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Decision-Support System-based Service Delivery in the Product-Service System Context: Literature Review and Gap Analysis

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Abstract

Manufacturing companies are revolutionizing the way they deal with customers, trying to satisfy their emerging needs with new, Product-Service System-centered (PSS), offerings. The shift towards this offering and its implementation are not easy since the proposal of badly structured offerings leads to unsatisfactory results for all the stakeholders. To obtain the maximum value in use, the way products and services are sold and delivered must be configured properly. In view of this, proper conceptualization, design and engineering methodologies must be adopted, along with suitable Decision Support Systems (DSS) to support them. DSS could help decision-makers in improving the service delivery process, proposing its scheduling, or deciding which kind service and how to provide it to customers. To be effective, DSS must be fed with right data and, in this sense, the implementation of Industry 4.0 technologies results crucial since the availability and exploitation of new, big, and structured datasets could improve DSS reliability. The aim of this work is to investigate how the presence of a DSS focused on service delivery process can enhance PSS offering in the context of Industry 4.0. The authors used a set of keywords related to PSS, service delivery process, DSS and Industry 4.0 to perform the research on the Scopus database. Following, they filtered results according to parameters of interest and, after reviewing the papers' pool, they identified the final set for the review. The analysis highlighted a gap in literature due to the lack of researches around the improvements in the service delivery process achievable through the implementation of smarter DSS exploiting the Industry 4.0 technologies.

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1. Introduction

The recent market evolution forced manufacturing companies to find new convenient ways to deal with their customers. In fact, the new needs emerged in the last decade pushed companies toward the proposal of new offerings based on bundles of products and services able to satisfy customer requirements namely Product-Service Systems (PSS) [1]. It must be cleared that shifting from a traditional, product-centred, business model, where the relationship with customer is purely transactional, to a new, customer-centred, PSS business model, characterized by different levels of intimacy, is not an easy task [2]. The provision of such complex and customer-tailored offering demands a profound revolution in the way products and services are designed, manufactured and

delivered to customers [3]. Researchers conducted several studies around this topic, proposing numerous methodologies aimed at improving different aspects of the PSS life cycle – e.g. conceptualization [4] and design [5] phases, while only a few authors have worked to improve PSS delivery and operations. Anyhow, a good design of product and services is not enough to guarantee the correct PSS provision and delivery. In order to create the maximum value in use, service provision must be supported by suitable Decision Support Systems (DSS), able to help decision-makers to make the right decisions and able to smooth PSS delivery process. In this regard, [6] states “DSS comprise a class of information system that draws on transaction processing systems and interacts with the other parts of the overall information system to support the decision-making activities of managers and other knowledge workers in

organizations”. In this sense, the wise exploitation and sharing of data collected from products and processes could lead to improved service delivery [7]. In parallel, the industrial world is witnessing a profound revolution under the umbrella of Industry 4.0 (I4.0) strategic programs [8]. One of the main benefits produced by the implementation of I4.0 technologies - such as Cyber-Physical Systems (CPS) [9] - is the availability of a consistent number of new data - e.g. collected from the production process [10]. Alternatively, the presence of sensors on the products, along with their ability to connect to the Internet, allows gathering and sharing useful data on all the product lifecycle stages. These data, if wisely exploited, can enhance significantly the way products and services are offered and delivered to customers [11]. Indeed, the adoption of I4.0 technologies could boost the diffusion of PSS offerings on the market, especially if these technologies are used to enhance and facilitate the delivery of tailored services to customers [12]. The aim of the authors is to investigate how the presence of a DSS focused on the service delivery process enhance PSS offering in the context of I4.0. This work intends to investigate the knowledge available on the topic, summarizing the results achieved until now and delineating the open gaps.

Section 2 presents the methodology used to perform the review and the reasons behind it. Section 3 and 4 deal respectively with the papers and DSSs’ analyses. Section 5 discusses the results delineating the gaps arose during the review. Section 6 concludes the paper summarizing the results and depicting the future work.

Table 1. Papers' Numbers and Filters

Filters	Number of Papers
Initial pool	671
Title filter	(504)
Pool after title	167
Abstract filter	(96)
Pool after abstract	71
Duplicates removal	(24)
Pool after duplicates	47
Full-text not available	(6)
Pool to read	41
Not useful	(21)
Final pool for the analysis	20

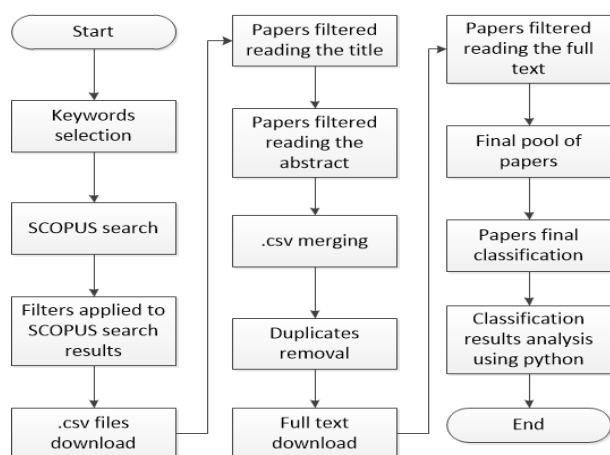


Fig. 1. Methodology

2. Literature Review

2.1. Methodology

In a PSS-centred business model, services have a central role in the creation of additional value for the company and the customers. Because of this, they must be associated with tailored instruments, able to support the service delivery process. In this sense, I4.0 technologies could play a significant role if well integrated into the decision-making and service delivery process [12]. A literature review has been conducted with the aim of investigating the work done until now on this topic and the maturity of this research field.

Fig. 1 depicts the methodology used to conduct the literature review while Table 1 reports how filters were applied to search results. The authors defined a set of keywords, and related synonyms, able to delineate the research context and useful to investigate the maturity of this field. To run the search, the authors used one of the major research database – SCOPUS. Keywords such as “decision support system”, “product service system”, “service delivery”, “service”, “service process”, “Industry 4.0”, “cyber-physical system”, “manufacturing” and “life cycle” were used to construct the queries, along with the operators “AND” and “OR”. To widen as much as possible the initial pool of papers, the authors run multiples searches with different combinations of the abovementioned keywords on the “Article title, Abstract, Keywords” field. Following, search results were refined using some of the SCOPUS filters, selected according to the authors’ research interests. The values used to filter the search results are the following:

- Publication Year: “2011”, “2012”, “2013”, “2014”, “2015”, “2016”, “2017”, “2018”;
- Subject Area: “Engineering”, “Computer Science”, “Business, Management and Accounting”, “Decision Sciences”;
- Document Type: “Conference Paper”, “Article”, “Article in Press”;
- Source Type: “Conference Proceedings”, “Journals”;
- Language: “English”.

The authors exported the filtered results as separate .csv files. Once collected, the authors started reading the papers’ title, using it as a proxy to select the ones interesting for the research. Papers with title explicitly not related to the research topic were discarded; papers with title interesting for the research or in doubt were kept. Once obtained the filtered list of papers, the authors started reading their abstract. Once again, papers with abstract not related to the scope of the research were discarded, while papers with abstract related or partially related to the research were kept. At this point, filtered .csv files were converted and merged in a single Excel file, and paper’s title was used as a proxy to remove duplicates. The authors downloaded the full-text of the remaining papers and started reading them to obtain the final pool for the detailed analysis. Once downloaded the full-texts, the authors started reading papers in the scope of classifying them according to their

content. Particular attention was devoted to the collection of content information (e.g. the nature of the research or the industry of application) and the scope of the research (e.g. PSS, DSS and enabling technologies). Accordingly, the following categories were used:

- Nature of the research;
- Presence of model or framework;
- Industry and area of application;
- PSS description;
- Product;
- Service;
- Technology/Architecture;
- B2B/B2C;
- DSS type;
- DSS scope;
- Input information (for the DSS);
- Output information (from the DSS);
- Life cycle phase of application.

Finally, the authors used Python 3.6 to perform a quantitative and qualitative analysis of the information contained in the Excel file. The results of the analysis are reported in the following.

2.2. Papers Analysis

This section reports the quantitative and qualitative analyses performed on the papers used in this literature review. Besides the categories listed in the previous section, the analysis also covered other indicators. The discussion around DSS topic in the PSS context is gaining importance. In fact, from the graph in Fig. 2, it is possible to notice a positive trend in the number of publications. Regarding the publishing source, no evidence of preference between journal articles and conference proceeding was observed. On the contrary, it is possible to affirm that CIPR IPSS community is the one who has the major interest on the topic. This is an expected result since it is a community working on PSS theme and since the keywords used for the search were PSS-related. Regarding keywords analysis, part of results is depicted in Fig. 3. To favour readability, only a subset of keywords is shown. As it is possible to notice, there is a strong presence of PSS-related keywords. Moreover, also DSS-related keywords constitute a relevant part of the total pool, with DSS as most popular keyword. Another interesting hint comes from the analysis of I4.0-related keywords. In fact, despite Cyber-Physical System (CPS) is one of the most popular topics in the I4.0 research stream [13], it appears only twice in the keywords' list. The full-text reading and categorization highlighted the presence of a model or a framework in the majority of papers and, in particular, the analysis pointed out that simulation (e.g. Agent-Based Simulation and Discrete Event Simulation) is the most used technique for system modelling. Other instruments used to model the system are flowchart, UML, BPMN 2.0, Petri-Nets. As shown in Fig. 4, 14 out of 20 papers deal with manufacturing industry. The result complies with the main scope of the research. Related to this, the papers covered a wide variety of application area, such as agriculture, energy, household appliances, machine tools, industrial complex

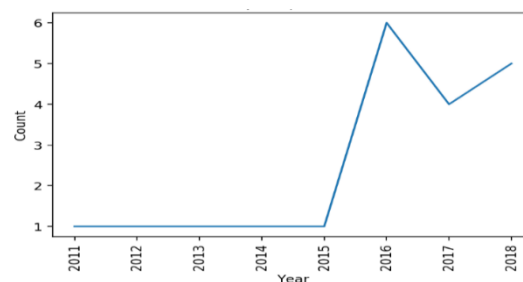


Fig. 2. Publication Year Analysis

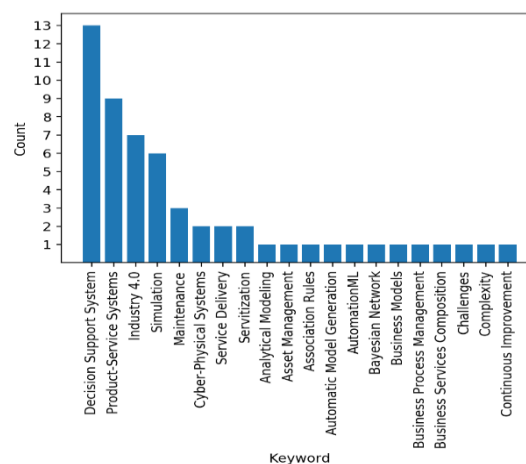


Fig. 3. Keywords Analysis

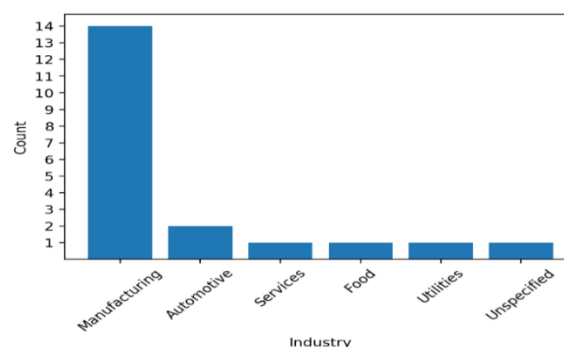


Fig. 4. Industry Analysis

systems, etc.

2.3. Decision Support System (DSS) Analysis

After an initial analysis of papers according to bibliographical and content data, the authors focused the attention on DSS. The authors used the DSS classification framework described in [14] to classify DSS type and capture trends in DSS implementation and usage for PSS decision-making. Model-Driven DSS is the most common category, followed by Document-Driven and Knowledge-Driven DSS. While some of the DSSs have been classified as Data-Driven DSS, no Communication-Driven DSS is present in the pool. In order to be effective, DSSs must be built around a clear scope [15], clear in the required inputs and expected outputs [16] and designed according to the life cycle phase to which they belong to [17]. The analysis points out that the majority of publications have a scope related to maintenance in terms of scheduling, maintenance type and/or priority. The second most common scope in the analyzed pool is operations management, detailed

in many cases as service delivery, which represents the main interest of this research. The full-text reading allowed defining the different inputs used in the DSSs. Due to the vast diversity of inputs, and to facilitate the comprehension and discussion of results, they are classified in categories. Fig. 5 provides a visual representation of the most common information required as inputs for the DSSs. As expected, business model information, such as costs (e.g. maintenance, planning, set-up, logistic, etc...) and market characteristics, are the most required inputs. This is because profits are a fundamental driver that companies have to take into consideration when making decisions. Of course, also product and service characteristics, along with production system information, have great importance in decision-making process. For what concerns services, it is important to mention that maintenance represents probably the most diffused service offered to customers and, for this reason, authors put maintenance-related inputs in a separate category. If the input information category is mainly related to business model, the most common output of DSS is related to maintenance decisions. As shown in Fig. 6 these decisions are mainly related to maintenance delivery policy, scheduling and quotation. Business decision constitutes another important category in the output information analysis. In particular, these are mainly related to the optimization of business process, to the management of business relations with the customer (e.g. penalties or discounts). Other important aspects addressed by the pool of papers are production (e.g. Kanban status, production schedule), requirements (e.g. expert systems, full cost model, etc...) and risk assessment. Furthermore, the authors categorized papers according to the life cycle phase [18] where they are used. According to Fig. 7, usage phase is the most covered one by DSS, followed by maintenance phase. In particular, four papers categorized in the usage phase deal with service delivery process, which is the focus of this research. Due to the necessity for companies to provide efficient PSS, some DSS focuses on Conceptualization and Design phase. The results are in accordance with what has resulted from the DSS scope analysis.

3. Discussion

PSS business model is spreading around manufacturing world because of the benefits it could bring to companies and customers. Multiple studies have demonstrated that an imperfect implementation could turn into poor results for both users and providers [19]. For this reason, besides the integration of product and services during the design phase, another relevant aspect for the creation of the maximum value in use is the correct service delivery process and, thus, the support of suitable DSS supporting it. This topic is of great importance due to the new, central role, which services gained in PSS business model. As demonstrated by this literature review, the discussion around this topic is starting, as researchers are becoming aware of the strategic role that service delivery has in value creation. As [15] states, it is necessary to distinguish between DSS and Specific DSS (SDSS) because of their different reliability and flexibility. In fact, begin focused on a specific task, SDSSs are more reliable in the domain they are acquainted with allowing, in certain cases, to reduce human intervention in the decision-making

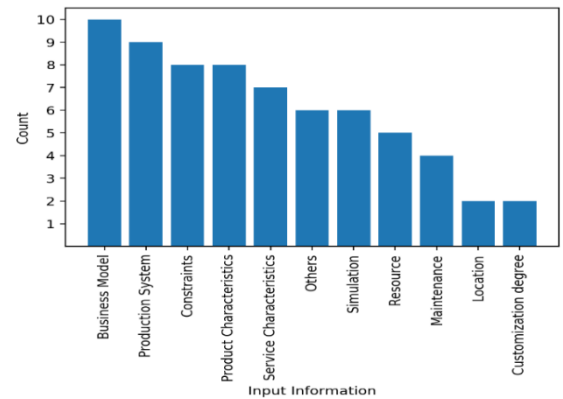


Fig. 5. Input Information Analysis

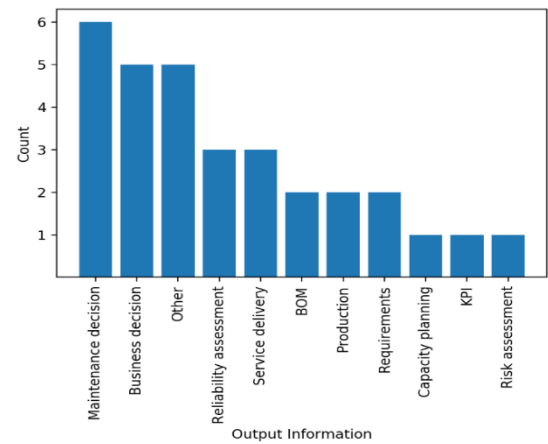


Fig. 6. Output Information Analysis

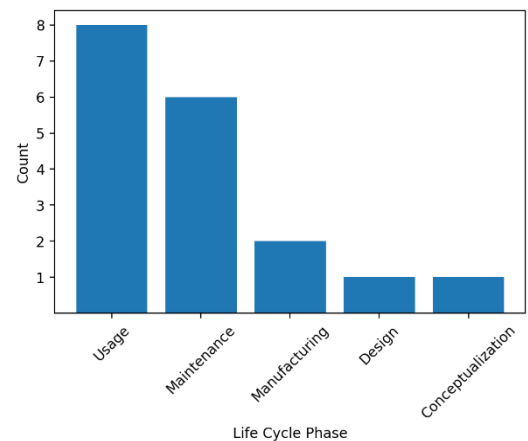


Fig. 7. Life Cycle Phase Analysis

process. On the other hand, their flexibility is very low, and they cannot be used outside their domain without diminishing their reliability. On the contrary, generic DSSs are more flexible and, because of this, less reliable due to the fact that they are not built to deal with single and specific knowledge-domain but to deal with different domains. DSS can be applied to different phases of PSS life cycle like conceptualization [20], design [21], manufacturing [22], [23], usage [15], [24]–[26], and maintenance [27], [28]. Being the life cycle phase crucial for the definition of the DSS characteristics, it also influences the DSS scope and DSS type, and vice versa [15], [17]. As emerged from the paper analysis, different DSS types are proposed in literature. Among these, simulation is very

common, especially in the middle phases of PSS life cycle (delivery, maintenance), while for the initial phases other approaches, such as Petri-Nets are preferred. If the simulation is the most diffused DSS type, maintenance is probably the most diffused service offered; this is why a considerable number of papers among the pool focused on that. Maintenance-oriented DSSs are strategic for the assets' End-of-Life (EOL) management and, consequently, for the value creation [29]. Moreover, as [30] affirms, DSS-oriented maintenance has a direct impact also on other phases of PSS life cycle like manufacturing and use phase, influencing production process and product availability directly. [31] discusses the importance of decision-making to support capacity planning in PSS delivery context, highlighting how, depending on the specific business model, it could significantly influence revenues and relationships with customers. In this sense, the integration of I4.0 technologies and data collection could impact the service delivery significantly, improving the reliability of Data-Driven and Model-Driven DSSs such as the ones described in [26], [27], [32] and, in turn, fostering cross-organizational processes [33]. As data availability constitutes one of the major advantages of I4.0, important problems like data collection [34], management [35] and usage [10] must be faced by decision-makers and DSS designers. In this sense, the majority of case studies and applications cases in the papers suggests the presence of sensors and cloud as fundamental technologies to support the service delivery. Despite this, the discussion around the possibilities offered by CPS in this context is very poor. Even though [13] states that CPS usage could be beneficial for a more reliable and autonomous decision-making process, among the pool only a few papers deal with the CPS concept [22], [30], [36]. The discussion around this topic should be deepened, especially since CPSs are used frequently as a synonym of I4.0 in literature. As [37] states, process and relations modelling can play a fundamental role in the improvement of the service delivery process. As proper DSS should support service delivery process, accurate process modelling should be used as a support to improve DSSs decisions. The paper analysis demonstrated that a wide variety of modelling languages and techniques - such as BPMN2.0 [33], flowchart [38], VSM [39] and UML [36] – can be used to support decision-makers. One of the most peculiar advantages of process modelling is the possibility to clarify the information flow, delineating in each step input and output information. As mentioned in the previous section, information related to business model and production system along with constraints and product and service characteristics are the most common input information for the DSS, especially in the service delivery phase. As a result, output information is mainly related to maintenance or business decisions. In particular, maintenance decision policy or scheduling and price discount or penalty decisions.

What emerges from the analysis is that despite the structure of the queries specifically focused on the service delivery, the number of paper related to this is only a minor part of the total pool [15], [26], [33], [39] and, none of them deals with the CPS concept. Thus, more efforts should be put on this theme due to the strategic importance that service delivery process has on value creation.

The research around DSSs enabled by the Industry 4.0 technologies in the service delivery process is still poor. Given the diffusion of Industry 4.0 related technologies, this theme

should be deepened.

None of the analysed papers has discussed the possibility of a service selection framework to use in the service delivery process, in order to understand which kind of service should be provided to the customer to answer to his/her specific need. The theme has been discussed only slightly in some of the maintenance papers, where different maintenance scenarios have been compared.

None of the analysed papers deals with the theme of the automation of decision-making in service delivery process. This could be interpreted as a hint that service delivery process is, as of now, still mainly managed manually and, thus, could be biased by the interests of the decision-maker.

Given these findings, it is clear that there is a gap around the research on how the implementation of DSSs able to automate the decision-making activity, and enabled by the Industry 4.0 technologies, could result in a more effective service delivery process. Examples of application could be the following:

- Data collected from CPS and uploaded in the cloud could be used by the DSS as input for the selection of the service to provide to customers (e.g. selection between supporting the customer through the remote Help desk, through a phone call or by sending a technician at the customer place);
- Similarly, a DSS could be used to automate the selection of the technician to send on the field to provide maintenance. In this case, the DSS could take as input information like machine location, skills required to execute maintenance, technicians' schedule, etc... and provide as output a list of technicians able to provide the service.

4. Conclusion

If companies offering PSS to the market want to maximize their profits and customer satisfaction, they should be aware of the importance that the service delivery phase has on the value creation. The scope behind this literature review was to investigate the role of DSS as support for the PSS delivery, paying particular attention to the presence, and the role, of I4.0 technologies in the process. Among the initial pool of more than 600 papers, only 20 satisfied the selection criteria. Among these, only 4 were strictly focused on the service delivery process, while the others were focused on other aspects of the PSS life cycle. In addition, only a minor part of the papers mentioned explicitly I4.0 technologies and, in this pool, only 3 dealt with the CPS theme. None of the papers in the pool discussed at the same time of service delivery process and CPS. The findings clearly highlight a gap in the research around DSSs enabled by I4.0 technologies and able to automate part of the service delivery process, improving it. Future research will be focused on this theme, trying to understand what kind of information are necessary to build a DSS with this scope and how to measure the benefits for the companies.

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References

- [1] Tukker A. Eight Types of Product-Service System: Eight Ways to Sustainability? Experiences from Suspronet. *Bus Strateg Environ* 2004;13:246–260.
- [2] Sala R, Zanetti V, Pezzotta G, Cavalieri S. The role of technology in designing and delivering Product-service Systems. In: 23rd ICE/IEEE International Technology Management Conference 2017; 281–304.
- [3] Sala R, Sassanelli C, Pezzotta G, Terzi S. A comprehensive Engineering Environment to conceptualize, design and monitor Product Service Systems (PSS): an application case. In: Proceedings of the Summer School Francesco Turco; 2017;194–200.
- [4] Rondini A, Pezzotta G, Pirola F, Rossi M, Pina P. How to design and evaluate early PSS concepts: the Product Service Concept Tree. In: 26th CIRP Design Conference; 2016;50:366–371.
- [5] Sassanelli C, Pezzotta G, Pirola F, Sala R, Margarito A, Lazoi M, Corallo A, Rossi M, Terzi S. Using design rules to guide the PSS design in an Engineering Platform based on the Product Service Lifecycle Management (PSLM) paradigms. *Int J Prod Lifecycle Manag* 2018;11:91–115.
- [6] Sprague RHJ. A Framework for the Development of Decision Support Systems. *MIS Q*; 1980;4:1–26.
- [7] Ardolino M, Rapaccini M, Saccani N, Gaiardelli P, Crespi G, Ruggeri C. The role of digital technologies for the service transformation of industrial companies. *Int J Prod Res* 2017;1–17.
- [8] Uhlmann E, Geisert C. Intelligent Production Systems in the Era of Industrie 4.0 - Changing Mindsets and Business Models. *J Mach Eng* 2017;17:5–24.
- [9] Lee J, Bagheri B, Kao HA. A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. *Manuf Lett* 2015;3:18–23.
- [10] Zhou J, Yao X, Zhang J. Big Data in Wisdom Manufacturing for Industry 4.0. 5th Int Conf Enterp Syst 2017;107–112.
- [11] Tao F, Qi Q. New IT Driven Service-Oriented Smart Manufacturing: Framework and Characteristics. *IEEE Trans Syst Man Cybern Syst* 2017; 1–11.
- [12] Bagozi A, Bianchini D, De Antonellis V, Marini A, Ragazzi D. Interactive Data Exploration as a Service for the Smart Factory. *IEEE Int Conf Web Serv* 2017;293–300.
- [13] Hermann M, Pentek T, Otto B. Design Principles for Industrie 4.0 Scenarios: A Literature Review. 2015.
- [14] Power DJ. Specifying An Expanded Framework for Classifying and Describing Decision Support Systems. *Commun Assoc Inf Syst* 2004;13:158–166.
- [15] Dong CSJ, Srinivasan A. Agent-enabled service-oriented decision support systems. *Decis Support Syst* 2013;55:364–373.
- [16] Nunes I, Jannach D. A systematic review and taxonomy of explanations in decision support and recommender systems. *User Model User-adapt Interact* 2017;27:393–444.
- [17] Molloy EM, Siemieniuch C, Sinclair M. Decision-making systems and the product-to-service shift. *J Manuf Technol Manag* 2009;20:606–625.
- [18] Sundin E. Life-Cycle Perspectives of Product/Service-Systems: In Design Theory. In: Introduction to Product/Service-System Design 2009:31–49.
- [19] Benedettini O, Swink M, Neely A. Examining the influence of service additions on manufacturing firms' bankruptcy likelihood. *Ind Mark Manag* 2015;60:112–125.
- [20] Dahmani S, Boucher X, Peillon S, Besombes B. A reliability diagnosis to support servitization decision-making process. *J Manuf Technol Manag* 2016;27:502–534.
- [21] Mourtzis D, Fotia S, Boli N, Pittaro P. Product-service system (PSS) complexity metrics within mass customization and Industry 4.0 environment. *Int J Adv Manuf Technol* 2018;97:91–103.
- [22] Latorre-Biel JJ, Faulín J, Juan AA, Jiménez-Macías E. Petri Net Model of a Smart Factory in the Frame of Industry 4.0. *IFAC-PapersOnLine* 2018;51:266–271.
- [23] Fischer J, Obst B, Lee B. Integrating material flow simulation tools in a service-oriented industrial context. *IEEE 15th Int Conf Ind Informatics* 2017:1135–1140.
- [24] Johanson M, Karlsson L. Service architectures for product and production availability: A system of systems approach. 11th Syst Syst Eng Conf 2016;1–6.
- [25] Reim W, Parida V, Sjödin DR. Risk management for product-service system operation. *Int J Oper Prod Manag* 2016;36:665–686.
- [26] Lagemann H, Boßlau M, Meier H. The influence of dynamic business models on IPS2 network planning - An agent-based simulation approach. *Procedia CIRP* 2015;30:102–107.
- [27] Zhou R, Hu Y, Xiao S, Wen J. A Multi-agent Based Decision -Making Approach for Field Service Delivery of IPS2. *Procedia CIRP* 2016;47:228–233.
- [28] Xiao S, Hu Y, Han J, Zhou R, Wen J. Bayesian Networks-based Association Rules and Knowledge Reuse in Maintenance Decision-Making of Industrial Product-Service Systems. *Procedia CIRP* 2016;47:198–203.
- [29] Fornasiero R, Zangiacomi A, Sorlini M. A cost evaluation approach for trucks maintenance planning. *Prod Plan Control* 2012;23:171–182.
- [30] Schreiber M, Klöber-Koch J, Richter C, Reinhart G. Integrated Production and Maintenance Planning for Cyber-physical Production Systems. *Procedia CIRP* 2018;72:934–939.
- [31] Lagemann H, Meier H. Robust capacity planning for the delivery of Industrial Product-Service Systems. *Procedia CIRP* 2014;19:99–104.
- [32] Bumblauskas D, Gemmill D, Igou A, Anzengruber J. Smart Maintenance Decision Support Systems (SMDSS) based on corporate big data analytics. *Expert Syst Appl* 2017;90:303–317.
- [33] Montarnal A, Mu W, Benaben F, Lamothe J, Laurus M, Salatge N. Automated deduction of cross-organizational collaborative business processes. *Inf Sci (Ny)* 2018;453:30–49.
- [34] Sokolov B, Ivanov D. Integrated scheduling of material flows and information services in industry 4.0 supply networks. *IFAC-PapersOnLine* 2015;28:1533–1538.
- [35] Stojanovic L, Dinic M, Stojanovic N, Stojadinovic A. Big-data-driven anomaly detection in industry (4.0): An approach and a case study. *IEEE Int Conf Big Data (Big Data)* 2016;1647–1652.
- [36] Lin J, Sedigh S, Hurson AR. An agent-based approach to reconciling data heterogeneity in cyber-physical systems. *IEEE Int Symp Parallel Distrib Process Work* 2011;93–103.
- [37] Wittenberg C. Human-CPS Interaction - requirements and human-machine interaction methods for the Industry 4.0. *IFAC-PapersOnLine* 2016;49:420–425.
- [38] Lee JCH, Choy KL, Leung KH. An intelligent fuzzy decision support system for flexible adjustment of dye pricing to manage customer-supplier relationship. In: Smart Manufacturing, Industrial & Logistics Engineering (SMILE), 2018 IEEE International Conference on 2018:7–11.
- [39] Krishnaiyer K, Chen FF. Web-based Visual Decision Support System (WVDSS) for letter shop. *Robot Comput Integr Manuf* 2017;43:148–154.