Halen, 2003; Weber and Deubel, 2003; Alonso-Rasgado, Thompson and Elfström, 2004; Van Halen, Vezzoli and Wimmer, 2005; Alonso-Rasgado and Thompson, 2006; Lindahl *et al.*, 2006; Matzen and McAloone, 2006; Tukker and Tischner, 2006a; Maussang, Zwolinski and Brissaud, 2009; Müller *et al.*, 2009; Shimomura, Hara and Arai, 2009; Geum and Park, 2011a; Tran and Park, 2014; S. Kim *et al.*, 2015; Sassanelli *et al.*, 2016; Idrissi, Boucher and Medini, 2017)
2.	B2B/B2C	(Morelli, 2002, 2003; Lindahl *et al.*, 2006; Tan, McAloone and Hagelskjær, 2009; Tran and Park, 2015)
3.	B2B/B2G/B2A	(Tukker and Tischner, 2006a; Kimita, Shimomura and Arai, 2009; Marques *et al.*, 2013)
4.	B2C/B2G/B2A	(Halme, Jasch and Scharp, 2004; Manzini, Collina and Evans, 2004; Evans, Partidário and Lambert, 2007; Kim *et al.*, 2012; Vezzoli *et al.*, 2014; Barquet *et al.*, 2015; Moser *et al.*, 2015; Chiu, Chu and Chen, 2018)
5.	B2B	(Engelhardt *et al.*, 2003; Aurich, Fuchs and Wagenknecht, 2006; Morelli, 2006; Uchihira *et al.*, 2007, 2008; Komoto and Tomiyama, 2008; Welp *et al.*, 2008; Kar, 2010; Lee *et al.*, 2011; Vasantha *et al.*, 2011; Dimache and Roche, 2013; Pezzotta *et al.*, 2014; Chiu, Kuo and Kuo, 2015; Muto, Kimita and Shimomura, 2015; Ziout and Azab, 2015; Khaled Medini and Boucher, 2016; Trevisan and Brissaud, 2016; Adrodegari, Pashou and Saccani, 2017; Campos *et al.*, 2017)
6.	B2C	(Rexfelt and Hiort af Ornäs, 2009; Wood and Tasker, 2011; Akasaka *et al.*, 2012; Andriankaja *et al.*, 2016)
7.	B2G/B2A	(Muto *et al.*, 2016; Scherer *et al.*, 2016)

The next part of the analysis focused on the types of PSS that can be designed based on the methods available in the literature. Based on the Neely classification, the design methods can be classified into integration-oriented PSS, product oriented PSS, service-oriented PSS, usage-oriented PSS, results-oriented PSS (Neely, 2008). The authors of the methods emphasize that one method can be addressed to several types of PSS.

Table 2.7: Classification according to type of PSS that can be designed.

No.	Integration-oriented PSS	Product oriented PSS	Service-oriented PSS	Usage-oriented PSS	Results-oriented PSS	Source PSS design methods
1.	■	■	■	■	■	(Luiten, Knot and van der Horst, 2001; Abdalla, 2003; Engelhardt *et al.*, 2003; Van Halen, Vezzoli and Wimmer, 2005; Aurich, Fuchs and Wagenknecht, 2006; Tukker and Tischner, 2006a; Geum and Park, 2011a; Vasantha *et al.*, 2011; Marques *et al.*, 2013; Tran and Park, 2014, 2015; Chiu, Kuo and Kuo, 2015; Ziout and Azab, 2015; Andriankaja *et al.*, 2016; Khaled Medini and Boucher, 2016; Muto *et al.*, 2016; Scherer *et al.*, 2016; Trevisan and Brissaud, 2016; Adrodegari, Pashou and Saccani, 2017; Idrissi, Boucher and Medini, 2017)
2.		■	■	■	■	(Brezet *et al.*, 2001)
3.			■	■	■	(James, Slob and Nijhuis, 2001; Tukker and Van Halen, 2003; Shimomura, Hara and Arai, 2009; Dimache and Roche, 2013; Vezzoli *et al.*, 2014; Barquet *et al.*, 2015)
4.				■	■	(Rexfelt and Hiort af Ornäs, 2009)

5.					■	(Green and Vergragt, 2002; Halme, Jasch and Scharp, 2004; Manzini, Collina and Evans, 2004; Tukker and Tischner, 2006a; Evans, Partidário and Lambert, 2007; Kimita, Shimomura and Arai, 2009)
6.		■	■			(Morelli, 2002, 2003, 2006)
7.	■	■	■			(Maxwell and van der Vorst, 2003; Lindahl *et al.*, 2006; Uchihira *et al.*, 2007, 2008; Lee *et al.*, 2011; Moser *et al.*, 2015; Pezzotta *et al.*, 2015; Chiu, Chu and Chen, 2018)
8.		■	■	■		(Akasaka *et al.*, 2012)
9.			■			(Matzen and McAloone, 2006; Tan, McAloone and Hagelskjær, 2009; Kar, 2010; Wood and Tasker, 2011; Pezzotta *et al.*, 2014; S. Kim *et al.*, 2015; Campos *et al.*, 2017)
10.	■	■				(Welp *et al.*, 2008; Muto, Kimita and Shimomura, 2015; Sassanelli *et al.*, 2016)
11.	■					(Weber and Deubel, 2003; Alonso-Rasgado, Thompson and Elfström, 2004; Alonso-Rasgado and Thompson, 2006; Komoto and Tomiyama, 2008; Maussang, Zwolinski and Brissaud, 2009; Müller *et al.*, 2009)
12.				■		(Sundin, Lindahl and Ijomah, 2009; Kim *et al.*, 2012)

2.1.3 Product-Service System in industry

Due to changes unfolding in the market and growing importance of the service sector, enterprises shift from a traditional business model oriented at selling products to a business model based on a PSS. Over recent years many examples of such transition can be found. The trend is growing in various industries and produces real changes in them. Table 3 is an overview of literature discussing the most frequently quoted examples of enterprises which have gone through such transformations of a business model and are successfully using the PSS model. In the conducted research, it was decided to search for

works using the keywords "Product-Service System in industry" or synonyms. The articles were searched in leading scientific databases (including Science Direct, Scopus, Web of Science). The time frame was 2001-2019. As a result, 120 works were obtained. The intention is to demonstrate that a PSS is not just a theoretical model but also a practical solution making a real difference in the economy.

Table 2.8: PSS in industry – examples.

Company	**Alstom**	**Caterpillar**	**MAN**	**Rolls-Royce**	**Xerox**
Product	Trains	Construction and mining equipment	Truck	Aircraft engines	Office equipment,
Type of PSS	Result-oriented PSS	Product-oriented PSS	Result-oriented PSS	Result-oriented PSS	Result-oriented PSS
Description	Pay per kilometers for train	Financing, insurance, equipment rental, maintenance, support, operator training	Pay per kilometers for trucks	Power-by-the-Hour service packages	Leasing or pay-per-copy modelse leasing
Name	Train Life Services	Equipment Management Services	Fleet Management	TotalCare	Managed Print Services
Standard duration	20-30 years	2-10 years	5 years	10 years	1-5 years
Delivered by	Alstom	Caterpillar dealerships or partner resellers	MAN or MAN dealerships or independent distributors	Rolls-Royce, and as joint ventures	Xerox or Xerox dealerships or distributors or partner resellers
Services	Maintenance and technical support, spare parts management, repair and renovation	Financing, insurance, equipment rental, maintenance, monitoring condition, use and location, preventive maintenance,	Inspection, maintenance and worthiness, along with visibility of driver and vehicle performance	Precise maintenance, repair and overhaul, logistics management	Print, maintenance and supply of consumables, print infrastructure optimization, fleet management

		unscheduled repair, support, operator training			document management
Revenues	Kilometers travelled/lost passenger hours Lost customer hours	Fixed dollar per operating hour/ hours out of service	Kilometers travelled/ time out of service	Fixed dollar per flying hour/hours out of service	Pay per copy, reduced 'total cost of ownership'
Target	B2B	B2B	B2B	B2B	B2B
Customers	Railway carriers	Mining and construction companies	Logistics service providers	Airline companies	Offices
Application sector	Transport	Industrial utilities	Transport	Transport	Office and computing
Country	France	USA	Germany	Great Britain	USA
Source	(Baines *et al.*, 2007)	(Tan, 2010)	(Baines *et al.*, 2007)	(Rolls Royce. 2009)	(Xerox, 2019)

The analysis demonstrates that PSS solutions are used by multinational enterprises which are big, renowned organisations with strong market position. They have specialist knowledge and expertise, their operations in the area of planning and implementation are highly professional. Moreover, they are leaders in their respective industries and have deep knowledge about markets in which they operate. They also have knowledge about optimum working conditions and the best use of products. These enterprises actively invest in new technologies and innovation, grasp new improvement and development opportunities to be able to improve their products. They have highly qualified specialist human resources and financial resources. Customer relations developed over many years give them deep insight into customer problems which is why they are highly appreciated by their clients. These companies closely follow the market and new solutions to expand ways of delivering customer value. The solutions offered by enterprises covered by the review exercise are viewed as hallmarks of high quality, functionality, and reliability. Offers are addressed to concrete customers; this could be considered a unique solution to a concrete problem meeting concrete needs.

Products offered by enterprises under the PSS arrangement represent high value, long product lifecycle, and high quality. Their manufacturing is a complex process requiring substantial financial outlays, specialist staff, and technologically advanced machinery.

During the research literature is not found PSS used in the printing industry (industrial printing), which uses industrial printing machines. Instead, PSS models were found that are used in related industries such as office printing. An example of this is Xerox.

Xerox is the flagship example of a company operating on the basis of PSS. The Xerox model is also most suited to the printing industry. Its main material element are photocopiers, which differ significantly from printing machines (construction, value, purpose) and printing industry. The purpose of using the model is also different. Xerox is used for printing office documents. The model developed in the dissertation is addressed to industrial printing. The analysis of the Xerox model was based on the available reports. Due to the limited availability of relevant information, it is modest. The restrictions result from the confidential nature of the data.

Xerox is one of the world's largest producers of digital printers and print outsourcing services, document management and back office processes. Pay-per-copy model in which the customer does not pay for the copier, but for each copy made. The main product in this model are photocopiers used in offices. Since switching to this model, the company has achieved a revenue growth rate of 41% over 12 years. In the last 17 years, approximately 77% of Xerox's annual revenue was from services (maintenance, supplies, financing, and more), while only 23% was from new equipment sales. In addition, the company retains ownership of its equipment and thus has access to a warehouse of reusable parts. The use of PSS allowed Xerox to develop a remanufacturing program that reduces waste and saves resources.

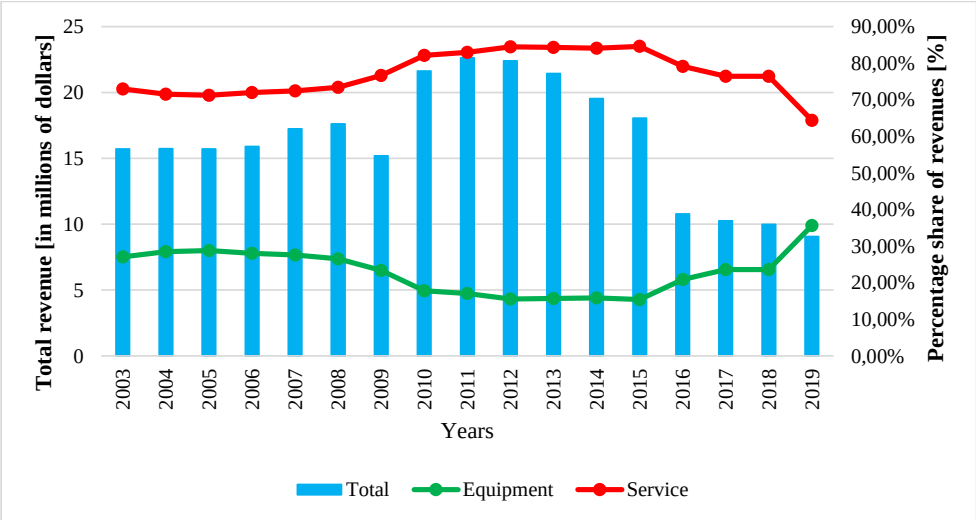

Figure 2.4. Xerox revenue over the years by product and service (Xerox, 2019)

The beginning of Xerox transformation was associated with the introduction of a new printing technology - electrophotography. Back then, the copies were made using "wet" photographic methods or low-quality dry thermal processes. The technology developed by Xerox avoids the use of wet chemicals, was faster and better than others on the market at the time, but very expensive. As Xerox (then Haloid) struggled to find partners for the 914, companies such as GE, IBM, and Kodak continued to decline the offer. As a result, instead of selling the 914, Xerox chose to lease it at a very low cost and then charge for a copy of more than 2,000. Xerox provided all the consumables, support, and service needed for the copier to operate properly. Thanks to this approach, the customer benefited from the effects of the device. In this lease model, the customer by notifying Xerox 15 days in advance could cancel the lease without any consequences. At that time it was a very bold move, as the copiers used at the time made an average of 15 to 20 copies a day. It should be noted that customers only paid a monthly fee for using the copier. There was an additional charge only for copying more than 2,000 items per day. This move increased the company's annual rate of return to 41% over 12 years. In addition, Xerox was even more motivated to create faster photocopiers that will work with greater availability, efficiency, and even better precision (Xerox, 2003, 2004, 2005).

Xerox tries to adapt to the needs of its users. Thanks to this model, customers have access to unlimited resources, and they only pay for what they use. The customer only uses the copier when he needs it, thus reducing waste and reducing environmental impact. In the event of a failure, it has experts, systems and spare parts to restore the copier to use as soon as possible (Xerox, 2006, 2007, 2008).

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By implementing PSS solutions, Xerox has radically changed its business model. Currently, it offers not only photocopiers, but also services that give the opportunity to improve the efficiency of the offices of its clients. Xerox is constantly developing its model. From a company selling office equipment and supplies, it has turned into a company selling comprehensive office solutions. The function of these solutions is to increase efficiency and productivity, and to reduce customer costs in document management. The solutions proposed by Xerox allowed one of his clients - United Health Services Hospitals of Binghamton - to reduce annual costs by approximately $ 60,000.

On the one hand, Xerox sees itself as a print management service company that helps customers optimize the number of copiers they own and how to use them today, and on the other hand, as helping their customers become more successful in their markets. This is important because when a customer is successful, it generates a new service business and the ability to sell more equipment. It is worth noting that the greater the contribution to the customer's success, the greater the value for the customer and the greater the chance

of generating income. As a result, customer actions are of particular importance to the business conducted by Xerox. In addition, it undertakes tasks in which the client already has competitors' photocopiers. Thanks to their service and maintenance, it maintains them in a proper condition, and after their end of use, it replaces them with its own photocopiers. Thanks to this solution, it supports its clients in achieving success in the markets in which they operate (Xerox, 2013, 2014).

A key aspect in the development of Xerox's business is the ability to continuously improve and open up new revenue streams with existing and prospective customers. Improvements can be made on products and processes thanks to the implementation of product and process innovations. Products can be redesigned to be more reliable, easier to operate and maintain, and faster to repair in the event of a failure. The same applies to processes that also need to be redesigned in order to better deal with failures, guarantee a quick response and reduce manpower and materials necessary in the event of a failure. Practical customer experience is used in process innovations. All this allows to reduce costs over the term of the contract, as well as improve the efficiency of solutions delivered to the customer (Xerox, 2015, 2016, 2017).

The company is constantly taking steps to develop and improve its solutions. To this end, it also works with external partners on issues that Xerox cannot handle alone. These initiatives are aimed at increasing profitability and improving the competitive position.

The key to the Xerox model is offering differentiation. The company tries to predict the future, define new areas of competence and research, and respond to the customer's future needs (Xerox, 2018).

Xerox creates services in response to customer needs. New solutions include Managed Print Services and Intelligent Workplace Services. The services include training and a range of solutions that help customers optimize their printing and communication infrastructure. Software for personalization, solutions used in content management and digitization services are also an important element. Thanks to the use of digitization, automation and the latest technologies, the services are focused on maximizing efficiency and guaranteeing the highest level of customer security (Xerox, 2018, 2019, 2020).

The Xerox model leverages manufacturing, global delivery, financial discipline, skilled human resources, and an incentive reward system for your employees. Everything is aimed at ensuring the excellence of service delivery and contributes to creating solutions that customers expect. The opportunity and priority of the company is to increase the margin in terms of services. This is to improve the financial situation and invest in new solutions (Xerox, 2018, 2019, 2020).

Increasing margins is a key service priority and an overall opportunity for Xerox that we will achieve through specific initiatives to improve our cost structure and portfolio mix (Xerox, 2019).

Xerox's PSS model uses technology and service know-how. It is a powerful combination in which employees play a key role. Employee development is one of the priorities of the discussed model. That's why Xerox is committed to providing them with training and tools to help them work more efficiently and advance their careers. This is due to the fact that employees are responsible for the development of new company offers (Xerox, 2019, 2020).

The Xerox model is most suited to the printing industry (industrial printing). Its main material element are photocopiers, which differ significantly from printing machines (construction, value, purpose). Analyses of the business model and the way in which the PSS approach is changing it also allowed for an analogy to be found with the industrial printing sector.

2.2 Printing industry

Printing industry is a characteristic type of the manufacturing sector and one of the largest light manufacturing industries. Its processes cover the design of master forms (printing forms) of original graphics (text and images) and their printing (Cost, 1997; Eisenstein, 2005). The printing industry is one of the biggest manufacturing industries in the European Union and world-wide. In most countries it ranks in the top 10 of the biggest contributors to the economy. It products are used by other industries, institutions, and public authorities. It prints books, newspapers, magazines, calendars, advertising materials, post cards, tickets, maps, security prints, envelopes, labels, and packaging using diverse printing techniques. The most highly appreciated among the latter are: offset, flexographic, and digital printing (KPMG, Polish Brotherhood of Gutenberg Knights and Faculty of Journalism, Information and Bibliology, University of Warsaw, 2018).

The printing industry played key role in the promotion of the Renaissance thought and scientific revolution; it also laid foundations for modern knowledge-based economy and its dissemination. Over the ages, printing had undergone deep changes. Nowadays, it is in the stage, in which development progresses at an even faster pace (Crompton, 2004; Kelley and Sorce, 2006).

Polish printing industry ranks seventh as to its size in the European Union (after Germany, the United Kingdom, Italy, France, Spain, and the Netherlands). At the same time, it is the biggest printing industry in Central and Eastern Europe (KPMG, Polish Brotherhood of Gutenberg Knights and Faculty of Journalism, Information and Bibliology, University of Warsaw, 2018). In 2018 in Poland the industry reported 8,725 enterprises (7,990 micro enterprises, 573 small enterprises, 146 medium-sized enterprises, and 16 large enterprises) out of which 13 represented the public sector. In the same year, Polish printing industry employed 55.5k people. Production sold in 2018 amounted to EUR 3,665.49 mio (PLN 15,761.6 mio), revenue to EUR 2,865.67 mio (PLN 12,322.4 mio), and costs to EUR 2,689.79 mio (PLN 11,566.1 mio) (Statistics Poland, 2020).

Printing houses operations go far beyond making printouts and handing them over to the customer. One must bear in mind that the process leading to the creation of a new product in the printing industry is highly complex and labour intensive. Printing enterprises must continuously monitor and supervise the core production process together with all other processes linked with it. In printing houses, these 'other processes' include: customer service, collection of orders, production phase (prepress-press-postpress processes), and distribution of finished products (Lipiak, 2017). Phases of the production of printing products: prepress-press-postpress processes are critical in this industry (Kelley and Sorce, 2006; Rees, 2006). These three terms describe subsequent stages of the development of a printed product. Prepress covers all preparatory operations. Today the stage takes much less time and is easier. Professionals use the abbreviation DTP (desktop publishing) to describe it. The stage starts with the input of a text and image into computer software to be printed on paper or on other substrate. Prepress stages also includes, inter alia, editing graphic files (colour correction, adjusting brightness and contrast, image retouching, cropping, and scaling), adjusting the colour profile, and correction. All of these operations occur at a graphic design studio of a printing house. Before printing starts, the printing house carries out many operations seeking to ensure the best effects possible and top quality of the print. These operations include: a test hard copy printout, checking for discrepancies in the postscript file, ripping (i.e., creating a raster image from a PostScript file separately for each colour), making test copies, printing plates irradiation from film or directly from postscript files (CtP). CtP (Computer-to-Plate) is one of two elementary techniques of making a printing form. The second one is CtF (Computer-to-Film), which is a contact, analogue method. The above operations have to be performed by the printing house. Each requires adequate concentration, knowledge, and precision. Knowledge about the complexity of the prepress process is important mainly because of the myriad of requests for corrections so typical of printing orders. That usually happens after the customer receives the sample printout. When this sample has been approved by the customer, press, the core stage of printing begins. It requires high precision, a lot of knowledge, and experience. In this stage, the printed product assumes its ultimate shape from the point of view of how the structure of information is reproduced. This stage takes place with the assistance of industrial printing machines suitable for large batch orders. Besides printing, this stage covers a lot of other operations. A printer must prepare and set up the machine, printing plates are installed, inks and printing substrate are delivered. Printing substrate comes as a roll (web-fed printing) or sheet (sheet-fed printing) and is placed in the printing machine. While passing through the printing press, printing elements are reflected on the surface of the printing substrate using one or more printing inks (dyes). Postpress is a stage covering all finishing touches and basic binding processes. Prints can be finished after printing has been completed, usually before binding. Finishing boosts visual effects of the printed material and gives it certain properties (improved durability, resilience to external factors (rain or UV radiation)). Lacquering is the most frequently type of finishing. It consists in placing a layer of lacquer over the printed surface. It improves durability and resilience of the final product and impacts its aesthetics. Laminating is another form of finishing. It consists in covering the prints with transparent plastic film. Another method consists in cold- stamping and hot-

stamping, i.e. in selective film extrusion. This technique allows achieving special metal-like finishing (in the colour of, e.g., copper, silver, or gold). Binding works at this stage include primarily cutting and trimming. Formally, these are two different operations: cutting does not generate waste while trimming does. If printed products are produced in covers trimming also takes place (to achieve 'perfect' edges when pages and cover are glued together at the spine – perfect binding), folding (consisting in adequate bending of a sheet (or roll) of paper to get a folded edge), creasing (for easier opening, e.g., of a leaflet), stitching (gathering folded sheets together one inside the other and then either stapling wire staples through the fold line along the spine or stitching them with a thread). Sheets can also be glued; a layer of glue is placed on the edge of inserted pages to join them with the cover. Binding and fixing covers is a long process that requires precision. Postpress also includes ironing performed to expel air from between the stack of printed sheets (Crompton, 2004; Eisenstein, 2005; Rees, 2006; Sorce and Pletka, 2006).

The production of printed products is a complex process, independently of the applied printing technique. In any case it has to cope with a number of variables linked with manual operations involved in making corrections, colour matching, washing ink cartridges, and other (Lipiak, 2017; Lipiak and Salwin, 2019). This is a series of handling operations which are time-consuming and generate waste. What is important in this case is speaking with one language (i.e. spectral data) practised by different departments in the printing house responsible for collecting orders, graphic processing, ink mixing, monitoring supplies of raw materials, printing, and, finally, quality control as this is the only way to stabilise the process. Having a lot of volatile printing parameters implies a number of problems in the printing process. Knowledge about why these problems emerge is very much helpful in their elimination. The task, however, is not an easy one. To be able to cope with it one needs professional knowledge and experience in printing industry. Only then is it possible to effectively solve such problems as the solution can be found when one knows how to approach them and what needs to be done. If the main cause is found, finding remedies becomes much easier. In most cases it leads directly to the solution of the problem.

Printing business is not only about printing and binding services, but also about printing machines used in production. These machines are crucial for many economies across the globe. They are critical equipment in printing houses used to print materials for many other industries. In addition, these are big, technologically advanced machines representing high value. From technological point of view, printing machines are highly complex mechatronic products. They bring together mechanical, IT, and electronic functions to ensure adequate functionality to users. Their design, manufacturing, maintenance, and repairs necessitate machinery designers/constructors having a wide spectrum of competences in several fields of technology and production processes. The engagement of a network of specialised suppliers manufacturing crucial components, such as drives, engines, printing systems, control and other systems is also indispensable. A decision as to what components will a printing machine be built from is strategic to the manufacturers. It carries consequences for these machines' printing capabilities,

longevity, or energy consumption, which is also important for a printing house. The market of printing machines is extremely narrow.

In the area of printing, you can most often meet product oriented PSS and use oriented PSS. It is about the traditional purchase of printing machines together with basic services available during the term of the service contract. Another well-known solution is leasing, which is currently the most common way to buy machinery. In the Polish printing sector, which form was used by as many as two thirds of companies. In the case of over 20% of printing houses, this method is the only option for financing investments in modern machinery. Currently, it is not the manufacturer, but mainly the leasing funds that cooperate with printing companies, offering financing of equipment. In 2015, printing companies leased 1,998 machines with a total net value of EUR 141,81 mio (PLN 593,38 mio). In 2016, it was 2,209 machines with a total net value of EUR 123.12 mio (PLN 537.26 mio). It follows that the average value of one printing machine in 2015 was EUR 70.98 thousand (PLN 297 thousand), and in 2016 EUR 55.69 thousand (PLN 243 thousand). In the first three quarters of 2017, printing companies leased machines with a net value of EUR 104.5 mio (PLN 446 mio). It was 31% more than in the same period of 2016. The standard lease term is 60 months, but there are also offers for 96 months. This is to reduce the amount of leasing instalments. Due to the value of the machine, some printers benefit from a longer payback period. Usually the own contribution oscillates at the level of 10-20%, but there are solutions where no pre-payment is needed. The machine redemption amount depends mainly on the printing house. Sometimes the machine dealer offers to take the used machine in the bill and sells a new one at the same time. Leasing significantly contributes to the fact that printing houses decide to buy new machines and develop the entire industry. There is still a lack of comprehensive solutions containing a wide range of services.

Recently, there has been a visible development of the new solutions, mainly in office printing in which photocopiers are used. In the industrial printing, we can meet the print on demand formula for books. A book is not printed until the reader has ordered and paid for it. In this option, the author does not bear any printing costs. Such services are provided in cooperation with printing and publishing houses or bookstores and authors.

As part of the work on the printing sector, 80 printing houses were surveyed. The aim of the study was to determine how the PSS and related trends are known in the Polish printing sector and what services added to the printing machine are most desired by printing houses.

The conducted research shows that PSS and related trends are little known among Polish printing houses (Figure 2.6.).

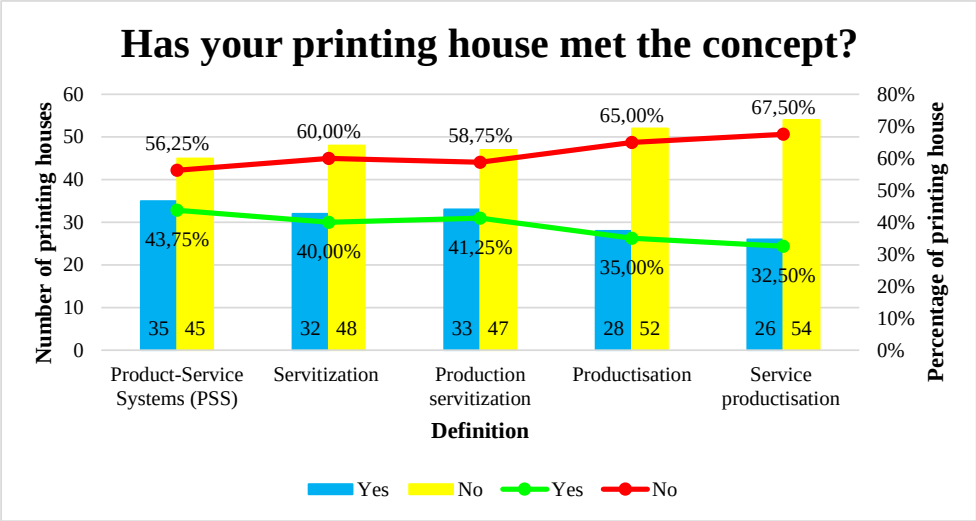

Figure 2.5. The state of knowledge of Polish printing houses

Service preference studies were carried out in four main areas:

- services according to the Polish Classification of Goods and Services (PKWiU),
- connected with a printing machine,
- related to printing process,
- ancillary services.

The conducted analyses show that:

- printing houses are interested in services presented first and second areas
- micro and small printing houses, working in one shift, printing small range of
- products, are interested in services from the third area;
- large and medium-sized printing houses, working in two and three shifts, and wide range of, are interested in services existing in fourth area;

The conducted research shows that the type of printing house is not a significant factor influencing the service preferences of the printing house. The statistical analysis of service preferences is given in Paper 5.

3 Research methodology

This section describes the overall research methodology and the research goal, followed by a data collection.

3.1 Research approach and the research goal

The overall methodology and structure of the overall scientific process from problematics definition till industrial validation is presented in the Fig. 3.1. in the first column. The research process was divided into six stages. The first was about obtaining basic knowledge of printing, printing processes and getting to know the functioning of the printing house. The first stage concerned the analysis of PSS design and classification methods. In the next stage, PSS operating in the industry was analysed. The fourth step is to identify the research gap - no practical cases of PSS in industrial printing and PSS design methods used in this industry have been found. The fifth stage is a detailed study of the printing sector (analysis of reports, statistical yearbooks and other industry sources) and study of printing houses (surveys, workshops). The last stage of research is the development of PSS for printing - industrial printing.

Diverse research methods have been used in different publications. This dissertation covers research studies based on several research methods and discussed in several publications (Fig. 3.2.). As shown in Figure 3.1., this dissertation rests on the eight methods: six research methods: (i) case study, (iii) survey research, (iv) systematic literature review, (v) workshops, (vi) statistical analyses (Spearman's correlation, and chi square test (χ^2)). experts consultation (vii); a design method: (ii) brainstorming; and an analytical tool to support problem analysis/problem solving: (viii) Pareto-Lorenz analysis. Methods are explained in respective publications; this section informs about goals set for individual publications that could be achieved by applying the above listed research methods.

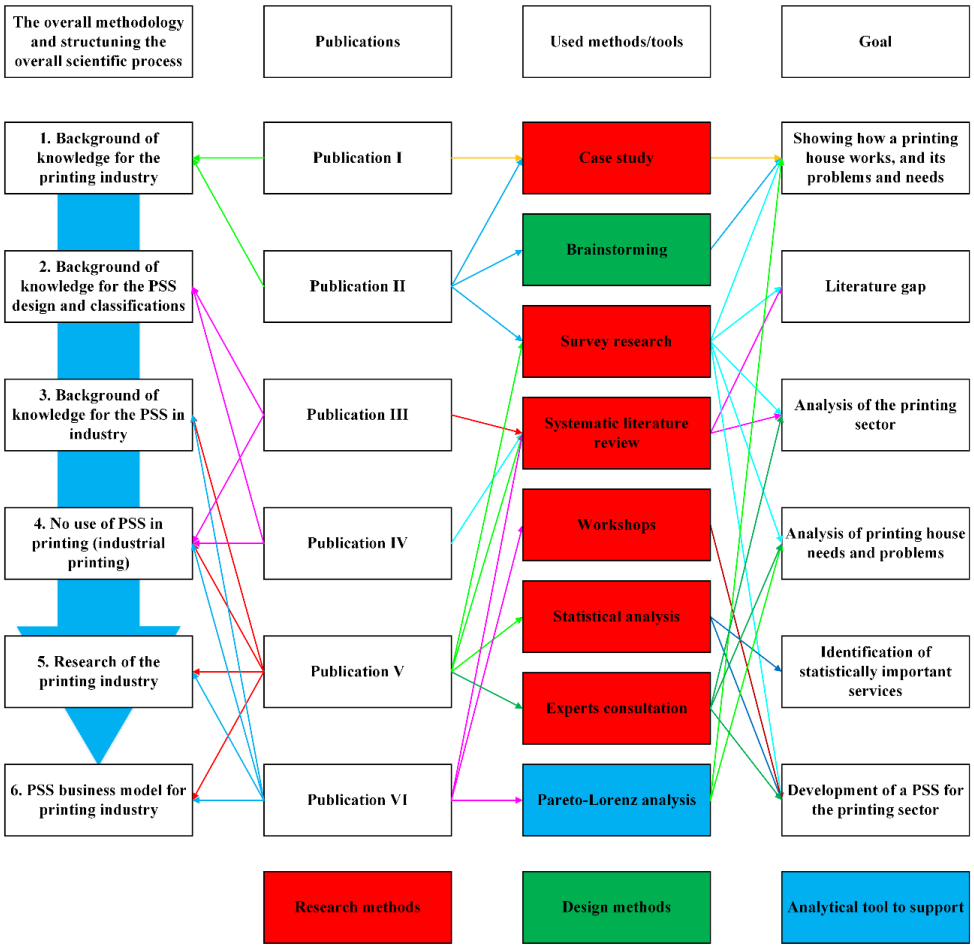

Figure 3.1: The overall methodology and structuring the overall scientific process and the methods applied in the dissertation

Each of these methods played a significant role in the dissertation. They were deployed, for instance, to develop a PSS business model based on the experience of a printing enterprise (publication VI), literature review (publications III and IV), survey research, and statistical analyses (publication V).

My research process began with studies carried out in a printing enterprise using a case study method. The study delivered information about how the enterprise operates, what are its needs, problems, solutions proposed to them, and printing technology. It enriched the research process with practical experiences in the printing industry. Besides, it contributed to further studies in the printing industry intended to offer support in bringing

forward the development of printing houses, creating innovation, promoting environmental protection and problem solving. Focus was placed on the PSS, that is on a solution linking products and services in an offering meeting customer needs.

Another applied method was brainstorming (publications II and VI). It is a heuristic method of creative problem solving applied in a printing enterprise discussed in both publications. The method was used to find ways to improve the work of a warehouse (publication II) and identify the principal service needs of the printing house covered by the study (publication VI). In the case of publication No. II, brainstorming engaged the management of the enterprise and workers from the warehouse department while in publication No. VI all of the workers of the enterprise were involved.

The work also uses Pareto-Lorentz analysis which helped in putting in order data on problems incurring the biggest costs to the printing house covered by the study.

The next stage consisted in conducting a systematic review of literature on design, classification, and practical use of PSS solutions. The goal was to acquire knowledge about the structure and methods of PSS design and its use in practice. Knowledge in this area is not structured in any precise way, which is why literature review was necessary. It gave a picture of to date situation with respect to studies on PSS design, classification, and practical deployment. That was extremely useful as the review confirmed that there are many PSS design methods targeting different industries. PSS arrangement is also used in practice by many enterprises. However, there is a number of issues and industries that need to be considered in developing PSS systems. The absence of a PSS in the printing industry is a serious issue. It shows there are no PSS design methods that would address this very industry and could be used in business practice. This research approach was aimed to find a gap in industrial structure. In the next stage, industry reports were examined to assess the potential of the printing industry in Poland.

A questionnaire was a research tool widely used in this exercise. Survey research was carried out in a printing enterprise (publications II and VI) as well as in the Polish printing industry (publication V). The questionnaire was designed to collect information about problems and needs of the printing houses, preferred services, and guidelines that could enhance the development of PSS in the printing industry.

Questionnaire-based studies were substantiated with statistical analyses: Spearman's correlation and chi square test (χ^2). Statistical analysis that indicates what services are relevant to concrete printing houses.

Consultation with experts (publication V) was another research tool used in the dissertation. They are conducted with ten experts with practical and theoretical knowledge in the analysed area (7 experts in the field of printing, 2 in the field of finance, 1 in the field of trade in industrial machinery). Consulates with experts aimed to gather consultations on the developed PSS and guidelines for the development of PSS in the

printing industry. Additional information and opinions regarding the printing industry were also obtained.

3.2 Data collection

Two case studies were founded on information collected in a printing enterprise. For instance, in the first case study (publication I) concerning an implementation of innovation, data for 20 months of operations of an enterprise were analysed. In this case, the enterprise made also other data available about a printing machine, printing process, the use of materials, and other indispensable data. The second case study (publication II) dealt with improvements to a warehouse performance. Besides observations and data acquired from the enterprise, interviews were carried out with employees. In both cases, the enterprise shared its internal documents which helped in understanding the specificity of the printing industry and operations of printing houses. The goal was to shorten the time needed for explanations and focus on the research.

Data used for literature review (publications III and IV) were acquired from the biggest multidisciplinary scientific databases (EBSCOhost, Emerald, IEEE Xplore Digital Library, Ingenta, Insight, ProQues, Science Direct, Scopus, Springler Link, Taylor & Francis Online, Web of Science, Wilma, and Google Scholar). Detailed analyses came up as a follow-up of a three-stage systemic overview of literature.

Questionnaire-based studies were conducted twice. For the first time as a face-to-face survey conducted in a printing enterprise (publication V). Interviews took from 10 to 20 minutes and they were held with all employees. The questionnaire used in the study contained proposed services broken down into three groups which were to address the problems and needs of the enterprise participating in the study. The second study was carried out on a group of 80 printing houses in Poland (publication VI) as direct and on the phone interviews. Studies concerning services connected with a printing machine covered an extremely wide area, unprecedented in practice and in literature. Therefore, questions about services were divided into four fields (services according to the Polish Classification of Goods and Services (Polish abbr. PKWiU), services connected with a printing machine, services connected with printing, ancillary services). Depending on an enterprise, the survey took between 30 and 50 minutes. Author's notes taken in the course of the survey were also examined. Respondents were selected for the study based on different criteria. They were representatives of printing houses, permanently working on a printing machine and engaged in the printing process, having practical knowledge about printing. Printing houses were identified on the basis of a database of printing companies. These are companies of various sizes (9 - micro; 36 - small; 23 - medium; 12 - large;), specializing in three leading printing techniques (40 - flexographic; 32 - offset; 8 - digital) with many years of experience (over 10 years on the market). In addition, selected respondents had to come from diverse levels in the printing house structure and occupy different positions. They also differed regarding the age, length of employment, position in a company, and education background. One of the principles of cooperation with the

analysed companies was their anonymity. Therefore, according to the general practice encountered in such type of research, no information allowing for identification of the respondents could be disclosed.

Consultation with experts (publication V) is another method that has been used. 10 experts with practical and theoretical knowledge in the analysed area were selected for consultation (7 experts in the field of printing, 2 in the field of finance, 1 in the field of trade in industrial machinery). The selection of experts was dictated by their level of education, many years of experience in various positions in the fields they represent, and practical knowledge. The selection of experts in these areas was dictated by a wide range of issues important for the assessment of the analysed problem (the nature of the PSS and the sector for which it was developed). On the one hand, it was necessary for it to meet the needs and requirements of the printing house, on the other hand, it was economically assessed and differed from the formulas for selling machines available on the market. Consultations with experts lasted 4 hours. The developed PSS was thoroughly analysed on them, areas needed for improvement were indicated and improved. Each of the experts presented their point of view. After the discussion, the final PSS was developed.

On top of the above presented sources of data, the author used secondary data from other sources, such as reports and statistical yearbooks providing data about the printing market in Poland and in Europe. Other data include data obtained from the printing enterprise, such as: contracts for the purchase of printing machines, cost of the service, costs connected with machine changeover, failures and stoppages of a printing machine, prices of materials, and other (publications V and VI).

The above confirms the multiplicity of methods used to collect data for this dissertation. They were intended to get as close as possible to facts and practice of the printing industry to be able to apply a PSS solution in the printing industry.

3.3 Research design

A PSS combines products and services in solutions tailored to customer needs. Each industry uses different machinery and equipment also the scope of services varies across industries. The printing industry and operations of printing houses are specific types of industrial operations. Publications I and II discuss experiences of printing houses in the implementation of innovation and solving warehouse problems. Publications III and IV analyse literature and identify research gaps. Publication VI discusses workshops during which a PSS for the printing industry was designed. Finally, publication V presents questionnaire-based studies, summarises all the accumulated knowledge, and practical experiences in printing and PSS; this was the foundation on which PSS business model for the printing industry was developed.

4 Overview of the publications

This section is a review of the publications. It summarises goals, findings, and contribution made by individual publications that make up this doctoral dissertation. The goal of the research is to identify possibilities and limitations of using PSS in the printing industry.

The above-mentioned goal is accomplished by bringing together individual publications. Publications I and II make an introduction into the printing industry business. Findings of publications I and II demonstrate operations of a printing enterprise involved in putting in place innovation and improving the operations of a warehouse. In both these cases, following long-lasting efforts, the enterprise succeeded in achieving the planned objectives. Findings of publications I and II broadly show the problems and needs of the printing house. They illustrate the experience of their actions related to solving them. They provide guidance on the service needs of these enterprises.

Regarding PSS design, literature analysis covered the aspects of design (publication III), classification (publication IV), and the use of PSS in industry (publications V and IV). The main conclusion from these analyses tells us about the lack of PSS deployment in the printing industry and the absence of PSS design methods for this industry.

Publications V and IV discuss steps undertaken to develop a PSS for the printing industry. Publication V introduces the reader into industry-specific workshops organised in a printing house during which a PSS was designed. Publication VI is devoted to the working out of a PSS business model for the printing industry. The paper was substantiated with a comprehensive examination of the printing market in Poland, manufacturers and users of printing machines, questionnaire-based studies, and consultations with practitioners from the industry in question, professionals selling printing machines, and financial experts. Research studies discussed in this work highlight the demand for PSS in the printing industry.

The dissertation stresses the importance of experience and contacts with the users of printing machines in PSS design and benefits that it produces to the environment, manufacturers, and customers. It also brings in a wider perspective on services added to products within the PSS.

4.1 Publication I

Research objective

This publication is a chapter in a book, which discusses the use of innovation as a tool in improving the printing process and as an instrument assisting the implementation of the idea of sustainable development. Moreover, this document illustrates empirical application of innovation and its effects. The implemented innovation relates to changes in the construction of the printing machine. Studies on it took twenty months. Due to the

complexity of the solution, the paper presents consumption of energy, film, paper, ink, and photopolymer forms.

Main contribution

The paper makes a twofold contribution. It shows the need for innovation in printing companies and explains how process innovation reduces the environmental impact of production. It illustrates a long time over which innovation is developed and implemented and the commitment of employees of the enterprises. It shows that when making a standard purchase, the enterprise is left to its own devices. Second, by introducing construction changes we can reduce the consumption of energy, film, paper, ink, and photopolymer forms. Reduction of the consumption of these materials leads to cost reduction. Saved resources can be spent on investment and recruiting new staff. In addition, the proposed innovation exerts positive effects on forestry, the use of printing substrates, manging materials used in production, and recycling.

The paper is an introduction to the practice of the printing industry. It provides data on the real problems and needs faced by users of printing machines. The information contained in the article is a basis that provides guidelines that could be taken into account by the manufacturer in developing new offers and models for this industry.

4.2 Publication II

Research objective

The publication proposes an improvement in warehouse performance in a medium-sized printing enterprise. The process was based on observations, expert questionnaire-based studies, and consultations with employees. The publication shows the importance of warehouse processes in a printing house, typical mistakes and ways of eliminating them. The paper represents an added value to a company. The approach adopted in this work can be implemented by small and medium-sized printing enterprises.

Main contribution

The publication shows the needs and problems of a printing company in a different area of operation than before. The paper illustrates the process of improving warehouse management in a printing house. The publication indicates problems related to this area and the need to implement improvements. The introduced solution is based on the company's employees and good communication between them. This shows that human potential is an essential feature that is the basis of development.

The paper sheds more light on the practice of the printing industry. It shows that printing houses are not only struggling with printing problems, but also with other problems, such as warehouse processes. The article provides information about the needs of the

enterprise. The data contained in the work indicate the need to develop and send offers supporting a wide area of their activities to printing houses.

4.3 Publication III

Research objective

The publication is a chapter in a book discussing the existing PSS design methods. To this end, it analyses 60 existing design methods. These methods were examined with regard to the degree of validation, company size, and industry, in which they are applied, product development path for products and services, and customer involvement in design. The publication shows gaps in PSS design methods and reveals the absence of a design method for the printing industry.

Main contribution

The discussed publication provides an analysis of frameworks of 60 PSS design methods. It identifies common features and differences between PSS design methods, and their limitations. The analysis shows that the needs of theoreticians and practitioners related with PSS design for different industries were not fully satisfied. There are many unresolved practical, theoretical, and methodological aspects connected with this design process. Its principal contribution lies in revealing gaps that need to be considered when creating new PSS design methods and when designing a PSS for a concrete industry. The methods do not inform about the business model adopted by an enterprise, they are imprecise as to economic aspects and disregard financial analyses. In addition, methods covered by the examination are not too much detailed and they are not always up to the objectives and tasks they are faced with. Usually next stages of the methods and their applications are described in a quite general and superficial way, which makes them little fit for practical uses. The study shows that despite a wide plethora of PSS design methods, we still lack methods that would precisely address many industries which is why PSS solutions should be developed for new industries.

4.4 Publication IV

Research objective

In an enterprise the adoption of a PSS arrangement is linked with shifting from selling products towards selling the usefulness or effects offered by products. This is why when developing a new PSS, PSS classification is crucial. Classification consists in breaking PSS systems down according to rules adopted by an enterprise. This publication is a chapter in a book, in which the existing PSS classifications are discussed. It examines 10 existing PSS classifications. They are analysed against objectives set for them, clustering structure, and vital PSS features quoted in literature (e.g., the right of ownership,

sustainable development aspects, product lifecycle). The publication highlights gaps in PSS classification.

Main contribution

The publication in question discusses the frameworks of 10 PSS classifications. It demonstrates that PSS classification is a very narrow research area. That is confirmed by the fact that some PSS classifications were created through the modification and transformation of other. The text identifies common features and differences in classifications, as well as their limitations. Classifications described in subject-matter literature were divided into two groups. The first one includes classifications that show that there is a multiplicity of combinations of products and services between selling products and rendering services. The second group of classifications is based on the transition from being a product manufacturer to becoming a service provider, i.e., on the transformation of an enterprise. The key contribution of the publication lies in the highlighting of gaps that need to be taken into account when a new classification is developed. Classifications disregard the mechanisms of revenue creation in manufacturer's enterprise and customer costs. Quality indicators for solutions delivered to customers are also ignored. Another important aspect that is missing in classification exercises is the combination of changes in offering with the change in the organisational structure. The study has demonstrated that although there are many PSS classifications available, they still fail to reveal all nuances and differences emerging in business practice.

4.5 Publication V

Research objective

This paper deals with the development of a PSS business model for the printing industry. It expands and integrates the business model of an enterprise with the PSS solution, drawing attention to sustainable development aspects and to customer needs. In the developed solution, services are grouped from elementary services to the ones offering concrete solutions. For that purpose, questionnaire-based studies of printing houses (users of printing machines) were used together with statistical analyses and consultations with experts in the printing industry, printing machines market, and finance. There is also a financial analysis underpinning these considerations. The paper bridges the gap in literature resulting from the lack of PSS for this industry.

Main contribution

The paper discusses how a PSS business model was developed for the printing industry. To find out whether there is an adequate potential, the printing industry in Poland was thoroughly investigated (revenues, output, production sold, number and size of enterprises, and employment). The analysis showed that in Poland this industry is composed of many enterprises, potential PSS users. To describe the printing industry

practices in the most precise way possible, questionnaire-based studies were conducted in 80 printing houses (printing machine users) in the next stage. The study has showed that as many as 63 printing houses are interested in PSS solutions. Research on services connected with printing machines was sketched very widely, at the scale previously unprecedented either in practice or in literature. That is why questions concerning services were divided into four areas (according to the Polish Classification of Goods and Services (Polish abbr. PKWiU), services connected with a printing machine, services connected with printing, ancillary services). Obtained results of questionnaire-based studies were subject to statistical analyses (Spearman's correlation, chi square test ($\chi 2$)). These analyses showed that micro and small printing enterprises, working one shift and offering a small range of products, need different services than medium-sized and large printing enterprises working more shifts and offering a wide assortment of products. In addition, questionnaire-based studies provided information about problems and needs of participating printing houses, also about the use pattern of printing machines (for how long and how they are used). These were the foundations for a PSS business model consulted with 10 experts. Consultations helped to improve the model in question. In the newly developed PSS business model services are divided into packages from standard ones to services offering concrete solutions. Print Service Engineering package is an important component of the solution. It includes services based on professional knowledge and know-how, which might assist printing houses in optimising many processes and in implementing innovation. When complete, the proposed solution was examined from the financial point of view which took account of the useful life of a printing machine (24 years), average period for which a printing machine is used by one printing house (8 years), a machine purchase price, cost of its manufacturing, and prices of ancillary services required over the useful life of a machine. The paper discusses specific features and components of a PSS business model (industry-specific knowledge, technology, human resources) for the printing industry. It makes an in-depth presentation of benefits available to machine manufacturers (longer period over which a single machine can bring profit, entering the secondary market, and getting access to new customers), printing houses (consultancy, better and more efficient use pattern of printing machines, having sufficient supplies of raw materials in the warehouse, preparing new projects), and to the environment (developing environment-friendly solutions for printing, waste reduction). Studies, analyses, and the developed model faithfully reflect the current market situation. They provide evidence that by offering a machine under the PSS model a manufacturer earns more than from a traditional sales transaction.

The developed model differs from the models operating in other industries in a much wider range of services aimed at use. It focuses on high-value industrial printing machines and services related to the machines and processes in which they are used. It uses eight-year cycles of machine use by the customer and elements of reverse logistics, which guarantees the possibility of a major overhaul and re-use of the machine by another or the same customer. Another distinguishing element is the supply of specialist services based on knowledge and know-how to printing houses. An important element distinguishing the developed model is care for the natural environment. Due to the large amount of materials used (farms, varnishes, foils, etc.) and the amount of generated waste, the printing

industry is not an environmentally friendly industry. Therefore, the developed PSS has packages of services related to material management and waste management that meet these problems and make the industry environmentally friendly.

4.6 Publication VI

Research objective

This publication brings forward the development of a PSS for the printing industry. It discusses workshops conducted in a printing house organised to design a PSS. Activities undertaken within the workshop framework offer a number of hints and suggestions concerning the development of a PSS for the printing sector. The publication presents a new approach to PSS design, which engages the user of a printing machine from the very beginning until the very end. Moreover, the work diagnoses major problems faced by the enterprise, its service needs, i.e., provides data which were used when creating a PSS. Such approach is intended to fully satisfy the needs and assist in solving problems in a printing house.

Main contribution

The paper takes us through the development of a PSS for the printing industry and explains how it should proceed to consider specific customer needs. The developed solution is tailored to the needs of a concrete printing house operating in Poland, in which workshops had taken place. To most precisely identify problems that generate the biggest costs in the enterprise, Pareto-Lorentz analysis was deployed. Next, as a result of brainstorming that engaged the staff of the enterprise, services of interest to them were identified. This information was used to draft the questionnaire for the survey. In the questionnaire, questions concerning services were divided into three groups (universal services relating to printing machinery, print process services, and ancillary services). The questionnaire-based study was carried out across the enterprise. Findings from the study helped to find out which services are the most demanded by the Management Board, middle management, and workers from the shop floor. That was the basis for a PSS having machine as its tangible component and three service packages (elementary, intermediate, advance) as an intangible component. Services in the designed PSS were tailored to enterprise needs. A developed PSS is a model made to measure whose creation fully engaged printing machine users.

The paper demonstrates that investigating customer problems and needs is crucial in PSS design. This is how it contributes to fostering the relations between manufacturers of printing machines and printing houses. These studies have proven that based on a thorough analysis conducted from the customer perspective, PSS can be generated and enriched with innovative services. They also present benefits to machine manufacturers (winning loyal customers), printing houses (catering for their needs, leasing/renting instead of purchasing a machine, elimination of investing huge sums of money in the purchase), and the environment (better waste management).

5 Discussion and concluding remarks

This dissertation is motivated by the wish to provide an input into the theory and practice of PSS design in the printing industry. It focuses on printing (industrial printing) and the industrial printing machines used in it, rather than on other related areas of printing, such as office document printing and copying and the photocopiers used in it.

The conducted research clearly showed that printing industry (industrial printing) has been omitted by authors of PSS design methods. Remarkably, there are no PSS models that would be used in the business practice of the printing industry. This suggests extremely limited research conducted in this area to date. That is why the goal of the study was to identify possibilities and limitations to the use of a PSS in the printing industry.

5.1 Answer to research questions

Conclusions from the dissertation are presented as answers to the following research questions:

RQ1. How to apply the users experience in design and implementation of PSS in printing industry? (Paper 1, 2)

When designing a successful PSS one needs to remember about coherence. Enterprises, which use the same printing machines may have diverse needs, problems, and carry out different studies. Using machines and sharing practical knowledge and experience may help in PSS design and become one of crucial design elements.

The user's preferences, impressions, experience and knowledge can be one of the important elements in the design of the PSS. To take full advantage of this, the manufacturer should get to know the current customers better. If a manufacturer has sufficient knowledge of who his customers are, what interest them, their problems and needs, and how they conduct their business, they can use this knowledge to develop the PSS.

Tools that can be used to obtain this information are questionnaires, research workshops and case studies. The survey is irreplaceable in this type of research. It allows to collect a large amount of information, and thus get to know service preferences, needs and problems that occur in printing houses. In the case of introducing a new solution to the market, it shows whether it meets the needs or solves the problems of potential customers. It also supports the verification of the concept by showing whether it attracts customers' attention.

In addition to obtaining the above-mentioned information, research workshops involve users in developing solutions. During the meetings of the representatives of the manufacturer and the user of the machines, common solutions and a vision of the future are developed. The main aim of the workshop is to gather current opinions and specific

suggestions and to build a consensus on the development of the PSS. Research workshops can be used both in the initial and final stages of work on the development of the PSS. The results of the workshops are often a significant stimulus in taking specific actions.

Case studies are another possibility. The main purpose of this method is to present the analysed case in the best possible way. Thanks to them, it is possible to analyse internal processes, the specifics of the sector, as well as capture the key features that are important to it. This enables an in-depth analysis of a specific phenomenon, goals, assumptions, motives and actions.

It must be born in mind that when designing a PSS for the printing industry account should be taken of the printing houses which will be directly included in this solution. Looking at printing houses it becomes obvious that they host not just printing machines but, above all, processes and people linked with them. Experiences and problems faced by printing houses and people working in them connected with the use of machines, printing processes, warehousing, sustainable development, research and development will provide an impulse for generating a wider array of services dedicated to printing machines in a PSS.

The conducted survey shows the service preferences of printing houses and provides information on the needs of these enterprises. The conducted workshops are at the same time the producers and users of machines working out a common solution. Studies carried out for the two case studies show the specificity of printing house operations. They illustrate the role of experience in implementing innovation and solving problems in the warehouse. In both cases only employees of the enterprises are engaged in the exercise which has revealed their knowledge, skills, and weaknesses. These case studies offer layers of knowledge that can be used in generating new PSS solutions enriched with services satisfying real customer needs.

RQ2. What are the peculiarities of using PSS business model in printing industry? (Paper 4, 5)

Attempts to apply a PSS in this industry have led to the conclusion that focus should not be only on services closely linked with a printing machine, but a wider perspective is necessary. Important aspects connected with the use of a PSS include the length of time when the system is used, fees for using the machines, how machines are made available, how spare parts and other materials are supplied, and the system of reverse logistics. One must bear in mind that a printing machine is a critical component of the equipment used in printing houses without which printing cannot take place. Printing process itself is an important feature as it requires proper setting and precision and is the source of problems specific to this industry.

An emerging challenge is the continuous verification of the PSS used (all or selected elements) in the context of the possibility of its improvement and updating. These activities are associated with increasing the efficiency of PSS operation and the degree of customer satisfaction. This action is necessary when the achieved results differ from the

assumed ones. It involves the analysis of many variables, a series of works related to the operation of PSS that generate costs.

Trust will be one of the key assets and, at the same time, a challenge for the PSS for the printing sector. Close cooperation between the producer and the customer based on trust is essential. This is a determinant of the PSS's success and a feature that will allow both the manufacturer and the printing house to achieve their goals. It is mainly related to the sharing of sensitive information, which until now has been left by both the manufacturer and the printing house. This allows to learn about the needs, and at the same time eliminate problems and improve the PSS solutions. Trust gives both parties the opportunity to achieve long-term benefits and greater flexibility. This will allow to jointly build the competitive advantage of the manufacturer's PSS solutions and take up challenges leading to increased efficiency of their operation. Lack of trust may limit the ability of the PSS to operate and lead to paralysis of information exchange and cooperation. This is conditioned by the lack of development of the PSS potential in the printing industry.

Other challenges posed by the PSS include comprehensive supply of materials used in printing production, for each order it carries out. The manufacturer cooperates here with a wide group of suppliers, is responsible for stock management and completion. The PSS emphasizes responsiveness and action.

One of the biggest challenges posed by the PSS will be the implementation of solutions such as remote printing or printing on demand for industrial printing.

The adoption of the PSS strategy in the printing sector will be influenced by specialization in printing technology, high funds for investment in machinery and financial constraints. An additional impulse will be provided by extensive service packages delivered to the printing house. Fast maintenance and production automation are also becoming very important. The combination of these elements will guarantee continuous operation and will be a response to various requirements and service needs of the printing house. Other factors are the growing demands of printing house customers and the increase in competition. Printing house customers expect faster order fulfillment, modern solutions and high-quality products. The PSS can help meet these requirements and improve the competitive position of the printing house. Additionally, it should be noted that printing houses face a low level of margins for their products with high costs of materials and devices. Currently, the printing sector relies on environmentally friendly machines and materials, innovative production methods that reduce the amount of waste is an additional factor in favor of the PSS. Thanks to the adoption of the PSS, it will be possible to develop more environmentally friendly solutions and reduce material consumption.

The adoption of the PSS is also evidenced by the fact that the manufacturer will be able to rent the same machine several times and benefit from it for longer. In addition, thanks to sharing, it will be possible to contact and cooperate with the client. He will be possible to monitor and analyse the operation of the machine. Thanks to this, the weakest elements

of the machine will be diagnosed, construction changes will be introduced and new generations of less emergency and more efficient machines will be developed.

All this will reduce the costs incurred by the manufacturer and the user of the machines.

RQ3. What are the main limitations of PSS design methods presented in the literature and by the practitioners? (Paper 2, 3)

The review of the PSS design and classification methods, which can be used in different industries, has brought interesting revelations. Sixty PSS design methods were identified.

There is no clear position in the literature as to the dissemination of the method or set of criteria for the PSS design. The analysis of the works included in the literature review did not reveal the methods and criteria widely accepted by business practitioners and scientists. Instead, there are common guidelines for applying a specific method in a particular industry. The literature also indicates the lack of work on a universally accepted method that could be universally applicable.

Their analysis, however, revealed weaknesses and limitations. Little precise description of subsequent stages of the design process may largely restrict their use in business practice. Available the PSS design methods can be used in enterprises of different sizes and in different industries, which shows their flexibility and versatility. Examples, in which the PSS methods are used in practice do not provide detailed analyses of the industry, neither do they inform precisely about customer needs.

In the method analysis, it can be seen that some features, steps and approaches are similar, without any noticeable advantage over the other. The analysed methods have specific features that distinguish them from each other. This includes emphasis on technical aspects, sustainable development, innovation and a business model.

A verbatim analysis of the methods shows that there are still very few articles on the details of using PSS design methods. Lack of detailed and precise information on effectively tested PSS and how they work. This creates uncertainty for manufacturing (and not only manufacturing) companies looking for the best approach to the PSS implementation.

The main conclusion was that the printing sector was not investigated in the context of the PSS and there is no use of the PSS in the printing sector.

RQ4. How to develop new PSS business models for printing industry? (Paper 4, 5)

When trying to answer this research question, an observation was made that when developing a PSS for the printing industry consideration must be given to the printing market, printing machine, printing process, needs of the printing house, and environmental requirements. Printing industry is one of the most dynamically developing sectors of the Polish economy. When designing a PSS, one needs to recognise market limitations and conditions which are often crucial for the performance of a printing house.

Machine manufacturers are large multinational corporations while the user market is filled mainly with micro and small enterprises and medium-sized and large operators make up its small fraction. Big employment in this industry does not translate into high labour productivity and generated added value. On the other hand, there are analyses of offerings of machine manufacturers addressed to printing houses.

An important element that should be taken into account are the already operating PSS solutions in similar industry sectors. In the analysed case, such a solution is the Xerox pay-per-copy model. It concerns photocopiers and office printing. In this model, Xerox provides the customer with a copier and they guarantee it full service (replacement of consumables, spare parts) and such Managed Print Services and Intelligent Workplace Services. Xerox also provides additional services including training and a range of solutions to help customers optimize their print infrastructure, document management and communications. The company constantly develops its model, implements innovations and creates services in response to customer needs. Xerox uses know-how in the field of technology and services in its solutions. The use in printing of such elements as the supply of printing materials (paints, varnishes, printing substrate, refining materials) or rental of printing machines in a subscription, we depend on the work units that the device can perform is a completely new solution. Another possibility is services related to know-how and optimization of the printing process. Therefore, it is important to analyze the solutions already available on the market.

A printing machine and features related with it constitute the main physical component in PSS design for the printing industry. It is a critical element of industrial equipment representing high value, complex in its structure, and technologically advanced. During continuous operation, the machine requires constant maintenance, replacement of spare parts and repair. Some components, such as bearings, aniloxies and UV units, wear out faster than the printing units. This entails more frequent replacement of components that wear out faster and shows a dissonance regarding the service life of individual components of the analysed devices. It is important that manufacturers use modularity in the design and construction of printing machines. This is related to the simplification of the structure, standardization of subassemblies, faster production and assembly, and reduction of its costs. This will allow for quick replacement of worn parts or systems, contribute to faster maintenance, repairs and even changeovers, which will increase the degree of its use. In addition, it will allow the use of new solutions in used machines and eliminate their obsolescence. Examples include printing and web guiding systems. Despite their long service life, they lose their features and may fail after a long period of use. It leads to imprecise prints or freezes the machine. The use of modern solutions in this case will make it possible to increase the reliability and quality of printing. Modularity will ensure the highest flexibility and the ability to quickly adapt to the changing expectations of the printing market. Additionally, it will facilitate transport and assembly or installation at the customer's site.

The machine is used in printing process which needs to be continuously analysed, controlled, and improved. In addition to services closely related with the machine,

examination of the printing process may provide a lot of answers to customer problems and needs which are transformed into services. To ensure an in-depth identification of customer needs and problems, one must be in touch with them. Apparently, questionnaire-based studies, workshops, and analysis of data from production are helpful in developing PSS solutions. One needs to bear in mind that service-related needs change depending on company's profits, product range, size, and employment.

Printing techniques also generate different harmful waste having adverse environmental effects. That should be seen in connection with technical capabilities of individual printing houses, their work organisation, the use of raw materials and materials, as well as the output. Waste and contamination reduction is one of the principal criterion considered in PSS design for the printing industry. It allows not only to significantly reduce costs of production but, above all, act rationally and reuse many of these materials.

RQ5. What benefits can PSS bring to machine manufacturers, customers in printing industry as well as the environment? (Paper 4, 5)

Benefits from a PSS are addressed to interested parties (a manufacturer of printing machines and a user - a printing house) and the natural environment. One of the principal benefits to a printing machine manufacturer is improved competitiveness and diversity. A manufacturer may offer to a printing house a printing machine, its functionality or effects of its operations. By using this business model, a manufacturer may attract new and retain the existing customers. It also means entering a new market: a market of second hand machines. Besides customers from the second hand market, a manufacturer attracts enterprises which for many reasons (price, human resources, lack of experience in the printing industry) were not able to purchase a printing machine. Other benefits include the collection and analysis of data on machine performance and printing process. This will enable a number of improvements to be made to the printing machine to improve its life cycle and generate new services in connection with the printing process. A longer useful life of the machine allows a manufacturer to reap profits for longer periods of time.

A customer, i.e., the printing house, receives a machine with a package of services tailored to it. By the same token, the manufacturer bears the obligation to maintain the machine and keep it in good shape. The printing house also receives assistance in the form of services connected with the use of the machine and its handling. In addition, throughout the whole period when the printing house uses the machine it may count on services that assist it in the printing process and monitor it, give access to specialist knowledge and know-how in the area of the printing business. As a result, the printing house can focus its efforts on its core business. Besides, it does not need to invest huge amounts of money in machine purchases. PSS-related fees are current expenses which are fully tax-deductible. The PSS developed for a printing house offers support to it and can lead to its further growth.

Principal environmental benefits include the expansion of a printing machine life cycle and reverse logistics of machines. Spare parts regeneration planned as part of machine repairs will reduce waste and the consumption of materials. Services and solutions

targeting the printing house will help in eradicating its problems and, subsequently, reduce the consumption of energy, water, and other utilities. The application of a PSS solution in the printing industry will also reduce the consumption of materials used in the production process and the recycling thereof.

The overall conclusion from conducted studies is that it is feasible to apply a PSS arrangement in the printing industry. Research studies have demonstrated that printing machine users are interested in the development and use of a PSS solution. The proposed solution was assessed using a financial model (formulas) that has not been used to analyse the possibilities of deployment of Product-Service Systems in printing industry. One needs to bear in mind that designing successful PSS systems for the printing industry needs taking a broader perspective on printing house operations, close cooperation with machine users, and in-depth analysis of the process, in which the system is used.

5.2 Contribution of the study

The analysis of case studies of printing houses confirmed that they often use only their own staff when developing innovations and solving problems related with them. However, quite often it may not be a satisfactory solution and some external support would be required. The review of literature has revealed that there are no PSS design methods that would target the printing industry, as well as no examples of such solutions exist.

This work expands the theory and knowledge on PSS development. The input of studies focuses on developing a new PSS business model for the printing industry. This publication discusses studies conducted in a printing enterprise in Poland.

The dissertation provides an in-depth insight into the printing market in Poland, user (printing house) needs and offerings of machine manufacturers. Workshops and case studies demonstrate the specificity and typical features of the printing industry. Studies that were carried out focused on the identification of services expected by machine users. That means that the developed PSS can be used as a template for manufacturers of printing machines which will be updated as the industry will evolve to fit newly emerging trends and meet new customer needs.

Another important contribution of the study consists in a novel and very practical approach to conducted studies. Studies and workshops carried out in a printing enterprise, questionnaires filled in by 80 printing houses, and consultations with experts fully reflect the everyday practices of the printing industry.

The developed PSS focuses on industrial printing machines which are critical capital goods for printing houses. Printing houses use them to fulfill orders for printing materials (including packaging, labels, newspapers) used in other sectors of the economy (including food, chemical, automotive, trade).

The elements that distinguish the developed PSS include a very wide range of services related to the machines and printing processes in which they are used. All services are sorted into packages and allow the printing house to choose the ones that are most suitable for them. A characteristic element is the specific time frame for the use of the printing machine and its comprehensive regeneration after this period. An important element is close cooperation and the flow of information between the producer and the user, i.e. the printing house.

In the developed PSS, it takes into account criteria that have a significant impact on the printing industry: process innovation, environmental protection, know-how, knowledge and experience, production efficiency and reliability. Process innovations focus on the implementation of a new or significantly improved method of printing production and management of printing processes. Environmental protection focuses on reducing the environmental impact of printing processes, material reuse, as well as waste segregation and management. Know-how, knowledge and experience means providing printers with practical information, resulting from experience and tests, of a classified, relevant and specific nature that will support various areas of the printing house's activities. Increasing production efficiency affects the production capacity and profitability of the printing house. Reliability focuses on the elimination of failure of printing machines, reduction of errors (including employee errors through training), elimination of emerging production problems and ensuring high-quality production. These criteria can help print shop managers adapt to changing market needs without having to invest heavily in the machines necessary for the operation of the printing house.

5.3 Future research topics

The future of printing is mainly related to printing labels and packaging (KPMG, Polish Brotherhood of Gutenberg Knights and Faculty of Journalism, Information and Bibliology, University of Warsaw, 2018). These activities will require specialized machines and service solutions to support printing houses. Solutions that may become popular will be print machine sharing, print machine pooling, payment for: hour of machine operation, printed running meter, printed square meter or for a printed product.

Interesting solutions that can be borrowed from the area of printing office may include: printing on demand, remote printing or mobile printing. Printing on demand can help protect the environment. However, due to the significant quantitative differences compared to traditional high-volume prints, it can be very costly. This solution can be perfect in an emergency. A given product is printed when the customer expects it. In addition, it is possible to print as many printed products as it is needed, which allows for savings related to their storage and warehousing. Thanks to this, it would be possible to print a label or packaging even in one copy. Remote printing or mobile printing will guarantee the freedom of order rotation regardless of where the printing machine and the client are located. Everything in the industrial printing would be possible by combining all the printing devices used. This guarantees flexibility and freedom of action. This may

turn out to be a very complicated solution, in which it is not the printing house, but the manufacturer of printing machines, that will play a key role.

Each of these solutions can lead to the elimination of traditional printing houses and the development of graphic studios that will check the graphics sent to print. In this situation, the role of the printing house will be taken over by machine manufacturers. The use of these solutions may lead to the creation of a global printing system, managed centrally by specific producers. The client sends the print element checked by his graphic designers, which is checked again by the graphic studio and sent to the appropriate machine. These solutions are relatively easy to adopt in digital printing, where there is the possibility of quick reprinting without having to cover the cost of preparation for printing. It will be slightly more difficult to apply this in offset and flexographic printing. They could be quickly and simply used in printing, non-refined printing products. In addition, each of these solutions can work in situations where low expenditure is needed.

However, the work at hand has got some limitations which open up possibilities for further studies. Printing machine life cycle and the needs of a printing house at each of its stages have not been investigated yet. The model will be substantiated with workshops and further questionnaire-based studies conducted amongst machine users. It will cover the complete life cycle of a printing machine what has not been studied so far.

The age of Industry 4.0 and digitisation of the economy have triggered the use of new technologies in many industries, including the printing industry. It creates new opportunities to generate value but also poses new challenges. Therefore, an analysis showing which of the digital technologies has got the greatest potential in PSS development for the printing industry would be a step in the right direction.

Studies have shown that printing houses have problems with waste management. The PSS developed for them takes account of these needs, however, further studies into the issue are necessary. Broadly understood recycling and reusing should be incorporated into these considerations. It is also recommended to focus future studies on the development of recycling and reusing indices for materials used for building printing machines and in printing processes. This would enable rational stocktaking of recovered materials before and after the implementation of a PSS. Since stress is put on environmental protection and because the printing industry uses many hazardous materials, these indices may become a priority and they may significantly improve environmental awareness in printing houses.

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Publication I

Lipiak, J., and Salwin, M.

The improvement of sustainability with reference to the printing industry – case study

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Advances in Manufacturing II, Volume 3 - Quality Engineering and Management, Lecture Notes in Mechanical Engineering
pp. 254-266, 2019

The Improvement of Sustainability with Reference to the Printing Industry – Case Study

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Abstract. The aim of the article is to present the manufacturing innovations as a tool supporting the implementation of the concept of sustainability. The improvement of sustainability will be monitored as the consumption of main media in the modern printing house. The impact for sustainability will be shown as a result of decrease media consumption. The innovations that are considered as one of the most significant subject matters with reference to sustainability have been widely discussed. The importance and the effectiveness of sustainability has been presented with the special attention paid to the social, economic and environment aspects. Furthermore, the significance and the efficiency of the innovative solutions aiming at the least possible impact on the environment has been identified. The theoretical part has been supplemented with the experience of the analyzed enterprise. On the basis of the analyses, it was demonstrated that the implemented manufacturing innovation (in terms of flexographic printing technology) contributed to the decrease of electricity consumption, production materials by 10–12% on a monthly basis and also to the increase of the employment by two employees. Innovations contribute to the decrease of inconvenience of production as far as the natural environment is concerned. Furthermore, the costs of production have been reduced and due to the increased employment, those have an impact on the social field of environment. Therefore, it can be stated that innovations can be considered as an indicator of efficient implementation of the sustainability with reference to eco-innovations in Poland.

Keywords: Innovations · Sustainability · Production improvement · Organization effectiveness · Printing industry

1 Introduction

Continuous climate changes, the increase of the temperature, the lowering ground water level, food and energy supplies that are progressively depleted are considered as ones of the most significant problems of the modern world. The environment in which humans live have been a subject matter of many researchers over several years, including environmentalists, natural science researchers, philosophers and finally, philosophy researchers. A quick advancement of science as well as a technical progress

A. Hamrol et al. (Eds.): *Advances in Manufacturing II* - Volume 3, LNME, pp. 254–266, 2019.
https://doi.org/10.1007/978-3-030-17269-5_19

contributed to a considerable deterioration of the natural environment what consequently threatens the life of humans, plants as well as animals. Concerning health care and environmental protection, as well as due to own international obligations, governments of numerous countries deal with environmental policy basing on the rules provided by sustainability. Sustainability is documented by both integration and cohesion of social, economic and ecological aspects in the country development process. Therefore, it can be stated that sustainability is one of the strategic area of economic activity as far as government administration is concerned.

Sustainability is characterized by the implementation of innovative solutions that allow to achieve a better quality and standards of living of a large number of people living all over the world, taking advantage of resources necessary for the production process in an efficient way. An enterprise, by providing novel solutions for sustainability should take a responsible implementation of its strategy in each area of activity into consideration as well as cover the entire activities chain up to the final product, its usage and last but not least, waste management.

Innovations can be considered as a determinant of the effectiveness as far as implementation of sustainability is concerned, not only on the macro-economic level – across the entire economy but primarily, on the micro-economic level – across one enterprise. The analyses provided in the following article are based on the innovation in terms of letterpress printing, implemented in the discussed company. The results of the research relate to the consequences of the indicated innovation in terms of enterprise functioning, with reference to the assumptions of sustainability concept.

The main aim of the present article is to discuss the good practices strictly connected with improvement of sustainability, basing on the example of the printing company.

The impact for sustainability will be shown as a result of decrease media consumption. The innovations that are considered as one of the most significant subject matters with reference to sustainability have been widely discussed.

The subject of the research is a printing company located in Masovian Voivodship, which produce labels and packaging.

2 Innovations as an Implication of Sustainability

2.1 The Notion and the Scope of Innovation

The concept of innovation was introduced by Schumpeter [1] and can be understood as launching either a novel product consumers are not familiar with yet, a novel production method, which was not tested before in any industry, a novel market, in which a certain industry of a certain country was not active before, regardless the previous existence or non-existence of that market. Furthermore, it can be defined as achieving a novel source of materials, regardless of the fact that it was already existing or it had to be created and last but not least, as implementing a novel organization of a certain industry [2–5].

It should be mentioned that innovations are observed to contribute to the technical development [6]. Innovations should be understood as a wide spectrum of all scientific,

technological, organizational, financial and commercial activities that actually lead or aim at leading to the implementation [7–11].

The main purposes of innovation implementation include improving the quality of products and services and retaining or enhancing one's market position. Another significant factor is the need of customer as well as lowering costs [12].

The significant obstacles for entrepreneurs, as far as innovation implementation is concerned, include costs, difficulties in terms of funding and last but not least, bureaucracy.

There is a wide range of potential effects of innovation implementation. Nevertheless, the following benefits are mostly observed: increase of the functionalities, increase of the utility of products and services, modernization of obsolete systems, technology improvement, enhancement of human communication, optimization of working time and last but not least, environmental protection. It can be concluded that those effects correspond with the objectives of sustainability and therefore, a relation between innovations and this approach can be observed. The concept of sustainability is described in the following sub-chapter.

2.2 The Concept of Sustainability

For the first time, the notion of sustainability was formulated and adapted during the UN Conference on Environment and Development (UNCED) organized by the United Nations in 1992.

Sustainability is a socio-economic development in which a process of integration of political, economic and social actions can be observed while maintaining environmental balance and the stability of basic natural processes in order to guarantee the possibility of satisfying the needs of particular societies or citizens of current and further generations [6, 13–20]. Meeting the sustainability challenges is possible due to the integration of environment, economic and social policy. It requires treating natural resources as limited economic resources as well as using natural capital in a way which allows for marinating the functions of ecosystems in long-term perspective. Sustainability should be connected with both formulation and implementation of the strategy which concerns providing novel work places and economic development, supporting and conducting a business by appropriate subjects [21, 22].

Nevertheless, it should be mentioned that the progress in the areas such as air and water pollutions was observed. However, the impact on the environment is still unsustainable. Therefore, looking for additional factors of sustainability is necessary. Innovations may be considered as one of them. This concept is described in the following sub-chapter.

2.3 Innovation as a Determinant of Sustainability

Any innovation is connected with sustainability, especially innovations regarding the changes in terms of the way of organization and management of the enterprise of the economy of a country, technological innovations and last but not least, ecological innovations. The companies that decrease the usage of resources and components in its

operations are perceived as "environmental-friendly" what consequently enables them to achieve additional incomes and to lead novel projects [23].

Innovative solutions are sometimes observed as serious threats for the environment due to the fact most of the problems regarding environment protection are difficult to be solved without implementing any innovation. The undertaken actions of an innovative character are considered as novel development opportunities and contribute to a considerable growth of attractiveness and market competitiveness [23].

It can be concluded that innovations and sustainability are connected with the cause-and-effect relationship. The wider analysis of this phenomenon is discussed in the research part.

3 Methodology of the Study-Case

3.1 Characteristics of the Analyzed Company

The analyzed company is a printing house with a long tradition, specialized in labels and laminate production. It is specialized in the production of labels and laminate. It is possible due to possessing a professional graphic studio, modern machinery, creative team and own digital production preparation. Thanks to it, the organization is able to face numerous tasks, starting from a graphic project, through printing, finishing and finally, delivering a finished product to the customer. Over a number of years, the mentioned company have been enjoying the confidence of numerous customers presenting the meat industry, food industry, pharmaceutical industry, cosmetics industry and last but not least, the chemical industry.

Among numerous types of labels produced by the described company, five of the main product-types can be listed:

- Self-adhesive labels,
- Heat shrinkable labels,
- Tea tags,
- OPP films,
- Laminates.

Basing on the observations of the pro-environmental tendencies of development and functioning of modern world economy, the company is aiming at being of top of such trends and take in into consideration while developing.

The assumptions of sustainability can be widely observed within the actions undertaken by the described organization. One of the areas which has an impact on adjusting to this phenomenon include technological innovations. It's assumed that all technological innovations taken over the years have the positive impact on the sustainability aspects as lower media consumption, and it will be commissioned in this article.

3.2 Innovation in Terms of Letterpress Printing Technology

The ability to adapt oneself to the quickly changing situation on the market, searching for novel outlets and novel customers, the development of printing techniques and technologies as well as using novel media, especially the Internet are observed to be the major factors of a proper development of a printing enterprise [12, 24–26].

The innovation was implemented in terms of letterpress printing technology, which is one of the basic graphic techniques (besides offset and intaglio), in which the print is made by the rebound of the ink placed on the protuberant parts of the printing form. It is the oldest graphic technique.

Currently, as far as the letterpress printing technology is concerned, the industry widely uses flexography and especially for special usage, typography. The flexographic units are also used for varnishing. Typography used to be a widely used printing technique before dissemination of exposure devices which enables to use the offset print in an easy way. It enhances the quality of prints and it is otherwise more economic.

The innovation is strictly connected with the technique of flexographic printing, used in the production of flexible packaging and labels on the non-absorbing surface (ABL and PBL barrier laminates). It allows to achieve the effects of overprint with relief through local application of a considerably thicker varnish layer what was previously used only in the technique of screen print. The described company owns a patent of letterpress printing no. 332/2016/PAT title: The way of creating flexographic prints.

One of the elements of the solution is to increase the capacity of the anilox which is a raster roller, one of the main elements of a printing press. Therefore, the quality of a raster roller has an enormous impact on the quality of print. The capacity of anilox is adjusted to the amount of ink that has to be placed on the material. Depending on the working ruling, the anilox ruling has to be adjusted.

The comparison of the transferring the varnish between a traditional printing plate and using the method implemented by the described company is presented in the (Fig. 1).

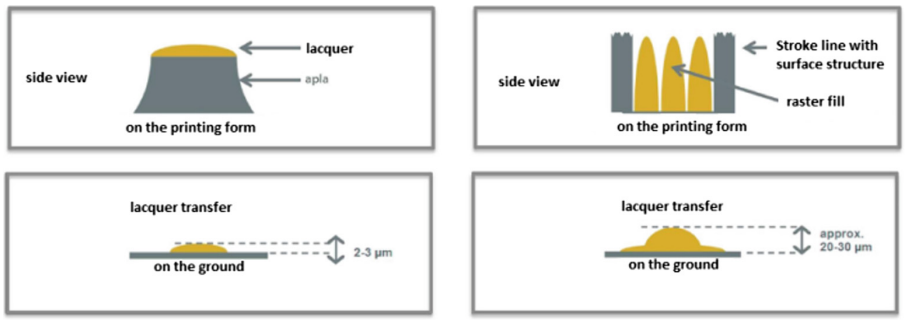

Fig. 1. The comparison of the type of printing plate and the letterpress printing technology.

Using this innovation enables to replace the screen printing varnishing unit with a properly modified varnishing unit in a flexographic technique. It eliminates the necessity of using screen printing varnishing and allows to print using low-migration inks and varnishes adapted to the current legal requirements of the food industry. The print of a considerable thickness is created in accordance to the description of the innovation allows to make the packaging with an increased value in use for recipients (producers) and customers. It is possible to make a printed inscription with a palpable thickness.

4 Results and Discussion

This chapter provides an analysis of the impact of the described innovation of the functioning of the analysed enterprise.

4.1 Analysis of the Impact of Innovation on the Functioning of the Enterprise with Reference to Sustainability

The concept of sustainability puts an emphasis on three areas, including economic, social and environmental areas. In order to consider all aspects of sustainability, the analysis connected with the impact of the described innovation on the functioning of the described organization, the following variables were selected: electricity consumption, consumption of film, consumption of paper, consumption of UV inks, consumption of UV varnish, photo polymers forms and employment. The data from the period before innovation implementation are compared to those after its implementation. The analyzed period of time amounts to 20 months (10 months before implementation of innovation and 10 months after it) – March 2016 – October 2017. The innovation was implemented at the beginning of January 2017.

The total electricity consumption in the period of time from March to December 2016 amounted to 898970 kWh. The average monthly consumption amounted to 89897 kWh. The comparison of electricity consumption before and after innovation implementation on a monthly basis is shown in the (Fig. 2).

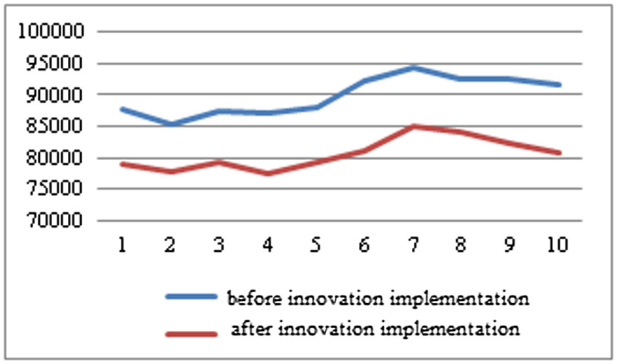

Fig. 2. The comparison of electricity consumption [kWh].

During the analyzed period of time the electricity consumption was observed to decrease by 10.31%. The average monthly electricity consumption decreased from 89897 kWh to 80625 kWh. Furthermore, the median before innovation implementation amounted to 89897 kWh, and after its implementation – 80062 kWh (Table 1).

Table 1. Comparison of electricity consumption [kWh].

Specification	Before	After
Mean	89897	80625,02342
Standard error	972,4770689	806,589151
Median	89897	80062,71769
Standard deviation	3075,24251	2550,658853
Scope	8989,7	7344,5849
Minimum	85402,15	77608,0801
Maximum	94391,85	84952,665

The total usage of film and paper from March to December 2016 amounted to 2923653 m^2. The average consumption of film and paper amounted to 2923650 m^2. The comparison of the consumption of film and paper before and after innovation implementation on a monthly basis is presented in the (Fig. 3).

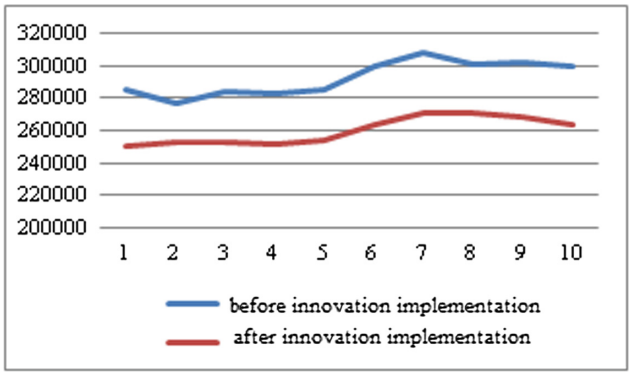

Fig. 3. Comparison of the consumption of film and paper [m^2].

During the analyzed period of time the decrease of consumption of film and paper by 9,81% can be observed. The average monthly usage of film and paper decreased from 292365 m^2 to 259868 m^2. What is more, before the implementation of innovation the median amounted to 292365 m^2, and after it - 258706,4794 m^2 (Table 2).

Table 2. Comparison of electricity consumption [kWh].

Specification	Before	After
Mean	292365	259868,0455
Standard error	3339,167	2667,051033
Median	292365	258706,4794
Standard deviation	10559,37	8433,9559
Scope	30405,96	20167,3377
Minimum	277162	250591,8888
Maximum	307568	270759,2265

The total consumption of UV inks from March to December 2016 amounted to 6050 kg. The average monthly consumption of UV paints amounted to 605 kg. The comparison of the consumption of UV inks before and after innovation implementation on the monthly basis is depicted in the (Fig. 4).

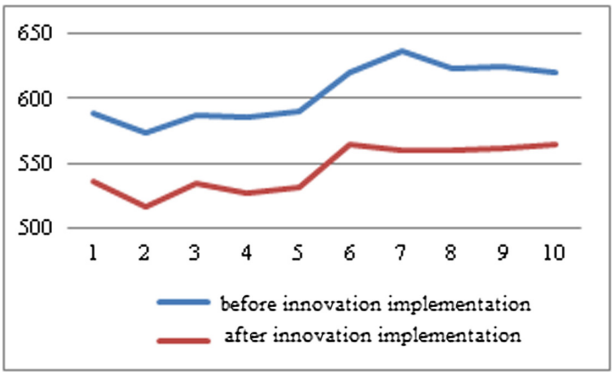

Fig. 4. The comparison of UV inks consumption [kg].

During the analyzed period of time the consumption of UV inks decreased by 11,12%. The average monthly consumption of UV inks decreased from 605 kg to 545,64 kg. Moreover, the median before implementation of the innovation amounted to 605 kg, whereas after it - 548,16 kg (Table 3).

Table 3. Comparison of electricity consumption [kWh].

Specification	Before	After
Mean	605	545,6447
Standard error	6,909842819	5,818755
Median	605	548,1603
Standard deviation	21,85084158	18,40052
Scope	62,92	48,6783
Minimum	573,54	516,186
Maximum	636,46	564,8643

The total consumption of UV varnish during the period of time from March to December 2016 amounted to 6100 kg. The average monthly consumption of UV varnish amounted to 611 kg. The comparison of the consumption of UV varnish before and after implementation of innovation on the monthly basis is shown in the (Fig. 5).

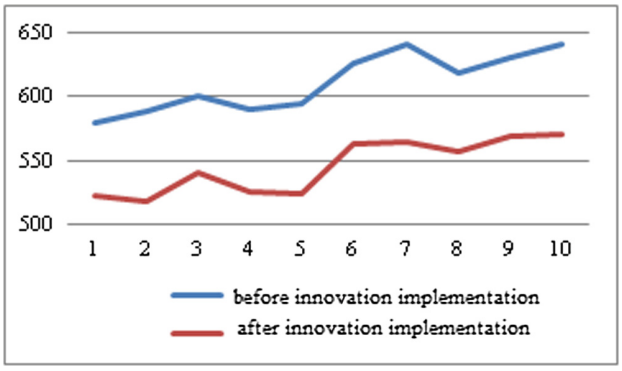

Fig. 5. Comparison of UV varnish consumption [kg].

During the analyzed period of time, the consumption of UV varnish decreased by 10.80%. The average monthly consumption of the UV varnish decreased from 611,28 kg to 545,27 kg. Furthermore, before implementation of innovation the median amounted to 610 kg, whereas after it decreased to 549 kg (Table 4).

Table 4. Comparison of the UV varnish consumption [kg].

Specification	Before	After
Mean	611,281	545,27168
Standard error	7,298760389	6,815435655
Median	610	549
Standard deviation	23,08070693	21,55229991
Scope	62,22	52,033
Minimum	579,5	518,012
Maximum	641,72	570,045

The total consumption of photo polymers form from March to December 2016 amounted to 1051,2 m^2. The average consumption of photo polymers form amounted to 105,32 m^2. The comparison of the consumption of photo polymers before and after the implementation of innovation during a month is shown in the (Fig. 6).

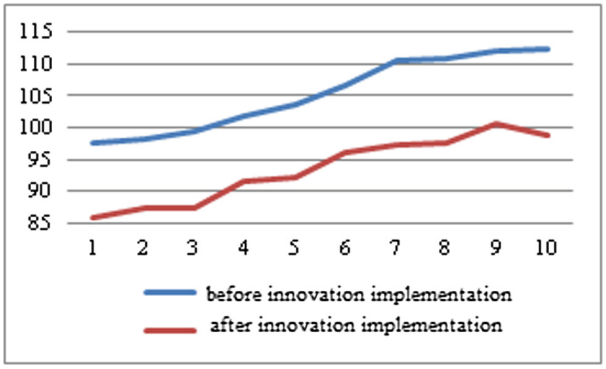

Fig. 6. The comparison of the consumption of photo polymers forms [m^2].

During the analyzed period of time the consumption of the photo polymers forms decreased by 11,20%. The average monthly consumption of them decreased from 105,32 m^2 to 93,52 m^2. What is more, the median before innovation implementation amounted to 105,15 m^2, whereas after its implementation it amounted to 94,12 m^2 (Table 5).

Table 5. Comparison of the consumption of photo polymers forms [m^2].

Specification	Before	After
Mean	105,32071	93,52492
Standard error	1,869116161	1,684471
Median	105,15255	94,11968
Standard deviation	5,91066428	5,326764
Scope	14,714	14,72451
Minimum	97,743	86,01384
Maximum	112,457	100,7384

The final analyzed element is employment which during the period of time from March to December 2016 amounted to 48 people. After the implementation of innovation, the company had to employ 2 more people. The decrease of electricity and production materials contributed to generating the savings. Consequently, the volume of production increased in order to satisfy the growing needs of recipients and that required the increase of the number of employed people.

Taking the effects of the discussed innovation implemented in the company into consideration, the decrease of consumption of both resources and energy contributed to generating savings (economic dimension), as well as the decrease of the negative impact on the environment (environmental dimension). Additionally, the increase of the employment has an impact on the social sphere of the enterprise surrounding, for example by decreasing the unemployment (Table 6).

Table 6. Effects of innovation implementation.

Specification	Effect
Electricity	−10,31%
Film and paper	−11,12%
UV inks	−9,81%
UV varnish	−10,80
Photo polymers forms	−11,20
Employment	4,17%

On the basis of the conducted analyses it can be stated that innovations can be considered as a catalysator for the sustainability from a micro-economic point of view. What is more, due to undertaking such actions by entrepreneurs, those can have a positive impact on wider implementation of sustainability of overall economy.

Furthermore, it can be stated that the sustainability with reference to the printing industry can be enhanced by the following aspects:

- sustainable forest management and the management of paper,
- effective management of materials and recycling,
- processes optimization,
- sustainable management of a company.

The described company is observed to introduce waste management in as sustainable way, minimize the amounts of pollutions emitted into the air and constantly monitor the used machinery and equipment in order to avoid the possibility of indicating the emergency occurrence reg. environment. What is more, the presented company used the materials and technologies which are examined in terms of safety for both people and environment. It is also constantly enhancing the technological processes in order to minimize the impact on the environment.

5 Conclusions

The assumption of technological innovation implementation with reference to sustainability is decreasing the negative impact on the natural environment. It is connected with almost each area of activity of modern enterprises as well as other market participants. In a sense, innovations are directed into the sustainability. They are beneficial for producer, consumers as well as other market participants.

Therefore, innovations can be considered as a solution to the modern global challenges due to the fact that the problems in terms of sustainability implementation occur, and in the longer term, it can cause permanent negative changes of widely understood environment.

Innovations can contribute the standard of living of current and future generations. Therefore, it can be stated that innovations constitute a tool, a catalysator used for sustainability.

The policy regarding environmental protection allows to avoid the problems connected with it. In a long term, sustainability gives a chance for the survival of civilization.

To conclude, it can be stated that the policy and good practices of the analyzed company are observed to improve sustainability.

This research was conducted only in one printing industry, therefore conclusions and findings from this study-case are not common for every printing industry. So the impact on the sustainability can be only set as a goal in narrow field. However in mentioned printing company, all implemented technological developments had significant impact – measured as consumption of media – on the sustainability. Further research with extended area of printing industries and impact on sustainability measured as a consumption of media will be needed.

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Publication II

Lipiak, J., and Salwin, M.

Improvement of the Warehouse Functionin: A Study Based on an Enterprise in the Printing Industry

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Advanced Manufacturing Processes II. InterPartner-2020, Lecture Notes in Mechanical Engineering
pp. 61-71, 2021

Improvement of the Warehouse Functioning: A Study Based on an Enterprise in the Printing Industry

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Abstract. A warehouse is a component of a logistical system. It appears as a link in both the supply chain and supply network. Goods are temporarily stored in a warehouse and then directed to other links. As far as a warehouse is concerned, the flows of goods are considered as the objects of both delivery and reception; those may be concentrated or separated. The roles of a warehouse have an impact on its organization of work, used technology as well as location. The article aims to present a method of improving the functioning of a warehouse concerning a chosen enterprise in the printing sector. A variety of recurring errors was found in the functioning of the warehouse of the analyzed enterprise. Those were disrupting the enterprise's activity (mostly in terms of logistics). The irregularities were connected with the structure of the information system as well as with the organization of work. The method of improvement of the warehousing process used by the chosen enterprise was presented. The changes in terms of the information system were observed to have a positive impact on solving the problems reported by the employees.

Keywords: Printing Industry · Warehouse · Logistical System

1 Introduction

Warehouse management is an important part of the whole logistics of companies. It covers operational activities in storage, internal and external transport, production and distribution. Year after year, companies develop more and more efficiently and therefore very good management of warehouse logistics can open their doors to new markets and new customers [1–3].

Warehouse management is constantly looking for innovative solutions that will generate added value for the customer with their functionality. The implementation of such solutions is the way to the company's success and, at the same time, allows them to be competitive in a difficult national and international market. Modern companies in the field of warehouse management use integrated IT systems. Their use eliminates unnecessary manipulation activities, affects the speed of information transfer between the company's departments, and thus contributes to the acceleration of the processes of receiving, storing, issuing, and documenting all activities. However, despite the use of

V. Tonkonogyi et al. (Eds.): InterPartner 2020, LNME, pp. 61–71, 2021.
https://doi.org/10.1007/978-3-030-68014-5_7

the latest technologies and qualified staff, it is not always possible to avoid problems in this area [4, 5].

Warehouse management combines various aspects of business management and transport. This expertise includes a thorough knowledge of the necessary processes, their technical and operational feasibility, and successful implementation into an overall functioning system. Due to the different requirements of the customer's order placement, production requirements, attractiveness, and size of products and many other factors, there are no universal and generally applicable rules to achieve this [3, 6, 7].

Warehouse management aspects are often a problem for companies. These problems are often a factor in generating financial losses. Companies need efficient warehouses regardless of what they produce. Mainly it depends on the nature of production, which type of warehouse is the best solution for the organization. For ensuring smooth production, the materials and raw used materials should be collected in sufficient quantity in a place from where they can be quickly delivered to the production line. This applies to every production process. Finished products coming off the production line must be stored on the factory premises until the appropriate quantity is sent to the recipients. The warehouse is, therefore the factory's gateway to and from the factory [8–10].

A characteristic industry that uses storage systems is printing. Printing houses need well-functioning warehouse management due to a number of materials (paints, inks, substrates, adhesives, varnishes) and tools used in production (printing rollers, dies, blanking dies), as well as the specificity of finished products (packaging, labels, book, newspapers). Efficient warehouse management is a way to organize the processes taking place inside the printing house, regain space for storing tool materials and finished products, and thus reduce operating costs [11, 12].

In the paper, we focused on the analysis of the functioning of the warehouse in a company from the printing industry. The conducted consultations with the management of the company and the employees of the warehouse allowed determining the emerging problems and their elimination, before which we managed to improve the functioning of the warehouse.

2 Literature Review

A warehouse is defined as a functional-organizational entity intended to the storage of tangible goods (stocks) in a distinguished, according to the established technology, area of a storage construction, equipped with proper technical measures, managed and serviced by the team of people [13–15]. It is a part of a logistic system, and it constitutes a junction in which the goods are temporarily stored and then directed to other phases of the process. The streams of goods occurring in a warehouse may be of both a delivery and a reception nature; those may either concentrate or separate. The functions performed by a warehouse are determined by factors such as work organization, location, and technology [5, 6, 16].

The functions performed by a warehouse in a logistic system are as follows [3, 4, 8]:

- coordination of the size of supply and demand caused by their fluctuations,
- support of the marketing processes through creating sets or gathering stocks necessary for launching a promotional campaign,
- reduction of the costs of transport, possible due to the decrease in the frequency of deliveries with a simultaneous increase of their size,
- support of the production processes that provide a continuous supply of the production in the necessary resources and packages on the one hand and a current reception of the finished product on the other hand.

Warehousing is a set of activities connected with reception, storage, stockpiling, completing, movement, maintenance, registration, controlling, and launching tangible goods – stocks on a temporary basis [13, 14]. Warehouses in the producing enterprises can be divided according to the criterion such as purpose, the character of the stored goods, storing conditions as well as technical-organizational solutions [1, 17]. Depending on the relative positions of zones, there are three crucial technological systems of warehouses [3, 4, 8]:

- through the warehouse (input and output zones are located at the opposite sides of the storage area),
- angled warehouse (input and output zones are located at the neighboring walls of the storage area),
- sack warehouse (input and output zones are located at the same wall of the storage area).

As far as the warehousing process in a service providing enterprise is concerned, both a character of piece loading units and a possibility of accumulation on stacks have an impact on a method of storing [13, 14]. Considering a physical form and a peculiar technological similarity, the following types of load units can be distinguished [3, 4, 8, 18]:

- micro-units (non-palletized – based on the logistics containers and packages),
- palletized units (formed on flat, bar, box or special pallets),
- package units (made from goods which length is considerably longer than other measurements and amounts to more than 1.2 m),
- container units (used in transport).

Currently, pallet cargo units are widely used in transport and warehousing. Among the cargo units, one can distinguish homogenous units which load includes only one part of one assortment position and heterogeneous units, which are made of at least two parts or two assortment positions [17, 19, 20].

A warehouse process is a set of operational actions connected with reception, storage, completion, and launching of tangible goods in properly adapted places while complying with the determined organizational and technological conditions. A warehouse process consists of material and information flows [17, 19]. According to the definition presented above, a warehouse process is divided into four basic phases: receiving, storing, completing (completion), and finally, launching. Reception of goods

from the supplier relates to the acknowledgement of receipt and giving the recipient (a warehouse) the responsibility for goods.

The essential operations implemented during the reception of goods, as far as a warehouse of a service enterprise is concerned, include as follows [3, 4, 8]:

- unloading, using the owned measures of internal transport and handling devices,
- sorting through dividing the goods into groups according to determining similarities,
- identification connected with the identification measures or the unequivocal identification of goods,
- qualitative and quantitative inspection,
- preparation of goods for storage which can be based on a development of load units or decreasing their height, transshipping to containers, proper provision of signs etc.,
- submission of the delivery to the storage area if the goods are transported by the employees completing the reception.

The next stage consists of storage, meaning a set of actions connected with both arrangement and placement of stock either on the surface or within the forming space of a warehouse (e.g., in the storage equipment) in an organized way, under the characteristics of stock as well as the existing conditions. Storage of goods is the most basic function of a warehouse connected with temporary warehousing [1, 17, 19].

Among the basic operations implemented during the storage of goods one may distinguish (in terms of the examined warehouse): receipt of goods from the receipt zone if the goods are not delivered to the storage area by the employees responsible for reception, an arrangement of goods in the storage area, storage of goods by maintaining required conditions, periodical inspection and finally, submission of goods to the completion zone.

Completing is defined as an operation that takes place in the warehouse process, which consists of a collection of stocks from the equipment used for storage or from stacks to complete the order of stocks in accordance with the assortment and quantity specifications for a particular recipient. Completing may take place inside or outside the warehousing place [17, 20, 21].

The basic operations executed in terms of the completion phase include as follows [3, 4, 8]:

- proper preparation of load units for the needs of completion,
- completion of orders implemented in the completion zone under the order,
- quantity inspection which confirms the completeness of the created load unit and the compliance with the order concerning both assortment and quantity,
- packaging and forming of transport units to protect the goods against damage.

Redemption of goods is understood as physical actions connected with the delivery of goods from a warehouse for the determined recipient, including confirmation of handover. The crucial operations executed during the redemption of goods in an enterprise of a service sector include [9]:

- packaging of goods in parcels and courier shipment to a proper recipient,
- control of redemption concerning checking the conformity of prepared goods with delivery documentation; control of completeness of prepared transport units and compliance of the way of forming and marking them with the requirements of the recipient.

Particular phases of warehousing, as well as the entire subsystem of a warehouse occurring in a holistic approach in a logistics system of an enterprise, are complicated. Those include numerous elements that are capable of causing mistakes, disrupting the activities, or completely disorganizing and, consequently, paralyzing the functioning of the organization [22, 23]. One of those factors is the human factor, meaning employees. The mistakes occurring during warehousing caused by the human factor include as follows [3, 24]:

- improper marking of goods and storing them in an inappropriate place,
- lack of respect to the determined procedures (procedural violations may also result from unconsciousness),
- defective communication of a warehouse with different departments or sections of an enterprise,
- incorrect set up of the information system,
- incorrectly filled documents or lack of them,
- irregularities during an inventorying,
- supplying an incorrect amount of goods from a warehouse,
- wrong address of shipment of goods from a warehouse,
- improper organization of work of a warehouse,
- insufficient training of workers,
- lack of procedures for emergencies,
- varying amounts of goods in terms of documentation and physical quantities,
- shelves not being adjusted to the gathered goods.

The future of warehousing is primarily related to data analysis, digitalization, and automation of storage systems towards intelligent solutions. A well-functioning warehouse system reduces costs and improves operational efficiency and the overall level of services provided by the company. Reducing warehousing costs is a major priority for many companies to enhance economic efficiency. Implementation of modern warehouse solutions is a high cost but also involves subsequent operating costs. For this reason, some companies are still using a conventional warehouse system to improve and modernize it with human resources [10, 24–26].

The implementation and service costs mentioned above may lead to interest in PSS-based solutions [27, 28]. Innovative warehouse solutions for PSS will eliminate the problem of investment and the lack of warehouses in printing houses. They will provide printing houses with individual solutions, necessary services, replacement and regeneration of worn components, flexibility and efficiency of the warehouse system in

terms of adjusting product changes. In addition, they will help to eliminate and solve a number of problems related to storage. PSS can reduce storage costs and improve economic efficiency, which is currently one of the priorities of many printing houses as well as companies from other industries [25, 29, 30].

3 Research Methodology

3.1 Research Aim and Methodology

The article aims to present a method of improving the functioning of the warehouse concerning a selected company from the printing industry. A case study method was used - a company from the printing industry. The research was conducted in the period from August 2019 to October 2019.

In the paper we formulated the following research questions:

- What mistakes made by employees adversely affect warehouse processes and have a significant impact on the functioning of the entire company?
- What methods can be used to improve the functioning of the warehouse in a printing company?

The research methodology used in this article included the following steps:

1. Identification of the causes of the problem – personal observations of the management of the department and the company to collect information about the warehouse process and problems occurring in the process.
2. In-depth interviews with employees - an expert questionnaire method was chosen to conduct the research. This method makes it possible to collect data to reveal the actual situation that takes place in the storage process and warehouse of the printing company.
3. Analysis of solutions – the brainstorming method was chosen, in which all employees of the storage department and the management of the company participated. At this stage, solutions for warehouse improvement were sought and analyzed.
4. Choice of the solution – based on the brainstorming, the head of the department in consultation with the president, which decides on the best solution.
5. Implementation and verification - the last stage includes the implementation of the best solution and assessment of the effectiveness of the project.

3.2 Research Problem

A printing company's warehouse was analyzed. The warehouse is used to store semi-finished products that are used in production and finished products that go to it from the production department. Concerning the warehouse of a selected company from the printing industry, the authors of this article have observed errors made by employees, which cause damage to the warehouse processes, having a significant impact on the functioning of the entire company.

The observations, interviews conducted with the employees, and the research using an expert questionnaire allowed determining the central irregularities in the functioning of the warehouse in the investigated printing company. These include:

- IT system structure – during the reception of e.g., ten pallets of one assortment with one batch of product, the system in possession required a 10-fold introduction of a batch of product, due to the lack of possibility to receive the whole delivered batch at the same time,
- recommendations for the return of the goods during the collection of the delivery were generated automatically, the system allocated the place where the goods were placed according to the shelves until they were finished, which resulted in placing the pallet with the goods on the upper level, even though the shelves standing next to it had free space on the lower levels,
- individual insertion of the placement space in the scanner for each finished pallet,
- one assortment in many places far away from each other.

For the above reasons, the changes were implemented what resulted in the improvement of warehousing processes.

4 Results

For solving the problems presented earlier, it was proposed to implement several improvements to the warehouse system in the analyzed company.

The employee, while receiving the determined amount of one assortment with one batch, does not have to enter each palette separately. The way of generating the placing location was also changed. The receiving employee, using a system, can choose a shelf in which a certain delivery should be placed. It requires choosing the number of a shelf. The system automatically finds empty locations and provides indications regarding placing a particular delivery. The ABC rotation scheme on shelves was created to generate locations for placing certain assortments, including their percentage in an overall sale. It was assumed that A products include those articles which constitute 60% of overall sold goods, B products – up to 30%, and C products are slow-moving items with only 10% of the overall sale. The ABC rotation scheme includes placing the items from A group in the lowest location, nearest to the release line, B group in the middle locations on the shelves, and the items from the C group are placed in the furthest locations on the shelves.

The completing employee can enter the location place only once for each sale order, without having to do it for each palette separately. What is more, a request for generating sustainable places in a warehouse was reported to arrange the goods there properly. However, after introducing the changes, each item is assigned a permanent place in the location (locations of cardboard/ piece collections). This solution contributed to the fact that the items of one type are located next to each other, instead of being placed all over the warehouse. The sustainable places can be modified using a computer, which can be done only by the store manager. The IT department improved also printing of pallet labels - after the implementation of the improvement concept

those are printed after the completion of the entire order, instead of being printed after the completion of one palette as it took place before.

It should be underlined that due to the implementation of a variety of changes in the warehouse of the described enterprise, the quality of provided services has improved. What is more, it has had a positive impact on the quality of working conditions. In Fig. 1, the average unloading time, the average systemic application time, as well as the average time of placing the delivery into shelves, are presented. Implementation of the systemic changes contributed to the decrease of those times, as far as each of those processes is concerned. Those changes are presented for one delivery. However, by multiplying them by the number of monthly or yearly deliveries, a considerable difference can be observed – the saved time is even larger (Fig. 1).

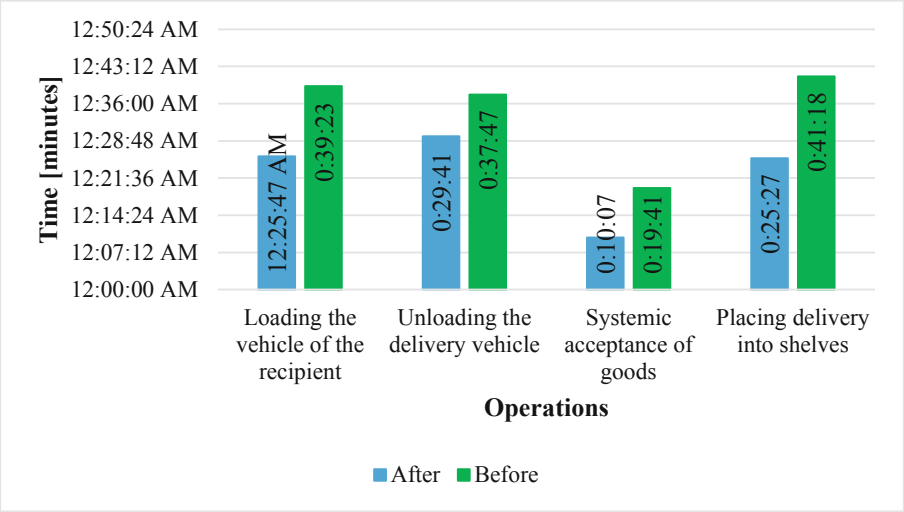

Fig. 1. Results of the changes in terms of the functioning of a warehouse – time of handling activities.

Due to the changes in terms of the informatics system, the problems reported by the employees were solved. As far as printed documents are concerned, those contain a place for barcodes regarding the numbers of orders. What is more, the possibility of printing the sales orders according to the direction of deliveries was introduced. The printed sale orders also include the information about the number of mixed and completed palettes.

5 Conclusions

Among the fundamental tasks performed by a warehouse, one may include the storage of goods and handling activities. Storage of items takes place whenever the item stays unmoved. Above all, it is connected with its storage in determining conditions of

storing, such as moisture, temperature, air quality, or protection against theft. As far as handling activities are concerned, those always take place during the receipt of goods as well as releasing goods. Those also include any movements inside a warehouse and, finally, the activities causing the change of the character of the load. The efficient management of the entire warehouse process is a major challenge for a large group of companies.

In the paper, a five-stage process of improving the functioning of the warehouse in a printing company was conducted. The process was based on observations, questionnaire research, and consultation with employees. The research revealed, first of all, problems with the proper placement of goods in the warehouse. The solutions to the problems were generated based on the brainstorming process, which involved the employees of the warehouse department and the management board of the company. The introduced changes contributed to improving warehouse processes. The analysis carried out underlines the importance of effective warehouse management. Thanks to this, the quality and effectiveness of services have improved.

The approach proposed in the paper is addressed to micro, small and medium-sized enterprises. This is since companies of this size have mostly small warehouses in which the presented solutions bring significant organizational and economic effects. Additionally, they have a small base of suppliers and customers, and in the storage department, where only a few employees work, is not their main source of income. It should be remembered that in this size of enterprises, there is a great potential to implement modern warehouse solutions. However, their implementation may prove unattractive due to limited financial resources. With this in mind, an appropriate warehouse organization based on well-known solutions is very attractive for companies of this size.

The paper was created in close cooperation with the printing company and represents an added value for the analyzed company. The conducted research has shown that effective improvement of the warehouse operation depends on a number of factors. The main emphasis was placed on the cooperation of the department's employees with the company's top management in order to find optimal solutions. An important element in improving the functioning of the warehouse for the described company was also to make the employees aware of the importance of generating unnecessary costs for the company, and thus for themselves. What is more, the emphasis was also placed on implementing the basis for changing the organizational culture of the workplace. The employees understood that the newly created order should be maintained, and attention should be paid to taking care of tools that are necessary for everyday work. It should be emphasized that significant success is connected not only with the involvement of the whole team in the search for further problems to be solved but also with their joint elimination. Therefore, the team identifies itself even more with the organization, having the feeling that all the changes are also introduced to their benefit.

The article shows an area where printing house experience can be used to design PSS. The article highlights problems related to storage in a printing company and how to solve them. Using this experience will allow you to design PSS that reflect the real industrial situation in the printing house. The problems and needs of the printing house will support the design of services that are to be an answer to them. Thanks to this, PSS will contain what the enterprise needs. PSS designed in this way can support the

printing house and eliminate emerging problems. It is worth noting that an important aspect in the design of PSS will be communication and trust between the printing house and the PSS provider.

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Publication III

Salwin, M., Kraslawski, A. and Lipiak, J.
State-of-the-Art in Product-Service System Design

Reprinted with permission from
The 10th International Conference on Engineering, Project, and Production Management, Lecture Notes in Mechanical Engineering
pp. 645–658, 2019

State-of-the-Art in Product-Service System Design

Mariusz Salwin, Andrzej Kraslawski and Jan Lipiak

Abstract Since the 1990s, a Product-Service System (PSS) has been seen as a concept that helps businesses in building their competitive advantage and allows them to increase the added value provided to customers by expanding product offer with dedicated services within an environmentally-friendly model. The needs voiced by practitioners and theoreticians concerning the development of new PSS models for different industries have not been met satisfactorily as many theoretical, methodological, and practical aspects involved in the process remain unresolved. The paper proposes a comprehensive classification of PSS design methods. The latter have been classified against criteria, such as industry and size of a company in which PSS models can be applied, product and service development paths or types of contacts with customers. In addition, the paper reviews literature on PSS design published over the recent 18 years. Its primary purpose is to identify the major aspects of PSS design, features common to different design methods, and their limitations. By examining the existing design methods, we hope to facilitate the adaptation of business models to specific PSS problems. This publication addresses and analyses 60 PSS design methods.

Keywords Product-Service system · Product-Service system design · Product-Service system method

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K. Panuwatwanich and C. Ko (eds.), *The 10th International Conference on Engineering, Project, and Production Management*, Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-15-1910-9_53

1 Introduction

Over a longer perspective, companies will no more acquire competitive advantage only by designing and manufacturing products (De Zan et al. 2015). The last twenty years witnessed a clear gain in popularity of research devoted to Product-Service Systems (PSS) (Annarelli et al. 2016; Park and Yoon 2015). Recently, traditionally oriented manufacturing companies have decided that services linked to products can be innovative and provide added value to customers, which ultimately translates into higher profits (Roy and Cheruvu 2009; Biotto et al. 2012). On top of that, growing interest in sustainable development and meeting customer needs are central to enterprises. Hence, the PSS attract increasing attention of business practitioners and researchers (Boons and Lüdeke-Freund 2013).

In order to develop diverse PSS models, manufacturers must develop new PSS design methods starting from product-oriented through service-oriented up to result-oriented ones (Tukker 2004; Muto et al. 2016). Within the last eighteen years, we observed a rapid expansion of research on the development of PSS design methods.

Conducted analyses revealed that a few traditionally operating manufacturers can work out and select a PSS model that would be adequate to their business. They find the task difficult as opportunities offered by PSS are far from what they have come across so far (Muto et al. 2016). That is why the development of PSS models needs to be supported by specific methods, techniques and tools (Gokula Vijaykumar et al. 2013). Available literature proposes a number of methods dedicated to developing such solutions. Even though each method aims at working out a new PSS model for an enterprise, proposed ways leading to achieve this goal differ in terms of the scope, industry and tools used to support contacts with customers. The selection of an adequate PSS design method is therefore not a trivial issue.

Literature on the Product-Service Systems offers a wide array of reviews of design methods (Becker et al. 2010; Vasantha et al. 2011; Cavalieri and Pezzotta 2012; Qu 2016; Idrissi et al. 2017). Becker et al (2010) demonstrated that the creation and offering of value bundles are crucial in a service-based economy. They also showed that it is a complex undertaking which can be accomplished in value networks of different business units or companies and cannot be separated from a broader context of the integration of business processes involved in services and manufacturing. The review worked out by Clayton, Backhouse and Dani (2012) was motivated by the reflection on how representative literature can be in specifying industrial practices in PSS design. Authors focused particularly on recommendations formulated for PSS design. Vasantha et al. (2011) carried out literature review based on eight methods to identify needs in future studies. The analysis covered authors' views, definitions of services and PSS. Gokula Vijaykumar et al. (2013) examined nine design methods and concluded that the role of actors involved in PSS design is not specified clearly enough and, more precisely, that there is not sufficient information about the possibilities of engaging the stakeholders in cooperation at subsequent PSS design stages. Literature review by Boehm and Thomas (2013) addressed the integration of three disciplines: the information system (IS), business management (BM), and

engineering and design (ED) to ensure uniform definition of PSS and terms within the three disciplines. Tukker (2015) focused mainly on engineering and design and dealt with aspects of PSS concept, PSS design methods, business and environmental advantages and drawbacks of PSS. He strived to assess the PSS contribution in efficient resource management. Reim et al (2015) reviewed literature to find out how companies implement PSS business models. They investigated the links between business models and tactics deployed by companies with respect to: drafting contracts, marketing, using network relations with external partners, designing products and services, as well as operational practices concerning sustainable growth. Qu et al (2016) aimed to understand the state-of-the-art knowledge concerning the design, assessment and operating methodologies. Authors focused on three research areas: PSS design methodologies (PSS-DM), PSS evaluation methodologies (PSS-EM), and PSS operating methodologies (PSS-OM). Idrissi et al (2017) drew attention to the gap in PSS modeling to support the decision-making process in the design stage. Their analysis considered seven methods that apply the Unified Modeling Language (UML) procedure.

The paper is structured as follows: the first section is an introduction. The next part introduces the research methodology. The third part contains analyses of the literature devoted to the existing PSS design methods. The final part is discussion and conclusion.

2 Research Methodology

2.1 Research Aim

The paper aims at identifying, analyzing, and classifying the existing body of knowledge on Product-Service System design by highlighting the major features of PSS design methods, their similarities and boundaries.

We have formulated the following research questions in the paper:

1. What is the state-of-the-art in PSS design?
2. What are the major limitations of PSS design methods available in literature?

This analysis also presents the suggestions for possible future directions of research on PSS development. By exploring existing design methods, we hope to facilitate the adaptation of business models to specific PSS problems.

2.2 Systematic Review

The methodology adopted in the article is a systematic review (Pittaway et al. 2004). This method has been chosen as it uses a scientific and transparent process aimed

at minimizing prejudice through a detailed search for works published in literature (Annarelli and Nonino 2016). The authors used the suggestions of Tranfield (2003) and his collaborators and took three main steps:

1. Planning the review: In this paper, the authors focused on PSS design and analysis of available methods, which is the main goal of this article. It was decided to search only for the articles that explicitly use the term "Product-Service System design" or indicate it as a synonym.
2. Conducting the review: The authors searched (in title, abstract and keywords) for the term "Product-Service System design" or its synonyms in a database such as ProQues, Springler Link, Science Direct, Taylor & Francis Online, EBSCOhost, Scopus, Emerald, Insight, Web of Science, Ingenta, Wilma, IEEE Xplore Digital Library and Google Scholar. The databases used in the review are a tool to search for literature sources in electronic form, particularly useful for works published after 1995, with a wide range of topics and journals.
3. Reporting and dissemination: In this phase, the available methods of PSS design were examined in detail. According to the presented guidelines, we obtained 400 articles covering the period from 2001 to 2017. The selection based on title and summary led us to a limited set of 64 articles covering articles, conference materials, monograph chapters and books, in which 60 methods of PSS design were found.

3 Literature Review

This section reviews PSS design methodologies proposed in literature. The main goal of this paper is to classify the available technologies. The analysis of 60 approaches to PSS design provides an extensive literature review. All methods available in literature can be divided into two categories: methods validated in industrial practice and methods proposed by researchers without any validation (Fig. 1).

Having examined the available literature, we can conclude that out of 60 PSS design methods, only 12 have been successfully implemented in industrial practice and continue to be used (Aurich et al. 2006; Shimomura et al. 2009; Sundin et al. 2009; Ziout and Azab 2015; Andriankaja et al. 2017; Halme et al. 2004; Kim et al.

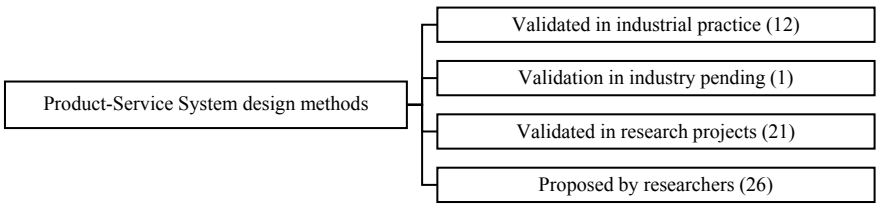

Fig. 1 Classification of PSS design methods

2015; Tuan and Park 2014; Barquet et al. 2015; Maxwell and Vorst 2003; Moser et al. 2015; Wood and Tasker 2011). Validation of one of these methods is still pending (Idrissi et al. 2017). Another 21 methods have been validated in research projects; however, they have not yet been used in practice (Abdalla 2003; Rexfelt and Hiort af Ornäs 2009; Tukker and Tischner 2006; Tukker and van Halen 2003; van Halen et al. 2005; Engelhardt et al. 2003; Muto et al. 2016; Brezet et al. 2001; Luiten et al. 2001; Marques et al. 2013; van de Kar 2010; Evans et al. 2007; Green and Vergragt 2002; Manzini et al. 2004; James et al. 2001; Müller et al. 2009; Adrodegari et al. 2017; Matzen and McAloone 2006; Muto et al. 2015; Morelli 2002, 2003; Vezzoli et al. 2014; Tuan and Park 2014). We distinguished 26 methods, which have the status of the researchers' proposals (Weber and Deubel 2003; Alonso-Rasgado and Thompson 2006; Alonso-Rasgado et al. 2004; Lindahl et al. 2009; Morelli 2006; Uchihira et al. 2007, 2008; Chiu et al. 2017; Komoto and Tomiyama 2008; Tan et al. 2009; Welp et al. 2008; Maussang et al. 2009; Kimita et al. 2009; van de Kar 2010; Geum and Park 2011; Lee et al. 2011; Kim et al. 2012; Akasaka et al. 2012; Gokula Vijaykumar et al. 2013; Dimache and Roche 2013; Pezzotta et al. 2014, 2015; Chiu et al. 2015; Medini and Boucher 2016; Trevisan and Brissaud 2016; Scherer et al. 2016; Sassanelli et al. 2016; Campos et al. 2017).

In the next stage of our analysis, we focused on how these methods emerged and have developed over the years (Fig. 2). Such a presentation helps in capturing a precise chronology of all developments linked to the launching of individual methods and providing a picture of the scale of the occurrence by the end of May 2018.

After examining how the methods developed over time, we can conclude that the first methods used to design a PSS emerged back in 2001 (DES, AEPSS, the PSS Innovation Workbook, the Kathalys method).

In the next stage of the analysis, we focused on the industries for which the methods have been developed and are in use, as shown in Fig. 3.

Some PSS design methods target several diverse (sometimes completely different) industries. On the one hand, this testifies to the versatility of solutions available in literature which can be adapted for different industries but, on the other hand, it means we need to develop new methods tailored specifically for specific industries. Most methods target mechanical engineering. They include solutions for cutting devices,

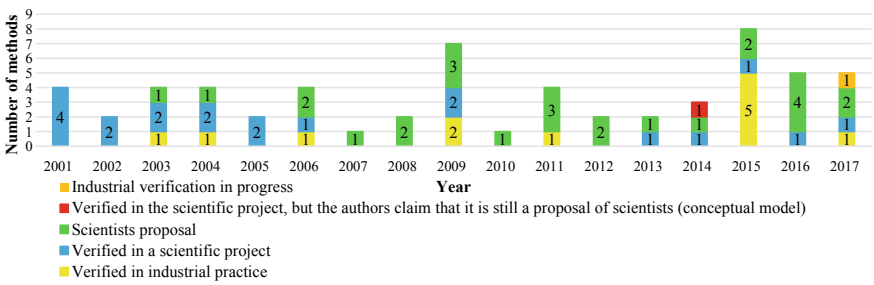

Fig. 2 Development of PSS design methods

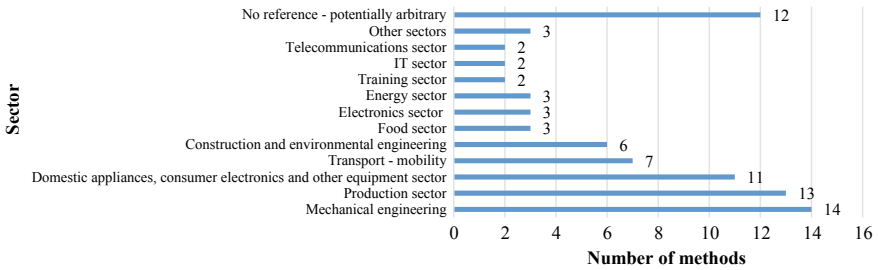

Fig. 3 Classification of PSS design methods by sector

angle grinders for cutting steel, heavy road construction machinery, valves, and tank gauging systems (Alonso-Rasgado and Thompson 2006; Alonso-Rasgado et al. 2004; Aurich et al. 2006; Matzen and McAloone 2006). Among them, we can find solutions for cooling devices, cranes, compactors, laser systems, and agricultural machinery (Dimache and Roche 2013; Sundin et al. 2009; Gokula Vijaykumar et al. 2013; Ziout and Azab 2015). Moreover, these methods include solutions targeting CNC machine tools, lifts, manufacturing machinery, and aircraft industry (Adrodegari et al. 2017; Campos et al. 2017; Shimomura et al. 2009; Wood and Tasker 2011).

Next, we considered the size of companies to which available design methods of Product-Service Systems are addressed. This classification shows we may select a method that is appropriate for the size of a business (Fig. 4).

As many as 48 methods out of the total analysed pool are not size specific and can potentially be used by a company of any size. Literature distinguishes one method, each with a precise focus on small enterprises (Evans et al. 2007; Manzini et al. 2004), medium-sized enterprises (Aurich et al. 2006) and large enterprises (Sundin et al. 2009). In literature, four methods are addressed to SMEs (Abdalla 2003; Engelhardt et al. 2003; Medini and Boucher 2016; Tukker and Tischner 2006), and four methods target small, medium and large companies (Lindahl et al. 2009; Luiten et al. 2001; Tukker and Tischner 2006; Tukker and van Halen 2003). One method is dedicated to small and large enterprises (Dimache and Roche 2013).

The next stage of examining PSS design methods focused on the paths of product and service design within the system (Fig. 5). This stage was intended to indicate the number of design methods in which products and services within a PSS are jointly developed and the number in which the process takes place separately.

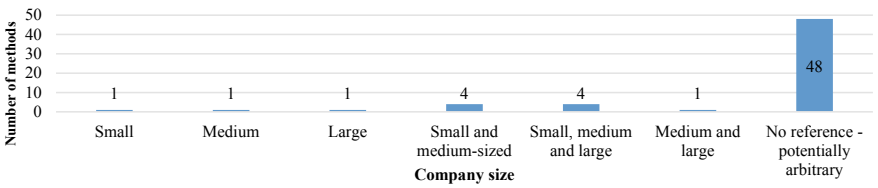

Fig. 4 Proposed PSS design methods by company size

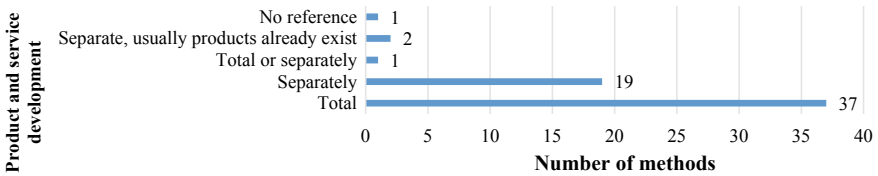

Fig. 5 Product and service development in PSS design methods

The development of products and services takes place together in 37 methods while these are separate development paths in 19 methods. Maxwell and Vorst (2003) gave plenty of leeway to develop products and services either jointly or separately. The methods developed by Morelli (2002, 2003) and Manzini et al. (2004) as well as Evans et al. (2007) enable adding services to already developed products. The method developed by Barquet et al. (2015) made no specific recommendations.

The next stage of the analysis of PSS design methods focused on the tools that support available design methods for such systems (Fig. 6). Our goal was to make an inventory of tools used when designing Product-Service Systems.

In total, we found about 150 tools that support the 60 PSS design methods. Figure 6 shows that seventeen of these tools are used more frequently than others, with blueprinting being the most frequently used tool in designing PSS. It is applied in 9 methods out of which only one has been validated in industrial practice. TraPSS is a design method that uses the biggest number (26) of tools (Dimache and Roche 2013). The literature review indicates that about 6 methods use no tools (Barquet et al. 2015; Moser et al. 2015; Tran and Park 2015; Müller et al. 2009; Rexfelt and Hiort af Ornäs 2009; Gokula Vijaykumar et al. 2013).

A further stage of analysis was devoted to contacts with customers when developing new PSS (Fig. 7). We wanted to find out whether the final user is involved and remains in touch with the company when a new system is being developed.

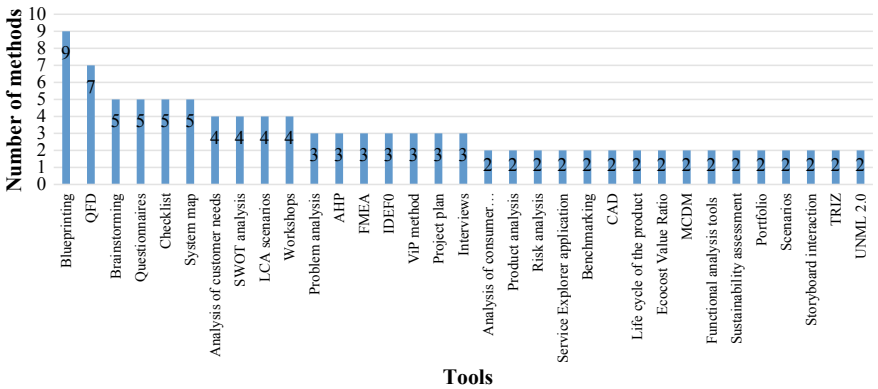

Fig. 6 Tools that support PSS design methods

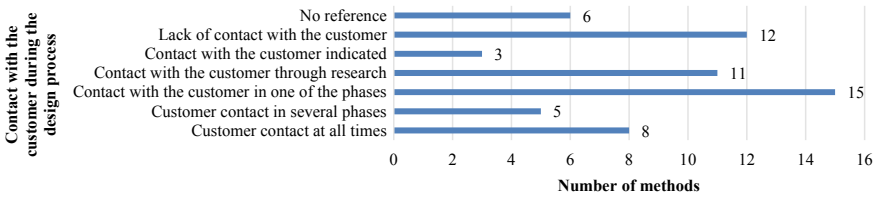

Fig. 7 Contact with the customer in PSS design methods

From the literature review, we have learnt that 42 PSS design methods address customer contacts in developing a new system. Out of these 42 methods, 8 provide for direct continuous contact throughout the process. In 6 methods, customer contacts while developing PSS are not specified precisely.

Subsequently, our analysis concentrated on the types of PSS that can be designed based on the methodologies available in literature (Fig. 8). Literature distinguishes between 5 types of PSS (integration, product, service, use, and result-oriented) (Neely 2008).

Our investigation shows that out of the 60 design methods for PPS available in literature, 30 can be used for the development of integration-oriented PSS and 39 for product-oriented PSS. Most design methods (45) can be used in developing service-oriented PSS. As shown in Fig. 8, there are 31 methods for a use-oriented PSS and 33 methods for a result-oriented PSS. We need to stress that some methodologies available in literature are intended for designing systems of specific types. Some methods can be used in designing several types of PSS (Geum and Park 2011; Lee et al. 2011; Vezzoli et al. 2014; Pezzotta et al. 2015; Chiu et al. 2017).

The next part of the analysis highlights environmental, economic and social aspects (Fig. 9). We aimed at finding out whether PSS design methods available in literature consider these aspects in developing a new system.

Whereas the environmental aspect is considered in 36 PSS design methods, the economic aspect is taken into account in 47 PSS design methods and the social aspect in 23 PSS design methods.

The structure of product system design methods available in literature is then examined. In most methods, a new system is developed in consecutive stages. Each stage comprises a series of actions that must be completed. We need to stress here that in the majority of methods, each stage is described in a rather imprecise manner; basic operations are just listed without any profound explanation. In some methods besides

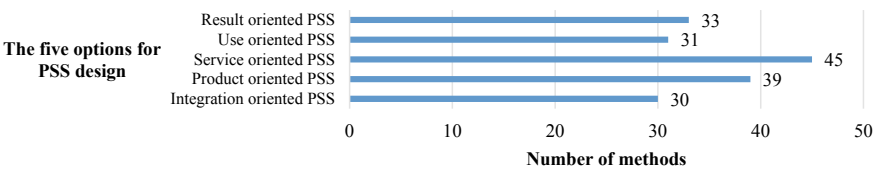

Fig. 8 Types of PSS

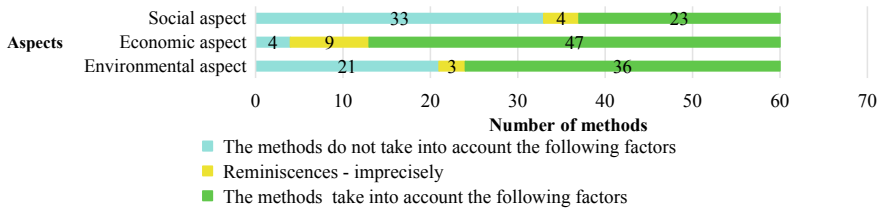

Fig. 9 Sustainable development aspects considered in PSS design

the main phases we can identify additional ones, such as: paths (Luiten et al. 2001), division into two spaces: problem space and the space of solutions (Morelli 2002, 2003), additional modules: diagnostic module, opportunity recognition module, and an implementation module (Tukker and Tischner 2006), division into two spaces: product design space and technical service design space (Aurich et al. 2006), DFACE-SI procedure (Uchihira et al. 2007, 2008), model of interdependence between the implementation of Product-Service Systems and customer satisfaction (Akasaka et al. 2012), business model dimension (Barquet et al. 2015), customer area and company area (Scherer et al. 2016), and additional steps in model building (Idrissi et al. 2017). In the PSS Innovation Workbook method when developing a new system, a company does not take any steps but answers the questions (James et al. 2001). The Service Thinking method brings together the conceptual side of developing a Product-Service System based on customer wishes and the social dimension as a competence of the expert team to perform services (Wood and Tasker 2011). Several methods available in literature include feedbacks that enable revisiting each previous design phase. Feedbacks are a crucial and useful functionality (Kim et al. 2015; Gokula Vijaykumar et al. 2013; Weber and Deubel 2003).

4 Discussion and Conclusion

Studies discussed in the paper were undertaken to identify the main PSS design areas, their limitations, and industries in which they are deployed most frequently.

We managed to identify 60 PSS design methods in literature, with 12 of them implemented in economic practice. Analyzed literature, available examples and case studies have led us to the conclusion that PSS design methods are not presented in too much detail, which significantly limits their practical application. The majority of available methods focus on three aspects: design processes that integrate products and services, definitions of new terms, and considerations on planning and design stages of a product lifecycle. Another relevant issue that needs to be considered is the flexibility and versatility of methods available in literature, which can be applied in several industries and by enterprises of different sizes to develop many PSS.

Each stage of available methods needs to be described in greater detail. For each method we should precisely identify costs and financial flows. More examples of

practical applications and case studies could help in providing a fuller picture of a given PSS. Literature should provide practitioners with examples telling them how they could potentially design new PSS in their organizations. We also lack details that could help develop new methods from old ones in an iterative approach geared towards continuous improvement and working out new solutions.

Literature review allows identifying the research gap in available PSS design methods to focus further actions on bridging this gap. The major shortcomings of PSS design methods include:

- No available method addresses the Canvas Business Model—further studies are needed to find out how methods available in literature may impact the corporate business model and how the business model changes before and after a PSS has been developed in an enterprise.
- No available method informs how a PSS should be implemented in a company.
- Methods available in literature are very imprecise about economic aspects, which are described superficially without any details as to costs or cash flows from manufacturer or customer viewpoint while these aspects are crucial for assessing the PSS performance. There are no methods to assess economic efficiency of PSS.
- No precisely specified stages of risk analysis for PSS design. The process is not systematic and does not facilitate risk identification, planning and management intended to eliminate risk or minimize it to acceptable levels.

Existing literature informs that only a handful of methods have been validated in industrial practice. Vast majority have not been evaluated for industrial organizations that seek such solutions.

The range of tools that support Product-Service System design methods is also important. It only confirms how complex exercise it is to develop a new system. In addition, tools used for that purpose are generally known and widely used in industrial and academic practice.

Moreover, the analysis provides solid foundations for working out new design methods for new industries and reveals for which industries such methods have already been developed and what aspects should be considered.

Business practitioners can also benefit from results shared in the paper. By looking at different aspects of methods available in literature they acquire a useful basis for the selection of method that best fits their respective activity field. The definition of Product-Service System design and literature studies are good points of departure for developing new PSS design methods in new industries.

The analysis shows that PSS design continues to develop and there is a constant demand for new design methods for new industries. Fundamental conclusions from the research suggest that the existing PSS design process described in literature does not fully reflect the industrial practice of PSS design. The analysis is the starting point for the development of a new method that will fill in the gaps in PSS design.

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Publication IV

Salwin, M., and Kraslawski, A.
State-of-the-Art in Product-Service System Classification

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Advances in Design, Simulation and Manufacturing III, Lecture Notes in Mechanical Engineering
pp. 187–200, 2019

State-of-the-Art in Product-Service System Classification

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Abstract. The Product-Service System (PSS) is an integrated combination of products and services. This concept includes a service-based competitive strategy, environmental sustainability and the basis for distinguishing itself from competitors offering cheaper products. The adoption of PSS involves focusing on selling the functionality of the product instead of selling the products. The important element of PSS is classification, i.e. the systematic division of PSS into classes according to a defined principle. The literature on the classification of PSS is very narrow and it does not sufficiently address the possibilities and categories that can be distinguished. The typologies developed have not captured the wealth of classes of PSS so far. The paper presents a comprehensive analysis of the PSS classification. In addition, the paper systematically reviews the literature on the PSS classification published over the last 18 years. Its main objective is to identify the main aspects of the PSS classification, the common features to the various classifications and their limitations. By researching the available classifications, we hope to make it easier for businesses to develop new PSS-based offers and to adapt their business models to specific types of PSS. This publication deals with and analyses 10 classifications of PSS.

Keywords: Product-Service System · Product-Service System classification · Product-Service System typology · Product-Service System continuum · Servitisation continuum

1 Introduction

Product Service Systems are particular cases of servitization. The concept emerged in Scandinavia in the late 1990s [1]. For the first time, the term "Product-Service System" was used in the report Product Service Systems, Ecological and Economic Basics in 1999 [1]. The definition of PSS proposed in this report says: 'A product service-system is a system of products, services, networks of "players" and supporting infrastructure that continuously strives to be competitive, satisfies customer needs and have a lower environmental impact than traditional business models' [1]. In the following years, the term was gaining in importance and evolved [2–5].

V. Ivanov et al. (Eds.): DSMIE 2020, LNME, pp. 187–200, 2020.
https://doi.org/10.1007/978-3-030-50794-7_19

PSS emerged because traditional manufacturing companies wanted to be able to cope with the changing market forces and realized that by linking services with products they might guarantee higher profits for themselves than by offering products only [6]. In the face of shrinking markets and increased commoditization of their products, these companies perceived rendering services as a new path to higher profits and growth [7, 8]. Increasingly more often they draw attention to possibilities it may produce. This, in turn, links with additional benefits because by using services to meet the needs instead of owning products we reduce demand for materials and energy [9].

PSS is a valuable concept for manufacturers from highly developed countries. The manufacturing industry is experiencing deep changes globally. Traditional manufacturers face growing challenges posed by countries with low costs of labor. However, in highly developed countries the will to retain profitable manufacturing capacity remains strong because manufacturing directly supports exports, service-based economy, and supplements scientific and technical base. This is why manufacturers are encouraged to apply solutions based on the PSS model, which may help them enhance competitiveness and deliver new value to customers [10, 11].

The classification of PSS is an important area of research in PSS that is still not sufficiently analyzed. The main objective of the classification is to break down according to specific rules and principles. The basis for classification is the introduction of clear and logical distribution criteria based on the typical and unique characteristics of the PSS. Such features include product ownership, functionality, environmental impact and the main revenue generating mechanism [12–14]. The PSS classification provides means by which specific events can be compared and understood. The available classifications show that between pure product sales and service provision there are a number of different PSS options where products and services are combined to varying degrees [13, 15]. The transformation from the manufacturing company to the service company and related issues is also taken into account [8, 16–18].

The paper is structured as follows: the first part is the introduction; the next part contains the literature analysis of the existing classifications of PSS; the third part presents the research methodology; the next part contains results; the last part is the conclusions.

2 Literature Review

This section reviews the classification of PSS proposed in the literature. The first step of the analysis shows what the available classifications are aimed at and what they are focused on, and the compilation of their number of citations is made (Table 1).

Table 1. Table captions should be placed above the tables.

Authors and years	Number of citations		Product-Service System classifications (Categorization PSS)			Focus
	Google Scholar	Research Gate				
Mathieu, 2001 [17]	738	439	1. Organizational intensity (X-axis) 1.1. Tactic 1.2. Strategic 1.3. Cultural 2. Service specificity (Y-axis) 2.1. Customer Services 2.2. Product Services 2.3. Service as a Product			Focusing on the nature of the offer, how service maneuvers are organized, the strength and dimension of their impact on the company
Mont, 2002 [22]	2030	1226	1. Products/services/combinations/substitutions 2. Services, at the point of sale 3. Different concepts of product use: 3.1. Use oriented 3.2. Result oriented 4. Maintenance services 5. Revalorisation services			Focusing on the main elements of a PSS that can serve as a common reference data for research and design of PSS
Oliva and Kallenberg, 2003 [8]	2559	1550		Product-oriented services	End-user's process-oriented services	Describing the process of transforming a manufacturing company into a more service-oriented one. In their deliberations, the authors particularly took into account the services accompanying durable, durable products, usually necessary to maintain their functionality during their life cycle
			Transaction-based services	Basic installed base services	Professional services	
			Relationship-based services	Maintenance services	Operational services	
Tukker, 2004 [13]	1806	1152	1. Product-oriented 1.1. Product related 1.2. Advice and consultancy 2. Use-oriented 2.1. Product lease 2.2. Product renting/sharing 2.3. Product pooling 3. Result-oriented 3.1. Activity management 3.2. Pay per service unit 3.3. Functional result			It is a classification according to a range of values determined based on a product or service. It is connected with the ease of their implementation and at the same time with the complexity of the system

(*continued*)

Table 1. (*continued*)

Authors and years	Number of citations		Product-Service System classifications (Categorization PSS)	Focus
	Google Scholar	Research Gate		
Uchihira and collaborators, 2007, 2008 [18, 23]	17	7	1. Adjustment Expansion 1.1. Consulting 1.2. Customizing 1.3. Downtime and Risk Reduction 2. Commitment Expansion 2.1. Financial Risk Reduction 2.2. Social Risk Reduction 2.3. Operational Efficiency 3. Territory Expansion 3.1. Seamless Services 3.2. Rich Content	Focusing on ways of expanding production activities, emphasizing the importance of contacts and customer relations
Neely, 2008 [12]	1204	790	1. Integration-oriented 2. Product-oriented 3. Service-oriented 4. Use-oriented 5. Result-oriented	Focusing on a fuller presentation of the scope of service strategies implemented by the company
Martinez and collaborators, 2010 [16]	484	315	1. Interaction mainly transactional; some addition of peripheral services 2. Product + service delivery 3. Customization of product and service 4. Product + service co-designed; total solutions	Focuses on the analysis of the customer-supplier interface
Fan and Zhang, 2010 [24]	14	7	1. Product-oriented 2. Application-oriented 3. Result-oriented 4. Integrated-oriented 5. Service-oriented	Scope of the strategy of services provided by manufacturing companies
Clayton and collaborators, 2012 [15]	64		1. Integration-oriented 2. Product-oriented 3. Service-oriented 4. Use-oriented 5. Result-oriented	Understanding how to create product and service offers
Van Ostaeyen and collaborators, 2013 [14]	101	84	1. Input-based 2. Availability based 3. Usage-based 4. Performance-based 4.1. Solution-oriented 4.2. Effect-oriented 4.3. Demand-oriented	Focusing on the performance orientation of the dominant revenue mechanism of the PSS and the level of integration of the elements of the PSS

The classification proposed by Mathieu [17] is based on two dimensions. The first is Service specificity (Customer Services, Product Services, Service as a Product), and the second is Organizational intensity (Tactic, Strategic, Cultural). It introduces the concept that service has the potential to be more than just an offer or a product service. The classification uses the term service maneuvers. Service specificity is partly derived from the logic of service classification and focuses on the nature of the offer. It refers to the type of content of a production service maneuver (Customer Services, Product Services, Service as a Product). The second dimension, Service specificity, focus on the way service maneuvers are organized, the strength and dimension of their impact on the company. The first dimension is the domain of the offer, takes a market view and focuses on delivering value to customers in an efficient way. On the other hand, Organizational intensity implies positions that an organization can take, it concerns the internal point of view. There is a correlation between these dimensions, namely the greater the intensity of the service maneuver, the greater the specificity of the service in general. The forces shaping these dimensions are also different. In the first dimension, the organization only has to make a plan, make a decision, while in the context of Organizational intensity it has to create a plan. The company introduces customer service or the product as the service or the organization creates tactical or cultural maneuvers [17].

The classification developed by Mont [22] provides a list of the main elements of PSS that can serve as a common reference date for PSS research and design. The author divides the PSS into five main categories based on the combination of a product with services at different stages of the life cycle of the product and covering different concepts for the use of the product [22].

Oliva and Kallenberg [8] are the authors of another approach to distinguishing between types of PSS systems. They described the process of transforming a manufacturing company into a more service-oriented company. In their conceptions, they considered primarily the services associated with durable products, typically necessary to maintain their functionality throughout their life cycle (e.g. installation, repair, improvement, decommissioning). The authors have introduced here the terms product installed base (product IB) and services installed base (services IB) (a range of services related to a product or process required by an end-user throughout the life of a product to function effectively in the context of its operating process). Focusing on the unique attributes of services IB enables a new classification of the opportunities in the services market that are needed to compete. The developed classification has two dimensions of organizational transformation. The first one concerns the change in the understanding of customer interaction from transaction-based to relationship-based. The second dimension of the transformation concerns the type of services provided and the values delivered, from product-oriented to end-user process-oriented [8].

The classification developed by Tukker [13] distinguishes three main types of PSS (product-oriented, use-oriented, result-oriented), which are divided into eight categories (product-related, advice and consultancy, product lease, product renting/sharing, product pooling; activity management, pay per service unit, functional result) distinguished according to the range of values determined based on the product or service. Moving from the first to the last of these types of PSS, dependence on the product as the main component of the PSS decreases and customer needs are formulated more

abstractly. In each case, the supplier has little more freedom to satisfy the actual needs of the customer. However, abstract requirements are often difficult to render into specific (qualitative) performance indicators, which make it difficult for suppliers to determine what they have to offer, and for customers to know whether they have what they are asking for [13].

A different approach to PSS classification was developed by Uchihira and collaborators [18, 23] focusing on how to develop contacts with customers. A Customer Expansion Model was presented that includes three types of expansion: adjustment expansion, commitment expansion, and territory expansion. These types of expansions can provide added value to services such as better product quality, customer protection, and product convenience. These three types of expansion are divided into more detail, detailing eight elementary patterns of service functions (consulting, customizing, downtime and risk reduction; financial risk reduction, social risk reduction, operational efficiency; seamless services, rich content) [18, 23].

Neely [12] has developed further PSS classification based on the Tukker [13] classification. The author, conducting his research, concluded that an extension of the PSS classification system is required to fully reflect the range of servicing strategies implemented by companies. Neely [12], using criteria similar to those of Tukker [13] for the traditional PSS (product-oriented, user-oriented result-oriented), added two new PSS types: integration oriented and service-oriented. PSS integration oriented is created when a company tries to add services downstream and introduce vertical integration. PSS service-oriented is when a company adds services to products by integrating these services into the product itself [12].

Another classification in the form of servitisation continuum closely related to PSS was developed by Martinez and collaborators [16]. Servitisation was defined as a strategic innovation of the organization's capabilities and processes, to start delivering value by selling integrated product and service offers. Martinez and collaborators [16] combined the challenges with the position in the servitisation continuum that the organization wants to achieve. Four criteria were distinguished to assess the level of servitisation of the organization. Low levels of servitisation can be achieved with relatively small changes, while deep levels of servitisation require wider interactions between suppliers and customers, so the challenges facing the company are more serious and need to be more supported in all of these aspects [16].

Another developed classification was created based on the Tukker [13] and Neely [12] classifications. The authors have added the Product-Service System application-oriented to the well-known PSS types. The classification takes into account the dimension of the market environment when formulating the strategy. The aim is to adapt the Product-Service System to the market forces that companies face. It allows companies to adopt the right PSS strategy to gain a competitive advantage [24].

Based on Neely [12] classification, Clayton and collaborators [15] have incorporated five types of PSS into a continuum from pure product to service. The aim is to help create a product and service offering. The author points out that in the classification the company is not able to offer only PSS user-oriented or result-oriented [15].

Van Ostaeyen and collaborators [14] distinguished four main types of PSS. This classification categorizes PSS types according to two distinguishing features: the efficiency orientation of the dominant revenue mechanism and the degree of integration

between the elements of the product and service. This classification makes it possible to convey the specific characteristics defining PSSs: which products and services are included in the offer, which of them are integrated and which are their revenue mechanisms. It attaches great importance to the concept of function in PSSs [14].

In the next stage of the analysis, we focused on the analysis of features important for the Product-Service System (Table 2), which are regularly repeated in the literature [1, 2, 10]. Such presentation helps to capture them precisely and show which of them are taken into account in particular PSS classifications.

Among 19 analyzed factors, 14 occur in the classification developed by Martinez and collaborators [16]. This author was the only one who took into account the time scale. Only Tukker [13] considered the environmental impact of PSSs in his classification. This aspect was not taken into account as a criterion for any other classification. Each classification takes into account material and intangible assets relevant to the PSS, as well as social aspects.

The next step in the analysis was to focus on the structure of the PSS classification. This analysis will allow us to capture the similarities and differences and gaps in the classifications available (Table 3).

It is noteworthy that certain types of PSS in the classifications have a different name and relate to the same name. Martinez and collaborators [16], whose classification is very close to Neely [12] despite its other names and additional aspects related to the issues of transformation of the enterprise, can be given as an example. Most of the classifications developed include three types of PSS, product-oriented, use-oriented, result-oriented, each of which also covers the transition from a pure product to pure service. It should be emphasized here that individual types are not described precisely, they are only signals without explaining how the product is combined with the service and to what extent this integration takes place. In the part of the classification, apart from these three types, the aspects related to the strategy and transformation of the enterprise and expansion can be identified.

The analyzed PSS classifications can be divided into two main groups (Table 4). The first is the classification in which important attention is paid to classifying the offer possibilities, i.e. showing that there are a number of possibilities offered by a PSS to an enterprise between the pure sale of products and the provision of services. The second group concerns classifications that pay attention to the transformation of an enterprise, i.e. the transition from a product manufacturer to a service provider.

It should be stressed that the classifications available in the literature are intended for enterprises of different sizes operating in different branches of the economy.

3 Research Methodology

3.1 Research Aim

The paper is aimed at the identification and analysis of the existing knowledge on the Product-Service System classifications by highlighting the main features of available PSS classifications, their similarities, and their limitations.

Table 2. Product-Service System classifications analysis

	Attributes	Authors										
		Mathieu [17]	Mont [22]	Oliva and Kallenberg [8]	Tukker [13]	Uchihira and collaborators [18, 23]	Neely [12]	Martinez and collaborators [16]	Fan and Zhang [24]	Clayton and collaborators [15]	Van Ostaeyen and collaborators [14]	Total
1.	Ownership				+		+	+	+	+	+	6
2.	Tangible	+	+	+	+	+	+	+	+	+	+	10
3.	Intangible	+	+	+	+	+	+	+	+	+	+	10
4.	Function							+			+	2
5.	Distinguishing features		+		+		+		+	+	+	6
6.	Comparison of specific events		+		+		+	+	+	+	+	7
7.	The dimension of the market environment	+							+			2
8.	Transformation of a company	+		+		+	+	+	+			6
9.	Product life cycle						+	+		+	+	4
10.	Customer relationship					+		+				2
11.	Innovation							+				1
12.	Change of organizational culture	+		+		+	+	+				5
13.	Role of the manufacturer/supplier	+	+	+	+	+	+	+	+	+	+	10
14.	Element integration level	+	+	+	+		+	+	+	+	+	9
15.	Economic aspect	+			+						+	3
16.	Environmental aspect				+							1
17.	Social aspect	+	+	+	+	+	+	+	+	+	+	10
18.	Time scale						+					1
19.	Company strategy	+		+				+				3
	Total	10	7	8	10	7	12	14	10	9	12	

Table 3. Structure of the PSS classification

Authors	Mathieu [17]	Mont [22]	Oliva and Kallenberg [8]	Tukker [13]	Uchihira and collaborators [18, 23]	Neely [12]	Martinez and collaborators [16]	Fan and Zhang [24]	Clayton and collaborators [15]	Van Ostaeyen and collaborators [14]
Integration-oriented		+	+			+			+	
Product-oriented	+	+	+	+	+	+	+	+	+	
Application-oriented							+	+		
Service-oriented		+				+	+	+	+	
Use-oriented		+		+		+	+	+	+	+
Result-oriented	+	+		+		+	+	+	+	+
Input-based										+
Availability based										+
Organizational intensity	+									
Service specificity	+									
Transaction-based services			+							
Aspects related to the enterprise transformation process	+		+		+		+			
Adjustment expansion					+					
Commitment expansion					+					
Territory expansion					+					

Table 4. Product-Service System classification group

Group 1	Group 2
Mont [22]	Mathieu [17]
Tukker [13]	Oliva and Kallenberg [8]
Neely [12]	Uchihira and collaborators [18, 23]
Fan and Zhang [24]	Martinez and collaborators [16]
Clayton and collaborators [15]	
Van Ostaeyen and collaborators [14]	

In the paper we formulated the following research questions:

- What is the state-of-the-art in the classification of PSS?
- What are the main limitations available in the literature of PSS classification?

The analysis carried out in this article also provides suggestions for possible future directions for research on the development of the PSS typology. By exploring existing classifications, we hope to help capture the wealth and business opportunities of PSS.

3.2 Systematic Review

The methodology adopted in this paper is the systematic review of the literature [19]. It was chosen for using a scientific and transparent process aimed at minimizing prejudice through a detailed search for works published in the literature [20]. The authors used suggestions from Tranfield and collaborators and took the following steps [21]:

1. Planning the review. In this paper, the authors focus on the classification of PSS and their analysis, which is the main objective of this paper. It was decided to search only for those articles which use the terms “Product-Service System classification” and “Servitisation continuum” or indicate them as synonyms.
2. Conducting the review. The authors searched (in the title, abstract and keywords) for the terms “Product-Service System classification” and “Servitisation continuum” or their synonyms in databases such as EBSCOhost, Emerald, IEEE Xplore Digital Library, Ingenta, Insight, ProQuest, Science Direct, Scopus, Springer Link, Taylor & Francis Online, Web of Science, Wilma and Google Scholar. The databases used in the review are a tool to search for sources of electronic literature, particularly useful for works published after 1995 with a wide range of topics and journals.
3. Reporting and dissemination. In this phase, the available classifications of PSS were examined in detail. According to the guidelines, we received 450 articles covering the period 2001 to 2019. The choice based on title and summary leads to a limited set of 10 articles in which 10 PSS classifications were found.

4 Results

Based on the literature review, it is possible to identify a research gap in the available PSS classifications to focus further efforts on filling this gap. The biggest gaps in the PSS classification are:

- None of the methodologies classifications mention the Canvas Business Model, especially the areas in which they will be taken into account in the transformation from product manufacturer to the service provider.
- None of the available classifications took into account quality criteria related to solutions delivered to the customer.
- Little emphasis was also placed on sustainability issues. These aspects were signaled in some, however, when creating any classification, these criteria were not taken into account. Therefore, none of the typologies presented included the classification in terms of environmental, economic/financial as well as social performance in the proposed PSS-based solutions.
- The available classifications do not combine the variability of the PSS offer with the change in the structure and culture of the organization caused by the transition from producer to service provider.
- The available typologies are not able to capture the full complexity and capabilities of PSS. The classifications are not able to capture the differences and nuances that exist in practice between the different variants of PSS.
- Most classifications do not take into account market conditions and the environment. Market forces (demand, supply and competition characteristics) which companies face and which allow them to adopt the right strategy are ignored in the classifications.
- Insufficient characterization and reference to PSS user-oriented, PSS result-oriented, and PSS performance-based practices is an important issue. These are general descriptions that do not take into account product-specific parameters, strategies implemented by companies, market requirements and business practice.
- While creating the classification, the mechanisms concerning the company's revenues and customer costs are omitted.

5 Conclusions

The research discussed in this paper has been undertaken to identify the main weaknesses in the classification of PSSs and their limitations.

When analyzing the different typologies of PSSs proposed in the literature, some similarities and differences can be identified. Some classifications have been derived from others by developing or modifying them, some divisions are repeated by different authors, but are presented in a different context, while others represent a completely different approach to PSSs. One of the main common features is the orientation towards a product or a service, an aspect that is hidden under different names in each classification.

In the literature, we have identified 10 PSS classifications, 6 of which relate to the offer opportunities offered by PSS to enterprises and 4 to the transformation of enterprises from product manufacturers to service providers. Based on the literature, examples and available case studies, the classifications are not capable of capturing the diversity of PSSs, are not very detailed, and are not always able to meet the objectives and tasks that are set and set by the market. This is a very incomplete presentation of the types of systems that a manufacturer can create and offer on the market. The low level of detail in their description can make the transition from product manufacturer to service provider very difficult. The classifications presented in the first group are distinguished according to the range of values determined based on the product or service, i.e. they lead from a pure product to pure service. In the second group, they are distinguished according to the transformation of the manufacturing company into a more service-oriented company (strategy, cultural changes). Regardless of the group to which they have been qualified, the PSS classifications focus on the tangible value of the product, the intangible value of the service, the level of integration of these elements, the ownership of the product and the role of the producer/supplier. Subsequent types of PSS are presented in the available classifications in a very general way, only specifying who owns the ownership of the product in each of them. An important feature of the classification is their flexibility and universality, which allows them to be used in enterprises of different sizes and industries.

In addition, the analysis provides a solid basis for the development of new PSS classifications that will be able to capture the richness of the PSS offer and how the enterprise is transformed. It shows what improvements need to be made and what aspects need to be considered when developing a classification to fully reflect the scope of a PSS.

The analysis shows that the subject matter of the PSS classification is still evolving and that there is a need for a new, more accurate classification reflecting business practice in the PSS area. The analysis is the starting point for developing a new method to fill the gaps in the PSS classification.

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Publication V

Salwin, M., Kraslawski, A., Lipiak, J., Gołębiewski, D., and Andrzejewski, M.

Product-Service System business model for printing houses

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Journal of Cleaner Production
Vol. 274, pp. 122939, 2020

Journal of Cleaner Production 274 (2020) 122939

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Product-Service System business model for printing houses

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ARTICLE INFO

Article history:
Received 26 May 2019
Received in revised form
16 June 2020
Accepted 17 June 2020
Available online 17 July 2020

Handling editor: Cecilia Maria Villas Bôas de Almeida

Keywords:
Product-Service System
Printing industry
Printing houses
Printing machines
Business model

ABSTRACT

In the light of intensifying competition, growing customer needs and requirements, and bigger awareness of environmental impact, entrepreneurs are looking for new ways to improve and develop their operations. Currently available business models based on sales and the transfer of ownership rights to products from a manufacturer to the user, which do not include any additional services, do not create a possibility for the customer to fully exploit the products. After some time, machinery sold under such an arrangement ceases to be used and those who bought it have problems with selling the machinery and recovering capital frozen in it.

Therefore, seeking new business models seems extremely important as they may improve customer satisfaction and experience with the way products are offered to them and, at the same time, bring a number of benefits to entrepreneurs. One of possible solutions to the above-mentioned issues is the PSS model, which allows selling the accessibility and functions offered by products and their re-use.

This publication is an attempt to develop such a model for the printing industry. To this end, questionnaire-based studies were conducted in 80 printing houses from which we learned how printing machines are used and about the needs and problems faced by entrepreneurs.

Results of analyses suggest there are deep differences between small, medium-sized, and large printing companies as to the services in which these categories of businesses are interested. Profound analyses conducted for industries to whom PSS design methods are addressed, industrial PSS cases, questionnaire-based studies, statistical analyses, and consultations with experts from different fields helped in developing a new PSS model whose detailed structure, in particular for the printing industry, have never been broadly commented, studied or evidenced so far. This paper is intended to bridge this gap. The approach to the subject is also innovative as it is based on questionnaire-based studies which correctly reflect market reality. Moreover, all services tied to machines have been selected following in-depth statistical analyses and the proposed approach is unusually comprehensive as it covers micro, small, medium-sized, and large enterprises.

1. Introduction

Recently, we have been witnessing changes in business thinking. Due to growing competition, pressure on the increasing of value added by rendering services, and stress put on environmental protection, manufacturing companies are seeking to come up with better solutions for their products, which could produce higher profits (Annarelli et al., 2020; Beuren et al., 2013; Mont et al., 2006; Smith et al., 2014). Instead of focusing entirely on products, manufacturers are expanding their offers with services shifting from selling products to delivering tailor-made solutions for their clients (Brax, 2005; Burton et al., 2017; Salwin and Kraslawski, 2020; Vandermerwe and Rada, 1988). Except changes in the offerings,

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https://doi.org/10.1016/j.jclepro.2020.122939
0959-6526/

interactions with customers also evolve from a transaction-based single occurrence into a lasting customer-oriented relationship (Baines et al., 2007; Fernandes et al., 2020; Hakanen et al., 2017; Oliva and Kallenberg, 2003).

On the other hand, customer needs continue growing (Hakanen et al., 2017). Equipment effectiveness is one of the most prominent factors that customers take into account. They do not want to invest a lot of money in purchasing the equipment but they want the manufacturer to know their problems, needs and wishes and help in solving and meeting them by delivering solutions based on the product and service mix available at minimum cost (Aurich et al., 2006; Dimache and Roche, 2013; Green and Vergragt, 2002; Halme et al., 2004; James et al., 2001; Komoto and Tomiyama, 2008; Salwin et al., 2020).

The growing share of the service sector in the GDP and its increasing employment lead to the servitization of the economy (Statista, 2019). The process reduces the share of industry and forces manufacturing enterprises to look for new markets; manufacturers are seeing new market opportunities in combining products and services within the Product-Service System (PSS) model (Sawhney et al., 2004). PSS has caused revolution in traditional business models by opening up possibilities of making profit on the utility, availability, and capabilities offered by a product instead of selling the product itself. PSS is an alternative to mass production; it improves the overall value delivered to the customer by expanding the service components, PSS gives a perspective to pursue an innovation-based development strategy in industries at more advanced development stages and enables reuse of products (Agri et al., 1999; Baines et al., 2007; Mont, 2002; Tukker, 2015, 2004).

Climate change, shortages of raw materials and water, pollution and aging society have all stirred growing interest in sustainable innovation and business models (Aghion et al., 2009; Boons et al., 2013; European Commission, 2010; European Commission and Environment Directorate-General, 2012; Pelli and Lähtinen, 2020). These issues, together with a growing social pressure and awareness of environmental problems, force printing houses to look for new solutions. The diversity of products, printing techniques, raw materials used in the process and generated waste depend on technical capabilities of individual printing houses, work organization, types of raw materials they use, and the output. Each printing house produces harmful waste and is committed to handle them in a safe way in accordance with binding regulations. Reduction of waste and mitigating environmental impact are the major factors that motivate printing houses to bring the costs of production down (Fairley et al., 2014; Kam et al., 2019; Kelley and Sorce, 2006; Lipiak and Salwin, 2019).

Printing industry is a specific area of the manufacturing sector which deals with the development of designs (printing plates) of original texts or drawings and mass printing of their copies. Like any other type of production, printing can be defined through technologies used in the process, product characteristics, and links with other industries (Johansson et al., 2011; Kelley and Sorce, 2006; Kipphan, 2001; Meggs, 1998).

Printing is considered the key phase in the printing industry with printing machines as equipment playing the central role (Kelley and Sorce, 2006; Kipphan, 2001; Rees, 2006). Manufacturers of printing machines are seeking new development opportunities by making offerings that encroach on areas previously seen as ancillary or peripheral. The paper focuses on industrial printing machines used in printing houses. These machines are substantially different from regular office copiers used for printing out texts and graphics. The machines discussed hereto are used to print polygraphic products in industrial quantities. They are complex structures composed of many component elements made from various materials using advanced technologies and of very high value. In addition, each industrial printing machine can be described by its parameters which specify its capacity and operating characteristics: the shape of printed material, construction of the printing block, the way ink is applied, number of colors, number of printed pages, printing format, printing speed, auxiliary processes (applying coating lacquer, drying, folding), and the degree of automation. They enable printing onto a variety of media substrates.

The article presents a new PSS business model for printing machines. The drafted model stems from the analysis of industry-specific literature for industries to whom PSS design methods are addressed and industrial PSS cases. The construction of the model is also based on questionnaire-based studies conducted among users of printing machines, statistical analyses and consultations with experts in printing, trade in machines and finances. The customers and users of this PSS model are printing companies that purchase printing machines from their manufacturers. Financial scenarios were developed on the basis of financial data related to the purchase and use of machines obtained from one of the surveyed printing houses.

The paper is structured as follows: its first part is an introduction. Section two explains research methodology. The third part presents the most important features of the printing industry, machines used in it, the analysis of the Polish printing market and the results of surveys. Next part proposes a new PSS business model for printing machines industry. Section five includes financial analysis of the proposed model. Section six discusses potential benefits of the implementation of a PSS. The final part of the work presents the conclusions.

2. Research methodology

The aim of the work was to create a PSS business model for printing machines and to present the possibilities it creates for manufacturers and customers - priniting houses.

Research question formulated in this article is:

> "What possibilities does PSS give to the manufacturers of printing machines and their customers (printing houses)?"

In order to accomplish the goal stated for the paper and answer the research question we adopted the following research methodology (Fig. 1) encompassing three stages:

1. Systematic literature review. The stage was divided into two phases devoted to the review of literature on designing PSS and PSS case study analysis available for the industry.
2. Printing industry analysis and questionnaire-based studies. This stage comprises three components. The first consists in the examination of printing machine manufacturers, the second one investigates the Polish printing industry while the third one takes a closer look at users of printing machines, their needs and problems. It is also the stage, in which questionnaire-based studies and statistical analyses were carried out.
3. Building a PSS business model, expert consultations, and financial analysis. Based on systematic literature review, analysis of the printing industry and research-based studies we have worked out the initial framework of a PSS business model for printing industry. They were consulted with 10 experts having practical and theoretical knowledge in the industry in question (7 experts in printing, 1 in finance and, 2 in selling industrial machinery). Consultations were expected to provide opinions, positions and proposals concerning the PSS business model. After the best solution had been worked out, we conducted a

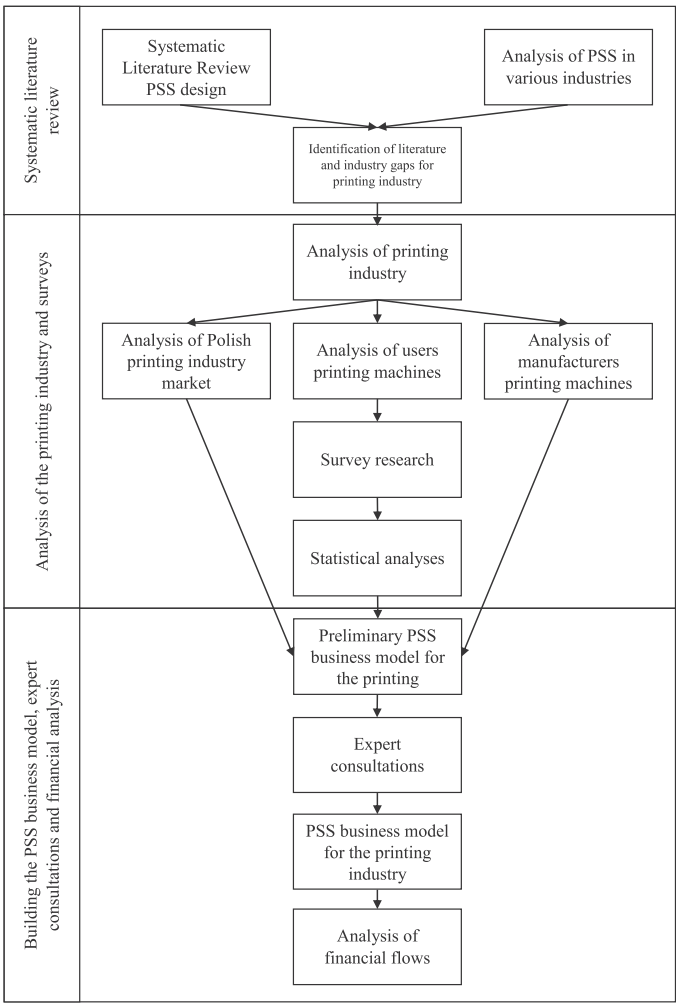


Fig. 1. Research methodology of the paper.

financial analysis to compare the traditional sales model with the PSS.

3. Literature review

3.1. Product-Service System design

Authors browsed the following databases: ProQues, Springler Link, Science Direct, Taylor & Francis Online, EBSCOhost, Scopus, Emerald, Insight, Web of Science, Ingenta, Wilma, IEEE Xplore Digital Library, and Google Scholar searching for the term "Product-Service System Design" or its synonyms (featuring in the title, abstract or keywords). As a result, we found 400 papers written over the period 2001–2019. Analysis of these papers gave us a set consisting of 64 publications including research papers, conference materials, chapters in monographs and books, in which we found 60 PSS design methods.).

The main sectors of economy to which the available PSS design methods are addressed have been identified (Fig. 2). Some PSS design methods target several different industries. Most of them, 14, have been designed for mechanical engineering. They cover solutions for cutting devices, angle grinders for cutting steel, heavy road machinery, valves, and tank gauging systems (Alonso-Rasgado et al., 2004; Aurich et al., 2006; Matzen and McAloone, 2006) as well as solutions for cooling equipment, cranes, compactor

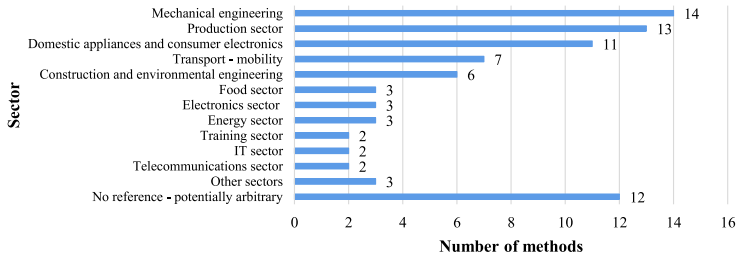


Fig. 2. Classification of PSS design methods by sector (Salwin et al., 2020).

machines, laser systems, and agricultural machinery (Dimache and Roche, 2013; Sundin et al., 2009; Vasantha et al., 2012; Ziout and Azab, 2015). In addition, these methods include solutions for CNC machine tools, lifts, manufacturing machines, and aviation industry (Adrodegari et al., 2017; Campos et al., 2017; Shimomura et al., 2009; Wood and Tasker, 2011). Remarkably, there are no design methods that would target the printing industry (Salwin et al., 2020).

3.2. Product-Service Systems in various industries

The authors focused on the analysis of PSS models that are used in industry. They searched for the term „Product-Service System in industry" or its synonyms (in titles, abstracts and keywords) in the above-mentioned databases. As a result, a collection of 120 works was obtained (research papers, conference materials, chapters in monographs and books, reports, and white papers) for the period 2001–2019. Table 1 is an overview of the most popular PSS models in individual industries.

The analysis shows that PSS models are used by large multinational corporations, leaders in their respective industries having deep specialist knowledge and experience. These enterprises exhibit a lot of professionalism in planning and executing their activities and have deep knowledge about the market. They have mastered technologies used to manufacture their products, actively and constantly seek technological innovation, have deep knowledge about their products because they have access to data, know optimum working conditions and potential improvement perspectives through continuous updating of their products or proposing better ways of using them. These multinational corporations also have financial resources and are very competent in recruiting human resources. Besides, they are strongly market-oriented which is why they are actively looking for new ways of providing value to their customers. Additional strength comes from their contacts and relationships with customers that have been developed over many years. On top of that, these companies offer high value products, machinery, and equipment based on top notch technologies and characterized with long service life. These are machines and equipment of critical importance to their clients' business. Moreover, these products require rather complex repairs and their unavailability may create serious problems to clients. When buying them, clients may face problems relating to their use and maintenance.

Xerox is a flagship example and one of precursors of PSS-based operations. The company manufactures xerox machines, critical components of office equipment. Compared to other examples, photocopying machines are much cheaper, easier to use and their return on investment rate is much shorter.

4. Printing industry

The EU printing industry comprises almost 120,000 companies employing ca. 770,000 people. It is dominated with family, medium, small, and micro enterprises operating mainly in domestic

Table 1
Examples of PSS in industry.

	Company	Type of product	PSS description	Source
1.	Alstom	Trains	Pay per kilometers for train	Baines et al. (2007)
2.	Arcomet	Construction cranes	Rental services, including assembling and disassembling	Van Ostaeyen (2014)
3.	Atlas Copco	Air compressors	Rental services or sales of compressed air per m^3	Van Ostaeyen (2014)
4.	Caterpillar	Construction and mining equipment	Financing, insurance, equipment rental, maintenance, support, operator training.	Tan (2010)
5.	Cockerill Maintenance & Ingénierie	Shunting locomotives	Leasing of shunting locomotives for steel manufacturing	Van Ostaeyen (2014)
6.	MAN	Truck	Pay per kilometers for trucks.	Baines et al. (2007)
7.	Rolls-Royce	Aircraft engines	Power-by-the-Hour service packages, whereby maintenance, repair and overhaul are charged at a fixed price per hour of flight to the customers (i.e. airline companies)	("Rolls Royce: Britain's lonely high-flier," 2009)
8.	Xerox	Office equipment	Leasing or pay-per-copy models—leasing, maintenance, equipment monitoring, paper and toner supply, document and data management, etc.	Xerox (2019)

markets. They generate annual turnover reaching almost EUR 88 bn.

Printing production processes are complex and their stages differ a lot when it comes to technologies or machines (International Paper Company, 2003; Kipphan, 2001; Kleper, 2001). In accordance with ISO, 20067, the production of printing products consists of three main stages: prepress (DTP studio, exposing images onto copying and printing plates), press (printing house, print), and postpress (bindery, finishing processes) (ISO, 20067–1:2006).

Printing industry products include books, brochures, newspapers, advertising leaflets, billboards, invitations, labels, packagings, etc. One of its features is the need to choose the type of printing production (specialized production tools, technological processes, and staff). Because of the costs, specialist knowledge, competition, and the size of output printing houses specialize in just one printing technique (Johansson et al., 2011).

Modern technologies and automation of processes increase the productivity of the sector and its ability to offer a full array of services. The latter may include database management while innovative processes, such as 3D printing, smart labels, and flexographic printing, offer potential for new services (KPMG et al., 2018).

4.1. The printing machinery

Technologically, printing machinery is very complex, filled with mechanical, electronic and IT functions. To design and manufacture them one needs designers and service staff competent and skillful in many technologies and printing processes.

A comprehensive offer covers specialist machines sold in diverse set-ups and basic services connected with installation, servicing, and training. As information on the subject is little available, knowledge about the market is very limited.

The list of major manufacturers of printing machines includes companies, such as: Nilpeter, Mark Andy, Comco, Gidue, Bobst, Edale, KDO, Omet, Lombardi, KPG (former KO-PACK), Gallus, Propheteer, Arsoma, Miyakoshi, Heidelberg, Koenig & Bauer.

4.2. Printing industry in Poland

The Polish printing sector ranks 7th in the European Union when it comes to revenues (4.1% of all revenue generated by the printing industry), 7th when it comes to the number of companies (7.3% of all printing businesses), and occupies 6th place in the employment ranking (6.9% share in total employment in the EU industry) (Fig. 3). On top of that, the Polish printing sector is the biggest in its category in Central and Eastern Europe (Fig. 4). It represents 36% of revenue and 34% of the total workforce employed in this sector in Central and Eastern Europe.

The printing industry in Poland has been growing very fast and is one among very few processing industries that has been growing continuously from 2009. In 2015 in Poland there were 8928 companies (8210 out of them were micro-businesses) (Fig. 5) employing 50,400 people (Fig. 6). The value of their production sold in 2015 amounted to EUR 3.4 bn (Fig. 7), revenues reached EUR 3.38 bn (Fig. 8), and exports of the printing industry was EUR 2018 million (Fig. 9). In 2016 the population of active printing businesses increased to 9361 (Fig. 5), their production sold was EUR 3.7 bn (Fig. 7) while exports reached EUR 2159 million. According to estimates, the value of production sold in 2019 will achieve EUR 4 bn (Fig. 7).

Dynamic expansion of the printing market and the growing number of printing houses in Poland expand the market for printing machines manufacturers.

4.3. Why printing machines?

Our focus on printing machines is dictated by the following factors:

1. The available literature on PSS does not provide models or design methods that would target printing machines.
2. In practice, there are no PSS business models related to printing machines. The PSS business model works for copiers, which are used for printing but differ significantly in terms of space, scope and performance, construction, price and service life.
3. Printing houses work continuously – hence machines are critical to the printing business.
4. According to recently conducted research, high costs of purchase and service of printing equipment are a barrier to the development of printing enterprises (KPMG et al., 2018, 2011).
5. Modularity of printing machine facilitates adaptation of new technological solutions in used machines.
6. Printing machines can have different configurations depending on the type of work, substrate, ink and print width. There are no two machines and printers that are identically configured, so service needs and printing houses requirements are different.

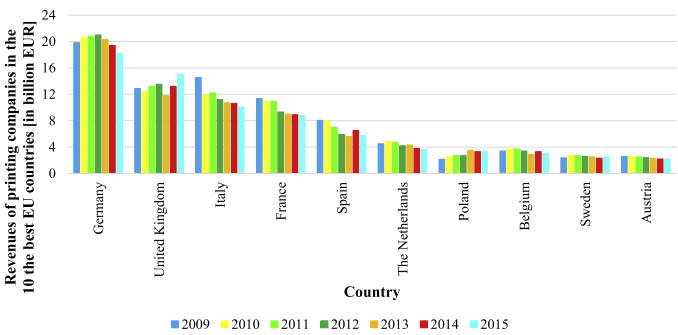


Fig. 3. Revenue of printing companies in ten of the biggest printing markets in the EU [in billions of EUR] (KPMG et al., 2018, 2016, 2014, 2011).

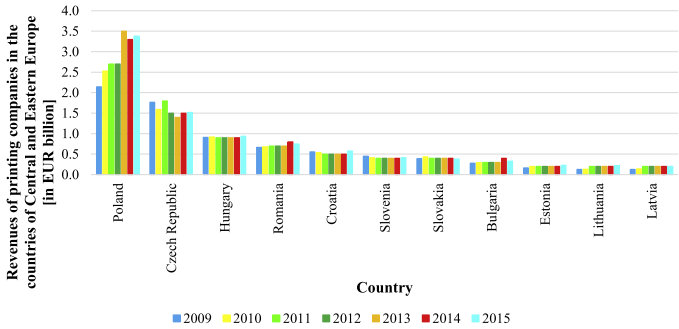


Fig. 4. Revenue of printing companies in countries of Central and Eastern Europe [in billions of EUR] (KPMG et al., 2018, 2016, 2014, 2011).

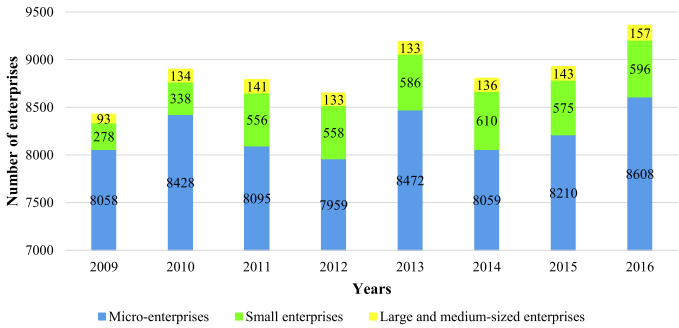


Fig. 5. Enterprises by size in the Polish printing sector in the years 2009–2016 (KPMG et al., 2018, 2016, 2014, 2011).

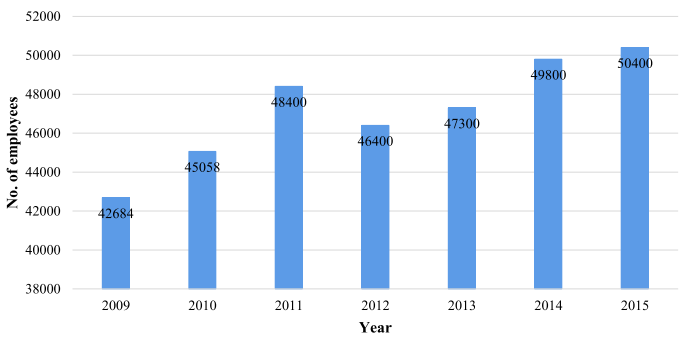


Fig. 6. Employment in the printing industry in Poland in the years 2009–2015 (KPMG et al., 2018, 2016, 2013, 2012).

7. Today we are witnessing the emergence of hybrid devices that combine the advantages of different printing systems. For example, the BOBST M5 servo flexo machine is used to print unlimited substrates, with full temperature control, tension and automatic fit.
8. Procurement solutions currently offered by manufacturers of the above-mentioned machines are based on traditional purchase models (own resources, leasing, bank loan), in which additional services under the warranty scheme are available to the printing houses only in the first year following the purchase. Initiatives undertaken by manufacturers are limited to machine design, ensuring basic services, and exchange of parts. An often occurring aspect is the delivery, putting into operation, work ergonomics, and

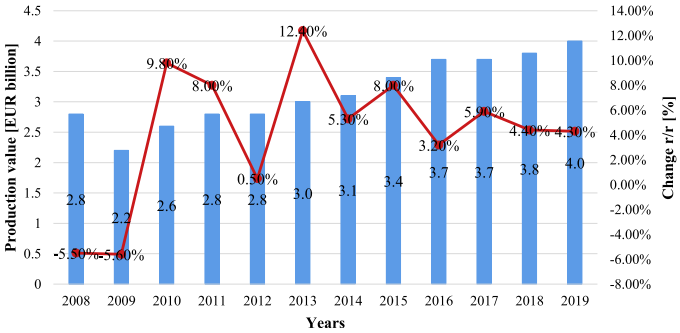


Fig. 7. Production sold in the printing industry in Poland in the years 2008–2019 (KPMG et al., 2018, 2016, 2014, 2011).

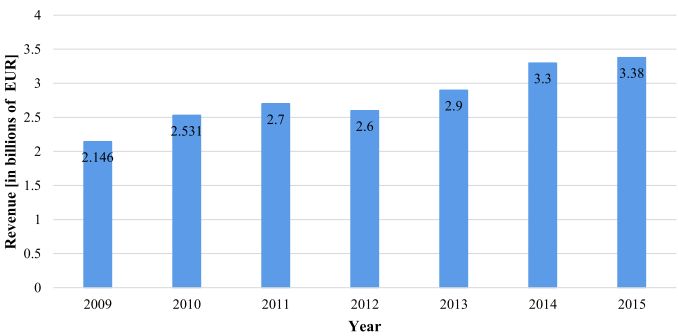


Fig. 8. Revenue of Polish printing companies in the years 2009–2015 [in billions of EUR] (KPMG et al., 2018, 2015, 2014, 2011).

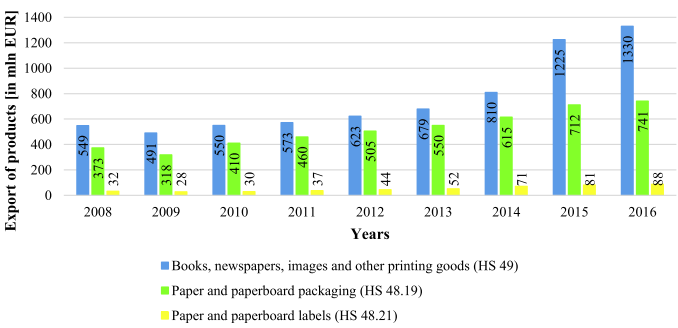


Fig. 9. Exports of printing industry products from Poland in the years 2008–2016 [in millions of EUR] (KPMG et al., 2018, 2015, 2013, 2011).

machine user training. Issues connected with broadly seen printing houses needs and the reduction of environmental hazards involved in exploiting a printing machine are considered to a very little extent. That is why it is interesting to investigate what services users need and how they can be reached with offerings that integrate products and services (based on the PSS) intended to satisfy their needs and reduce harmful environmental impact created by their use.

9. High value of printing machines that are no more used by printing houses is a valid reason why we should examine this market. Major features of printing machines include workmanship quality, printing precision, printing speed, shape of printed material, the set-up of the printing component, way

in which ink is transferred onto the printed surface, number of available colors, printing format, additional processes (lacquering, drying, folding), degree of automation and longevity. Printing machines are durable and with proper maintenance they can work in a printing house for many years. We need to bear in mind that some components (in flexographic printing machines), such as, e.g., UV lamps, UV lamps filters and mirrors, anilox rollers, and bearings get worn out much more quickly than printing components. In the case of digital printing machines, such elements are heads consisting of expensive modules (there can be 24 or more of them). Depending on the intensity of use, inspection and maintenance, the modules have to be replaced every 2–3 years. Hence, there are differences in the longevity of individual components of a printing machine. On top of that, after some time of being used or when there are no orders for products printed on some specific machines, printing machines are usually set aside and stay idle in a printing house. It all leads to ineffective use of resources and puts the users at an economic disadvantage.

10. Other factors include the price and the size of a printing house (customer). Printing machines are very expensive and not all small or medium-sized enterprises can afford buying them. By introducing a new model, we expand the market for manufacturers not only by making the same machines available to other users but also by coming up with offers to companies which would want to develop and use such machines but for financial reasons cannot afford them.
11. There is also an important difference between workmanship quality (manufacturers declare that with proper maintenance a machine can work for 20–30 years or print 800,000,000 running meters) and the real time for which such a machine is used by its first owner. Studies conducted in 80 printing houses have shown that only 7 out of them (8.75%) use a printing machine for longer than 10 years (Fig. 10).

In this case, a combination of a product and a service may ensure longer useful life of a machine for one user. Another opportunity offered by the PSS is to take a second hand machine from its current user, repair or modify it, if needed, and to make it available again in the market of second hand printing machines. Every machine that is not used in printing houses is taken away by the manufacturer and made available to another printing house. It means manufacturers are paid not only by the first buyer but also by subsequent customers. In the meantime when the machine is being modernized and repaired to expand its lifespan and the number of clients using it to the maximum.

12. Another important factor is the divergence between the useful life of a printing machine proposed by the manufacturer and the period within a machine is used by one printing house and the possibilities of improving the machine by one printing house and fine-tuning its technical parameters from the viewpoint of the economy and environmental protection.

The above stated reasons explain why the printing machines industry needs a new business model which will provide a printing machine and services connected with it at adequate prices. A PSS model that makes high quality new and/or second hand machines available to printing houses for as long as they plan to use them could help companies generate higher profits as a result of having a machine and a service package linked with it. It also helps printing houses in disposing the machine when its further use is not effective from the viewpoint of the printing house (customer) or when replacing it with a new one could bring in more benefits. Besides, the model eliminates the necessity to look for a potential buyer who would like to purchase the machine.

4.4. Customer of printing industry in Poland

We conducted a study among 80 printing houses to identify services they need the most when they purchase a printing machine. The study was conducted among printing houses from all over the country. We received 80 questionnaires with answers that we could further analyze. At the beginning of our questionnaire-based study we approached 140 printing houses meaning the return rate was 57%. The companies were identified through a database of printing companies. The research focused mainly on flexographic (50%), offset (40%) and digital (10%) printing houses. The used research tool was a questionnaire. Printing houses, which participated in the study were mostly SMEs, only 12 out of them (15%) were large enterprises (Fig. 11). The aim of the research was to understand the industrial practice and obtain information that will help to build a PSS business model.

In order to segregate and get more information about the services that printers need for their printing machines, the questions about services have been divided into four main areas (Figs. 12–15):

- services according to the Polish Classification of Goods and Services (PKWiU),
- services connected with a printing machine,
- services connected with printing,
- ancillary services.

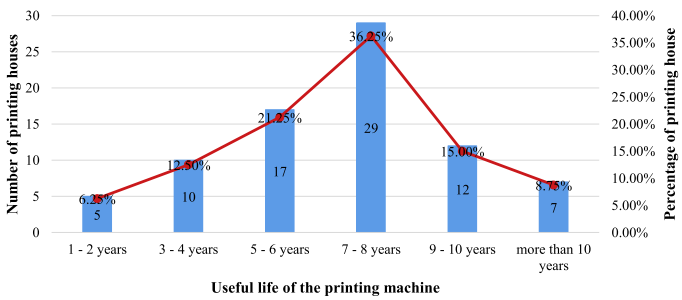


Fig. 10. Useful life of printing machines in companies.

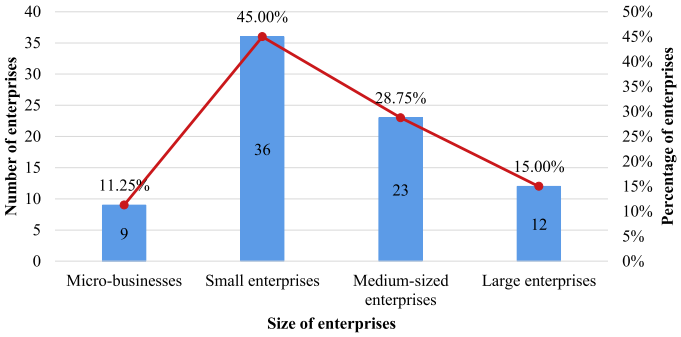
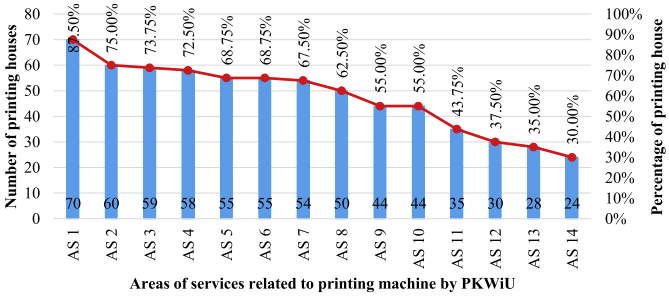
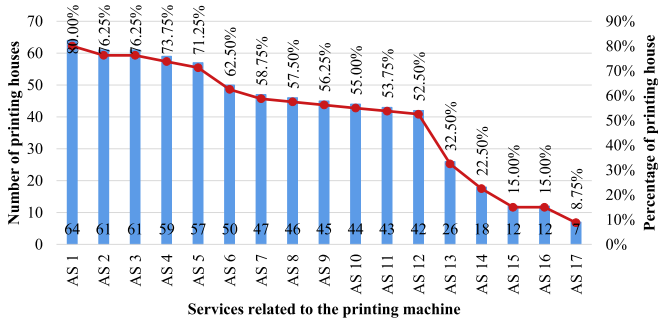


Fig. 11. Size of enterprises covered by the study.



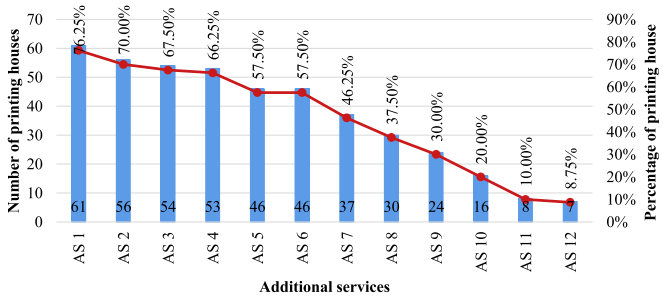
AS 1 - Professional, scientific and technical services; **AS 2 -** Information and communication services; **AS 3 -** Financial and insurance services; **AS 4 -** Transport and storage; **AS 5 -** Education; **AS 6 -** Commercial services; **AS 7 -** Administrative and support services; **AS 8 -** Support services; **AS 9 -** Electrical services; **AS 10 -** Water supply services; sewage and refuse and remediation services; **AS 11 -** Industrial production services; **AS 12 -** Health and social work services; **AS 13 -** Real estate services; **AS 14 -** Cultural, entertainment, sports and leisure services;

Fig. 12. Areas of services relating to a printing machine by PKWiU [Polish Classification of Products and Services].



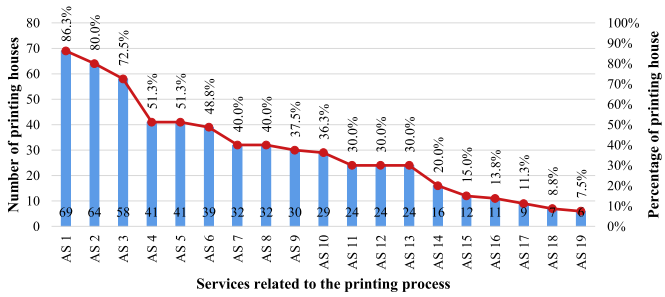
AS 1 - Installation and commissioning of the machine; **AS 2 -** Delivery of the machine to the customer; **AS 3 -** Supply of spare parts; **AS 4 -** Supply of consumables; **AS 5 -** Waste management services; **AS 6 -** Regeneration, overhaul, repair, maintenance; **AS 7 -** Health and safety at work services; **AS 8 –** Warranty; **AS 9 -** Financial services; **AS 10 -** Cloud data storage; **AS 11 -** Machine documentation (paper or online); **AS 12 -** Help Desk (machine, process, business); **AS 13 -** Take-back; **AS 14 –** Cleaning; **AS 15 -** Management of the working environment; **AS 16 -** Noise reduction; **AS 17 –** Disassembly;

Fig. 13. Basic services related to the printing machine relevant to printing houses.



AS 1 - Optimisation of the use of materials; **AS 2 -** Optimising the use of equipment; **AS 3 -** Full control of the operation of the device after a fixed period of use; **AS 4 -** Diagnostics, error recovery and repair; **AS 5 -** Monitoring, testing and diagnosis of the machine; **AS 6 -** Training; **AS 7 -** Waste management; **AS 8 -** Update (Reconstruction, modernisation); **AS 9 -** Lean tools; **AS 10 -** Production planning and monitoring; **AS 11 -** Manages one or more activities on behalf of a client; **AS 12** – Audits;

Fig. 14. Ancillary services linked with a machine that a printing house wishes to purchase.



AS 1 - Selection, delivery and optimization of paint consumption for a specific order; **AS 2 -** Printers' training; **AS 3 -** Replacement of mirrors, filters and UV lamps; **AS 4 -** Preparation of CTP boards; **AS 5 -** Optimization of changeovers of printing machines; **AS 6 -** Printing equipment cleaning; **AS 7 -** Optimal time for changing printing forms; **AS 8 -** Mixing of paints; **AS 9 -** Optimisation of the delivery time of clean equipment to the printing machine; **AS 10 -** Technological process design; **AS 11 -** Preparation of materials for production; **AS 12 -** Optimal quality and cleanliness of the supplied printing equipment; **AS 13 -** Designing materials for printing; **AS 14 -** Preparation of tools for production; **AS 15 -** Help in selling used machine; **AS 16 -** Selection of printing substrate; **AS 17 -** Calibration, settings and adjustments; **AS 18 -** Design, production, assembly and assembly of a printing plate; **AS 19 -** Disposal of paints;

Fig. 15. Services linked with printing and with a printing machine that printing houses would like to buy.

In order to increase the freedom of expression, questions on: problems during the printing process, improvement tools used in printer houses, aspects that printer houses would take into account when creating a new business model for PSS and the risks associated with it were dealt with in open questions. The remaining questions were closed ones. Collected answers have revealed a wide array of diverse services which may target printing houses in the PSS model.

Results of studies show big interest of printing houses in services integrated with printing machines in each of the above four areas. Results of our studies are summarized in the Table 2 below.

4.5. Statistical analysis

To examine the relationship between the intention to get a given service and the factor that characterizes an enterprise, we used the following indicators of statistical dependence:

- Spearman's rank correlation coefficient for variables that can be presented on an ordinal scale
- Chi square (χ^2) independence test for variables that can be presented on a nominal scale.

Each service within the four main areas (services according to the Polish Classification of Goods and Services (PKWiU), services connected with a printing machine, services connected with printing, and ancillary services) was statistically tested against features typical of printing houses.

4.5.1. Spearman's correlation

Four main service areas were statistically tested for Spearman's correlation against the following features of a printing house:

o Company size (micro, small, medium, large);

Table 2
Summary of study results.

Study results
When purchasing a printing machine, printing houses consider: ancillary services and productivity (speed of printing, number of available colors), time and speed of reset, technological advancement and capabilities of a machine, printing precision and print quality.
The length of warranty period is a vital component of the offering
The most frequent purchase format for printing machines is leasing, the most rare: purchasing with own funds.
Fifty printing houses (62.5%) purchased machines together with services, the contract is usually concluded for several years. Twenty printing houses (25%) concluded service contracts for not more than 2 years, while for 16 printing houses (20%) it has been signed for between 3 and 4 years.
Companies have problems with maintaining an adequate air temperature and humidity in the production hall, which deteriorates print quality
Main problems involved in printing include:
- in flexographic printing houses: long reset times, difficulties with mixing and supplying ink, cleaning printing equipment and molds, insufficient skills of the staff, and paper dust.
- in offset printing houses: ink consistency, toning (i.e., visible traces of ink in places where it should not be applied), cleaning printing equipment, gluing and fixing product layers, paper dust and humidity, scratches, strokes on printed surface, rolling and folding of paper, difficulties with color matching, double printing, uneven placement of sheets, paper sticking.
- in digital printing houses: maintaining identical color on repeated works, stripes and lines on prints, toner falling on paper, differences between the design and actual print, wear and tear of drums, lasers and developer units
The problem common to all types of printing houses is a large amount of waste (printing inks, varnishes, adhesives, liquid waste, developers for offset plates, solid waste, silver-bearing waste i.e. fixatives and films from the light room, hazardous waste, cleaners, sorbents, offset plates, used oils, plastic packaging waste, metals), their disposal and lack of possibility of reuse.
63 printing houses (78.75%) would be ready to cooperate with the manufacturer of printing machines under the PSS model.
49 printing houses (61.25%) could shift from a traditional purchase model of a printing machine to a PSS model
Due to big distances and procedures followed by printing machine manufacturers, printing houses covered by the study considered the speed with which manufacturers respond to emergencies (unexpected damages/failures, etc.), urgent occurrences and problems in their company to be the main risk factor.
In 50 (62.50%) printing houses reset time exceeds 10 h a week. It accounts for almost 50% of all losses. Other time-related and financial losses, linked with the elimination of problems in production and failures account for ca. 20% of wastages.
Important tools used in printing houses include: 5S, OEE, RFID, Six Sigma, SMED, SPC, TPM, Ishikawa diagram, spaghetti diagram, and QFD.
Main aspects to be taken into account by printing houses when developing a new PSS are: computerization, monitoring, well-developed network of manufacturer's service points, spare parts availability, assistance in optimizing the printing process, possibility to acquire a new machine when the company does not need the old one any more, major and periodic check-ups and timely execution of manufacturer's obligations.

- o Product range (1–20; 21–40; 41–60; 61–80; 81–100, and more than 100 products);
- o No. of shifts per working day (1, 2, 3);
- o Total weekly breakdown time (less than 2 h; 2–4; 4–6; 6–8; 8–10, and more than 10 h).

In order to examine the dependence between a feature of a given printing house and the wish to get a particular service we used Spearman correlation coefficient. We also statistically tested a null hypothesis according to which such a correlation does not exist. All tests were conducted at the 0.05 level of significance. If the null hypothesis is correct, i.e., if a particular printing house does not want to get a certain service, test statistics used in the study has a t-distribution with N-2 degrees of freedom where N means the number of various printing houses covered by the statistical analysis. To learn about the correctness of the null hypothesis, we used p-value indicator, meaning the null hypothesis is rejected when p-value is below the adopted level of significance of 0.05. Spearman coefficient, in turn, is a helpful tool in identifying the strength of the association. If it is positive and close to 1, the likelihood that a printing house will want to get a particular service is the higher, the higher the rank-order of a given feature of a business. Otherwise, i.e., when Spearman coefficient is negative and close to −1, the dependence is as follows: the likelihood that a printing house will want to get a particular service is the higher, the lower the rank-order of a given feature of an printing house. Detailed information concerning results obtained for Spearman coefficient, Student's t-distribution test statistics and the p-value can be found in the Appendix.

All cases in which p-value coefficient was below the significance level, i.e., situations when an association was found between the feature represented by a printing house and the wish to get a service, are marked in red (Appendix Tables 9–12).

Analysis conducted using the Spearman coefficient shows that the features of printing houses exhibiting the biggest association with the wish (or the absence of it) to get a given service include: company size, product range and number of shifts per working day. Total weekly breakdown duration appears to be much less correlated with services (Table 3).

The analysis reveals a clear division into:

- micro and small printing houses offering a small range of production types and working one shift
- large and medium-sized printing houses whose production range is very wide, working more than one shift.

In each of the four areas both groups of companies focused on completely different services. The selection of services from each area covered by the study is presented in the table below. Statistical test demonstrated also that:

- printing houses are interested in services defined according to the Polish Classification of Goods and Services (PKWiU); and services connected with a printing machine,
- large and medium-sized printing houses offering wide range of production types and working more than one shift, are interested in ancillary services.
- micro and small printing houses offering small range of production types and working one shift only, are interested in services related to the printing process.

4.5.2. Test chi square (χ^2)

For a nominal variable, such as the type of a printing house (flexographic, offset or digital), we used chi square test of independence, a non-parametric test, to test the existing dependences. As the test is non-parametric it can be used for any distribution of analyzed variables.

Null hypothesis and alternative hypothesis for the chi square test were expected to show whether there is any association between the following variables: type of the printing house and a service can be presented as follows:

Table 3
Spearman's correlation results.

Area of services	Results
Areas of services relating to a printing machine by PKWiU	Micro and small printing houses offering small range of production types, working one shift are interested in financial and insurance services, provision of electricity and water supply; sewerage system, waste management and remediation services connected with it; professional, scientific and technical services, administrative educational services and support services. Large and medium-sized printing houses offering a wide range of production types and working more than one shift are interested in information and communication services, industrial, trade services, services connected with real estate market, cultural, sports and recreational services, medical care and welfare services.
Services connected with a printing machine	Micro and small printing houses offering small range of production types and working one shift are interested in services connected with supplies of spare parts, supplies of machinery to customers, financial services, supplies of exploitation materials, disassembly. Large and medium-sized printing houses offering a wide range of production types and working more than one shift are interested in security and health and safety services, data storage in cloud, waste management, and take-back services.
Additional services	Large and medium-sized printing houses offering a wide range of production types and working more than one shift are interested in waste management, optimization of material use, managing one or more operational lines on behalf of the client, diagnostics, elimination of errors and repairs, lean tools, optimization of the use of equipment.
Services related to the printing process	Micro and small printing houses offering a small range of production types and working one shift are interested in services such as the replacement of UV mirrors, filters, and lamps, optimum quality and cleanness of supplied printing equipment, pigment mixing, preparing tools for production, optimizing the time needed to deliver clean equipment to the printing machine, technological process design, ink disposal, preparation of materials for production, optimum time of printing plates replacement, washing printing equipment, CTP plates preparation, selection, delivery and optimization of the use of inks for individual orders, training courses for printers.

- Null hypothesis: variables X and Y are independent (the type of a printing house impacts its wish to get a particular service).
- Alternative hypothesis: variables X and Y are not independent (the type of a printing house has no impact upon the wish to get a particular service).

Chi square test compares observed values (obtained in the study) and theoretical values (calculated under the assumption that the variables are not related at all). Big differences are indicative of dependences between variables.

Assuming that variable X (type of a printing house) changes at k levels and variable Y (type of service) at s levels, test statistics is calculated from the formula:

$$\chi^2 = \sum_{i=1}^{k} \sum_{j=1}^{s} \frac{(n_{ij} - n'_{ij})^2}{n'_{ij}}$$

where:

- n_{ij} – observed cardinalities,
- n_{ij}' - theoretical cardinalities.

If we assume that the null hypothesis H0 is correct, test statistics has chi square distribution with $(k-1)\cdot(s-1)$ degrees of freedom. Critical area in this test lies on the right-hand side $[\chi^2\alpha,\infty)$, where $\chi^2\alpha$ is a value taken from χ^2-distribution tables for the level of significance = 0.05.

All cases in which p-value coefficient was below the significance level, i.e., situations when an association was found between the type of a printing house and the wish to get a service, are marked in red (Appendix Tables 13–16).

Analysis of χ^2 shows that in general, the type of a printing house is not the key factor that impacts the wish to get individual services from different areas. Out of all 62 services significant dependence was found for 10. In most cases for which the dependence was identified, the wish to have the service was the biggest amongst flexographic printing houses (Table 4).

5. Proposed business model for printing industry

Analyzing the needs and problems of users of printing machines (printing companies), New Concept Canvas (Table 5) was developed. It gives the possibility to systematize the acquired information in order to develop further concept of the business model.

Manufacturer will be able to make printing machines available in 8-year cycles together with a package of services tailored to printing houses needs. It will help in the best use of the potential of printing machinery and reduce their environmental impact. Manufacturers will also be able to monitor the productivity of the machinery and the condition of its components. After the end of the service life of the machinery, manufacturers will take the machines back from the clients to carry out necessary renovations and check-ups. Then they will be able to make them available again to the same or different customers.

Studies that we conducted allowed dividing services into certain packages. Service packages, Table 6, are ranked starting from standard ones and finishing in specialist solutions. In the new PSS business model (Figs. 16 and 17), a manufacturer offers his customers (printing houses) services in the area of printing engineering, a package of services founded on specialist knowledge and know-how connected with printing machines and all processes that take place at individual stages of the printing process. Services in printing engineering aim at optimizing processes taking place in the printing house which are expected to contribute to printing house successes and good financial performance.

Our studies demonstrated that users of printing machines would be interested in such a solution. Out of 80 printing houses covered by the study, 49 (61.25%) were in favor of the change of the traditional model of purchasing a printing machine to a PSS-based model. It confirms a big market potential for PSS-type systems.

Reverse logistics is the central element of the model. After 8 years a machine will be returned to the manufacturer who will repair it. The system of reverse logistics should be environmentally friendly and economically viable. When planning receiving a machine from the current user and its repair a company may minimize environmental impact and reduce cost by taking several machines at a time.

Table 4
Test chi square (χ^2) results.

Area of services	Results
Areas of services relating to a printing machine by PKWiU	The type of a printing house is a variable exerting statistically significant impact upon three types of services from the area. There is a clear association between the type of a printing house and the wish to get ancillary services (p-value = 0.00000011104, df = 2, χ^2 = 32.02666667), industrial production (p-value = 0.000641064, df = 2, χ^2 = 14.7047619), and educational services (p-value = 0.0000053903, df = 2, χ^2 = 24.26181818). These services are most frequently selected by flexographic printing houses. The offset printing houses are the least interested in the services in question. The likelihood of having an ancillary service is the highest for flexographic and the lowest for offset printing houses.
Services connected with a printing machine	There is a clear dependence between the type of a printing house and the wish to get a cleaning service (p-value = 0.01456126, df = 2, $\chi 2$ = 8.458781362). These services are most frequently selected by flexographic printing houses. The offset printing houses are the least interested in the service in question, while flexographic printing houses are the most interested in it. The likelihood of having an ancillary service is the highest for flexographic and the lowest for offset printing houses.
Ancillary services	The type of a printing house is a variable that exerts statistically significant impact on three types of services from this area. There is a clear association between the type of a printing house and the wish to get the service optimizing the use of materials (p-value = 0.00005866954774036, df = 2, $\chi 2$ = 19.48717949), optimizing the use of equipment (p-value = 0.000026230457, df = 2, $\chi 2$ = 21.09717868), and lean tools (p-value = 0.000998665, df = 2, $\chi 2$ = 13.81818182). These services are most frequently selected by flexographic printing houses. For services consisting in the optimization of the use of materials the offset printing houses are the least interested in this service while flexographic printing houses are the most interested. The likelihood of getting this service is the biggest for flexographic printing houses and the smallest for digital printing houses. For services consisting in the optimization of the use of equipment and lean tools the digital printing houses are the least interested in such services while flexographic printing houses are the most interested. The likelihood of having these services is the biggest for flexographic printing houses and the lowest for digital ones.
Services related to the printing process	The type of a printing house is a variable that exerts statistically significant impact on three types of services from this area. There is a clear association between the type of a printing house and the wish to get a service in optimizing set-up costs for printing machines (p-value = 0.000000000235, df = 2, χ^2 = 44.34285714), washing the printing equipment (p-value = 0.003322391, df = 2, χ^2 = 11.41414141), optimum time of replacing printing plates (p-value = 0.021351414, df = 2, χ^2 = 7.69327467), ink mixing (p-value = 0.021351414, df = 2, χ^2 = 7.69327467), optimizing the time of delivery of clean equipment of the printing machine (p-value = 0.023912993, df = 2, χ^2 = 7.466666667), calibration, setting and adjustment (p-value = 0.00, df = 2, χ^2 = 70.23474178). Calibration, setting and adjustment services are most frequently selected by digital printing houses, other by flexographic printing houses. Offset printing houses are the least interested in calibration, setting and adjustment services while digital printing houses are the most interested. The likelihood of getting the service is the highest for a digital printing house and the smallest for an offset printing house. For the remaining services, we can observe that digital printing houses are the least interested in the services in question while flexographic printing houses are the most interested. The likelihood of having the remaining listed services is the biggest for flexographic printing houses and the lowest for digital ones.

Vital components of the system are the location of a service centre and logistics. Most activities connected with the diagnostics and monitoring the technical condition of a machine can be performed by the service provider remotely, however, replacement of parts requires physical presence of skillful servicemen. One also needs to investigate how machines are transported as in the case of these big and complex units it can be a problem. Dismantling and transporting the machines is an option when new or renovated machines are supplied to the printing house or when a machine is returned to the manufacturer. To carry out these costly and time-consuming operations a company must have very skillful people. Before leaving for the printing house, new and renovated machines are tested by the manufacturer, dismantled and prepared for the shipment. Transport and installation of a new printing machine at user's premises are very complicated. After being installed in a new place machines can reveal some imperfections in their performance over the start-up period. The bigger the machine, the more complex the operations and the bigger the possibility of such shortcomings.

Another vital element of the proposed model is a system of delivering spare parts to printing houses, recycling and storing waste (Figs. 16–18). It is necessary to create information channels between a manufacturer and a customer concerning supplies, returns, and parts classification as waste. Machine condition monitoring plays an extremely important role as it helps both sides realize what may be necessary in a given moment. (See Figs. 16 and 18).

How services are delivered to a printing house is fundamental. A company may take advantage of external assistance or designate a special department or a group of employees to deal with this aspect.

6. Financial analysis: new concept

The analysis of financial flows was based on the price of a new flexographic printing machine the value of EUR 885,000 (production cost is EUR 350,000) after a period of 8 and 16 years, service

Table 5
New concept Canvas.

The problem	Solution	Competition
High costs of purchase and service of printing equipment are a barrier to the development of printing companies.	Product-Service System business model for printing industry - a solution divided into packages of print engineering services (it deals with product design, selection of materials and printing processes, as well as control, operation, organization and management of printing processes and operation of printing machines), depending on printing houses (customer) needs.	There is no such solution on the market for printing machines (not to be confused with photocopiers)
Machines are usually used for no more than 8 years.	Making printing machines available to printers of different sizes (printing houses) in 8-year cycles	Leading manufacturers offer only standard services related to the printing machine
Printing machines must be handled in an appropriate manner	Standard services associated with a printing machine during its life cycle	
Waste problems	Choice of waste treatment and disposal	
Regardless of printing technology, printers face problems at every stage of the printing process	On printing houses request, delivery of raw materials used in printing (paints, adhesives, foils, substrates)	
Waste of large quantities of materials (mainly paints, films and substrates)	At the printing houses request, provide specialists (a fixed period of time) with printing expertise to help solve printing problems, arrange processes in an appropriate way, eliminate/reduce waste	
Waste of time - many operations, which should take place off-line, are performed on-line, which extends the time of order execution.	Assistance in the implementation of existing and new orders, staff and training courses	
In case of emerging problems (with the machine or printing), printers can count on their employees, service technicians and consulting companies.	On printing houses request, the possibility of taking full responsibility for the printing process and the order process	
Many printing houses, due to the lack of professional equipment, expertise, skills and staff, are unable to meet the requirements of their customers and avoid/resign from some of their orders.		
Continuous development of economy and technology will force the use of new techniques and tools, which are often unknown to printers.		
Key customer needs	Value for the Customer	Where is our solution better than competition?
Quick changeover of machines between jobs (5)	Printing houses receive high quality printing machines (new or regenerated), thanks to which they can carry out their core business.	There is no such solution on the market
Keeping the machine in top condition (5)	The printing house with services receives know-how concerning printing processes	A special opportunity for small and medium enterprises and people who want to start their business in the printing sector
Lack of sense of non-satisfaction with customer needs (5)	Printing houses have at their disposal a reliable person who helps solve emerging problems	Access to specialists and know-how
Transparent arrangement of processes in the printing house and their quick implementation	Eliminate/reduce waste	Continuous monitoring of machine operation and condition
Clear waste management and environmental actions (5)	Time saving	
No need for own employees responsible for print engineering service (4)	Cost-effective solution	
Customer Segment	Technical features	Technological knowledge and know-how needed
Large printing works using a large number of printing machines	High quality, technologically advanced printing machines	Extensive knowledge of printing service engineering (product design (selection of materials and printing processes), as well as control, operation, organization and management of printing processes and operation of printing machines).
Micro, small and medium-sized printing houses without sufficient funds to purchase printing machines, their own printing and human resources facilities	Printing cloud computing - a platform that provides integration between different cloud printing service engineering services, protection, assessment and monitoring of security status	Advice on the implementation of business-critical tools
Entrepreneurs and natural persons who want to start their business in the field of printing	Calendar and application for booking and consulting selected professionals	Risks: trust between the manufacturer and the printing houses is needed due to the monitoring of the machine and the availability of information to the specialist.
	Information system and Helpdesk	

Table 6
Service packages in the new PSS business model.

	Package of services	Description	Additional actions of the manufacturer
1.	Standard	Delivery and installation, standard service and maintenance of printing machines, training, financial and insurance services.	Collection of data and monitoring of the function of the machine in use. Analysis of the information obtained to provide new solutions for the customer (printing houses). Close cooperation with the manufacturer and the customer throughout the entire life cycle of the machine - faster response to emerging needs. Registration of the quality of printed products (color, fit, etc.) to ensure the requirements of printing house customers. Providing knowledge and skills in the use and maintenance of machines and the improvement of printing processes
2.	Material management services	Ordering and management services for materials used in production (paints, substrates, foils, etc.).	
3.	Waste management	Collection, sorting, reuse (where possible), treatment and disposal of waste.	
4.	Print service engineering	Expert consultations and related services (access to specialists and know-how): • advanced operation and maintenance of printing machines; • product design (selection of materials and printing processes); • control, operation, organization and management of printing processes; • consulting in the implementation of tools essential for the company; • health and safety services; • IT solutions.	
5.	Printing for the customer	Implementation of all activities related to the customer's printing processes	

fees during use and costs related to repairs. Financial analysis for PSS model has been developed for 24 years, meaning each of the three users exploits the machine for 8 years. This time-frame has been selected based on the answers given in questionnaires to questions about the length of period through which printing machines are used (Fig. 10).

Financial flow analysis was conducted for two models:

- a model, in which a manufacturer sells a machine through a lease fund, the lease goes on for 5 years, a printing house uses a machine for 24 years, pays for its servicing, repairs, and depreciation (distributed across 24 years);
- a proposed PSS model for printing machines – a manufacturer makes a machine available for subsequent 8-year cycles to three printing houses. Manufacturer pays for depreciation and servicing throughout each period and for repairs after the completion of each cycle. The printing house pays only a monthly fee for the machine.

$$PPS\ fee = (Usage\ fee + Service\ fee) - (Depreciation + Actual\ service\ costs\ of\ the\ machine)$$

$$Usage\ fee = \frac{Initial\ value\ of\ the\ machine - Final\ value\ of\ the\ machine}{Life\ cycle\ period}$$

$$Service\ fee = Daily\ effective\ time\ of\ the\ machine \cdot Print\ speed\ in\ meters\ per\ minute \cdot 5\%\ of\ the\ value\ of\ the\ printed\ meter$$

$$Conventional\ system = Machine\ sale\ price + Service\ fees$$

By comparing these two cases (Fig. 19) we may conclude that in the first option the manufacturer collects the full price of a machine from the lease fund in one go. If one printing house purchases a machine for 24 years, a company reports high profit already in the first year while in subsequent years it earns only on services ordered by the printing house. In the PSS model a company makes small profits at the very beginning because it does not sell a machine but makes it available in return for a monthly subscription fee. After 10 years the model becomes more profitable to the manufacturer than the one, in which a machine is just sold to one printing house. Throughout the entire life cycle of the machine, manufacturer earns by 139% more than in the traditional option.

$$PPS\ fee = (Usage\ fee + Service\ fee)$$

$$Conventional\ system = Own\ contribution + 59\ leasing\ fees + Service\ fees$$

The PSS model is also more beneficial from the printing house perspective (Fig. 20). A company does not pay a lot for lease installments. In addition, the cost of machine depreciation remains on manufacturer's side because the user does not acquire ownership right to the machine. Users do not pay for servicing the machine, check-ups, and repairs. By monitoring machine performance, a manufacturer is striving to prevent major failures through earlier replacement of parts. Additional benefits of the model consist in

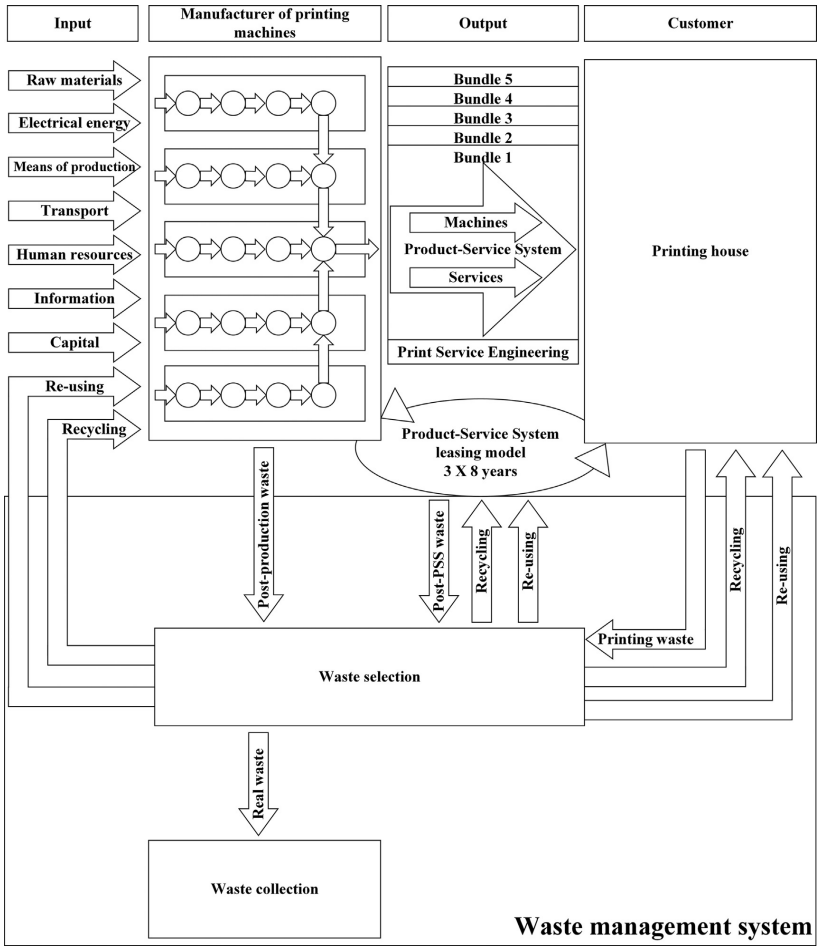


Fig. 16. Proposed PSS model for printing machines.

shortening the downtime caused by failures, achieving higher OEE indicator and enhancing a company's production capacity, which altogether increases profits.

7. Discussion and conclusions

7.1. Discussion

The absence of PSS business models for printing machines is the main gap addressed by the paper. Conducted studies and consultations with experts in the printing industry resulted in three frameworks for the PSS business model. The model was designed to meet specific needs of the printing industry emerging in relation with problems popping up during the use of the machine and in the course of printing. The proposed model can ensure necessary working environment that might act as a catalyst, especially for small printing houses and people who want to start their businesses in the printing industry, as it seeks to offer optimum conditions for their growth.

Conducted studies have some relevant consequences for the development of PSS model. By integrating two areas of research (Polish printing industry market and user needs) we demonstrated that there is market and potential for the development of PSS-based business models. These studies should help in developing a

Key Partners	Key Activities	Value Proposition	Customer Relationships	Customer Segments
Banks Insurers Suppliers of materials Media providers Universities Paint producers Manufacturers of substrates Salespeople Visionaries	Monitoring the operation of the machine Maintenance, repair and overhaul Consultation and improvement of processes in all phases of printing and management Re-launch of second-hand printing machinery on the market **Key resources** Printing machine tailored to the customer's needs Specialists in the field of printing machines, printing and production processes Printing systems Training and advisory services Dealers facilitating maintenance and replacement of machines Information system Financing of fixed assets	Elimination of capital expenditures by the customer Sophisticated solutions to meet customer needs. Print service engineering Know-how Capabilities based on operations and customer needs	Solutions require coordinated efforts to understand the customer's needs. The manufacturer interacts with the customer throughout the life of the product. **Channels** Company department and/or dealer network that monitors the maintenance of the printing machine and supports the printing process Industrial Fair	SME customers, micro-businesses, multinational corporations, printing houses representing various printing and product processing technologies

Cost structure	Revenue streams
Operating costs include: depreciation, maintenance, insurance, maintenance, repair, repair and overhaul of the printing machine. Capital investments in the rental of printing machinery Equity investments in persons with expertise and experience in technology and production processes	Revenues based on usage fee (calculated on the basis of depreciation) and service fee (calculated on the basis of the effective working time of the machine, production capacity and value of the manufactured product) Revenues are maximized by selling integrated solutions. Additional revenues include training and consulting Additional revenues include overcapacity and contractual penalties Final fee if the printing house wants to buy a machine

Fig. 17. Canvas Business Model for new solution.

new Value Proposition for printing houses. Printing houses do not expect services connected with machines only any more but also services connected with processes, in which they are used to solve problems occurring in production. Rendering such services seeks to identify innovative solutions in the printing industry, which would have never been identified without the cooperation with machine users. The study has expanded our knowledge on PSS in Polish printing houses.

In the proposed business model, features which may significantly impact the approval of printing house include supplying materials used in printing and the know-how. Integrating these two areas encourages the use of the model. It is also important in the context of

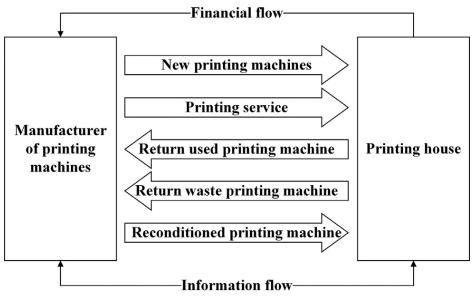


Fig. 18. Flows in the PSS system.

the printing industry, in which many materials are necessary to manufacture the final product (printing inks, water varnishes, paper, film, and glue) and each product is manufactured in a process whose set up is individually selected and carried out. This combination also improves the logistics because everything is supplied by a machine manufacturer. In addition, it produces economic and environmental benefits, such as, e.g., no need to maintain inventories at warehouses, pay for used materials, and elimination of waste.

Five levels of services have been proposed in the model to respond to printing house needs. By offering a wide array of services, a manufacturer gives printing house a choice. Such an approach positively contributes to the understanding of the PSS system. Printing engineering service is a specific case here. These services closely link with problems faced at different stages of printing, printing know-how, and the evolution of printing processes over time through the development of innovation in this area. The proposed model highlights the need to combine services not just with the printing machines but also with processes, in which they are used. On top of that, services targeting printing enable not only developing unique solutions but also monitoring and enriching the service offer.

Presented business model may help in developing the printing industry by building lasting relationships with clients, access to information about problems that may arise in the course of printing, technologies, and printing know-how. The model may also have significant impact upon the development of new printing technologies, substrates, and inks. In addition, under less favorable economic situation, the option of having a contract based on that model is more attractive to users than a leasing contract or traditional purchase. That is because under such an arrangement, clients pay only for days when machines are used effectively, without paying a constant monthly installment. In this case, business model is the key to the transformation of a manufacturer into a service provider. Instead of manufacturing machines over which manufacturers have got a full control, they get engaged in a much broader scope of actions.

Using this approach in printing industry is beneficial to both a manufacturer and a user of printing machines. Instead of trying to learn how to use a machine, ordering materials, designing, setting up and optimizing printing processes, monitoring and eliminating errors, a user receives a machine and a package of printing engineering services. Manufacturer shares his specialist knowledge with the printing house who, in turn, can reduce costs resulting from stoppages in production, consumption of materials, and faults in production. In addition, the user does not pay the costs of consulting services. As a result of permanent cooperation a manufacturer monitors the operation of the machine and can identify its components that get used up the most quickly. By taking part in printing process, a manufacturer can also faster develop new, more precise and environmentally friendly printing and

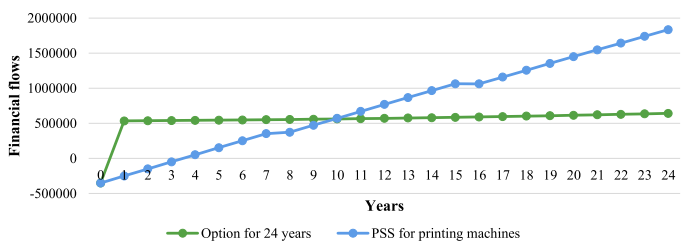


Fig. 19. Annual financial flows in each option in the 24-year cycle of a machine.

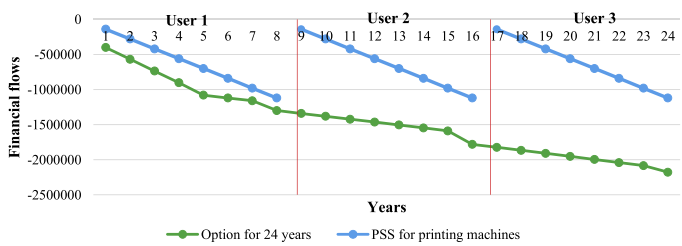


Fig. 20. Printing house fee perspective.

Table 7
Benefits of the proposed PSS business model for printing machines.

Customer (printing house)	Manufacturer	Environment
A model customized to the customer's needs	Improvement of the competitive position	Extending the life cycle of a printing machine
Support in the operation and use of the machine during the contract period	Increasing the chances of retaining existing customers and gaining new ones	Developing more environmentally friendly printing process solutions
Attention to your core business, winning new orders and expanding your business	Aftermarket entry and access to new customers	Reduce or even eliminate waste Regeneration of machine parts
No need to invest huge amounts of money in the purchase of a machine	A manufacturer operating on the aftermarket in a new model gets an additional return on quality	Optimal use of materials
Reduction of taxes paid - PSS will be treated as current expenditure rather than capital expenditure	Attracting a new customer segment, especially companies that have not yet been able to afford to buy such a machine due to its price and the subsequent emergence of maintenance services, as well as people who want to start their business in the printing sector.	Eliminating paint problems eliminates the prospect of substrate consumption, which reduces the amount of waste
Expansion of the machine park with low own resources	Life cycle analysis of the printing machine and the printing process	Machine return logistics program
This model will help printers grow and benefit from economies of scale.	Longer time to profit from a single machine	Washing-water, paints, foils
Does not incur costs of depreciation and repairs	Diagnosis of the least durable machine parts	Paper and other raw materials are sourced from environmentally friendly sources
Access to know-how and printing expertise		
Access to print engineering service	Innovative design changes based on practical experience and suggestions from the printing house through ongoing cooperation with the printing house	
Ensuring the right amount of inks for the printing process (preparing the right amount of inks for a given order)	Development of parameters affecting the quality of production processes, which will increase the efficiency of the printing process	
Having a sufficient amount of raw materials in stock: paints, varnishes, additives to ensure current production, as well as being prepared for possible new projects	Machine series configurations	
Color control technology and print inspection	Collecting industrial data from the production process, which can result in improved machine design and technology, improved manufacturing quality or increased process efficiency.	
Improvement of the efficiency of the use of printing machines		
Advice on raising funds for investments, solutions improving company management, integrated IT systems, process and cost management		

dyeing systems and software for them. Designing machines which can be modernized by just replacing the printing and dyeing systems may come as an additional benefit.

Manufacturers must draft environmentally friendly manuals for the machines and printing processes and offer environmentally friendly services because the industry uses chemical substances and preparations, and printing substrates. The problem consists in ensuring an adequate amount of inks in the printing process as well as substances that refine the final product. Supplying, dosing, and mixing an adequate amount of substance for an individual order can eliminate practically totally turning them into waste. Eliminating these problems restricts the perspective of using up the printing substrate, which again limits the amount of waste.

The above presented concept provides manufacturers with a PSS business model framework which includes services needed by a client. It assumes co-operation between manufacturers, printing houses and other organizations (mainly the suppliers of electricity and water). It combines environmental, economic, and social values. Moreover, it ensures developing links between an individual company and a wider production-consumption system, in which it operates. By putting every single service package of the model in place customers (printing houses), manufacturers and the environment get several potential benefits (Table 7). Manufacturers retain the ownership and by operating in 8-year cycles maintain control over the condition of the machine and can support users in printing processes. As a result, manufacturers can develop a system that would minimize the consumption of raw materials (used to manufacture the machine, necessary for it to work and needed for printing), waste, emissions and energy losses. Waste from one process is used as raw material in other processes which reduces waste from production.

By supplying materials used in printing production, a manufacturer of machines is able to show initiative and ensure that paper and other raw materials come from environmentally friendly sources. The same can be said about inks (dyes). The model can assist the development of environmentally friendly inks and dyes used in the printing industry and gradually reduce using traditional printing dyes based on oil and volatile organic compounds.

Elements that will change compared to the current way in which printing machines manufacturers operate are presented in Table 8.

Digitalization of economy and Industry 4.0 are linked with the rise of the age of data-based manufacturing. Many new technologies, such as Big Data, the Internet of Things, Cloud Computing, Blockchain, and digital twins will be used in printing industry and in PSS design. They will impact changes in the printing industry and manufacturers of printing machines will have to adapt their

Table 8
Changes in the business model used by printing machine manufacturers.

	Traditional business model	PSS business model for printing machines
Key Partners	The basic element is cooperation with suppliers of subassemblies for printing machines and banks.	Closer cooperation with a much larger group of partners. Need for additional analyses (demand forecasts, opinions, complaints and customer satisfaction)
Key Activities	Production and design of printing machines	This area will be significantly expanded and will include not only production-related activities, but also all activities necessary for the implementation of the new offer. In this area, apart from activities related to the production of the new machine, there will be a number of activities related to its service, optimization of its operation and optimization of printing processes in which it is used. Activities related to services and their management will be necessary here. New and constantly created services of printing engineering services, regeneration of machines and its subassemblies. An important element will be activities related to return logistics, re-launch of used machines and waste management. Research and development will be an important element.
Value Proposition	A printing machine is the basis for the value directed to the printing house. Printing houses have the right of ownership.	The value for the printing house is no longer the printing machine, but also the sorted services and expertise in the field of printing - the service of printing engineering. Ownership of the machine is on the manufacturer's side, the printing house only gets access to it.
Customer Relationships	Based on transactions.	Customer relations are the basis. The model enables a long-term business relationship and strong interaction with printing houses. The manufacturer works with the printing house to monitor machine performance and innovative printing solutions. The exchange of information with customers includes: knowledge, training and opportunities.
Customer Segments	Different types and sizes of printers who want or need to own the product	Different types and sizes of printers who want to make low investments, do not prefer to own machines, need consulting and print engineering services. They accept that they do not own the machines.
Key resources	Key resources include employees' materials, information and energy.	Key resources will of course be based on human resources, machines, materials, information and energy. However, due to the expansion of the business, human resources with a high level of knowledge and skills, who are treated as critical capital and know-how, will play an important role.
Channels	Indirect contact with the end customer. Direct contact for large customers.	Direct contact with the end customer. Long-term cooperation with service providers.
Cost structure	Traditional production costs, additional material and human resources costs.	High capital requirements due to the responsibility for the printing machine throughout its entire life cycle. Costs associated with hiring specialists and developing new solutions for customers, often at the customer's premises.
Revenue streams	Revenues based on sales of the printing machine and services related to machine repairs that the customer will need.	Revenues based on the availability of the machine (subscription) and the effective daily working time of the machine.

products and services to them. Printing houses will expect fast and simple access to highly specialized equipment or feedback about print-outs, anticipated future events, trusted transactions, and information exchange.

Blockchain technology lies between IT, finance, and supply chain management (Leng et al., 2019a). It provides innovative information exchange mechanisms and their coordination offering new possibilities to create previously unknown services tied with a printing machine. Using blockchain in PSS design for printing machines will improve communication between the manufacturer and a user without engaging intermediaries. It may also help in reducing information asymmetry between PSS participants and building confidence in specific products. By providing precise information and eliminating understatements we can enhance clients' will to use PSS and be ready to pay for it. That would ensure the protection of PSS-related data and improve reliability of information management (Huang et al., 2019; Leng et al., 2019a; Vogel et al., 2019). We would also be able to better trace and record the history of a printing machine, type of services tied with it, reveal strengths and weaknesses of a machine and PSS, which could lead to better management of a printing machine and ensure a permanent base for developing new PSS.

Digital Twins link with digital representation of objects and environments, as well as entrepreneurs, companies, and real processes, which can be reflected in more detail in a digital environment for needs pertaining to PSS simulation, examination, and control (Leng et al., 2019b; Tao et al., 2019, 2018). As a result, a digital PSS model can be created that operates in real time in parallel with a PSS in a printing house leading to the convergence between physical and virtual PSS space. Digital Twins is thus a faithful reproduction of a physical product which may make client-designer communication more transparent and faster by using data sent in real time. This may facilitate the control over the improvement of a new PSS model carried out by considering customer opinions and problems that have emerged when using products of previous generation. By continuous monitoring of system operations, digital models will continuously be updated with collected data. Digital Twins will also help in integrating various data (e.g., operational, process or environmental data), which may additionally respond to changes in states observed during operations (Leng et al., 2019b; Rosen et al., 2015; Tao et al., 2019, 2018).

The future of printing lies, above all, in printing packaging and labels which require specialist printing machines. Looking at the practice of the industry, downsizing printing machines seems very hard to imagine. Against this background, besides the business model described in this paper, other popular solutions may include printing machine pooling or printing machine sharing, i.e.

solutions, in which a manufacturer with a printing centre equipped with the latest state-of-the-art technologies can make printing machines available to printing houses according to their orders. Printing houses will not have an unlimited and exclusive access to machinery which can be used by other companies in other periods. Neither will they have ownership rights to machines they will be using depending on their needs. The most advanced result-oriented PSS business model may eliminate a model of a printing house as we know it today. Today's printing houses may become intermediaries between the ordering party and a manufacturer of printing machines who executes orders placed by companies which so far have acted as printing houses or directly by end customers.

7.2. Conclusions

The paper is intended to answer the following research question: "What possibilities does PSS give to the manufacturers of printing machines and their customers (printing houses)?"

A questionnaire-based study, one of very few, on service preferences of printing companies was carried out. It provided us with the following pieces of information:

- a printing machine is used on average for 8 years,
- upon purchasing one and the same type of machine service-related expectations of micro- or small printing houses whose production range is rather limited and which work one shift only are completely different from those of large or middle-sized printing companies offering a wide range of products and working more than one shift,
- big amount of waste is a problem typical of all printing houses,
- changeover time losses are the most acute and account for almost 50% of all losses,
- printing houses are interested in a new business model,
- only in Poland back in 2016 there were 9204 micro- and small printing houses (419 more than in 2015) meaning just this country is a huge market for printing machine manufacturers,
- the model may ensure faster growth to micro and small businesses and services offered within its framework, especially the maintenance service in printing engineering may significantly reduce the economic and organizational challenge involved in printing operations,
- when developing a business model for printing machines, a manufacturer should propose packages, in which some services are addressed to micro- and small companies and some to middle-sized and large ones and customers can flexibly choose between the two.

Results of studies helped us in drafting the initial framework for the PSS business model. The model was consulted with experts in printing, finance, and trade in machines. Their practical advice and hints have further improved the model.

An improved PSS business model is the answer to the research question. When drafting and building it we managed to distinguish a package comprising concrete issues faced by printing companies and areas which could be improved by adopting the PSS model. While identifying all such aspects account was taken of a number of diverse parameters that can be used as differentiating features for printing companies (e.g., the size, number of staff, type of technology applied, etc.), which makes the model applicable to almost any company in the printing industry. Having such a model, a company may get detailed answers to questions about opportunities offered by PSS implementation.

Further directions of works will include:

- the development of the worked-out PSS business model focused on the machine lifecycle,
- questionnaire-based studies conducted among printing houses and concerning printing machines lifecycle and service needs related to it.

In addition, we hope to work out a comprehensive method of designing PSS systems validated in the industrial environment.

CRediT authorship contribution statement

Mariusz Salwin: Conceptualization, Methodology, Formal analysis, Writing - original draft. **Andrzej Kraslawski:** Supervision. **Jan Lipiak:** Formal analysis. **Damian Gołębiewski:** Formal analysis. **Michał Andrzejewski:** Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to thank the following experts in printing industry who work with printing machines for their time and valuable consultations:

Krzysztof Krystosiak – Sleeving Services Manager at Masterpress Printing House, 4 Jacka Kuronia Street, 15-001 Białystok, Poland.

Piotr Słoński – Manager of the Bookbinding Department at ELLERT Printing House, 17 Nadrzeczna Street, 05–462 Wiązowna Kościelna, Poland.

Radosław Płóska - Production worker at Quad/Graphics Europe, 120 Pułtuska Street, 07–200 Wyszków, Poland.

Michał Korzeniewski – Technical referee at the Publishing House of the Warsaw University of Technology, Polna 50 Street, 00–644 Warszawa, Poland.

Katarzyna Krajewska - Quality Manager at Edelmann Poland Printing House, 8 3 Maja Street, 05–800 Pruszków.

Jacek Żyła - CEO of EUROBORD, 23 1905 Year Street, 26–600 Radom, Poland.

Sebastian Dąbski - Sales Director at Totalizator Sportowy, 25 Targowa Street, 03–728 Warszawa, Poland.

Appendix

Spearman's correlation - calculations

Table 9
Spearman's correlation – calculations - areas of services relating to a printing machine by PKWiU [Polish Classification of Products and Services]

Pair of variables	Strength	R Spearmana	t(N-2)	p-value
Company size & Financial and insurance services	80	-0,706700	-8,8216	0,000000
Company size & Information and communication services	80	0,556222	5,9112	0,000000
Company size & Transport and storage	80	-0,018734	-0,1655	0,868993
Company size & Support services	80	0,095925	0,8511	0,397312
Company size & Electrical services	80	-0,783303	-11,1285	0,000000
Company size & Industrial production services	80	0,077333	0,6850	0,495352
Company size & Water supply services; sewage and refuse and remediation services	80	-0,783303	-11,1285	0,000000
Company size & Commercial services	80	0,265723	2,4343	0,017205
Company size & Real estate services	80	0,498309	5,0761	0,000003
Company size & Professional, scientific and technical services	80	-0,593078	-6,5056	0,000000
Company size & Administrative and support services	80	-0,331322	-3,1013	0,002681
Company size & Education	80	-0,365913	-3,4725	0,000844
Company size & Cultural, entertainment, sports and leisure services	80	0,762878	10,4209	0,000000
Company size & Health and social care services	80	0,778126	10,9411	0,000000
Product range & Financial and insurance services	80	-0,569170	-6,1137	0,000000
Product range & Information and communication services	80	0,459794	4,5728	0,000018
Product range & Transport and storage	80	0,182294	1,6374	0,105572
Product range & Support services	80	0,082016	0,7268	0,469527
Product range & Electrical services	80	-0,229744	-2,0848	0,040358
Product range & Industrial production services	80	0,310439	2,8842	0,005070
Product range & Water supply services; sewage and refuse and remediation services	80	-0,229744	-2,0848	0,040358
Product range & Commercial services	80	0,774638	10,8181	0,000000
Product range & Real estate services	80	0,482828	4,8694	0,000006
Product range & Professional, scientific and technical services	80	-0,241834	-2,2012	0,030682
Product range & Administrative and support services	80	-0,153198	-1,3692	0,174875
Product range & Education	80	-0,152970	-1,3671	0,175527
Product range & Cultural, entertainment, sports and leisure services	80	0,549579	5,8098	0,000000
Product range & Health and social care services	80	0,471007	4,7157	0,000010
Number of shifts per working day & Financial and insurance services	80	-0,462919	-4,6124	0,000015
Number of shifts per working day & Information and communication services	80	0,567488	6,0870	0,000000
Number of shifts per working day & Transport and storage	80	-0,047419	-0,4193	0,676174
Number of shifts per working day & Support services	80	0,111494	0,9909	0,324813
Number of shifts per working day & Electrical services	80	-0,492137	-4,9929	0,000004
Number of shifts per working day & Industrial production services	80	0,113617	1,0100	0,315630
Number of shifts per working day & Water supply services; sewage and refuse and remediation services	80	-0,492137	-4,9929	0,000004
Number of shifts per working day & Commercial services	80	0,110662	0,9834	0,328462
Number of shifts per working day & Real estate services	80	0,263222	2,4097	0,018322
Number of shifts per working day & Professional, scientific and technical services	80	-0,290354	-2,6798	0,008984

	Number of shifts per working day & Professional, scientific and technical services	80	-0,290354	-2,6798	0,008984
	Number of shifts per working day & Administrative and support services	80	-0,162996	-1,4591	0,148566
	Number of shifts per working day & Education	80	-0,339706	-3,1899	0,002050
	Number of shifts per working day & Cultural, entertainment, sports and leisure services	80	0,520608	5,3852	0,000001
	Number of shifts per working day & Health and social care services	80	0,571024	6,1432	0,000000
	Total duration of failure per week & Financial and insurance services	80	0,117644	1,0463	0,298667
	Total duration of failure per week & Information and communication services	80	-0,028921	-0,2555	0,798985
	Total duration of failure per week & Transport and storage	80	0,034279	0,3029	0,762754
	Total duration of failure per week & Support services	80	-0,040239	-0,3557	0,723049
	Total duration of failure per week & Electrical services	80	0,031885	0,2817	0,778884
	Total duration of failure per week & Industrial production services	80	-0,006732	-0,0595	0,952741
	Total duration of failure per week & Water supply services; sewage and refuse and remediation services	80	0,031885	0,2817	0,778884
	Total duration of failure per week & Commercial services	80	0,161508	1,4454	0,152358
	Total duration of failure per week & Real estate services	80	-0,074683	-0,6614	0,510285
	Total duration of failure per week & Professional, scientific and technical services	80	0,122856	1,0933	0,277619
	Total duration of failure per week & Administrative and support services	80	0,043374	0,3834	0,702442
	Total duration of failure per week & Education	80	0,108673	0,9655	0,337284
	Total duration of failure per week & Cultural, entertainment, sports and leisure services	80	-0,144534	-1,2900	0,200849
	Total duration of failure per week & Health and social care services	80	-0,094274	-0,8363	0,405525

Table 10
Spearman's correlation – calculations - Basic services related to the printing machine relevant to printing houses

	Pair of variables	Strength	R Spearmana	t(N-2)	p-value
	Company size & Installation and commissioning of the machine	80	-0,143037	-1,27639	0,205605
	Company size & Delivery of the machine to the customer	80	-0,526991	-5,47643	0,000001
	Company size & Supply of spare parts	80	-0,250203	-2,28233	0,025195
	Company size & Supply of consumables	80	-0,563125	-6,01834	0,000000
	Company size & Regeneration, overhaul, repair, maintenance	80	0,064719	0,57279	0,568437
	Company size & Cleaning	80	-0,044899	-0,39693	0,692500
	Company size & Health and safety at work services	80	0,638243	7,32210	0,000000
	Company size & Take-back	80	0,357462	3,38037	0,001133
	Company size & Disassembly	80	-0,203140	-1,83228	0,070726
	Company size & Waste management services	80	0,534942	5,59184	0,000000
	Company size & Financial services	80	-0,527886	-5,48932	0,000000
	Company size & Warranty	80	0,106054	0,94195	0,349124
	Company size & Machine documentation (paper or online)	80	0,099608	0,88411	0,379352
	Company size & Help Desk (machine, process, business)	80	-0,011133	-0,09833	0,921925
	Company size & Cloud data storage	80	0,609954	6,79798	0,000000
	Company size & Management of the working environment	80	-0,025020	-0,22104	0,825637
	Company size & Noise reduction	80	0,158330	1,41620	0,160699
	Product range & Installation and commissioning of the machine	80	0,050596	0,44743	0,655806
	Product range & Delivery of the machine to the customer	80	-0,389776	-3,73806	0,000352
	Product range & Supply of spare parts	80	-0,220643	-1,99790	0,049213
	Product range & Supply of consumables	80	-0,251415	-2,29412	0,024475
	Product range & Regeneration, overhaul, repair, maintenance	80	0,009790	0,08647	0,931316
	Product Range & Cleaning	80	-0,130402	-1,16160	0,248939
	Product range & Health and safety at work services	80	0,262831	2,40585	0,018502
	Product range & Take-back	80	0,296894	2,74591	0,007489
	Product range & Disassembly	80	-0,305126	-2,82975	0,005921
	Product range & Waste management services	80	0,712268	8,96212	0,000000
	Product range & Financial services	80	-0,400707	-3,86261	0,000230
	Product range & Warranty	80	0,067370	0,59635	0,552666
	Product range & Machine documentation (paper or online)	80	0,085265	0,75580	0,452048
	Product range & Help Desk (machine, process, business)	80	-0,198760	-1,79114	0,077150
	Product range & Cloud data storage	80	0,206250	1,86158	0,066430
	Product range & Management of the working environment	80	-0,115318	-1,02531	0,308388
	Product Range & Noise reduction	80	-0,005560	-0,04910	0,960961
	Number of shifts per working day & Installation and commissioning of the machine	80	-0,045086	-0,39859	0,691282
	Number of shifts per working day & Delivery of the machine to the customer	80	-0,354875	-3,35237	0,001238
	Number of shifts per working day & Supply of spare parts	80	-0,189967	-1,70886	0,091453
	Number of shifts per working day & Supply of consumables	80	-0,291101	-2,68731	0,008801
	Number of shifts per working day & Regeneration, overhaul, repair, maintenance	80	0,060478	0,53511	0,594099

	Number of shifts per working day & Cleaning	80	0,182108	1,63568	0,105935
	Number of shifts per working day & Health and safety at work services	80	0,767000	10,55714	0,000000
	Number of shifts per working day & Take-back	80	0,179740	1,61370	0,110630
	Number of shifts per working day & Disassembly	80	-0,122424	-1,08942	0,279324
	Number of shifts per working day & Waste management services	80	0,202654	1,82772	0,071416
	Number of shifts per working day & Financial services	80	-0,271652	-2,49291	0,014789
	Number of shifts per working day & Warranty	80	0,093631	0,83057	0,408750
	Number of shifts per working day & Machine documentation (paper or online)	80	0,073905	0,65450	0,514714
	Number of shifts per working day & Help Desk (machine, process, business)	80	0,056337	0,49835	0,619639
	Number of shifts per working day & Cloud data storage	80	0,839610	13,65128	0,000000
	Number of shifts per working day & Management of the working environment	80	-0,006467	-0,05712	0,954599
	Number of shifts per working day & Noise reduction	80	0,187913	1,68971	0,095077
	Total duration of failure per week & Installation and commissioning of the machine	80	-0,019354	-0,17096	0,864696
	Total duration of failure per week & Delivery of the machine to the customer	80	0,089016	0,78930	0,432331
	Total duration of failure per week & Supply of spare parts	80	0,173505	1,55595	0,123767
	Total duration of failure per week & Supply of consumables	80	0,178964	1,60650	0,112205
	Total duration of failure per week & Regeneration, overhaul, repair, maintenance	80	-0,004203	-0,03712	0,970485
	Total duration of failure per week & Cleaning	80	0,060646	0,53660	0,593072
	Total duration of failure per week & Health and safety at work services	80	0,051126	0,45212	0,652436
	Total duration of failure per week & Take-back	80	0,360773	3,41634	0,001011
	Total duration of failure per week & Disassembly	80	-0,046289	-0,40925	0,683474
	Total duration of failures per week & Waste management services	80	0,108157	0,96085	0,339596
	Total duration of failure per week & Financial services	80	0,075879	0,67208	0,503517
	Total duration of failure per week & Warranty	80	-0,012072	-0,10662	0,915363
	Total duration of failure per week & Machine documentation (paper or online)	80	-0,110801	-0,98463	0,327850
	Total duration of failure per week & Help Desk (machine, process, business)	80	0,068403	0,60553	0,546582
	Total duration of failure per week & Cloud data storage	80	-0,091580	-0,81223	0,419132
	Total duration of failure per week & Management of the working environment	80	-0,113155	-1,00582	0,317611
	Total duration of failure per week & Noise reduction	80	-0,085732	-0,75996	0,449570

Table 11
Spearman's correlation – calculations - ancillary services linked with a machine that a printing house wishes to purchase

Pair of variables	Strength	R Spearmana	t(N-2)	p-value
Company size & Optimisation of the use of materials	80	-0,385024	-3,68449	0,000421
Company size & Optimising the use of equipment	80	0,075581	0,66943	0,505199
Company size & Update (Reconstruction, modernisation)	80	0,675644	8,09401	0,000000
Company size & Monitoring, testing and diagnosis of the machine	80	0,671426	8,00176	0,000000
Company size & Waste management	80	-0,696022	-8,56117	0,000000
Company size & Full control of the operation of the device after a fixed period of use	80	0,548228	5,78938	0,000000
Company size & Diagnostics, error recovery and repair	80	-0,267511	-2,45195	0,016443
Company size & Production planning and monitoring	80	0,529373	5,51079	0,000000
Company size & Training	80	-0,023237	-0,20527	0,837892
Company size & Manages one or more activities on behalf of a client	80	-0,269292	-2,46955	0,015713
Company size & Lean tools	80	-0,110147	-0,97875	0,330729
Company size & Audits	80	0,181703	1,63192	0,106727
Product range & Optimisation of the use of materials	80	-0,112656	-1,00133	0,319765
Product range & Optimising the use of equipment	80	-0,318936	-2,97198	0,003933
Product range & Update (Reconstruction, modernisation)	80	0,049751	0,43994	0,661200
Product range & Monitoring, testing and diagnosis of the machine	80	0,215985	1,95364	0,054330
Product range & Waste management	80	-0,345392	-3,25046	0,001702
Product range & Full control of the operation of the device after a fixed period of use	80	0,143476	1,28039	0,204202
Product range & Diagnostics, error recovery and repair	80	-0,336763	-3,15872	0,002255
Product range & Production planning and monitoring	80	-0,042664	-0,37714	0,707091
Product range & Training	80	-0,033401	-0,29515	0,768663
Product range & Manages one or more activities on behalf of a client	80	-0,135566	-1,20845	0,230526
Product Range & Lean tools	80	-0,361711	-3,42656	0,000978
Product range & Audits	80	-0,045178	-0,39941	0,690683
Number of shifts per working day & Optimisation of the use of materials	80	-0,459190	-4,56522	0,000018
Number of shifts per working day & Optimising the use of equipment	80	0,014693	0,12978	0,897074
Number of shifts per working day & Update (Reconstruction, modernisation)	80	0,809744	12,18756	0,000000
Number of shifts per working day & Monitoring, testing and diagnosis of the machine	80	0,406329	3,92743	0,000184
Number of shifts per working day & Waste management	80	-0,496255	-5,04829	0,000003
Number of shifts on a working day & Full control of the operation of the device after a fixed period of use	80	0,135674	1,20942	0,230154
Number of shifts per working day & Diagnostics, error recovery and repair	80	-0,428200	-4,18482	0,000074
Number of shifts per working day & Production planning and monitoring	80	0,618784	6,95675	0,000000
Number of shifts per working day & Training	80	-0,009856	-0,08705	0,930856
Number of shifts per working day & Manages one or more activities on behalf of a client	80	-0,202912	-1,83015	0,071048
Number of shifts per working day & Lean tools	80	-0,095864	-0,85056	0,397615
Number of shifts per working day & Audits	80	0,081264	0,72009	0,473622
Total duration of failure per week & Optimisation of the use of materials	80	-0,317286	-2,95487	0,004134

	Total duration of failure per week & Optimising the use of equipment	80	0,115303	1,02516	0,308455
	Total duration of failure per week & Update (Reconstruction, modernisation)	80	0,027488	0,24286	0,808749
	Total duration of failure per week & Monitoring, testing and diagnosis of the machine	80	0,149937	1,33935	0,184347
	Total duration of failure per week & Waste management	80	-0,170529	-1,52846	0,130444
	Total duration of failure per week & Full control of the operation of the device after a fixed period of use	80	0,008998	0,07947	0,936863
	Total duration of failure per week & Diagnostics, error recovery and repair	80	0,024291	0,21460	0,830640
	Total duration of failure per week & Production planning and monitoring	80	0,134716	1,20072	0,233492
	Total duration of failure per week & Training	80	-0,097148	-0,86207	0,391294
	Total duration of failure per week & Manages one or more activities on behalf of a client	80	-0,036110	-0,31912	0,750487
	Total duration of failure per week & Lean tools	80	-0,005404	-0,04772	0,962058
	Total duration of failure per week & Audits	80	0,000985	0,00870	0,993082

Table 12
Spearman's correlation – calculations - services linked with printing and with a printing machine that printing houses would like to buy

Pair of variables	Strength	R Spearmana	t(N-2)	p-value
Company size & Selection, delivery and optimization of paint consumption for a specific order	80	-0,251431	-2,2943	0,024465
Company size & Optimization of changeovers of printing machines	80	0,098265	0,8721	0,385845
Company size & Printers training	80	-0,391992	-3,7631	0,000323
Company size & Replacement of mirrors, filters and UV lamps	80	-0,598522	-6,5984	0,000000
Company size & Printing equipment cleaning	80	-0,662706	-7,8155	0,000000
Size of the company & Optimal time for changing printing forms	80	-0,576204	-6,2264	0,000000
Company size & Mixing of paints	80	-0,425211	-4,1491	0,000084
Company size & Optimisation of the delivery time of clean equipment to the printing machine	80	-0,459926	-4,5745	0,000018
Company size & Technological process design	80	-0,464458	-4,6319	0,000014
Company size & Preparation of CTP boards	80	-0,749785	-10,0077	0,000000
Company size & Preparation of materials for production	80	-0,529756	-5,5163	0,000000
Company size & Optimal quality and cleanliness of the supplied printing equipment	80	-0,281212	-2,5880	0,011509
Company size & Designing materials for printing	80	-0,203131	-1,8322	0,070738
Company size & Preparation of tools for production	80	-0,428085	-4,1834	0,000075
Company size & Selection of printing substrate	80	-0,054732	-0,4841	0,629668
Company size & Help in selling used machine	80	0,086007	0,7624	0,448108
Company size & Calibration, settings and adjustments	80	0,005477	0,0484	0,961542
Company size & Design, production, assembly and assembly of a printing plate	80	-0,216333	-1,9569	0,053932
Company size & Disposal of paints	80	-0,488377	-4,9428	0,000004
Product range & Selection, delivery and optimization of paint consumption for a specific order	80	-0,115994	-1,0314	0,305543
Product range & Optimization of changeovers of printing machines	80	-0,026299	-0,2323	0,816879
Product range & Printers training	80	-0,004118	-0,0364	0,971082
Product range & Replacement of mirrors, filters and UV lamps	80	-0,278650	-2,5625	0,012319
Product range & Printing equipment cleaning	80	-0,207511	-1,8735	0,064750
Product range & Optimal time for changing printing forms	80	-0,148464	-1,3259	0,188744
Product range & Mixing of paints	80	-0,075085	-0,6650	0,508003
Product range & Optimisation of the delivery time of clean equipment to the printing machine	80	-0,198384	-1,7876	0,077724
Product range & Technological process design	80	-0,179000	-1,6068	0,112131
Product range & Preparation of CTP boards	80	-0,177279	-1,5909	0,115681
Product range & Preparation of materials for production	80	-0,202169	-1,8232	0,072111
Product range & Optimal quality and cleanliness of the supplied printing equipment	80	-0,134352	-1,1974	0,234768
Product range & Designing materials for printing	80	-0,146348	-1,3066	0,195196
Product range & Preparation of tools for production	80	-0,197888	-1,7830	0,078484
Product range & Selection of printing substrate	80	0,132232	1,1782	0,242305
Product range & Help in selling used machine	80	0,047665	0,4214	0,674590
Product range & Calibration, settings and adjustments	80	0,037698	0,3332	0,739897
Product range & Design, production, assembly and assembly of a printing plate	80	-0,001891	-0,0167	0,986720
Product range & Disposal of paints	80	-0,203747	-1,8380	0,069869

	Type of printing house & Selection, delivery and optimization of paint consumption for a specific order	80	-0,156462	-1,3991	0,165758
	Type of printing house & Optimization of changeovers of printing machines	80	0,120229	1,0696	0,288101
	Type of printing house & Printers training	80	-0,194842	-1,7544	0,083286
	Printing house type & Replacement of mirrors, filters and UV lamps	80	-0,313126	-2,9119	0,004683
	Type of printer & Printing equipment cleaning	80	-0,340480	-3,1981	0,002000
	Type of printing house & Optimal time for changing printing forms	80	-0,462343	-4,6051	0,000016
	Type of printing house & Mixing of paints	80	-0,282311	-2,5990	0,011176
	Type of printing house & Optimisation of the delivery time of clean equipment to the printing machine	80	-0,307186	-2,8508	0,005577
	Type of printing house & Technological process design	80	-0,501909	-5,1250	0,000002
	Type of printing house & Preparation of CTP boards	80	-0,448219	-4,4283	0,000031
	Type of printing house & Preparation of materials for production	80	-0,350754	-3,3079	0,001423
	Type of printer & Optimal quality and cleanliness of the supplied printing equipment	80	-0,329208	-3,0791	0,002866
	Type of printing house & Designing materials for printing	80	-0,175956	-1,5786	0,118467
	Type of printing house & Preparation of tools for production	80	-0,294832	-2,7250	0,007935
	Type of printing house & Selection of printing substrate	80	-0,046077	-0,4074	0,684848
	Type of printing house & Help in selling used machine	80	0,025060	0,2214	0,825368
	Type of printing house & Calibration, settings and adjustments	80	-0,100040	-0,8880	0,377277
	Type of printing house & Design, production, assembly and assembly of a printing plate	80	-0,144138	-1,2864	0,202101
	Type of printing house & Disposal of paints	80	-0,476608	-4,7881	0,000008
	Number of shifts per working day & Selection, delivery and optimization of paint consumption for a specific order	80	0,148309	1,3245	0,189213
	Number of shifts per working day & Optimization of changeovers of printing machines	80	0,092563	0,8210	0,414138
	Number of shifts per working day & Printers training	80	-0,067073	-0,5937	0,554422
	Number of shifts per working day & Replacement of mirrors, filters and UV lamps	80	0,162106	1,4509	0,150825
	Number of shifts per working day & Printing equipment cleaning	80	-0,090062	-0,7987	0,426918
	Number of shifts per working day & Optimal time for changing printing forms	80	-0,046327	-0,4096	0,683229
	Number of shifts per working day & Mixing of paints	80	-0,149587	-1,3361	0,185386
	Number of shifts per working day & Optimisation of the delivery time of clean equipment to the printing machine	80	-0,152589	-1,3636	0,176618
	Number of shifts per working day & Technological process design	80	0,128917	1,1481	0,254418
	Number of shifts per working day & Preparation of CTP boards	80	0,051792	0,4580	0,648205
	Number of shifts per working day & Preparation of materials for production	80	0,089853	0,7968	0,427995
	Number of shifts per working day & Optimal quality and cleanliness of the supplied printing equipment	80	0,085338	0,7564	0,451663
	Number of shifts per working day & Designing materials for printing	80	0,047083	0,4163	0,678343
	Number of shifts per working day & Preparation of tools for production	80	0,151799	1,3564	0,178894
	Number of shifts per working day & Selection of printing substrate	80	-0,003017	-0,0266	0,978807
	Number of shifts per working day & Help in selling used machine	80	-0,101086	-0,8974	0,372289
	Number of shifts per working day & Calibration, settings and adjustments	80	0,147082	1,3133	0,192941
	Number of shifts per working day & Design, production, assembly and assembly of a printing plate	80	-0,041744	-0,3690	0,713131
	Number of shifts per working day & Disposal of paints	80	0,167339	1,4990	0,137902
	Total duration of failure per week & Selection, delivery and optimization of paint consumption for a specific order	80	-0,156462	-1,3991	0,165758

	Total duration of failure per week & Optimization of changeovers of printing machines	80	0,120229	1,0696	0,288101
	Total duration of failure per week & Printers training	80	-0,194842	-1,7544	0,083286
	Total duration of failure per week & Replacement of mirrors, filters and UV lamps	80	-0,313126	-2,9119	0,004683
	Total duration of failure per week & Printing equipment cleaning	80	-0,340480	-3,1981	0,002000
	Total duration of failure per week & Optimal time for changing printing forms	80	-0,462343	-4,6051	0,000016
	Total duration of failure per week & Mixing of paints	80	-0,282311	-2,5990	0,011176
	Total duration of failure per week & Optimisation of the delivery time of clean equipment to the printing machine	80	-0,307186	-2,8508	0,005577
	Total duration of failure per week & Technological process design	80	-0,501909	-5,1250	0,000002
	Total duration of failure per week & Preparation of CTP boards	80	-0,448219	-4,4283	0,000031
	Total duration of failure per week & Preparation of materials for production	80	-0,350754	-3,3079	0,001423
	Total duration of failure per week & Optimal quality and cleanliness of the supplied printing equipment	80	-0,329208	-3,0791	0,002866
	Total duration of failure per week & Designing materials for printing	80	-0,175956	-1,5786	0,118467
	Total duration of failure per week & Preparation of tools for production	80	-0,294832	-2,7250	0,007935
	Total duration of failure per week & Selection of printing substrate	80	-0,046077	-0,4074	0,684848
	Total duration of failure per week & Help in selling used machine	80	0,025060	0,2214	0,825368
	Total duration of failure per week & Calibration, settings and adjustments	80	-0,100040	-0,8880	0,377277
	Total duration of failure per week & Design, production, assembly and assembly of a printing plate	80	-0,144138	-1,2864	0,202101
	Total duration of failure per week & Disposal of paints	80	-0,476608	-4,7881	0,000008

Test chi square (χ^2) - calculations

Table 13
Test chi square (χ^2) – calculations - areas of services relating to a printing machine by PKWiU [Polish Classification of Products and Services]

Services	Number of degrees of freedom	Test statistics chi square (χ^2)	p-value
Financial and insurance services	2	0,581113801	0,747846975
Information and communication services	2	0,3	0,860707976
Transport and storage	2	0,031347962	0,984448216
Support services	2	32,02666667	0,000000111
Electrical services	2	0,429292929	0,806826632
Industrial production services	2	14,7047619	0,000641064
Water supply services; sewage and refuse and remediation services	2	0,429292929	0,806826632
Commercial services	2	1,570909091	0,455912422
Real estate services	2	0,906593407	0,635529542
Professional, scientific and technical services	2	0,514285714	0,77325774
Administrative and support services	2	2,507122507	0,285486295
Education	2	24,26181818	0,000005390
Cultural, entertainment, sports and leisure services	2	0,982142857	0,61197036
Health and social care services	2	1,093333333	0,578876185

Table 14
Test chi square (χ^2) – calculations - basic services related to the printing machine relevant to printing houses

Services	Number of degrees of freedom	Test statistics chi square (χ^2)	p-value
Installation and commissioning of the machine	2	4,628571429	0,098836756
Delivery of the machine to the customer	2	2,342135476	0,310035727
Supply of spare parts	2	1,239954076	0,53795679
Supply of consumables	2	1,394871795	0,497860233
Regeneration, overhaul, repair, maintenance	2	4,974545455	0,083136393
Cleaning	2	8,458781362	0,014561260
Health and safety at work services	2	1,901041667	0,386539648
Take-back	2	0,167714885	0,919562337
Disassembly	2	3,992172211	0,135866009
Waste management services	2	1,097659403	0,577625409
Financial services	2	0,96	0,618783392
Warranty	2	3,84	0,146606962
Machine documentation (paper or online)	2	1,70212766	0,426960477
Help Desk (machine, process, business)	2	0,077369439	0,962053978
Cloud data storage	2	2,140554481	0,342913435
Management of the working environment	2	0,505166475	0,776791552
Noise reduction	2	3,725490196	0,15524588

Table 15
Test chi square (χ^2) – calculations - ancillary services linked with a machine that a printing house wishes to purchase

Services	Number of degrees of freedom	Test statistics chi square (χ^2)	p-value
Optimisation of the use of materials	2	19,48717949	0,000058669
Optimising the use of equipment	2	21,09717868	0,000026230
Update (Reconstruction, modernisation)	2	0,482539683	0,785629602
Monitoring, testing and diagnosis of the machine	2	1,595672752	0,450302196
Waste management	2	0,025062657	0,987546862
Full control of the operation of the device after a fixed period of use	2	0,3	0,860707976
Diagnostics, error recovery and repair	2	1,696428571	0,428178855
Production planning and monitoring	2	1,31147541	0,519059009
Training	2	0,96	0,618783392
Manages one or more activities on behalf of a client	2	1,690140845	0,429527109
Lean tools	2	13,81818182	0,000998665
Audits	2	0,234833659	0,889214465

Table 16
Test chi square (χ^2) – calculations - services linked with printing and with a printing machine that printing houses would like to buy

Services	Number of degrees of freedom	Test statistics chi square (χ^2)	p-value
Selection, delivery and optimization of paint consumption for a specific order	2	0,64	0,726149037
Optimization of changeovers of printing machines	2	44,34285714	0,000000000235
Printers training	2	1,001317523	0,606131232
Replacement of mirrors, filters and UV lamps	2	0,9375	0,62578401
Printing equipment cleaning	2	11,41414141	0,003322391
Optimal time for changing printing forms	2	7,69327467	0,021351414
Mixing of paints	2	7,69327467	0,021351414
Optimisation of the delivery time of clean equipment to the printing machine	2	7,466666667	0,023912993
Technological process design	2	1,457800512	0,482439258
Preparation of CTP boards	2	0,230179028	0,891286358
Preparation of materials for production	2	0,989010989	0,609872418
Optimal quality and cleanliness of the supplied printing equipment	2	0,167714885	0,919562337
Designing materials for printing	2	0,083857442	0,95893813
Preparation of tools for production	2	1,097659403	0,577625409
Selection of printing substrate	2	0,826636051	0,661451891
Help in selling used machine	2	0,826636051	0,661451891
Calibration, settings and adjustments	2	70,23474178	0,0000000000
Design, production, assembly and assembly of a printing plate	2	5,069444444	0,079283739
Disposal of paints	2	1,690140845	0,429527109

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Publication VI

Salwin, M., Santarek, K., Kraslawski, A., and Lipiak, J.
Product-Service System: New Opportunity for Printing Industry

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Advanced Manufacturing Processes II. InterPartner-2020, Lecture Notes in Mechanical Engineering
pp. 83-95, 2021

Product-Service System: A New Opportunity for the Printing Industry

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Abstract. Product-Service System (PSS) is a combination of products and services to meet specific customer needs. It is a concept that allows companies to build a competitive edge and supports sustainable development. The area of PSS design methods, as well as industrial practice, do not show examples of how this approach can be used in the printing industry. This article aims to develop a conceptual model of PSS for the printing industry. The presented example was developed during a workshop conducted in a printing company. Creating a conceptual model of PSS based on real problems, needs, and service expectations of the company, we hope to draw attention to a number of important issues. The created PSS model provides the printing house with tools in the form of services that will eliminate production problems, improve production efficiency, minimize the adverse impact of printing production on the environment and affect the extension of the machine life cycle.

Keywords: Product-Service System (PSS) · Business model · Printing machines

1 Introduction

Changes in the economic structures in which manufacturing companies move away from production only, towards the provision of products to which services are added. This paradigm shift is related to the global trend of increasing the share of the services sector in national economies [1–3]. In 2018, the industry accounted for over 65% of global GDP. In the service economy, the satisfaction of individual customer needs plays a key role. Customers themselves are not interested in purchasing from owning a product, but in the opportunities, it offers [4]. All this makes the research in the area of the Product-Service System intensify in recent years [5, 6].

Product-Service System is a concept developed in Scandinavia. It is a special case of servicing [7]. The strategy based on the Product-Service System focuses on meeting the needs of customers and not on the product itself, which is a response to changes in the economy and society. Although this concept may bring more profit to the company, the real goal of its implementation is to achieve the best possible product and service

V. Tonkonogyi et al. (Eds.): InterPartner 2020, LNME, pp. 83–95, 2021.
https://doi.org/10.1007/978-3-030-68014-5_9

configuration. This configuration is to meet customer needs as much as possible, be environmentally friendly, and enable the manufacturer to achieve maximum profit at the lowest cost [8–11].

The Product-Service System is closely linked to sustainability [12]. This is primarily related to the more efficient use of materials and reduction of waste [13]. This is very important for increasing public awareness and environmental policy [14].

Environmental and sustainability issues are significant for the printing industry, which generates different types of waste. Each printing house is committed to pro-environmental measures and responsible waste management. Waste management creates high costs for companies and forces them to take very thoughtful action [15].

Printing is a characteristic production sector, which includes not only printing and bookbinding services but also machines and equipment and materials used in the production process. Printing has played a key role in the development of the Renaissance and the scientific revolution and laid the foundations for a modern economy based on knowledge and its dissemination. Over the centuries, printing has undergone significant changes. It has entered an industrial phase, whose development is taking place at an even faster pace. In modern printing, we distinguish several basic printing methods and machines used in each of them [16–18].

Printing company owners, analysts, and researchers gathered at the 22nd Polygraphic Symposium in 2019 identified ten trends that will affect the printing industry. One of the issues discussed in detail was the implementation of solutions based on the Product-Service System in printing houses, where the customer does not pay for the printing machines and equipment, but for using them. This issue was considered to be the way forward for the printing industry.

The article aims to develop the Product-Service System model for the printing sector. The presented example was developed during a workshop conducted in a printing company.

2 Literature Review

2.1 Product-Service System in Industrial Practice

This stage of analysis concerned PSS models used in the industry. The analyzed PSS models have been developed in large companies and are addressed to various industries. Another characteristic feature of the products offered in this model is their high value, technological level, and long life cycle. Among the listed PSS models, it was not possible to find a model used in the printing industry.

2.2 Product-Service System Design

The literature analyzed gives a number of examples of case studies in which given PSS design methods were applied in practice. Not all of the methods examined were precisely assigned to a specific industry, therefore, for the purpose of this study, we have assigned the techniques to particular economic sectors (Fig. 1).

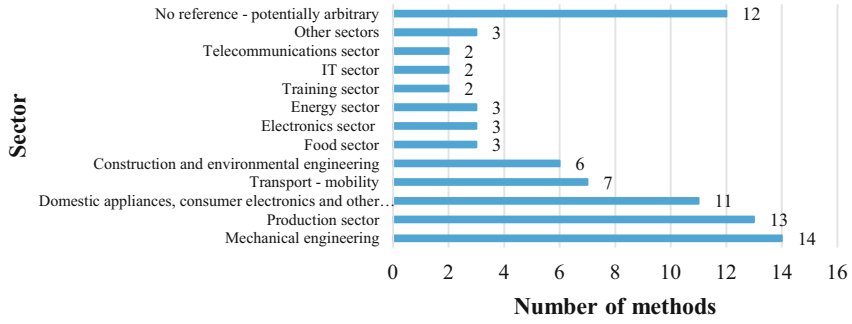

Fig. 1. Classification of PSS design methods by sector [19].

At this moment, it should be noted that some methods are addressed to several completely different industries. Most of the methods, 14, are aimed at mechanical engineering [19]. As many as 12 design methods for PSSs could not be allocated to any industry, which proves that they can be used in any sector of the economy [19]. It is worth noting that the available literature does not provide PSS design methods addressed to the printing industry.

2.3 Printing Industry

The printing sector is responsible for producing newspapers, books, magazines, packaging, brochures, labels, advertising catalogs, direct marketing materials, and other promotional materials. The unique feature distinguishing them from other products are in the possession and transmission of information. They are printed with the appropriate text and illustrations [20–22].

The largest printing markets include China, USA, India, Brazil, and EU countries. In Europe, the printing industry is an important employer and has a long tradition. This sector is linked to other industries.

The revenues of printing companies operating in the EU countries in 2009–2015 amounted to an average of 87,985,000,000 EUR (Figs. 2 and 3). In the EU countries, 725,800 people work in this sector in 119,591 companies [20–22].

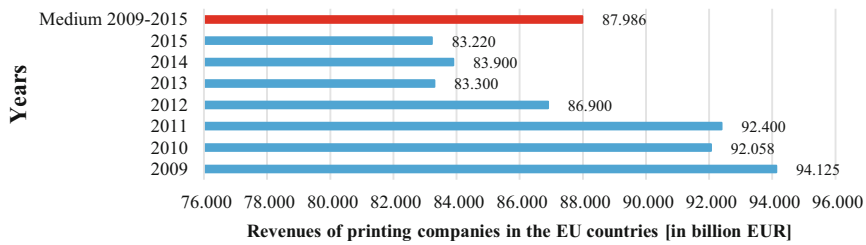

Fig. 2. Revenues of printing companies in the EU countries [in billion EUR] [20–22].

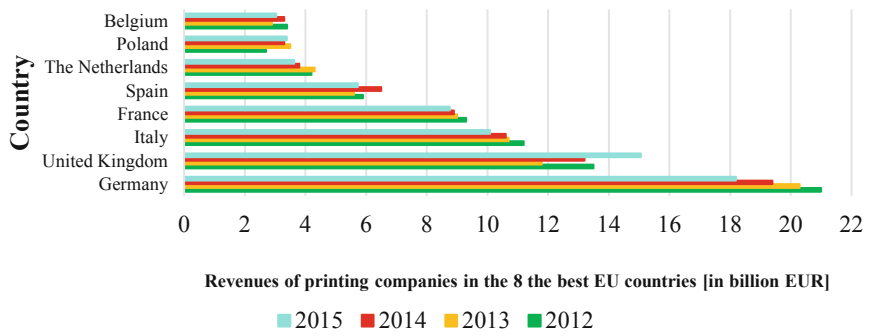

Fig. 3. Revenues of printing companies in the EU countries [in billion EUR] [20–22].

2.4 Printing Machines

Printing machines are a strategic sector for world economies. They are key capital goods because the products they produce are essential for the functioning of other branches of the economy.

Printing machines are the main element of the printing house equipment. They are used to make prints on an industrial scale. The machines differ in construction, the way the fonts are assembled, and the method of printing on a given substrate. They are durable, technically advanced devices that, when used properly, are efficient and fast in operation. The essential features of printing machines from the customer's point of view include roll and print width, roll diameter, and print speed.

At present, the main manufacturers offer on the market specialized printing machines in various variants of equipment together with basic services (installation, maintenance, training).

3 Research Methodology

The article aims to develop the Product-Service System model for the printing sector. The article formulates the following research questions:

- What are the possibilities of using PSS in the printing industry?
- What benefits can PSS bring to machine manufacturers, customers and the environment?

The analyses carried out in this article contain a number of suggestions that can be used in the development of a PSS for the printing industry.

The methodology adopted in this paper consists of the following phases:

1. Systematic literature review. This phase focuses on two equivalent activities, namely a literature review of industrial PSS cases and a review of PSS design methods. The authors searched for the term "Product-Service System in industry" or its synonyms. Databases were used in the search (ProQuest, Springer Link, Science Direct, Taylor & Francis Online, EBSCOhost, Scopus, Emerald, Insight, Web of

Science, Ingenta, Dimensions, Wilma, IEEE Xplore Digital Library and Google Scholar). The next step was to define the selection criteria. The authors focused on works written in English (articles published in magazines, conference materials, book chapters, reports, and white papers). The result was 120 works, in which PSS models operating in the industry were characterized. The works covered the period 2001–2019. Using the same databases and time frames, the authors searched for the term "Product-Service System design" or its synonyms. The result was 64 articles (including scientific articles, conference materials, monographic chapters, and books), in which 60 PSS design methods were found.

2. Analysis of the printing industry. This stage focuses on the analysis of users and manufacturers of printing machines. In this stage, industry reports were used for analysis.
3. Company survey. They were investigating problems and needs related to the industrial printing machine, demand for additional services dedicated to printing machines in a flexographic printing house. The Pareto–Lorentz analysis was used in the analyzed company to identify problems that generate significant losses and costs for the company. Then, using brainstorming, the primary service needs of the enterprise were identified. Based on this information, a questionnaire was developed containing proposals of services that were to respond to the problems and needs of the enterprise. The services in the questionnaire were divided into three groups. From each group, the company's employees selected the essential services from their point of view.
4. Designing the Product-Service System model. Based on a literature review and company research, the PSS model for industrial printing machines was developed. The new PSS model contains the services that were the most popular and the most beneficial for the company.

4 Results

4.1 Characteristics of the Analyzed Company

The analyzed company for flexographic printing is with a long tradition and experience. The company specializes in the production of labels and laminates. The printing house has a professional graphic studio, modern machinery. The printing house employees are a creative team with many years of experience. Thanks to these resources, the company can meet many tasks, starting from graphic design, through printing, finishing, and ending with delivering the finished product to the customer. Throughout its activity, the company enjoys the trust of a large group of customers from many industries (meat, food, pharmaceutical, cosmetic, and chemical). Among the wide range of labels produced by the company, there are five main types of products: self-adhesive labels, heat-shrinkable labels, OPP films, tea tags, laminates.

Thanks to continuous development, we are able to print any type of label up to a maximum width of 430 mm and a repeatable length of 600 mm on all types of paper and film. In the analyzed flexographic printing house, there are printing machines which are built in a modular system (BOBST M5). The modern machine park allows us

to print materials of up to 12 colors and to be additionally refined with UV varnish, foil, gilding with cold-stamping and hot-stamping and in-line embossing. There is also a possibility of multi-layered label printing from the adhesive side.

4.2 Company Problems and Needs

This phase aimed to identify the problems and needs of the printing house, which is a user of printing machines. The analysis took place in the form of workshops carried out in the analyzed company.

4.2.1 Company Problems

As mentioned above, the company is well established on the market. However, I am still struggling with a number of problems. In the analyzed company, use Pareto-Lorentz analysis to identify them (Fig. 4). These problems are still being reduced but still generate high costs for the company. In 2018, the key ones were the rebuilding of the printing machine, printer failures and stoppages, finished product incompatibilities, waste disposal, material losses, and training. All these factors are linked to each other and result in losses for the company.

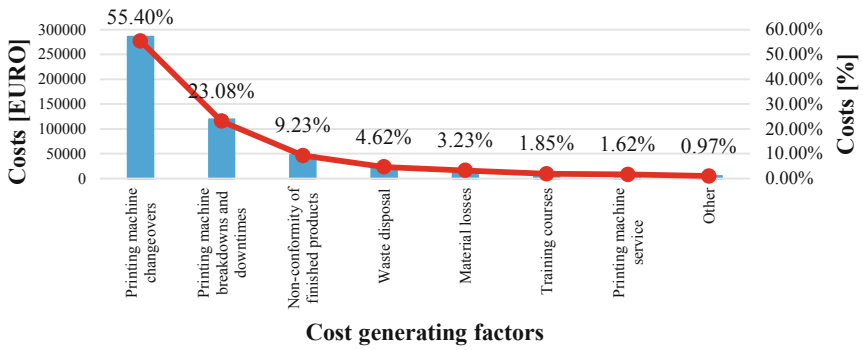

Fig. 4. Analysis of losses of a printing company in 2018.

The most significant losses for the printing house are caused by machine changeovers, breakdowns and downtimes is in total 77.8%. The factor worth looking at is waste disposal. All this creates the effective working time of a printing machine during a working day is 55%. This is also related to the low Overall Equipment Effectiveness, which averaged 50% in 2018.

The high machine changeover time is specific for the printing industry, especially for flexography. This type of production takes place on order, so a dozen or so different orders can be carried out daily, between which there is always a changeover and a number of activities related to it. An important role in the whole printing process is played by operators who, based on their own knowledge, determine the order of orders themselves. The order of orders outside the execution date is influenced by the changeover time, color or raw material width. Therefore, the training of operators in

which the analyzed company invests becomes a significant issue. The cost of waste disposal is a noteworthy fact.

It is worth noting that almost every printing company faces similar problems.

4.2.2 Company Needs

The workshops have identified the main needs that are related to the following areas:

- training - purchasing, upgrading, or retrofitting a machine with available options and tools that were not purchased early, requires re-training of the machine operators.
- the printing process - selection and mixing of ink, cleaning of printing equipment, changeover, and development of new printing forms, diagnosis of printing errors.
- operation and service of the machine – replacement of lamps, filters, UV mirrors, and other machine parts do not take place immediately, but after a certain time indicated by the service.
- waste management – despite the fact that the company has international certificates and standards and is constantly improving, this area of activity is very troublesome and, at the same time, involves high financial costs.

These points have a significant impact on the machine's performance and, therefore, on financial losses. There is also a burden on the environment due to unnecessary use of energy, water, and disposal of paint and products that do not meet quality requirements.

4.2.3 The Service Needs of the Company

In the next stage of the workshop, service proposals for the PSS model for printing machines were developed. The services were developed in order to respond to the problems and needs of the company so that the new PSS model meets its strict requirements. Three groups of services were created: universal services related to the printing machine, services related to the printing process, additional services.

From each of the groups of services, representatives of the management board, middle management, and production employees selected the most essential services from their point of view (Table 1).

Table 1. Services selected by the company's employees from the broadened areas.

	Universal services relating to printing machine	Print process services	Additional services
The Management Board	Financial services	Selection, delivery, and optimization of paint consumption for a specific order	Take-back
	Delivery, installation, and start-up of the machine	Optimization of printing machine conversions	Optimizing the use of equipment
	Health and safety services	Optimal time of preparation and realization of printing forms	Optimizing the use of materials
	Training courses	Preparation of CTP discs	Disposal of production waste
		Disposal of paint and substrates	Update (Reconstruction, upgrade)
		Exchange of mirrors, filters and UV lamps	Quality control
Middle management	Guarantee	Choice of inks and printing substrate	Diagnostics and error recovery
	Training courses	Technological process design	Lean tools
	Supply of spare parts	Exchange of mirrors, filters and UV lamps	Production planning and monitoring
	Regeneration, overhaul, repair, maintenance	Selection, delivery, and optimization of paint consumption for a specific order	Monitoring, testing, and diagnosis of machine operation
		Optimization of printing machine conversions	Quality control
		Optimal time of preparation and realization of printing forms	
		Preparation of CTP discs	
Production workers	Cleaning	Washing rollers, aniloxes	Optimizing the use of equipment
	Noise reduction	Selection, delivery, and optimization of paint consumption for a specific order	Optimizing the use of materials
	Training courses	Optimization of printing machine conversions	Disposal of production waste
	Health and safety services	Optimal time of preparation and realization of printing forms	Quality control
		Preparation of CTP discs	

At this stage, the company has confirmed its interest in hiring a machine and services that will improve the machine and the printing process. Additionally, the analyzed company was interested in a monthly subscription for using the machine more than in buying it.

4.3 Product-Service System for Printing Industry

Using an approach based on the PSS philosophy, as well as the knowledge gained on the problems and needs of the company, the next stage of the workshop was to build a PSS model. In the analyzed system, the main sides of the system, in this case include the machine manufacturer and the customer. In the model, the main components will be the printing machine and services the company is interested in (Table 2).

Table 2. Service packages in Product-Service System for the printing industry.

Area	Service package 1 – elementary	Service package 2 – intermediate	Service package 3 – advance
Training	Training courses	Health and safety services	Technological process design
Printing process	Cleaning	Selection, delivery, and optimization of paint consumption for a specific order	Optimizing the use of equipment
	Noise reduction	Optimization of printing machine conversions	Optimizing the use of materials
		Optimal time of preparation and realization of printing forms	Production planning and monitoring
		Preparation of CTP discs	Quality control
		Exchange of mirrors, filters and UV lamps	Lean tools
Operation and service of the machine	Delivery, installation, and start-up of the machine	Choice of inks and printing substrate	Monitoring, testing, and diagnosis of machine operation
	Supply of spare parts	Washing rollers, aniloxes	Take-back
	Guarantee		Diagnostics and error recovery
	Regeneration, overhaul, repair, maintenance		Update (Reconstruction, upgrade)
Waste management		Disposal of paint and substrates	Disposal of production waste
Additionally	Financial services	Financial services	Financial services

A company producing flexographic printing machines delivers them to the customer. Together with the machine, the customer receives a service package (Table 2, Fig. 5). The manufacturer charges a fixed fee per printing hour and a fixed monthly subscription fee. It is worth noting that the ownership will not be transferred to the user but remains with the machine manufacturer. The customer only needs to use the machine, i.e., to print as many orders as possible, and not to own the machine itself and deal with a number of issues related to its maintenance. The machine itself can be exchanged for a new one after a fixed period of time.

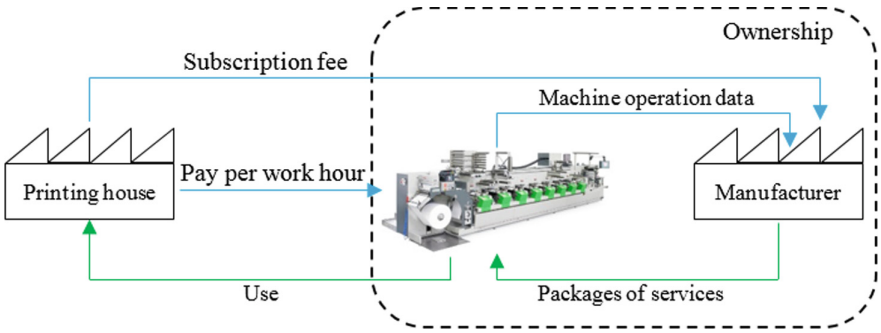

Fig. 5. Product-Service System for the printing industry —a concept.

An approach based on the philosophy of product and service systems brings a lot of benefits to all parties to the transaction. The client focuses primarily on his core business, i.e., printing and expanding the printing house. It is also not interested in service and repair activities as well as cleaning. An additional benefit for him is that he does not have to train people and buy the equipment needed for the mentioned activities himself, which saves time and resources. Also very important here are situations in which it can be enough to break down. The manufacturer is also obliged to remove it quickly because it is also in his interest to keep the machine running continuously. This approach allows the customer to increase the number of orders (Table 3).

A manufacturer of a printing machine earns money at the same time from the production of machines and services that are related to this machine. It is primarily in his interest to use the best possible materials and technological solutions to build from a high-quality machine that will have a long life cycle. This will ensure the possibility of data collection so that the manufacturer will be able to improve their parameters in new generations of machines and improve the printing process. It is essential that the elements of the printing machine which have a short life cycle can be quickly replaced. This is all to guarantee the reliability, minimize expenses on possible repairs and maintenance of the machine.

Table 3. Product-Service System for the printing industry —a concept.

Ownership	Sale	Services	Advantages for the manufacturer	Customer benefits
Ownership is retained by the manufacturer of the printing machine	Monthly subscription	Service package 1 - elements	Longer and more lasting relationships with customers	Focus on core business
		Service package 2 - intermediate	Control and monitoring of machines	Elimination of unnecessary costs
	Fee per worked hour	Service package 3 - advance	Improving the performance of printing machines	Increase in production
		Additional services	Less impact on the environment	

5 Conclusion

The article analyses the printing market. This sector is characterized by a large number of small and micro-enterprises. Such a large number of this size of enterprises proves a great application potential, a wide network of clients, and a large sales market. The specificity and size of this sector give a wide range of new business models for manufacturers of printing machines. It is worth noting that the manufacturers' offer for new offers based on PSS is very limited.

Product-Service System is a comprehensive solution that meets the needs and requirements of customers. An essential element of worldwide research is the use of all theoretical aspects of PSS and its implementation in industrial practice. In the article, there were conducted PSS design workshops for the printing industry. On this basis, the main problems and needs of the company and services that meet them were integrated. The printing machine, integrated with the services that the company really needs, has been integrated into the whole PSS system.

The following conclusions can be drawn from the design workshops conducted:

- in generating new PSS models, it is necessary to examine customer needs and problems. The active participation of representatives of the organization using the product is indicated in these activities.
- by properly adjusting services to the customer's problems and needs, it can radically minimize the adverse impact of printing production on the environment and at the same time extend the machine life cycle,
- the selected services should be divided into packages, so that the customer is not forced to use all the services at once, but can only choose the ones he needs,
- the package of services related to the printing process is significant support for users of printing machines, which has not been offered on the market so far,

- the developed concept of the PSS model for printing machines can directly or indirectly increase the production capacity of a printing house by eliminating time losses related to changeovers and breakdowns,
- the subscription fee does not generate costs associated with the depreciation of the machine for the customer. Additionally, the customer does not have to invest large amounts of money to purchase the machine,
- retaining ownership on the manufacturer's side allows him to continuously control the operation of the machine so that he sees the weakest links and components of the machine, which he will improve in future generations,
- this model may be addressed in particular to micro, small and medium-sized enterprises and people wishing to start-up in the printing industry,
- in the model in question, there are practically no restrictions on adding services related to printing machines,
- an important challenge for the manufacturer may be to create a service network and to standardize and standardize the production of machines.

Besides, the design workshops provide a solid basis for developing and implementing a PSS model for printing machines. It shows which aspects need to be addressed and which elements need to be addressed when creating a fully customized PSS.

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ISBN 978-952-335-700-6
ISBN 978-952-335-701-3 (PDF)
ISSN-L 1456-4491
ISSN 1456-4491
Lappeenranta 2021