Sustainable Production through Advanced Manufacturing, Intelligent Automation and Work Integrated Learning, J. Andersson et al. (Eds.)

doi:10.3233/ATDE240194

Remanufacturing Components Using Twin Transition – An Exploratory Study in the Heavy-Duty Vehicle Industry

Nicolas LEBERRUYER[1], Natalie AGERSKANS, Malin ELVIN, and Koteshwar CHIRUMALLA
Mälardalen University
ORCiD ID: Nicolas Leberruyer https://orcid.org/0000-0002-4251-366X,
Natalie Agerskans https://orcid.org/0000-0002-6842-0648,
Malin Elvin https://orcid.org/0009-0006-7026-3561,
Koteshwar Chirumalla https://orcid.org/0000-0002-7512-4425

Abstract. Remanufacturing is a life cycle renewal process by which previously used products such as vehicle components can be maintained and rebuilt. Although knowledge in remanufacturing processes is advanced from a scientific perspective, many traditional technology-driven manufacturing companies are facing challenges related to remanufacturing of various components in their specific industry. An underlying reason is that existing components have been sold for many years, and it is unclear what modifications should be made to the manufacturing process to accommodate both new and remanufactured products. Furthermore, it is unclear what organizational changes such as culture and training of operators are required. At the same time, the manufacturing industry is undergoing a digital transformation. It is therefore relevant to investigate how digitalization and sustainability practices can be combined, commonly referred to as Twin Transition. The purpose of this paper is to explore how a manufacturing company can approach a change towards remanufacturing of components using Twin Transition. This is accomplished by using a qualitative-based case study method at a large manufacturing company in the heavy-duty vehicle industry. The data collection method involved workshops following a SWOT analysis and rich picturing approach. The results from the rich picturing workshop identified four main themes to facilitate remanufacturing. The SWOT analysis identified 20 key aspects related to facilitate remanufacturing. Finally, the paper concludes by proposing five key enablers for achieving remanufacturing using Twin Transition.

Keywords. Circularity, Sustainability, Smart Production, Industry 5.0, Production Development

1. Introduction

The incorporation of science-based targets in the automotive industry is of utmost importance in order to match sustainable objectives and address the challenges posed by climate change. To achieve the European aim of zero emissions by 2050 [1], it is imperative for the automotive industry to include not only the emissions resulting from the usage of its products but also the emissions generated during a company's own

[1] Corresponding author: Nicolas Leberruyer, nicolas.leberruyer@mdu.se

operations. Remanufacturing is a life cycle renewal process by which previously used products such as vehicle components can be maintained and rebuilt [2]. By replacing worn out and obsolete parts in components, products can be returned to a well-functioning condition, hence reducing the environmental impact.

Although knowledge in remanufacturing processes is advanced from a scientific perspective, many traditional technology-driven manufacturing companies are facing challenges related to remanufacturing of various components in their specific industry [3]. An underlying reason is that existing components have been sold for many years, and it is unclear what modifications should be made to the manufacturing process to accommodate both new and remanufactured products. Furthermore, it is unclear what organizational changes such as culture and training of operators are required. Other challenges are related to how improved quality control processes should be implemented to ensure that both newly manufactured and remanufactured products meet the required standards [4]. This could include inspection, testing, and certification processes.

A promising way of tackling some of these challenges is to integrate digital technologies to data to facilitate fact-based and time-efficient decisions [5]. However, only having digital technologies in place is not enough, rather there is a need to investigate how they can be used to achieve remanufacturing objectives before integrating new technology. A systematic integration of digitalization and sustainability practices such as remanufacturing is commonly referred to as Twin Transition [6], which is a strategic approach for a climate neutral manufacturing industry [7, 8]. Therefore, the purpose of this paper is to explore how a manufacturing company can approach a change towards remanufacturing using Twin Transition.

The contribution of this paper is threefold. Firstly, we present 20 key aspects related to facilitating remanufacturing in a traditional engineering setting. Secondly, the paper opens up an academic dialog on the use of Twin Transition concept in a remanufacturing context. Thirdly, key enablers are highlighted for integrating remanufacturing into traditional production lines.

2. Theory on Twin Transition

The European Commission has suggested that one way forward towards becoming a climate-neutral continent by 2050 is the so-called *Twin Transition* [2, 9]. This combines the two concepts of circularity and digitalization and suggests the transition is made simultaneously. Twin transition is a term coined to display the change towards both a digital and sustainable future. Just as for circularity, twin transition also faces many challenges in various categories including social, technological, environmental, economic and political [9]. There is also a need for trade-offs between where the digital technologies should be applied since these could negatively affect the environment and there is need of further research on that particular topic [10].

The focal point for circularity can vary but is usually divided into the categories technical, social, and environmental, which is in line with the triple-bottom line perspective [11]. Whilst discussing circularity, the R-imperatives are often brought up. They can occur in many variations of terms and amount of them but the three most common are reduce, reuse, and recycle [12, 13]. It can be argued that extended frameworks with additional R:s include the whole life cycle in a better way [14]. One of the R:s in the extended framework is Remanufacturing which could be defined as "*restoration of used products to a like-new condition, providing them with performance* *characteristics and durability at least as good as those of the original product.*" [15]. This process involves seven steps: 1) collection and inspection of used products, 2) disassembly of products, 3) cleansing and surface processing of subparts, 4) inspection and sorting, 5) component remanufacture and replenishment by new components, 6) product reassembly, and 7) final testing. There are tools to calculate the optimal time to remanufacture production equipment for the most profit considering the production plan, remanufacturing plan and the spare parts used. In addition to this, the cost can be analysed to decide whether to invest in new equipment, recondition or continue to run the machines with a higher risk of breakdown [16]. However, research is needed to also evaluate the sustainability part of these actions and not only to find economic benefits [17].

As stated in the introduction, digitalization combined with circularity has shown great potential to both give companies a competitive advantage [18] as well as improve sustainability [7, 8]. Since this paper focuses digitalization in a production context, we use the term Smart Production. Smart Production considers a desired state that manufacturing companies aim to achieve in terms of sustainability, value-driven production, and efficiency by integrating digital technologies into the production system [19, 20]. Accordingly, Smart Production requires a process innovation, i.e., *"...the implementation of a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software."* [14, p. 49]. Second, changes in production require a holistic approach. Therefore, production can be seen from a system perspective involving a combination of different elements such as people, production equipment, processes, information systems, and networks. In order to produce products, all these mentioned elements are interrelated in an organized but complex way [22]. For this reason, when making changes in one part of the system, it affects other parts of the system as well as sub-processes [23]. This highlights the complex nature of production and shows that the development towards Smart Production requires consideration of many parameters and their relationship to each other. Third, Smart Production is related to Industry 5.0, which focuses on human-centric and value-driven production [24]. Therefore, manufacturing companies integrating digital technologies without addressing human aspects risk failing to achieve full integration of the technologies [25]. Examples of important human aspects include active participation of key stakeholders in problem-solving activities and developing capabilities to explore opportunities of using new digital technologies [26]. Fourth, Smart Production involves digitalization and connectivity to achieve a high level of smartness [27]. This requires using technologies with capabilities of managing digitalized and real-time data, i.e., digital technologies must be used [28-30]. Moreover, digital technologies must be integrated with existing elements in the production system to collect relevant data and transform this data into valuable insights to support actions and decisions in production [31, 32]. However, it is not enough to only have digital technologies installed in the production; it is how they are integrated within the production system to manage the key resource, which is the data, that will determine what benefits will be achieved [19, 33, 34]. Therefore, Smart production requires having a holistic perspective on the entire data value chain including four phases [27, 35]:

- *Data sources and collection.* Refers to the points of origin where data is being generated and the methods used for collecting the data.

- *Data communication.* Refers to the transportation of data from their sources to the places where data will be stored, processed, visualized, and used.
- *Data processing and storage.* Data processing refers to the operations conducted to extract information from data.
- *Data visualization and usage.* Refers to the techniques used to present data to end-users and the context in which data is applied to fulfill a purpose.

3. Method

This study follows a qualitative-based case study design at a large manufacturing company in the heavy-duty vehicle industry. A case study design [36] was selected based on two reasons. First, case studies are suitable when exploring novel subjects where increased theoretical insights are needed. Second, in case studies, empirically rich data are used, including the context and experience of practitioners. This was considered important to increase the practical relevance of the findings in this paper. First documents related to the company's strategic objectives and vision were collected. Then a review of the remanufacturing capacity of the company was done. The intention was to set a common understanding to prepare the workshop. The company's remanufacturing capacity was then evaluated. The goal was to establish an understanding of the company's position related to its sustainability commitment and remanufacturing practices. Then, data was gathered during a single meeting with five participants who had, in average, over ten years of experience within the organization:

- Global development and governance leader for Industry 4.0 technologies
- Global environmental sustainability leader in Operations
- Local manufacturing engineering manager for assembly process
- Local manufacturing engineering manager for new projects
- Local manufacturing engineering project leader

The meeting was two hours long and consisted of two workshops of one hour each. The first workshop focused on defining the desired future state of remanufacturing within the case company by using a rich picturing method [37, 38] and performing a SWOT analysis [39] where strengths, weaknesses, opportunities, and threats for assessing the current state and reflecting on how to achieve the desired future state. The rich picturing is a practice of creating a pictorial representation of a specific problematic situation and it intends to convey richness of the situation as a whole. It is a tool used to gain multiple perspective understanding within a complex situation and offers insight into an organizational climate by showing processes, structures, and issues [38]. The SWOT analysis method has been chosen to stimulate the interaction across relevant stakeholders and get different perspectives [39, 40]. SWOT provides a simplistic structure to facilitate discussion between relevant stakeholders who do not frequently work together to engage in conversations [41].

The second workshop involved presenting the results from the workshop (from rich picturing and SWOT analysis) to the participants in order to get feedback and validate the findings. To supplement the data collected from the workshops, secondary data was collected from internal documents and the company's web pages. This helped expand the knowledge of the company's practices and validate the findings further. The empirical data was analyzed using thematic analysis, which is a systematic approach for capturing patterns in qualitative datasets. The data analysis included an iterative comparison of the empirical data and literature by following six concurrent activities: (i) data familiarization, (ii) generation of codes, (iii) searching for themes, (iv) reviewing themes, (v) defining and naming themes, and (vi) writing the paper [42]. The collected data was processed using Artificial Intelligence (AI) tools. The discussion recording was transcribed using Microsoft Azure Speech Studio. The transcribed discussion was then translated and analyzed using language models such as ChatGPT from OpenAI and Bard from Google. The researchers employed these tools iteratively until relevant and satisfactory outcomes were reached. Finally, the researchers double-checked that the AI tools' analysis was relevant and accurate. The tools supported the researchers in summarizing the main themes of the first workshop and key aspects components from the SWOT analysis and correct citations.

4. Results

The following sections consists of a thematic analysis done with the discussion that the participants had during the rich picturing workshop and a summary of the strengths, weaknesses, opportunities, and threats that the participants expressed during the SWOT workshop.

4.1. Findings from rich picturing workshop

During the first workshop, participants engaged in a discussion that revolved around the complex process of remanufacturing or reusing components and parts in a manufacturing context. The participants created a rich picture, and several key themes emerged from this dialogue, offering insights into the challenges and considerations involved in managing production systems with a focus on remanufacturing. A summary of the identified themes during the workshop is presented in Table 1.

Table 1. Summary of the rich picturing workshop

Theme of remanufacturing	Key points
Designing for remanufacturing	Focus on easy disassembly, standardized components and interfaces, and exploring feasibility of reusing components after multiple lifecycles and partnerships.
Managing the flow of materials	Track component origins, manage inventory, use demand forecasting, and ensure flexible material supply.
Upskilling the workforce	Workers need training programs and a remanufacturing culture.
Quality assurance and traceability	Maintain high-quality standards, develop quality control procedures, track component origin, and tracking systems for components throughout its lifecycles.

Theme 1: Designing for remanufacturing

The workshop participants discussed the **importance of designing products for remanufacturing**. They discussed the importance of designing products so that they can be easily disassembled, repaired, and reused. They mentioned the importance of having standardized components and interfaces. Central to the discussion is the concept of prolonging the lifecycle of components. The participants explore the feasibility of reusing various components after multiple cycles of use. They deliberate over whether it's possible to **seamlessly integrate both new and refurbished parts** into the manufacturing process. One participant asked: *"Can we think like this or should the part be new?"*. The group discusses the possibility of not disassembling products into their smallest parts, but rather keeping certain modules intact. This could potentially save time during the remanufacturing process, as suggested with the example of building complete pumps. The participants also discussed the need to **develop new technologies for remanufacturing**. For example, they discussed the potential of using additive manufacturing (AM) to repair damaged components. AM could also be used to create new components that are not available from the original equipment manufacturer (OEM). The group expressed a need to develop standards for remanufactured products. This would help to ensure that remanufactured products are of a high quality and that they are compatible with new products. They also suggest partnering with other organizations, such as OEMs and suppliers to develop standardized components and materials that are easy to remanufacture. This would help to reduce the costs of remanufacturing and to increase the availability of remanufactured products. Finally, they mentioned a need to invest in research and development to develop new remanufacturing technologies and processes. This theme emphasizes the primary goal of optimizing resource consumption and decreasing waste by making the best use of existing components. This theme indicates a change toward a more efficient and practical approach to reengineering, in which the retention of specific components may boost total productivity.

Theme 2: Managing the flow of materials

The workshop participants discussed the challenges of managing the flow of materials in a remanufacturing environment. This is because remanufactured products can be made up of a mix of new and used components. The participants discussed the need to **develop systems to track the provenance of components** and to ensure that they are used in the correct products. The participants also discussed the need to **develop systems to manage the inventory of remanufactured components**. This is because the demand for remanufactured components can be unpredictable. The participants discussed the potential of using demand forecasting and just-in-time delivery to manage the inventory of remanufactured components. The participants discussed the place issue that having to **store many remanufactured components together with new ones** might create. They expressed a need to rationalize the remanufacturing process when taking in account several generations for each product: *"We can get a bunch of different axle generations back to the factory, and that can really ramp up quickly. We've got to figure out an easy fix for that, and we can't let it turn into a maze of thousands of different parts."*. The participants reflected on the necessity of **flexible material supply to each station** and provided an illustration of AGVs delivering assembly kits for individual products. This theme emphasizes the significance of developing a well-organized and efficient system for acquiring and managing materials, ensuring a steady supply for the production process.

Theme 3: Upskilling the workforce

The workshop participants discussed the need to **reskill the workforce to support remanufacturing**. This is because, in order to account for the various product generations, remanufacturing necessitates that workers manage a significantly greater number of variants of the same product. It is possible that some procedure has been entirely altered, and no one can recall how things were carried out. The participants discussed the need to develop training programs to teach workers remanufacturing procedures and quality control. The participants also discussed the need to **create a culture of remanufacturing within the organization.** This means communicating the benefits of remanufacturing to workers and encouraging them to get involved in the remanufacturing process. This theme emphasizes the role of knowledge sharing and professional development to maintain a competent workforce capable of handling evolving product lines.

Theme 4: Quality assurance and traceability

The workshop participants discussed the **importance of quality assurance in remanufacturing**. This is because remanufactured products must meet the same quality standards as new products. The participants discussed the need to develop quality control procedures to ensure that remanufactured products meet these standards. The participants also discussed the need to **develop quality assurance systems** that can track the provenance of components and ensure that they are used in the correct products. The need to document each component's history was also discussed. They also discussed the need for a system to track the condition of components throughout the different lifecycles. This theme underscores the significance of quality control and traceability in guaranteeing product reliability and safety.

4.2. Findings from SWOT analysis workshop

During the second workshop, participants were presented with the findings from the first workshop and later engaged in a discussion that provided insights for the SWOT analysis. A summary is presented in Table 2, and the following sections present the results in more depth.

Table 2. Summary of the SWOT-analysis workshop

SWOT aspect	Key points
Strengths	Internal competence, knowledge sharing, sustainability commitment, quality control, and global reach.
Weaknesses	Competence maintenance, material handling complexity, lack of product feedback loop.
Opportunities	Digitalization, innovation, sustainability, product variant expansion, partnerships.
Threats	Regulatory challenges, customer resistance, competitive pressure, material availability, production efficiency.

Strengths

Participants recognized that their organization had **strong internal competence and knowledge sharing**. They emphasized the ability to learn from within the organization, which could be advantageous for addressing challenges and pursuing opportunities. The company is committed to sustainability, and remanufacturing is a way to reduce waste and improve the company's environmental impact. The conversation also highlighted the organization's strong emphasis on quality control and product knowledge. The participants pointed out that their **depth of knowledge about their products and processes** allowed for a consistent level of quality.

Weaknesses

The conversation revealed concerns about **maintaining competence and skills within the workforce**. With an increasing number of product variants, they noted that it could become challenging to keep their employees up to date with the necessary competencies. Participants acknowledged that **managing materials** could be a weakness. They discussed the complexity of material handling, particularly in dealing with various components and variants, which might lead to space-related challenges and could potentially lead to inefficiencies. The company does not currently have a strong feedback loop for its products, which could make it difficult to **identify opportunities** for remanufacturing.

Opportunities

The conversation touched on the **potential of digitalization and innovation**. They discussed how adopting digital tools and innovative technologies could streamline their operations, enhance quality control, and improve efficiency. The participants explored opportunities related to sustainability. They recognized that a commitment to sustainability, such as reducing waste and implementing more environmentally responsible practices, could be a competitive advantage in the market. The participants considered the **opportunity to expand their product variants**. They saw this as a way to increase value and offer more options to customers, potentially leading to increased sales and growth. The company could partner with other companies, such as suppliers of raw materials or components, to develop and implement remanufacturing programs.

Threats

The company may face **regulatory challenges** in implementing remanufacturing. For example, the company may need to obtain new permits or licenses. The company may also **face resistance from customers** who are concerned about the quality of remanufactured components. The participants identified **competitive pressure** as a significant threat. They discussed how choosing to prioritize long-lasting products over new product developments may impact on their capacity to meet market demands, which could lead to falling behind competitors in customer satisfaction. **Material availability** was acknowledged as a potential threat. The participants pointed out that relying on external suppliers for certain materials could pose a risk, especially if those materials become scarce or unavailable. The conversation revealed concerns about **maintaining production efficiency** while accommodating more product variants. They considered the potential threat of declining efficiency and increased production costs.

5. Discussion

The two workshops provided valuable insights on the integration of remanufacturing into a conventional production line, owing to the diverse range of participants with knowledge spanning several disciplines. Through the utilization of the data gathered during these workshops, it is possible to identify several enablers that can be regarded as keys in promoting the twin transition. The first enabler is related to the need to have a ***system to track lifecycles and composition for each component***. This can help improve the company's ability to collect customers' feedback and keep detailed records of component composition. This complete component monitoring and management system should not only guarantee that the correct components are used in products, but it should also be capable to maintain remanufactured component inventory efficiently, estimates demand for these components, and implements just-in-time deliveries. ***Smart quality control and vision system*** is another enabler. Predictive quality control with AI-driven quality control systems to predict defects and quality issues, reducing waste and rework. This technology can ensure that products meet the required quality standards and sustainability criteria. A third enabler is to have a ***data handling system with integrated flexibility***. This type of system can enhance the Manufacturing Execution System (MES) with real-time supply chain visibility and smart inventory management, allowing for more efficient resource allocation and waste reduction. This visibility can help in sourcing materials sustainably and reducing transportation-related emissions. The fourth enabler is ***flexible material supply to the assembly stations.*** Optimized material handling with, for example, Automated Guided Vehicles, can improve the efficiency of material handling within the production process. By optimizing material flow, they reduce energy consumption and the environmental impact of material transportation. A ***system for workforce upskilling*** is the fifth enabler. By using digital training platforms and augmented reality applications to upskill the workforce for older product assembly processes, the workforce can adapt to changing product lines and technology, supporting the transition to more sustainable processes. Implementing knowledge transfer systems that capture and share the expertise of experienced workers with new employees can be crucial in the context of older product assembly where tribal knowledge is valuable.

The identified enablers consider the use of digitalization to support remanufacturing of components. However, our analysis is not specifying what digital technologies should be applied to achieve the mentioned benefits. For example, a smart quality control and vision system should include AI technology, but there is still a need to identify what specific AI is most suitable for a specific production system. Moreover, to ensure useful data to support remanufacturing, there is a need to investigate the other phases of the data value chain, not only the data processing. This includes defining what data is missing and must be collected and what digital technologies should be used for collecting, communicating, storing, visualizing, and using data [35]. However, even though digital technology plays an important role when building data value chains for remanufacturing, it is important not to overlook the aspects related to people and processes since there is a need to have a holistic perspective on the production system element [22, 24]. Humans will still play a key role in taking decisions and actions, with the support of data that has been generated and processed by digital technologies [33]. Considering human factors such as training, resistance to change and design for human decision support is therefore critical. Work processes and organizational processes require consideration since they have an impact on how the company's way of working, both at the shop floor, within the organization, and interacts with other stakeholders in the supply chain such as customers [5].

6. Conclusion, limitations, future research

This paper has three contributions. First, our paper gives detailed insights into the strengths, weaknesses, opportunities, and threats of achieving remanufacturing from a traditional engineering setting. This exemplary case shows that remanufacturing is a promising approach to reducing waste and improving sustainability, but also that remanufacturing is very complex as it requires consideration of multiple factors from different perspectives. Considering these multiple factors, manufacturing companies can further investigate how they can achieve remanufacturing of components. Second, this paper opens up an academic dialog on the use of Twin Transition concept in manufacturing setting considering the case of remanufacturing of components. We hope that this can create a constructive discussion on conceptualizing Twin Transition concept in manufacturing. There is a clear overlap in the investments needed within an organization for remanufacturing and digitalization initiatives. For instance, there is a need to consider several internal functions within the organization but also external partners such as customers. Moreover, there is a need to have a holistic perspective on the different elements in the production system such as people, processes, and technology. Third, this paper highlighted key enablers for integrating remanufacturing into traditional production lines, including the need for component lifecycle tracking, smart quality control systems, flexible material supply, enhanced supply chain visibility, smart inventory management and optimized material handling, workforce upskilling through digital training platforms, and knowledge transfer systems. By addressing these challenges, companies can position themselves to reap the environmental, economic, and customer benefits of remanufacturing.

One limitation of this research is that it only includes collaboration with one company in the heavy-duty vehicle industry and five participants representing the company. This limits the generalizability of the results and might not represent the whole situation of the company and the heavy-duty vehicle industry. The results from this research can be transferred to other research contexts but its suitability needs to be critically reflected upon before its application. One practical implication of the results is that the remanufacturing enablers could differentiate between companies in the heavy-duty vehicle industry and other industry sectors, as well as their size, due to the maturity level of the already integrated or need to integrate digital technologies.

Future research should focus on how remanufacturing can reduce waste and improve sustainability from a practical standpoint by, for example, conducting more in-depth case study research investigating what digital technologies should be selected and how they should be integrated for remanufacturing. Future research should include more participants and companies from the heavy-duty vehicle industry and other industry sectors. One interesting focus could be on conducting cross-case analysis highlighting different remanufacturing strategies for reducing waste and improving sustainability.

7. Acknowledgements

This work was partially supported by the Industrial Technology (IndTech) Graduate School founded by the Knowledge Foundation (KKS, Stockholm, Sweden) and the XPRES project funded by Vinnova (Stockholm, Sweden).

8. References

[1] European C, Directorate-General for C. Circular economy action plan : for a cleaner and more competitive Europe: Publications Office of the European Union; 2020.

[2] MatsumotoDr M, IjomahDr W. Remanufacturing. In: Kauffman J, Lee K-M, editors. Handbook of Sustainable Engineering. Dordrecht: Springer Netherlands; 2013. p. 389-408.

[3] European Remanufacturing Network. Remanufacturing Market Study. ERN, Network ER; 2015 Contract No.: EC--09 404 ERN WP2.2.docx.

[4] Kurilova-Palisaitiene J, Sundin E, Poksinska B. Remanufacturing challenges and possible lean improvements. Journal of Cleaner Production. 2018;172:3225-36. doi: https://doi.org/10.1016/j.jclepro.2017.11.023.

[5] Agerskans N. Digital Technologies for Enabling Smart Production : Examining the Aspects of Selection and Integration [Licentiate thesis, comprehensive summary]. Västerås: Mälardalens universitet; 2023.

[6] Muench S, Stoermer E, Jensen K, Asikainen T, Salvi M, Scapolo F. Towards a green & digital future: key requirements for successful twin transitions in the European Union. 2022;31075.

[7] Manavalan E, Jayakrishna K. An Analysis on Sustainable Supply Chain for Circular Economy. Procedia Manuf. 2019;33:477-84. doi: https://doi.org/10.1016/j.promfg.2019.04.059.

[8] Ghobakhloo M. Industry 4.0, digitization, and opportunities for sustainability. Journal of Cleaner Production. 2020;252:119869. doi: https://doi.org/10.1016/j.jclepro.2019.119869.

[9] Muench S, Störmer E, Jensen K, Asikainen T, Salvi M, Scapolo F. Towards a green and digital future. Key requirements for successful twin transitions in the European Union2022.

[10] Mäkitie T, Hanson J, Damman S, Wardeberg M. Digital innovation's contribution to sustainability transitions. Technology in Society. 2023;73:102255. doi: https://doi.org/10.1016/j.techsoc.2023.102255.

[11] Elkington J. Partnerships from cannibals with forks: The triple bottom line of 21st-century business. Environmental Quality Management. 1998;8(1):37-51. doi: https://doi.org/10.1002/tqem.3310080106.

[12] Kirchherr J, Reike D, Hekkert M. Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling. 2017;127:221-32. doi: https://doi.org/10.1016/j.resconrec.2017.09.005.

[13] Reike D, Vermeulen WJV, Witjes S. The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. Resources, Conservation and Recycling. 2018;135:246-64. doi: https://doi.org/10.1016/j.resconrec.2017.08.027.

[14] Potting J, Hekkert MP, Worrell E, Hanemaaijer A. Circular economy: measuring innovation in the product chain. Planbureau voor de Leefomgeving. 2017(2544).

[15] Lund RT. Remanufacturing : the experience of the United States and implications for developing countries: World Bank; 1984.

[16] Bengtsson M, Kurdve M. Machining Equipment Life Cycle Costing Model with Dynamic Maintenance Cost. Procedia CIRP. 2016;48:102-7. doi: https://doi.org/10.1016/j.procir.2016.03.110.

[17] Bensmain Y, Dahane M, Bennekrouf M, Sari Z. Preventive remanufacturing planning of production equipment under operational and imperfect maintenance constraints: A hybrid genetic algorithm based approach. Reliability Engineering & System Safety. 2019;185:546-66. doi: https://doi.org/10.1016/j.ress.2018.09.001.

[18] Okorie O, Russell J, Cherrington R, Fisher O, Charnley F. Digital transformation and the circular economy: Creating a competitive advantage from the transition towards Net Zero Manufacturing. Resources, Conservation and Recycling. 2023;189:106756. doi: https://doi.org/10.1016/j.resconrec.2022.106756.

[19] Schuh G, Anderl R, Dumitrescu R, Krüger A, ten Hompel M. Industrie 4.0 Maturity Index: Managing the Digital Transformation of Companies. Munich: 2020.

[20] Maddikunta PKR, Pham Q-V, B P, Deepa N, Dev K, Gadekallu TR, et al. Industry 5.0: A survey on enabling technologies and potential applications. Journal of Industrial Information Integration. 2022;26:100257. doi: https://doi.org/10.1016/j.jii.2021.100257.

[21] OECD, Communities SOotE. Oslo Manual2005.

[22] Bellgran M, Säfsten K. Production development: Design and operation of production systems: Springer London; 2010. 1-340 p.

[23] Gopalakrishnan S, Bierly P, Kessler EH. A reexamination of product and process innovations using a knowledge-based view. The Journal of High Technology Management Research. 1999;10(1):147-66. doi: https://doi.org/10.1016/S1047-8310(99)80007-8.

[24] Zizic MC, Mladineo M, Gjeldum N, Celent L. From Industry 4.0 towards Industry 5.0: A Review and Analysis of Paradigm Shift for the People, Organization and Technology. Energies. 2022;15(14):5221. PubMed PMID: doi:10.3390/en15145221.

[25] Heidemann Lassen A, Waehrens BV. Labour 4.0: developing competences for smart production. Journal of Global Operations and Strategic Sourcing. 2021;14(4):659-79. doi: 10.1108/JGOSS-11-2019-0064.
[26] Tortorella GL, Cawley Vergara AM, Garza-Reyes JA, Sawhney R. Organizational learning paths based upon industry 4.0 adoption: An empirical study with Brazilian manufacturers. Int J Prod Econ. 2020;219:284-94. doi: https://doi.org/10.1016/j.ijpe.2019.06.023.
[27] Tao F, Qi Q, Liu A, Kusiak A. Data-driven smart manufacturing. Journal of Manufacturing Systems. 2018;48:157-69. doi: 10.1016/j.jmsy.2018.01.006.
[28] Berger S, Denner MS, Röglinger M, editors. The nature of digital technologies - Development of a multi-layer taxonomy. 26th European Conference on Information Systems: Beyond Digitization - Facets of Socio-Technical Change, ECIS 2018; 2018.
[29] Ghobakhloo M. Determinants of information and digital technology implementation for smart manufacturing. Int J Prod Res. 2020;58(8):2384-405. doi: 10.1080/00207543.2019.1630775.
[30] Parhi S, Joshi K, Wuest T, Akarte M. Factors affecting Industry 4.0 adoption – A hybrid SEM-ANN approach. Computers & Industrial Engineering. 2022;168:108062. doi: https://doi.org/10.1016/j.cie.2022.108062.
[31] Manimuthu A, Venkatesh VG, Shi Y, Sreedharan VR, Koh SCL. Design and development of automobile assembly model using federated artificial intelligence with smart contract. Int J Prod Res. 2022;60(1):111-35. doi: 10.1080/00207543.2021.1988750.
[32] Tripathi V, Chattopadhyaya S, Mukhopadhyay AK, Saraswat S, Sharma S, Li C, et al. Development of a Data-Driven Decision-Making System Using Lean and Smart Manufacturing Concept in Industry 4.0: A Case Study. Mathematical Problems in Engineering. 2022;2022:3012215. doi: 10.1155/2022/3012215.
[33] Klingenberg CO, Borges MAV, Antunes Jr JAV. Industry 4.0 as a data-driven paradigm: a systematic literature review on technologies. Journal of Manufacturing Technology Management. 2019. doi: 10.1108/JMTM-09-2018-0325.
[34] Cioffi R, Travaglioni M, Piscitelli G, Petrillo A, De Felice F. Artificial Intelligence and Machine Learning Applications in Smart Production: Progress, Trends, and Directions. Sustainability. 2020;12(2):492. PubMed PMID: doi:10.3390/su12020492.
[35] Agerskans N, Ashjaei M, Bruch J, Chirumalla K, editors. Critical Factors for Selecting and Integrating Digital Technologies to Enable Smart Production: A Data Value Chain Perspective. IFIP International Conference on Advances in Production Management Systems; 2023: Springer.
[36] Yin RK. Case study research and applications: design and methods. Los Angeles.: SAGE; 2018.
[37] Bronte-Stewart M. Regarding Rich Pictures. 2013.
[38] Berg T, Pooley R. Rich Pictures: Collaborative Communication Through Icons. Systemic Practice and Action Research. 2013;26(4):361-76. doi: 10.1007/s11213-012-9238-8.
[39] Hill T, Westbrook R. SWOT analysis: It's time for a product recall. Long Range Planning. 1997;30(1):46-52. doi: https://doi.org/10.1016/S0024-6301(96)00095-7.
[40] Bertoni M, Chirumalla K, Johansson C. Social Technologies for Cross-Functional Product Development: SWOT Analysis and Implications2012. 3918-27 p.
[41] Pickton D, Wright S. What's SWOT in strategic analysis? Strategic Change. 1998;7:101-9. doi: 10.1002/(SICI)1099-1697(199803/04)7:23.0.CO;2-6.
[42] Braun V, Clarke V. Using thematic analysis in psychology. Qualitative Research in Psychology. 2006;3:77-101. doi: 10.1191/1478088706qp063oa.