XXVII Summer School “Francesco Turco” – «Unconventional Plants»

A flow chart analysis of the Smart Products End of Life

Valentina Popolo*, Silvestro Vespoli*, Andrea Grassi*, Giuseppe Converso*

** Dipartimento di Ingegneria Chimica, dei Materiali e della Produzione Industriale, Università degli Studi di Napoli Federico II, Piazzale Tecchio, 80 80125 – Napoli – Italy*
(valentina.popolo@unina.it, silvestro.vespoli@unina.it, andrea.grassi@unina.it, giuseppe.converso@unina.it)

Abstract: With the advent of the fourth industrial revolution, digital innovation appears to be spreading like wildfire around the world. Innovative technologies surround us and connect us to everything. Waste, on the other hand, is wreaking havoc on our planet and our future. In this article, we will look at how advanced technologies found in new smart products can help us find a better end-of-life recovery process. To this end, after a literature review of the most recent work, the first research question of this paper (RQ1) is to identify the widely accepted vision for such an intelligent object, referring to them with the term Smart Product (SP). After that, the second research question of this paper deal with the analysis by means of a flow chart of the impact that such a product may have on the End of Life (EoL) phase of its Product Lifecycle Management (PLM).

Keywords: Smart Product, Product 4.0, End of Life, Recovery Process, Industry 4.0

I. INTRODUCTION

The current world is filled with objects and products able to communicate and interact with each other. These products are becoming increasingly common in business and leisure settings as new technologies emerge. Because of the new trend, manufacturing firms started to focus on the creation and development of new innovative products that can be made available to customers while remaining competitive in the market. From the operational aspect, *Liu et al.* suggested that manufacturing companies should prioritise the incorporation of digital technologies into their innovation processes and products in order to maximise operational efficiency [1].

The resulting increase in demand for smart products, tailored to the customers’ needs must be considered the primary reason for the emergence of Industry 4.0, which started in the late 1990s with the process of Digital Innovation (DI). The DI is a form of innovation that combines digital and physical components to create digital objects that propose new uses of value for goods, services, or procedures [2]. According to the view of *Frank et al.*, the digital innovation process has been supported by the implementation of four core technologies: Internet of Things (IoT), Cloud Computing (CC), Big Data (BD) and Artificial Intelligence (AI) [3]. However, it should be noted that other key technologies for implementing Industry 4.0, such as Digital Twin (DT), Machine Learning (ML), Cyber-Physical System (CPS), and Human-Machine Cooperation (HMC), are also mentioned in the literature and may be considered as innovation driver [4]–[7].

These technologies, typical of the fourth industrial revolution, can be found throughout the manufacturing world. From machines to factories, innovative technologies enable us to make processes more automated and facilitate the creation of intelligent value chains [8]. Such technologies, applied to products, make it possible to create what is now called intelligent products. In the existing literature, many researchers refer to these objects with terms such as a *smart object, connected object, smart thing, intelligent product, and smart product* [9].

As a result, there are various visions of a SP in the scientific literature that are similar in the general idea of interconnection and capabilities but not unique in the conceptualisation. SPs are widely used and as previously stated, may be identified in a variety of different environments, ranging from the office to manufacturing. Manufacturing (e.g., intelligent machines, intelligent robots, intelligent factories), mobility (e.g., intelligent cars, self-driving vehicles), logistics (e.g., intelligent packers, intelligent containers), health care (e.g., intelligent clothes, intelligent hospitals), and energy (e.g., intelligent energy grid) are examples in the industrial fields[10].

To this end, after a literature review of the most recent work, the first research question of this paper (RQ1) is to identify the widely accepted vision for the aforementioned intelligent object, referring to them with the term Smart Product (SP).

From conception to manufacturing, from design to product recovery, industries must follow the entire life cycle undergone by the product. Hence it is of interest to integrate the designing process of such a SP with the classical Product Lifecycle Management (PLM) in all its phases, from Beginning of Life (BoL) to Middle of Life (MoL) to End of Life (EoL).

Regarding the PLM, there are different visions in the literature. For the sake of clarity, in this work, we assume the PLM the definition and the concept proposed by *Duda et al.*. They considered the concept of connected PLM, which is defined as the association of data representing the product structure with other relevant data, allowing product development process participants to easily access a wide range of product information. This type of PLM makes it possible to track the product throughout its entire life cycle.

In an era when waste and pollution are threatening the environment, it is of interest to evaluate the impact that a SP may have on the recovery phase of its PLM. However, to the best authors' knowledge, no studies have been conducted on investigating the impact that such a product may have on the remanufacturing process or EoL. To this end, the second research question (RQ2) of this paper is to analyse by means of a flow chart the impact that such a product may have on the EoL phase of its PLM.

The remainder of the paper is organised as follows. Section 2 deals with the review of Smart Products with a Systematic Literature Review (SLR) approach. Section 3 applies the flow-chart analysis to the EoL phase of SP. Finally, Section 4 concludes the papers, proposing future research direction.

II. REVIEW ON SMART PRODUCT

The fourth industrial revolution encompasses a series of technological advancements that affect both products and processes. As analysed in the Introduction section, Smart Products (SP) are one of the most important aspects of this new industrial paradigm, offering numerous opportunities for businesses and markets [11].

Dealing with the first research question of this paper, academic publications have been investigated as part of the Literature Review process. In fact, in order to fill research gaps and strengthen the field of study, the review summarises existing knowledge and evaluates available research works on a specific phenomenon [12].

A structured selection process was used to ensure rigour and generalisability, and structured criteria were used to include related articles and exclude unrelated cases. The authors began by searching for the term "Smart Product" and its derivatives as keywords in article titles, abstracts, and keywords in Scopus databases to create the source database. Even though the topics of digitisation and the adoption of digital technologies in manufacturing companies have been debated from a variety of perspectives other than "Smart Products" (e.g., "Digital Product", "Digital Object") the publication data were gathered using the term "Smart Products" and its derivatives, searching in the Scopus database. The initial screening showed around 2,000 articles.

Following the creation of the initial database, articles were screened using the standard fields provided by the databases, including only articles written in English. Furthermore, only peer-reviewed journal articles were considered; book chapters, conference papers, proceedings, and other non-referenced publications were excluded. This procedure is common in systematic reviews because it serves as a quality control mechanism for the knowledge provided by the articles included [13].

Only the most relevant articles in relation to the study's research question were included in the subject areas. Following, we summarise the works devoted to describing the capabilities of smart products, with the final aim of analysing and comparing the various visions discovered.

According to *Abramovici et al.* [14], Smart Products (SP) are Cyber-Physical Systems (CPS) defined as intelligent mechatronic products capable of communicating and interacting with other CPS by means of Internet. The authors described the characteristics of a SP by comparing them to automobile components. In their vision, mechatronic products evolve into smart mechatronic products. The same authors discuss also about the EoL phase for a smart product. Always with the car example, they consider data on the condition of the components to be an important factor in determining the state of the vehicle. If this data can still be used in a different way, it must be evaluated. Configuration data are also important in this case to track any new parts that have been integrated during the usage phase. The physical counterpart of this data must be collected as condition data from each instance's sensors.

Tomiyama et al. provide a different definition for the SP. They define smart products as "CPS, which use and further integrate Internet-based services to perform a required functionality" [15] after surveying the evolution of smart products from mechatronic products to cyber-physical systems. They also consider how smart product design must account for life cycle phases, analysing some examples, such as smartphones, smart vehicles, or smart robots, and extracting the technical characteristics and functional capabilities they must have, such as resilience, reconfiguration, reliability, autonomy, and so on. Finally, they gave an overview of the technologies that must be implemented in smart products, such as artificial intelligence and data analysis.

Other authors have focused on the operational aspects of SPs. As an example, *Frank et al.* attempt to comprehend what technologies and capabilities such products should have [3]. Indeed, they argue that intelligent components that enable digital capabilities and services with product offerings can be encapsulated in front-end technologies for intelligent products. Here, they consider the technological capabilities required for various levels of Smart Product, as proposed by *Porter and Heppelmann* in [16]. According to the authors, smart and connected products should have the following functionalities:

product connectivity, product monitoring, product control, product optimization, and product autonomy.

Another definition of Smart Products is proposed by *Raff et al.* in [17] where they managed to encapsulate different types of smart products into 4 archetypes. These archetypes encapsulate different characteristics of software and hardware, starting from digital products to smart products. They also identify 16 (capability-based criteria) characteristics that these products must have, augmenting these characteristics and incorporating them into the next archetype. Then it is shown how the last 'intelligent product' archetype contains all the capabilities of the previous archetypes.

Finally, the concept proposed by *Popolo et al.* is found [18]. They introduced the concept of Product 4.0 (P4.0) [Fig. 1] identifying it as smart products that can communicate with humans as well as objects, with basic hardware and intrinsic characteristics (sensors, actuators, and connections) and implementing the following I4.0 technologies: IoT, CC, BD, DT, ML and HMC, expanding the concepts presented by *Raff et al.* [17]. To this extent, their P4.0 may be considered as an integration result of the last advancement in the topic.

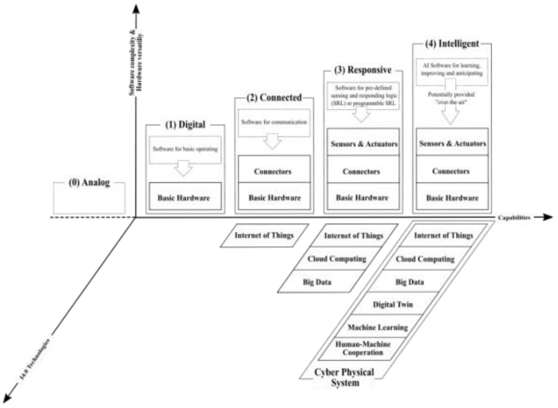

Fig. 1 – The Product 4.0 (reprinted from [18])

P4.0 appears to be the object that best defines both the features and technologies that a typical SP must have. The most important technologies, typical of Industry 4.0, are implemented in this such a tool, allowing new innovative processes to be developed. Given that P4.0 can be viewed as a generalisation of all the SP concepts examined thus far, the second research question of the paper will be based on this definition.

III. END OF LIFE FLOW CHARTS ANALYSIS

Smart products necessitate the creation and management of new business models, resulting in increased responsibilities for product manufacturers throughout the product life cycle. At the same time, these SP characteristics necessitate significant changes in traditional engineering life cycle processes [10]. A SP, like the one defined by *Popolo et al.* in [18], provides numerous benefits because of the product’s real-time data collection.

The ability to use this data, but more importantly, to access it quickly, allows for intervention in a variety of areas. Knowing the state of the product, in fact, enables the determination of its health, thereby enabling the intervention if the product has a problem and the performance of timely maintenance while allowing the manufacturer to be aware of the problem prior to its occurrence and the performance of preventative maintenance. As a result of this innovative technology and the utilisation of sensors, the firms that propose product-as-a-service see the greatest advantages of such a production.

The implementation of the SP allows for more accurate and automated customer service and support. Technical support and supply of consumables would be more effective and efficient if they intervened only when required.

Following the second research question of this work, the EoL phase would benefit the most from such a product. In fact, benefiting from the data that SP send in real-time, it may be possible to anticipate the possible recovery option when the SP reach is EoL phase. Remanufacturing, reusing, refurbishing, repairing, recycling, repurposing, cannibalization, and disposal are common terms used to describe EoL phases in the literature. Several authors [19]–[21] have analysed these terms and described their objectives and characteristics. However, in this paper we will focus on the terms that appear most frequently in the literature: remanufacturing, reuse, recycle, cannibalisation, and disposal. After a review of the most authoritative studies, we summarise the following definitions of these terms in relation to the aspects we will be analysing.

Hence, we adopt the following definition for the recovery options. **Reuse** is a non-destructive process leading to the eventual repair of small elements and then putting the product back on the market. It is a non-invasive intervention on the product and its components. **Recycling**, on the other hand, occurs when a product has stopped working and only the components are to be recovered. The intervention in this case is more invasive, and the part is completely disassembled. R**emanufacturing** is a more complex process in which the product is disassembled and worn, or broken components are replaced. **Cannibalisation** is the process of recovering only the materials from which the products and their components are made. This involves destroying the product and recovering only the materials with which it is made, before ending up the disposal. Finally, **disposal** is the final possible operation, where the product cannot be reclaimed and is therefore discarded.

After we have conceptualised the terms we will refer in the EoL phase, let's focus on analysing the benefits of SP, and specifically Product 4.0, in this area. The intention is to compare two recovery processes that differ by whether or not innovative technologies are used by means of comparing the logic of recovery with the advent of digital innovation to the recovery of products without tools.

To this end, we propose two different flowcharts that schematise the different logic adopted for the recovery process of a standard product and Product 4.0. after it returns to the factory for disposal. Figure 2 depicts how the recovery process is examined for a standard product. In fact, once the product is returned, a lengthy phase of inspection and problem identification begins. This first phase is followed by increasingly invasive product disassembly phases. After identifying the issue, an attempt is made to resolve it by replacing the component. After the replacement, the process enters a flowchart loop in which if the product still does not work, the process must be restarted from the problem analysis phase and possibly returned to product disassembly. One of the major issues in this type of recovery process analysis is the loop. Because we don't know where the real problem is, we have to keep going back and doing the same things we did before. Only after the true problem has been identified it may be possible to proceed and choose the most accurate recovery option for the product. If the problem is resolved, the product can be reclaimed and resume its life. If the product continues to fail, it may be possible to try to recover only its components or, if these fail, its materials, until to and including the complete dismantling of the product and its components for disposal in a landfill.

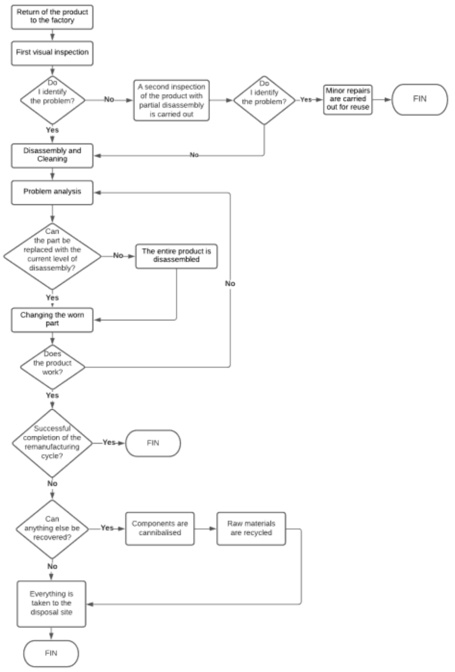

Fig. 2 - Flowchart of the recovery process of a standard product (without the use of innovative technologies)

Let us now turn to the explanation of the flowchart's tools (see Fig. 3). This process is based on the analysis of data in real-time, as well as secondary data analysed when the product is returned to the factory. In reality, there are two types of data: real-time data and recorded data. The difference is that the former can be sent from the product throughout its life, allowing for the tracking of any potential issues. In the second case, the data, by connecting to the factory (Industry 4.0), enables the exploitation of other types of data, such as the wear of a component or the number of times the product has been used, and so on. After collecting all possible data, the actual phase of recovering the product or its components commences.

In fact, it is possible to observe that there are two primary parameters, namely, intensive use and health condition. Then, following a thorough cleaning, it is possible to use the two parameters to choose between various recovery options. In the event of intensive use of the product and good health, it would be possible to cannibalise the still-valuable components, recover materials from parts and components, and then dispose of the remaining parts. If the parameters 'use' and 'state of health' are adequate, the product could be submitted for the reuse option, provided that minor repairs and replacements are carried out.

If despite the low values of the 'use' and the 'state of health' parameters are insufficient, the product may be remanufactured by disassembling it at the component level and replacing the relevant parts.

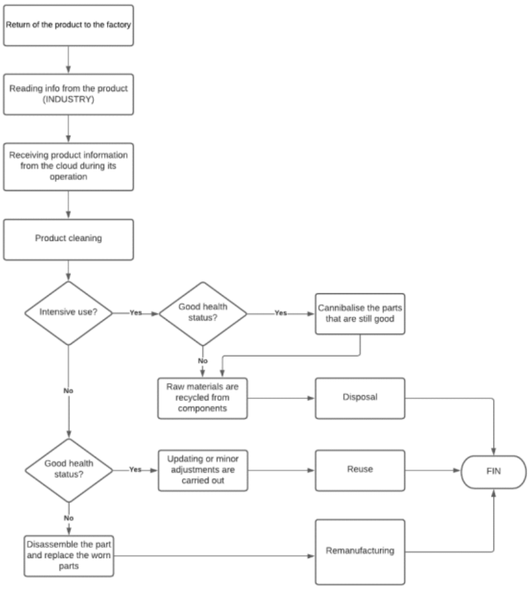

Fig. 3 - Flowchart of the recovery process of a Smart Product (with the use of innovative technologies)

Analysing the difference, it is possible to conclude that the first flowchart depicts a process that is significantly longer than the second. This is the first conclusion that can be drawn when comparing the two types of flowcharts. In fact, it is evident that the process involving the tools has significantly fewer steps than its competitor. This significant difference stems from the fact that in the first case, both the product and its components undergo multiple phases of inspection and cleaning. The inspection phase is required to identify the issue because we cannot utilise innovative technologies that can identify the issue more quickly. Disassembly and functional analysis of the product and its components, always with the goal of identifying the issue, are additional phases found in the first case but not the second.

IV. CONCLUSION AND FUTURE RESEARCH

Today the whole world is in an environmental and energy crisis that is difficult to underestimate. The environment is increasingly compromised by waste and pollution, and industries are among the first to create such damage. Waste comes from both the manufacturing and everyday sectors. In this article, we attempted to comprehend how an intelligent product, with a robust connection to the surrounding system, can contribute to waste reduction.

After an extensive search of today's literature, several definitions were presented for intelligent objects, known as Smart Products. Among the different definitions and proposals investigated in the literature, the one proposed by *Popolo et al.* in [18] resulted to be the most general and comprehensive, proposing a unique definition for SPs considering the innovative technologies they must have.

In response to the second research question, an attempt was made to provide a single definition of the most common end-of-life recovery processes after analysing the various perspectives on the EoL phase of PLM. Given this, two flow diagrams for the recovery of end-of-life products have been described and compared, one for traditional products and the other for SP.

As a result, it has been demonstrated how an SP can better support its recovery process by leveraging 4.0 technologies. Unlike a tool-less recovery, which requires generic inspections, the SP's real-time and recorded data transmission allows the product's health status to be known even before any inspection. The knowledge of this state allows pinpointing precisely where the problem is and which recovery process to employ for complete recovery. This innovative logic for end-of-life recovery processes may have a great impact on waste reduction and thus an additional step toward environmental protection.

Future research could focus not only on the other aspects of PLM, and thus carry out a detailed analysis of the data that the product can send during the MoL phase, but it would be useful to study during the design phase (BoL) of the product and its components other aspects that could be useful to us throughout the product's life.

Once the product's life cycle has been optimised, another aspect to consider is analysing all the logistics that surround such products, which can be applied to the entire supply chain. In fact, receiving data throughout the supply chain can also be useful to find useful information during this process, making it possible to increase the resilience of a supply chain and the mitigation of the disruption risk.

REFERENCES

[1] Y. Liu, J. Dong, L. Mei, and R. Shen, “Digital innovation and performance of manufacturing firms: An affordance perspective,” *Technovation*, no. December 2021, p. 102458, 2022, doi: 10.1016/j.technovation.2022.102458.

[2] C. Cheng and L. Wang, “How companies configure digital innovation attributes for business model innovation? A configurational view,” *Technovation*, vol. 112, no. January 2021, p. 102398, 2022, doi: 10.1016/j.technovation.2021.102398.

[3] 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.

[4] E. Bottani, A. Cammardella, T. Murino, and S. Vespoli, “From the cyber-physical system to the digital twin: The process development for behaviour modelling of a cyber guided vehicle in M2M logic,” *Proc. Summer Sch. Fr. Turco*, vol. 2017-Septe, pp. 96–102, 2017.

[5] H. Wang, C. Ma, and L. Zhou, “A brief review of machine learning and its application,” *Proc. - 2009 Int. Conf. Inf. Eng. Comput. Sci. ICIECS 2009*, pp. 2–5, 2009, doi: 10.1109/ICIECS.2009.5362936.

[6] K.-D. Thoben, S. Wiesner, and T. Wuest, “‘Industrie 4.0’ and smart manufacturing-a review of research issues and application examples,” *Int. J. Autom. Technol.*, vol. 11, no. 1, pp. 4–16, 2017, doi: 10.20965/ijat.2017.p0004.

[7] M. P. Pacaux-Lemoine, D. Trentesaux, G. Zambrano Rey, and P. Millot, “Designing intelligent manufacturing systems through Human-Machine Cooperation principles: A human-centered approach,” *Comput. Ind. Eng.*, vol. 111, pp. 581–595, 2017, doi: 10.1016/j.cie.2017.05.014.

[8] J. Duda, S. Oleszek, and K. Santarek, *Product Lifecycle Management (PLM) in the Context of Industry 4.0*, vol. 1. Springer International Publishing, 2022.

[9] M. Rokonuzzaman, K. (Kate) Kim, K. K. Dugar, and J. Fox, “What makes an object smart? Conceptualization, development, and validation of a scale to measure the Smartness of a Thing (SoT),” *J. Bus. Res.*, vol. 141, no. October 2020, pp. 337–354, 2022, doi: 10.1016/j.jbusres.2021.11.040.

[10] M. Abramovici, J. C. Göbel, and P. Savarino, “Reconfiguration of smart products during their use phase based on virtual product twins,” *CIRP Ann. - Manuf. Technol.*, vol. 66, no. 1, pp. 165–168, 2017, doi: 10.1016/j.cirp.2017.04.042.

[11] 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.

[12] M. Petticrew and H. Roberts, *Systematic Reviews in the Social Sciences A PRACTICAL GUIDE*. .

[13] R. Light and D. PILLEMER, *Summing Up: The Science of Reviewing Research*. Harvard University Press, 1984.

[14] M. Abramovici, J. C. Göbel, and P. Savarino, “Virtual twins as integrative components of smart products,” *IFIP Adv. Inf. Commun. Technol.*, vol. 492, pp. 217–226, 2016, doi: 10.1007/978-3-319-54660-5_20.

[15] T. Tomiyama, E. Lutters, R. Stark, and M. Abramovici, “Development capabilities for smart products,” *CIRP Ann.*, vol. 68, no. 2, pp. 727–750, 2019, doi: 10.1016/j.cirp.2019.05.010.

[16] M. E. Porter and J. E. Heppelmann, “How smart, connected products are transforming competition,” *Harv. Bus. Rev.*, no. November 2014, 2014.

[17] S. Raff, D. Wentzel, and N. Obwegeser, “Smart Products: Conceptual Review, Synthesis, and Research Directions,” *J. Prod. Innov. Manag.*, vol. 37, no. 5, pp. 379–404, 2020, doi: 10.1111/jpim.12544.

[18] V. Popolo, M. Gallo, A. Grassi, and M. G. Marchesano, *Exploiting the Full Potential of I4.0 Technologies for*

Products EOL Recovery Process, vol. 632 IFIP. Springer International Publishing, 2021.
[19] S. G. Lee, S. W. Lye, and M. K. Khoo, “A multi-objective methodology for evaluating product end-of-life options and disassembly,” *Int. J. Adv. Manuf. Technol.*, vol. 18, no. 2, pp. 148–156, 2001, doi: 10.1007/s001700170086.
[20] P. Morseletto, “Targets for a circular economy,” *Resour. Conserv. Recycl.*, vol. 153, p. 104553, Feb. 2020, doi: 10.1016/J.RESCONREC.2019.104553.
[21] S. Sitcharangsie, W. Ijomah, and T. C. Wong, “Decision makings in key remanufacturing activities to optimise remanufacturing outcomes: A review,” *J. Clean. Prod.*, vol. 232, pp. 1465–1481, 2019, doi: 10.1016/j.jclepro.2019.05.204.