Research Trends on Smart Connected Products in The Industry 4.0: A Systematic Literatur Review

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Abstract. The Industry 4.0 concept is a new manufacturing approach that integrates smart factories, smart machines, smart systems, smart production, and smart processes into a unified network. Through applying CPS (Cyber-Physical Systems) technology, Industry 4.0 combines the physical and virtual worlds to increase company productivity and efficiency. This paper aims to explore research trends related to smart (connected) products in the Industry 4.0 era and find studies that can be developed in the future using a systematic literature review (SLR). The results of the SLR show that from 57 papers, it was found that product engineering and CPS technology were the aspects of the study that were mainly carried out. New research potentials that can be developed in the future have been identified in product engineering, smart factory, and standardization studies. Future research on SCP can be applied to the case of electric motorcycles swappable battery (EMSB).

1 Introduction

The concept of Industry 4.0 has become the focus of attention from both academics and organizations. This paradigm represents a new manufacturing approach by integrating smart factories, smart machines, smart systems, smart production, and smart processes in a unified network. Through the application of CPS (Cyber-Physical Systems) technology, Industry 4.0 brings together the physical and virtual worlds to achieve increased company productivity and efficiency. It is hoped that various technological advances that will occur in the future will make an important contribution to industrial development and improve company performance [1].

The Industry 4.0 implementation framework model, according to [2], was developed by the Industry 4.0 working group, which the German Ministry of Education and Technology Research established in 2013. According to the recommendations, three factors need to be considered for Industry 4.0 to successfully transition technology: (1) Endto-end engineering of the complete value chain, (2) Horizontal integration through the value chain. (3) Vertical integration and network working of manufacturing or service systems. To achieve this integration, it is also necessary to take into account eight key areas, including (1) standardization, (2) complex system modeling, (3) communication network infrastructure, (4) safety and security assurance, (5) organizational design and employment, (6) human resource training, and (7) legal framework indeed and (8). resources efficiency. From these eight key areas, 14 aspects of the study on Industry 4.0 can be identified. These aspects are presented in Table 1.

Table 1. Study aspects of industry 4.0

No	Aspects	Description
1	Standardization	These are all activities related to efforts to prepare standards or references in the implementation of Industry 4.0
2	modeling	The process of representing complex integral systems to obtain solutions to real problems.
3	Communication network	Includes hardware or software technology available to exchange information and data quickly, accurately, and in real-time.
4	Safety and Security	Everything here is about data system security and how humans use technology.
5	Human Resources	All Efforts to prepare Human resources in the transformation to Industry 4.0
6	Legal	Efforts related to the preparation of legal frameworks and foundations in the implementation of Industry 4.0
7.	CPS Technology	Developing and implementing critical technologies in Industry 4.0 (CPS, IoT, virtualization, cloud computing, etc.)
8.	Resource Efficiency	Represents all efforts in resource efficiency (e.g., energy, costs, etc.) in the implementation of Industry 4.0

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9.	Smart Factory	These are all efforts to develop automated, intelligent, modular, and adaptive manufacturing systems or production processes.
10.	Business	Development of business model transformation as a result of the application of Industry 4.0
11.	Work Design	These are all development and research efforts related to changes in work systems that workers will face due to the implementation of Industry 4.0.
12.	Service	Development and utilization of applications and processing of big data
13.	Management and organization	Development of management and organizational models in the implementation of Industry 4.0
14.	End to end Product Engineering	All the efforts in engineering products and services are digitized during the product cycle.

Products have revolutionized due to information technology's emergence, which continues to grow fast. Initially, the technology was only part of the mechanical and electrical systems of the product. However, effects have evolved into complex systems that combine hardware, software, sensors, data storage, microprocessors, and networks in various ways. These products are now referred to as “smart and connected products” or Smart (Connected) Products (SCP)[3].

SCP is referred to by a variety of names, including Smart Objects [4], Intelligent Product [5], and Smart Product [6]. They've both been used interchangeably and synonymously. The definition of a smart product, according to the "Smart Products Consortium," is "an autonomous object designed for self-regulated embedding into different environments throughout its life cycle and which enables natural productto-human interaction." By utilizing sensing capabilities, input, and output from the environment, smart devices can proactively interact with consumers so that they can learn to control themselves according to circumstance and context. Various smart items that develop over time can share and distribute knowledge and related functionality. According to [7], the six design specification features of context awareness, embeddedness, personalization, connectivity, service bundling, and systemic design significantly impact the capabilities of smart products.

This paper explores the study of smart (connected) products in the industrial era 4.0 through a systematic literature review. There are three research questions (RQ) that have been formulated in this study, namely: (1). What are the critical characteristics of smart (connected) products?; (2). What are the research trends and challenges regarding smart connected products in the Industry 4.0 era?; (3). What is the future research agenda regarding smart (connected) products?

2 Methodology

The five systematic steps of the literature review by Denyer and Tranfield[8] include (A.) research question formulation, (B.) study locating, (C.) study selection and evaluation, (D.) analysis and synthesis, and (E.) reporting and using results, are modified in this paper's methodology. These five steps are shown in Fig.1.

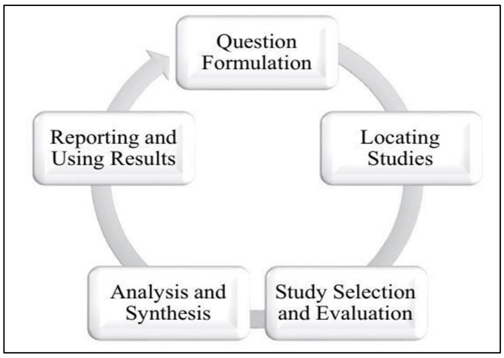

Fig. 1. Systematic literature review methodology

2.1 Research question (RQ) formulation

Two RQs will have been formulated in this study: (1). What are the critical characteristics of smart (connected) products?; (2). What are the research trends, challenges and opportunities regarding smart (connected) products in the Industry 4.0 era?; and (3). What is the future research agenda regarding smart (connected) products?

2.2 Locating studies

At this stage, the object of study is decided by choosing keywords to respond to the RQ. The keywords used in this paper are: "smart connected product" and its synonyms ("smart product," "intelligent product", "digitized product,” "industry 4.0," and its synonyms ("fourth industrial revolution,” "Industrie 4.0"). The process of inputting keywords on search engines uses Boolean logic: AND, OR, ("__") for a more accurate search. So the keywords used in this study are: "smart connected product" OR "smart product" OR "intelligent product” OR “digitized product” AND "Industry 4.0" OR "industrie 4.0" OR "fourth industrial revolution.” SCOPUS is the search engine used to look for early literature. The following five requirements must be fulfilled by all papers submitted: The documents must (1) be in the fields of engineering, computer science, business management, and accounting; (2) contain at least one of the two search terms in the title, abstract, or keywords; (3) have been published in journals and conference proceedings; (4) be final articles; and (5) be written in English. In addition, a snowball search was done on Google Scholar because there weren't many papers available there.

2.3 Study selection and evaluation

Each publication is objectively reviewed and rated using the standards listed in Table 2 to ensure the literature acquired is pertinent to this issue. The table identifies the five requirements. The CR and PR categories include papers that can be reviewed and studied further.

Table 2. Criteria for selecting papers for review

Criteria	Sub Criteria	Description
Included	Closely Related (CR)	Specifically and formally in the realm of research on SCPs or SPs in the Industry 4.0 era.
	Partially Related (PR)	The focus is related to one of the studies, namely SCP or SP
Not Included	Without FullText (WF)	The full text cannot be accessed/obtained
	Non-Academic (NA)	Not academic papers such as company profiles, bulletin materials, etc
	Not Related (NR)	The paper does not focus on smart products or is only part of a noun phrase or systematic literature review.

2.4 Analysis and synthesis

Based on the selection and evaluation process at the previous stage, 71 papers were collected at the initial step. Figure 2 shows the number of documents included or excluded according to the criteria listed in Table 2. Finally, 54 papers were entered, and a final review was completed. A paper review is carried out by looking at (1) the number of publications and their trends; (2) the most productive publishers/journals; (3) Terms, definitions, and specifications for smart (connected) products in every literature reviewed; (4) The research method used; (5) The topic/theme of study on smart products in the industrial era 4.0. Reviews regarding smart (connected) product specifications refer to [7], while reviews related to research methods are carried out using Kothari (2004) references (presented in Table 3. Data processing uses MS Excel and VosViewer Software.

2.5 Reporting and using results

In sub-chapter 3 (Result), the review paper's results are displayed in Fig. 3, Fig. 4, Fig. 5, and Table 4, Tabel 5, and Table 6.

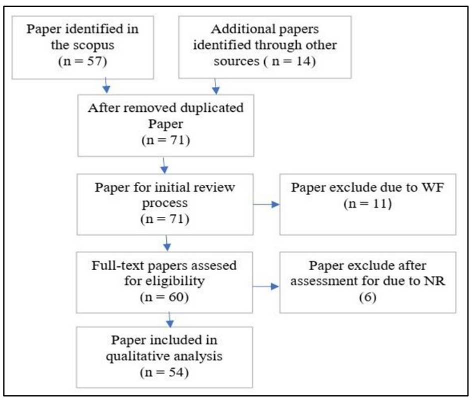

Fig. 2. Flowchart od the data collection and selection process

Table 3. Classification of research methodology approac

No.	Research Methodology	Description
1	Descriptive	Research that aims to present findings based on facts and information.
2	Conceptual	Research-oriented to generate concepts and ideas.
3	Applied/Case study	Research that aims to provide solutions to real industrial problems or cases raised.
4	Empirical	Research is conducted to prove the hypothesis based on data collection obtained through observation or experiment.
5	Simulation	The research was conducted to prove the hypothesis through an accurate system simulation, which is the object of study.

3 Result

3.1 Research publications per year

According to a literature review, research on smart products began in 2008; however, publications are only sometimes readily available yearly. Every year since 2013, there have been extensive publications. There were only a few publications between 2013 and 2015, with an average of one paper published yearly. With the initial release of three papers in 2016, the trend toward more publications started. In 2020, 20 papers were published, which is the most. Figure 3 shows the overall trend of the annual number of publications.

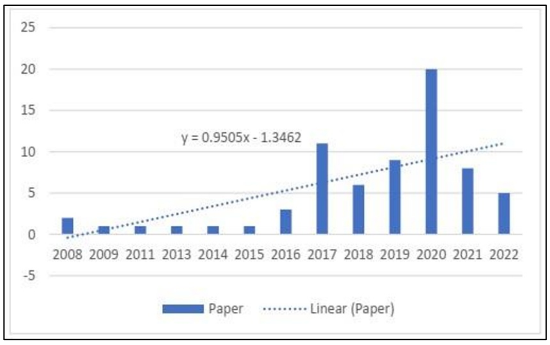

Fig. 3. Number of publications per year

Based on the data collected, it is known that the Procedia Manufacture journal is the most productive journal publishing research on smart connected products in the industrial era in the period 2016 -2022 (five papers). They were followed by sustainability journals and Technology Forecasting Social Change (four pieces each). Figure 4. Present the top 15 journals that publish research on smart (connected) products in the industry 4.0 era.

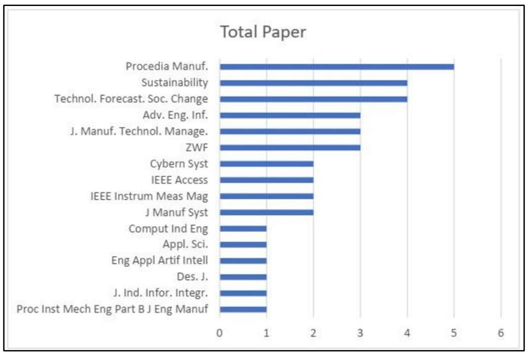

Fig. 4. The most popular journals in research publications

3.2 Smart (Connected) product terminology

There are 54 papers; only 13 (24%) provide specific definitions, while 41 (76%) do not. There are four terms related to smart products used by the author, namely: smart product (seven papers), intelligent product (one paper), digitized connected product (one paper), and smart connected product (four papers). Based on this definition, intelligent and smart products have the same terminology as the digitized, connected product, which is a synonym for a smart connected product—then classified based on the design specifications stated in the paper. The results are presented in Table 4 and Table 5.

Table 4. Result of a review of design specifications on smart product

Spesification of Design	Paper that uses the terminology of smart products							
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Context-Awareness	x	x	x	x	x	x	x	x
Personalization		x		x				x
Connectivity	x	x	x	x	x	x	x	
Embeddedness	x	x	x	x		x	x	x
Service Bundling						x	x	
System Design					x	x	x	
Total	3	4	3	4	3	5	5	3

Table 5. Results of a review of design specifications on smart (connected) products

Spesification of Design	Paper that uses the terminology of smart (connected) products				
	[9]	[10]	[11]	[12]	[13]
Context-Awareness	x	x	x	x	x
Personalization	x	x	x	x	x
Connectivity	x	x	x	x	x
Embeddedness	x	x	x	x	x
Service Bundling	x	x	x	x	x
System Design	x	x	x	x	x
Total	6	6	6	6	6

3.3 Aspects of the study

A review of the research themes in this study is associated with the Industry 4.0 framework model. There are 14 aspects in Industry 4.0, but only nine parts related to smart (connected) products were found in the literature review: CPS technology, end-to-end product engineering, smart factory, certification, modeling, safety and security, service, management and organization, and business. Details are presented in Table 6.

Table 6. Paper classification based on study aspects

No	Study Aspects	Total (%)	Author
1.	CPS Technology	12 (22,2%)	[14];[15]; [16] ; [17] ; [18] ; [19] ; [20] ; [21] ; [8] ; [22] ; [9] ; [10]
2.	End to end Product Engineering	17 (31,5%)	[23]; [24] ; [1] ;[2] ; [25] ; [26] ; [27] ; [28] ; [29] ; [30] ; [4] ; [31] ; [32] ;[6] ; [33] ; [34] ; [35]
3.	Smart factory/smart manufacturing	5 (9,3%)	[36] ; [37] ; [38] ; [3] ; [39]
4.	Modelling	6 (11,1%)	[40] ; [41] ;[42]; [43] ;[44];[45]
5.	Standardization	1 (1,9%)	[46]
6.	Service	5 (9,3%)	[47] ; [48] ; [49] ; [50] ; [51]
7.	Business	4 (7,4%)	[13] ; [12] ; [11] ; [7]
8.	Safety and Security	1 (1,9%)	[52]
9.	Management and Organization	3 (5,6%)	[53] ; [5] ; [7]

While the review results are in terms of the research method approach, it is known that the conceptual approach is the most widely used research method (31 papers or 57%). The empirical method (12 articles or 22%), the applied method (seven articles or 13%), and the ranking at the bottom are descriptive and simulation methods, respectively (two papers or 4%). The complete distribution of the amount of research based on the research method used is presented in Fig. 5.

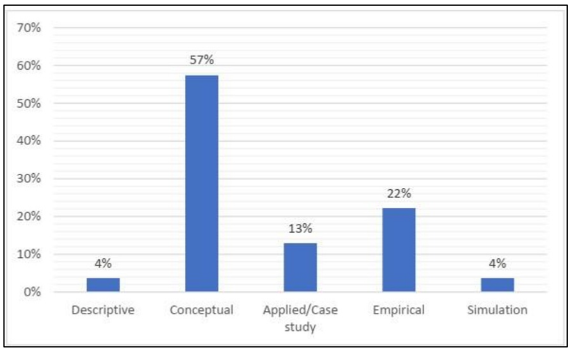

Fig. 5. Distribution of research based on the research method used

3.4 Vosviewer output: Co-occurrence of author keywords

The author's keyword served as the basis for the analysis. In this study, a total of 54 publications were discovered, and after merging many keywords with the same meaning (e.g., smart product = smart products, etc.), 178 keywords were obtained. Next, the threshold for the number of occurrences of keywords is two. Fig.6 shows the visualization findings, while Table 7 contains information on the number of events and link strength.

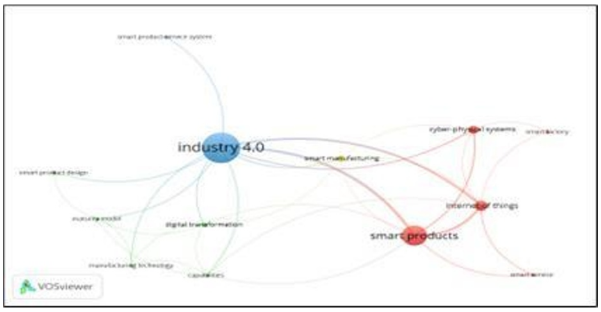

Fig. 6. Visualization of vosviewer output based on the Co-occurrence of author keywords

Table 7. Numer of occurrence and link strength on the top five keywords

No.	Keyword	Occurrence	Total Link Strength
1.	Industry 4.0	28	28
2.	Smart Product	17	19
3.	Internet of Think	8	16
4.	Cyber-physical System	6	9
5.	Capabilities	2	7

3.5 Vosviewer output results: Co-authorship of author

This study revealed 187 authors after doing an analysis based on co-authorship. Additionally, one paper is the minimum requirement for each author's number of documents. Fig. 7 displays the visualization findings, and Table 8 shows the number of documents and their link strength.

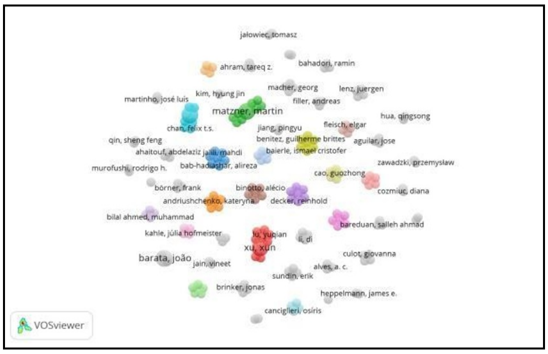

Fig. 7. Vosviewer output visualization based on co-authorship of author

Table 8. The number of documents and their link strength on top five author

No.	Author	Documents	Total Link strength
1.	Matzner, martin	2	8
2.	Xu, xun	2	8
3.	Aheleroff, shohin	1	6
4.	Aristizabal, mauriero	1	6
5.	Bab-hadiushar	1	6

4 Discussion

The research question (RQ) that was posed at the beginning will be attempted to be answered in this sub-chapter.

4.1 RQ1: What are the critical characteristics of smart (connected) products ?

It is possible to distinguish between the characteristics of SP and SCP based on their design specification. Table 4 and Table 5 reveal that SCP features more design specification features. Six criteria: context awareness, embeddedness, connectivity, personalization, service bundling, and systemic design must be present in an SCP. In addition, the primary criterion in both products (SCP and SP) is context awareness.

First, the Context-Awareness specification can be seen as an "Intelligence" product related to context awareness, emphasizing information gathering using sensor technologies, according to [36]. Furthermore, personalization requirements are associated with product user demands adaptation (product adaptation from the user's perspective). In the opinion of [17], personalization is symbolized by control. Users can modify the technology to suit their demands thanks to software built inside the product. The product's capacity for interaction with consumers, systems, and other products is then described in the connection specification. Connectivity has two functions: it facilitates information exchange between a product and its surroundings and adds to the device's functionality. Specifications for embeddedness include embedded information technology (i.e., sensors, hardware, software, microprocessors, etc.) in "Classic" Products. Mechatronic components in traditional products provide the product's core features, whereas IT components might offer logical processing. Next, service bundling requirements include products and value-added services to optimize results [3].

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The systemic design definition indicates that the ecosystem for smart products is a network of interconnected nodes. Individuals and businesses collaborate inside these networks to bundle goods and services to add value. The system may contain other subsystems to form a "system of systems."

4.2 RQ2: What are the research trend and challenges regarding smart connected products in industry 4.0 ?

According to Fig. 3, more studies have been published, but the trend could be more robust (forecast of a linear increase with a gradient of 0.95), i.e., only one paper is published yearly. Regarding the study (Table 6), product engineering and CPS technology research are in the lead (54%). This outcome is consistent with what Vosviewer produced. As observed in Fig.6 and Table 7, industry 4.0 (28 occurrences), which is denoted by the circle and the most significant font size, is followed in frequency by the keywords smart product (17 occurrences), IoT (8 occurrences), CPS (6 occurrences), etc. Analysis using Vosviewer helps to show the position of the research and its relation to other studies with the same theme. Fig.6 and Table 7 show a research link (based on keywords) between industry 4.0 – smart product – IoT-CPS (ordered by strength from strongest to weakest), led by the thickness of the line that connects keywords. In the 54 paper documents reviewed, the keywords "industry 4.0" and "smart product" have the most occurrences. It shows that the research theme with the keyword "industry 4.0" is often associated with the research theme with the keyword "smart product."

Furthermore, the keyword "smart product" has a strong association with the keywords "Industry 4.0", "IoT," and "CPS," but the relationship is weaker when associated with the keyword "smart factory." The search results (Table 6) show that paper related to smart factories is only 9.3%, much less than paper related to CPS technology. Papers related to smart factories include smart line balancing [42], Smart Product Planning Control/PPC [41], and optimization manufacturing systems [6]. Based on these results, the study aspect of the smart factory is still open to development, for example, real-time quality control, etc.

In terms of the potential for a renewal of research on smart products, there is no connecting line between the keyword "smart product" and the keyword "smart product service system" and the keyword "smart product design" in the Vosviewer output (Fig.6). According to [17], SCP allows companies to shift business models from selling products to services. It has implications for product design. When the product is a service, the responsibility and maintenance costs are in the hands of the manufacturer, so it is necessary to make changes to several design parameters, especially when customers have to share products; for example, bicycle rental services need a design that considers anti-theft, punctureresistant tires, etc. In addition, it must also be able to capture usage data accurately so that charging fees to customers becomes transparent and measurable. It requires considering the type and placement of sensors, what data to collect, and how often to analyze it.

From the perspective of the author network (in Fig. 7 and Table 8), it can be seen that there is no prominent or dominant author. Two authors (Matzner and Xu Xun) have slightly more published documents (2 papers), while the others only have one manuscript. It is indicated by the circle and font size, which are almost identical. In addition, the network of authors also has a small and nearly the same link strength so that it appears scattered and independent.

The minor study aspect is research related to standardization and safety security (2%). Research opportunities in these two aspects are still very open to be carried out. Standardization and safety security studies are not visible in the Vosviewer visualization because they are below the two-keyword threshold. After all, there is only one research related to this study.

Finally, regarding research methods, the conceptual approach is dominant (57%) (Fig.5). The successful implementation of Industry 4.0 requires a system not only at the conceptual level. Applied or case study-based research methods and more empirical methods are needed to be carried out in the future.

4.3 RQ 3: What is the future research agenda regarding smart (connected) products ?

The study of SCP in the digital supply chain era is still fascinating. Supply chain management (SCM) covers the flow of raw materials, work-in-process inventory, finished goods, and services from the point of origin to the end of consumption or user [57]. The entities in the supply chain that ultimately deliver goods and services to consumers include suppliers, manufacturers, intermediaries, retailers, and service providers. Planning, executing, and managing operations is necessary for supply chain management. To increase competitiveness, these tasks must be completed effectively and efficiently. A successful supply chain depends on managing these flows. Effective supply chain management includes managing supply chain assets and products, information, and cash flow, which is expected to increase the total supply chain surplus. As a result, in the digital supply chain era, supply chain activities must be guided by design agility in the supply chain and developing collaboration to improve demand. Integration (vertical and horizontal) is necessary for collaboration to enable unrestricted information sharing and component interaction between different manufacturers (interoperability). The challenge of product interoperability is becoming increasingly complex due to the complicated characteristics of SCP.

For future research, relevant objects in SCP can use actual cases, for example, the Electric Motorcycle Swappable Battery (EMSB) problem. The swap battery (SB) is an example of a real SCP [58]. Currently, electric motorcycles in circulation have different SB specifications so that vehicle owners can only exchange them at stations that match the brand of their respective motorbikes. This is an obstacle downstream because producers as providers of EMSB technology require a sizable investment in SB and Battery Swapp Charging Stations (BSCS). In addition, the problem from the consumer side is the uncertainty of coverage when using EMSB. The EMSB business model may need to be revamped due to this problem, and it also has an impact on delaying the adoption of electric motorbikes in Indonesia. This requires supply chain engineering at an early stage that supports the "interchangeability and cross-brand interoperability" of the SB and BSCS systems. Some studies that can be explored from the case study include :

- How to develop interoperability standards/requirements on SCP with complex characteristics?
- How is the implementation of interoperability standards for product quality control with SCP characteristics?
- How to develop a model for estimating the economic impact of implementing interoperability standards for companies ?

5 Conclusion

- Six design specifications: context awareness, personalization, connectivity, embeddedness, service bundling, and systemic design—must be met by the features of a smart connected product.
- Research trends on smart connected products in the Industry 4.0 era are dominated by studies on aspects of product engineering and CPS technology (57%), and reflections on standardization and safety security (2%) are rarely carried out. New research potentials that can be developed in the future have been identified in product engineering, smart factory, and standardization studies.
- Future research on SCP can be applied to the case of electric motorcycles swappable battery (EMSB).

References

1. K. Zhou, T. Liu, and L. Zhou, "Industry 4.0: Towards future industrial opportunities and challenges," 2015 12th Int. Conf. Fuzzy Syst. Knowl. Discov. FSKD 2015, pp. 2147–2152, (2016), doi: 10.1109/FSKD.2015.7382284.
2. H. Kagermann, W. Wahlster, and J. Helbig, "Recommendations for {Implementing} the {Strategic} {Initiative} {INDUSTRIE} 4.0 – {Securing} the {Future} of {German} {Manufacturing} {Industry}," no. April, (2013), [Online]. Available: https://www.bibsonomy.org/bibtex/25c352acf1857c1c1839c1a11fe9b 7e6c/flint63%0A http://forschungsunion.de/pdf/industrie_4_0_final_re port.pdf
3. H. Mohelska and M. Sokolova, "Smart, connected products change a company's business strategy orientation," Appl. Econ., vol. **48**, no. 47, pp. 4502–4509, (2016), doi 10.1080/00036846.2016.1158924.
4. M. Sabou, J. Kantorovitch, A. Nikolov, A. Tokmakoff, X. Zhou, and E. Motta, "Position paper on realizing smart products: Challenges for semantic web technologies," CEUR Workshop Proc., vol. **522**, pp. 135–147, (2009).
5. A. D. Neal, R. G. Sharpe, P. P. Conway, and A. A. West, "smaRTI— A cyber-physical intelligent container for industry 4.0 manufacturing," J. Manuf. Syst., vol. **52**, no. April, pp. 63–75, (2019), doi 10.1016/j.jmsy.2019.04.011.
6. J. Lenz, E. MacDonald, R. Harik, and T. Wuest, "Optimizing smart manufacturing systems by extending the smart products paradigm to the beginning of life," J. Manuf. Syst., vol. **57**, no. July, pp. 274–286, (2020), doi: 10.1016/j.jmsy.2020.10.001.
7. F. Kammler, D. H. Kemmerich, J. Brinker, and O. Thomas, "Scrutinizing the design specifications of smart products: A practical evaluation in yachting," 27th Eur. Conf. Inf. Syst. - Inf. Syst. a Shar. Soc. ECIS 2019, no. August 2020, (2020).
8. M. Abdirad and K. Krishnan, "Industry 4.0 in Logistics and Supply Chain Management: A Systematic Literature Review," EMJ - Eng. Manag. J., vol. 00, no. 00, pp. 1–15, (2020), doi: 10.1080/10429247.2020.1783935.
9. K. Santos, E. Loures, F. Piechnicki, and O. Canciglieri, "Opportunities Assessment of Product Development Process in Industry 4.0," Procedia Manuf., vol. **11**, no. June, pp. 1358–1365, (2017), doi: 10.1016/j.promfg.2017.07.265.
10. J. H. Kahle, É. Marcon, A. Ghezzi, and A. G. Frank, "Smart Products value creation in SMEs innovation ecosystems," Technol. Forecast. Soc. Change, vol. **156**, no. February, p. 120024, (2020), doi 10.1016/j.techfore.2020.120024.
11. W. Maass, A. Filler, and S. Janzen, "Reasoning on smart products in consumer good domains," Commun. Comput. Inf. Sci., vol. **11**, pp. 165–173, (2008), doi: 10.1007/978-3-540-85379-4_21.
12. H. Dawid et al., "Management science in the era of smart consumer products: challenges and research perspectives," Cent. Eur. J. Oper. Res., vol. **25**, no. 1, pp. 203–230, (2017), doi: 10.1007/s10100-0160436-9.
13. P. Mayer, D. Volland, F. Thiesse, and E. Fleisch, "User Acceptance of ' Smart Products ': An Empirical Investigation," Wi, vol. Vol. **2**, no. 2011, pp. 1063–1072, (2011).
14. E. J. Hultink and S. A. Rijsdijk, "How Today's Consumers Perceive Tomorrow's Smart Products," J. Prod. Innov. Manag., vol. **26**, no. 1, pp. 24–42, (2009).

15. M. Mikusz, “Channel multiplicity in digitized, connected products,” Int. Conf. Inf. Syst. 2018, ICIS 2018, no. December, (2018).
16. P. Zheng, X. Xu, and C. H. Chen, “A data-driven cyber-physical approach for personalized smart, connected product co-development in a cloud-based environment,” J. Intell. Manuf., vol. **31**, no. 1, pp. 3– 18, (2020), doi: 10.1007/s10845-018-1430-y.
17. M. E. Porter and J. E. Heppelmann, “How smart, connected products are transforming competition,” Harv. Bus. Rev., no. November 2014, (2014).
18. P. E. Michael and H. E. James, “How smart, connected products are transforming companies,” Harv. Bus. Rev., vol. **93**, no. 10, pp. 96– 114, (2015), [Online]. Available: https://hbr.org/2015/10/how-smartconnected-products-are-transforming-companies
19. A. G. Frank, L. S. Dalenogare, and N. F. Ayala, “Industry 4.0 technologies: Implementation patterns in manufacturing companies,” Int. J. Prod. Econ., vol. **210**, no. September 2018, pp. 15–26, (2019), doi: 10.1016/j.ijpe.2019.01.004.
20. S. Aheleroff et al., “IoT-enabled smart appliances under industry 4.0: A case study,” Adv. Eng. Informatics, vol. **43**, no. December 2019, p. 101043, (2020), doi: 10.1016/j.aei.2020.101043.
21. M. Sanchez, E. Exposito, and J. Aguilar, “Autonomic computing in manufacturing process coordination in industry 4.0 context,” J. Ind. Inf. Integr., vol. **19**, no. November 2019, p. 100159, (2020), doi: 10.1016/j.jii.2020.100159.
22. I. Bisio, C. Garibotto, A. Grattarola, F. Lavagetto, and A. Sciarrone, “Exploiting context-aware capabilities over the internet of things for industry 4.0 applications,” IEEE Netw., vol. **32**, no. 3, pp. 108–114, (2018), doi: 10.1109/MNET.2018.1700355.
23. K. Ding and P. Jiang, “Incorporating social sensors, cyber-physical system nodes, and smart products for personalized production in a social manufacturing environment,” Proc. Inst. Mech. Eng. Part B J. Eng. Manuf., vol. **232**, no. 13, pp. 2323–2338, (2018), doi: 10.1177/0954405417716728.
24. R. H. Murofushi and J. J. P. Z. S. Tavares, “Towards fourth industrial revolution impact: Smart product based on RFID technology,” IEEE Instrum. Meas. Mag., vol. **20**, no. 2, pp. 51–55, (2017), doi: 10.1109/MIM.2017.7919135.
25. R. Kunst, L. Avila, A. Binotto, E. Pignaton, S. Bampi, and J. Rochol, “Improving devices communication in Industry 4.0 wireless networks,” Eng. Appl. Artif. Intell., vol. **83**, no. September 2018, pp. 1–12, (2019), doi: 10.1016/j.engappai.2019.04.014.
26. D. Cozmiuc and I. Petrisor, “Industrie 4.0 by Siemens: Steps made next,” J. Cases Inf. Technol., vol. **20**, no. 1, pp. 31–45, (2018), doi: 10.4018/JCIT.2018010103.
27. H. Khayyam et al., “A Novel Hybrid Machine Learning Algorithm for Limited and Big Data Modeling with Application in Industry 4.0,” IEEE Access, vol. **8**, pp. 111381–111393, (2020), doi: 10.1109/ACCESS.2020.2999898.
28. P. Zawadzki and K. Zywicki, “Smart product design and production control for effective mass customization in the industry 4.0 concept,” Manag. Prod. Eng. Rev., vol. **7**, no. 3, pp. 105–112, (2016), doi: 10.1515/mper-2016-0030.
29. M. L. Nunes, A. C. Pereira, and A. C. Alves, “Smart products development approaches for Industry 4.0,” Procedia Manuf., vol. **13**, pp. 1215–1222, (2017), doi: 10.1016/j.promfg.2017.09.035.
30. M. Bilal Ahmed, S. Imran Shafiq, C. Sanin, and E. Szczerbicki, “Towards Experience-Based Smart Product Design for Industry 4.0,” Cybern. Syst., vol. **50**, no. 2, pp. 165–175, (2019), doi: 10.1080/01969722.2019.1565123.
31. H. Zhang, S. Qin, R. Li, Y. Zou, and G. Ding, “Environment interaction model-driven smart products through-life design framework,” Int. J. Comput. Integr. Manuf., vol. **33**, no. 4, pp. 360–376, (2020), doi: 10.1080/0951192X.2019.1686176.
32. R. Subramoniam, E. Sundin, S. Subramoniam, and D. Huisingh, “Riding the digital product life cycle waves towards a circular economy,” Sustain., vol. **13**, no. 16, pp. 1–23, (2021), doi: 10.3390/su13168960.
33. J. Barata and P. R. da Cunha, “The Viable Smart Product Model: Designing Products that Undergo Disruptive Transformations,” Cybern. Syst., vol. **50**, no. 7, pp. 629–655, (2019), doi: 10.1080/01969722.2019.1646021.
34. G. Cao, Y. Sun, R. Tan, J. Zhang, and W. Liu, “A function-oriented biologically analogical approach for constructing the design concept of smart product in Industry 4.0,” Adv. Eng. Informatics, vol. **49**, no. January, p. 101352, (2021), doi: 10.1016/j.aei.2021.101352.
35. E. Rauch, P. Dallasega, and D. T. Matt, “The Way from Lean Product Development (LPD) to Smart Product Development (SPD),” Procedia CIRP, vol. **50**, pp. 26–31, (2016), doi: 10.1016/j.procir.2016.05.081.
36. M. Mühlhäuser, “Smart products: An introduction,” Commun. Comput. Inf. Sci., vol. **11**, pp. 158–164, (2008), doi: 10.1007/978-3540-85379-4_20.
37. A. Ângelo and J. Barata, “Digital transformation of legionella-safe cooling towers: an ecosystem design approach,” J. Facil. Manag., vol. **20**, no. 3, pp. 485–500, (2021), doi: 10.1108/JFM-12-2020-0100.
38. C. Münch, E. Marx, L. Benz, E. Hartmann, and M. Matzner, “Capabilities of digital servitization: Evidence from the sociotechnical systems theory,” Technol. Forecast. Soc. Change, vol. **176**, no.

February 2021, p. 121361, (2022), doi 10.1016/j.techfore.2021.121361.

39. M. A. Pisching, M. A. O. Pessoa, F. Junqueira, D. J. dos Santos Filho, and P. E. Miyagi, “An architecture based on RAMI 4.0 to discover equipment to process operations required by-products,” Comput. Ind. Eng., vol. **125**, pp. 574–591, (2018), doi: 10.1016/j.cie.2017.12.029.
40. G. Culot, G. Orzes, M. Sartor, and G. Nassimbeni, “The future of manufacturing: A Delphi-based scenario analysis on Industry 4.0,” Technol. Forecast. Soc. Change, vol. **157**, no. December (2019), p. 120092, 2020, doi 10.1016/j.techfore.2020.120092.
41. O. E. Oluyisola, F. Sgarbossa, and J. O. Strandhagen, “Smart production planning and control: Concept, use-cases, and sustainability implications,” Sustain., vol. **12**, no. 9, (2020), doi: 10.3390/su12093791.
42. J. Huo, F. T. S. Chan, C. K. M. Lee, J. O. Strandhagen, and B. Niu, “Smart control of the assembly process with a fuzzy control system in the context of Industry 4.0,” Adv. Eng. Informatics, vol. **43**, no. April 2019, p. 101031, (2020), doi: 10.1016/j.aei.2019.101031.
43. R. C. Santos and J. L. Martinho, “An Industry 4.0 maturity model proposal,” J. Manuf. Technol. Manag., vol. **31**, no. 5, pp. 1023–1043, (2020), doi: 10.1108/JMTM-09-2018-0284.
44. V. Jain and P. Ajmera, “Modelling the enablers of industry 4.0 in the Indian manufacturing industry,” Int. J. Product. Perform. Manag., vol. **70**, no. 6, pp. 1233–1262, (2020), doi: 10.1108/IJPPM-07-2019-0317.
45. Y. Yin and S. F. Qin, “A smart performance measurement approach for collaborative design in Industry 4.0,” Adv. Mech. Eng., vol. **11**, no. 1, pp. 1–15, (2019), doi: 10.1177/1687814018822570.
46. L. M. A. L. Dos Santos et al., “Industry 4.0 collaborative networks for industrial performance,” J. Manuf. Technol. Manag., vol. **32**, no. 2, pp. 245–265, (2021), doi: 10.1108/JMTM-04-2020-0156.
47. S. M. Saad, R. Bahadori, and H. Jafarnejad, “The smart SME technology readiness assessment methodology in the context of industry 4.0,” J. Manuf. Technol. Manag., vol. **32**, no. 5, pp. 1037–1065, (2021), doi: 10.1108/JMTM-07-2020-0267.
48. H. Hasbullah, S. A. Bareduan, and S. Hasibuan, “Developing I4.0 Readiness Index for Factory Operation in Indonesia to Enhance INDI 4.0,” Int. J. Adv. Sci. Eng. Inf. Technol., vol. **11**, no. 4, pp. 1668– 1677, (2021), doi: 10.18517/ijaseit.11.4.14280.
49. H. J. Kim, “Verifying the test methods and certification criteria for new technological convergence products: Using living labs as a methodology,” Appl. Sci., vol. **10**, no. 9, (2020), doi: 10.3390/app10093269.
50. D. Beverungen, O. Müller, M. Matzner, J. Mendling, and J. vom Brocke, “Conceptualizing smart service systems,” Electron. Mark., vol. **29**, no. 1, pp. 7–18, (2019), doi: 10.1007/s12525-017-0270-5.
51. X. Xu and Q. Hua, “Industrial Big Data Analysis in Smart Factory: Current Status and Research Strategies,” IEEE Access, vol. **5**, no. c, pp. 17543–17551, (2017), doi: 10.1109/ACCESS.2017.2741105.
52. D. Li, H. Tang, S. Wang, and C. Liu, “A big data enabled loadbalancing control for smart manufacturing of Industry 4.0,” Cluster Comput., vol. **20**, no. 2, pp. 1855–1864, (2017), doi: 10.1007/s10586017-0852-1.
53. H. Unger, F. Börner, and E. Müller, “Context Related Information Provision in Industry 4.0 Environments,” Procedia Manuf., vol. **11**, no. June, pp. 796–805, (2017), doi: 10.1016/j.promfg.2017.07.181.
54. A. Bougdira, I. Akharraz, and A. Ahaitouf, “A traceability proposal for industry 4.0,” J. Ambient Intell. Humaniz. Comput., vol. **11**, no. 8, pp. 3355–3369, (2020), doi: 10.1007/s12652-019-01532-7.
55. A. Riel, C. Kreiner, G. Macher, and R. Messnarz, “Integrated design for tackling safety and security challenges of smart products and digital manufacturing,” CIRP Ann. - Manuf. Technol., vol. **66**, no. 1, pp. 177–180, (2017), doi: 10.1016/j.cirp.2017.04.037.
56. T. Jałowiec and H. Wojtaszek, “Analysis of Directional Activities for Industry 4.0 in the Example of Poland and Germany,” Sustain., vol. **14**, no. 7, (2022), doi: 10.3390/su14073848.
57. Chopra, S., & Meindl, P. Supply Chain Management: Global Edition. In Supply Chain Management: Global Edition. (2016).
58. Fahma, F., Sutopo, W., Pujiyanto, E., & Nizam, M. Developing Model of Technological Base Interoperability For Collaborating Multivariate-attribute Quality Control in Digital Supply Chain : A Preliminary Study. 71–83. https://doi.org/10.46254/au01.20220023. (2022).