CRITICAL ANALYSIS USING TECHNOLOGIES AT AUTOMOTIVE REMANUFACTURING OPERATION

Gabriella Carlucci Tavares Colombo (UNICAMP)
g265747@dac.unicamp.br

Muriel de Oliveira Gavira (UNICAMP)
muriel.gavira@fca.unicamp.br

Paulo Sergio de Arruda Ignacio (UNICAMP)
paulo.ignacio@fca.unicamp.br

Pedro Henrique Ribeiro Botene (UNICAMP)
p265751@dac.unicamp.br

Tairiny Cunha Pereira (UNICAMP)
t232717@dac.unicamp.br

As part of the circular economy, remanufacturing plays an important role in the economic and sustainable development of automotive industries. In this way, this article, through a systematic literature review, presents the main challenges faced by remanufacturing companies in their operations and how technologies towards Industry 4.0 can help to mitigate some of these problems. A case-study in an automotive company was carried out and compared with the results from the literature. It can be seen that even remanufacturing operation being done manually, and all parts replaced in case of uncertainties the cost saving from material recovered is still significant, which opens opportunities for future studies to consider the application of current used manufacturing technologies in the remanufacturing operation.

Keywords: remanufacturing, industry 4.0, automotive industry

1. Introduction

The concern with high consumption and energy limitations, made companies rethink their processes and adopt an increasingly cleaner production. Thus, remanufacturing has been an area of interest in the automotive industry due its largest economic impact.

Remanufacturing is part of the circular economy, which reduces waste, increases resource efficiency, and supports cleaner and more sustainable production. Thus, the remanufacturing proposal was chosen due to the new industrial scenario, which determines responsibility to the destination of rejected products (KERIN et al. 2019).

In a remanufacturing environment, the lack of information about the condition of returned products and the lack of advanced technologies for cleaner production, bring difficulties to achieve organization goals. In addition, uncertainties about the costs made companies reluctant to adopt them. Thus, the use of Industry 4.0 technologies can break these barriers and help spread the concepts of remanufacturing and Circular Economy.

Motived from the aforementioned points, this article aims to show the applications of Industry 4.0 technologies in remanufacturing, highlighting its benefits, helping manufacturers overcome the main problems related to the remanufacturing operation. For this, a systematic review of the literature was carried out to identify the main challenges faced by remanufacturers in their operations and the potential of Industry 4.0 technologies to solve them. Additionally, a case study was carried out using data from an automotive company in Brazil, in order to compare the results with the published literature on this research topic.

2. Theoretical review

Driven by the high ecological and economical potential and stringent environmental regulations, remanufacturing is receiving increasing awareness, as it is a process that enables the reuse of end-to-life products back to good as new condition, through a series of repair operation and refurbishment process (YANG et al. 2018; GROß et al. 2020). It also supports economically aftermarket activities when it keeps supply of spare parts or components to warranty return. Additionally, refurbishment and repair operation offer low-cost products alternative for secondary markets, recovering both material content and energy from manufacturing (GOODALL et al. 2019).

According to Steinhilper (1998), the remanufacturing process follow five steps: Disassembly, Cleaning, Inspection, Reconditioning and Reassembly. During those steps, quality assurance measures are integrated part of the operation. However, uncertainties within

remanufacturing are caused by limited information such as: condition and quality of returned product, quantity of cores, inefficient manual process, and variance in the remanufacturing operation. It causes double work in form of inspection and disassembly to determine the right task suitable for remanufacturing. Moreover, the costs benefit bring reluctance from companies in adopting principles from Circular Economy (TIWARI et al. 2021; GOODALL et al. 2019).

The adoption of digital technologies drives remanufacturing industry into a new era to overcome some of the barriers associated with the lack of information about unpredictability in the quality and condition of the returned products. The industry 4.0 brings connectivity and integrated systems which allows companies to exchange information and monitoring parts machine and equipment through sensors and devices. In addition, the development of automated process, condition monitoring and integrated operation can also make the end-of-life production cost-effective, environment friendly and more efficient. (TIWARI et al. 2021; WANG et al. 2020).

Technology evolves rapidly, so in most cases it is more advantageous to remanufacture the product, adding improvements at a much lower cost, than designing and producing new products from scratch. Due to the costs of manufacturing process and high-volume products, the automotive industry has encouraged the adoption of remanufacturing operation. (BENOY et al. 2014).

According to Kamper et al. (2019), the automotive aftermarket is one example of the most developed remanufacturing industry, and the components, alternators, turbocharger, water pumps, starter motors, clutches, including internal combustion engines and automatic transmissions, account for two thirds of all remanufacturing activities.

3. Methods

In this paper, a systematic literature review methodology was carried out to identify, assess, and interpret relevant literature about the subject matter. According to Kitchenham et al. (2004), this method allows summarizing the existing studies published and identifying gaps in current research to suggest any further analyzes. To ensure the comprehension of this systematic review, table 1 presents the research protocol. The data was conducted in May of 2022 with no time restriction through Scopus and Web of Science databases. As a research criterion to collect samples related to Remanufacturing and Industry 4.0 in the automotive field, the keyword strings for analysis were “Remanufacturing”, “Industry 4.0”, and “auto and vehicle”.

Table 1: Research protocol

Topic	Description
Main Question	Which technologies related to Industry 4.0 have been used in remanufacturing operations
Objective	Literature review of industry 4.0 technologies at remanufacturing
Database	Scopus and Web of Science
Search String	Scopus: TITLE-ABS-KEY(("remanufacturing" AND "industry 4.0" AND ("auto*" OR "vehicle*"))) Web of Science: ("remanufacturing" AND "industry 4.0" AND ("auto*" OR "vehicle*")) (Topic)
Document type	Articles, conference papers
Studies languages	English
Criteria	Inclusion: - Open access - Papers published and fully available - Papers using Industry 4.0 technologies for remanufacturing Exclusion: - Duplicates - Papers not focused on remanufacturing operation

Source: Adapted from BOTENE, Pedro et al. (2021)

Based on Moher et al (2009), for the search and selection of papers, the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) was used as a guideline through a four-phase flow diagram (Fig.1):

i Identification

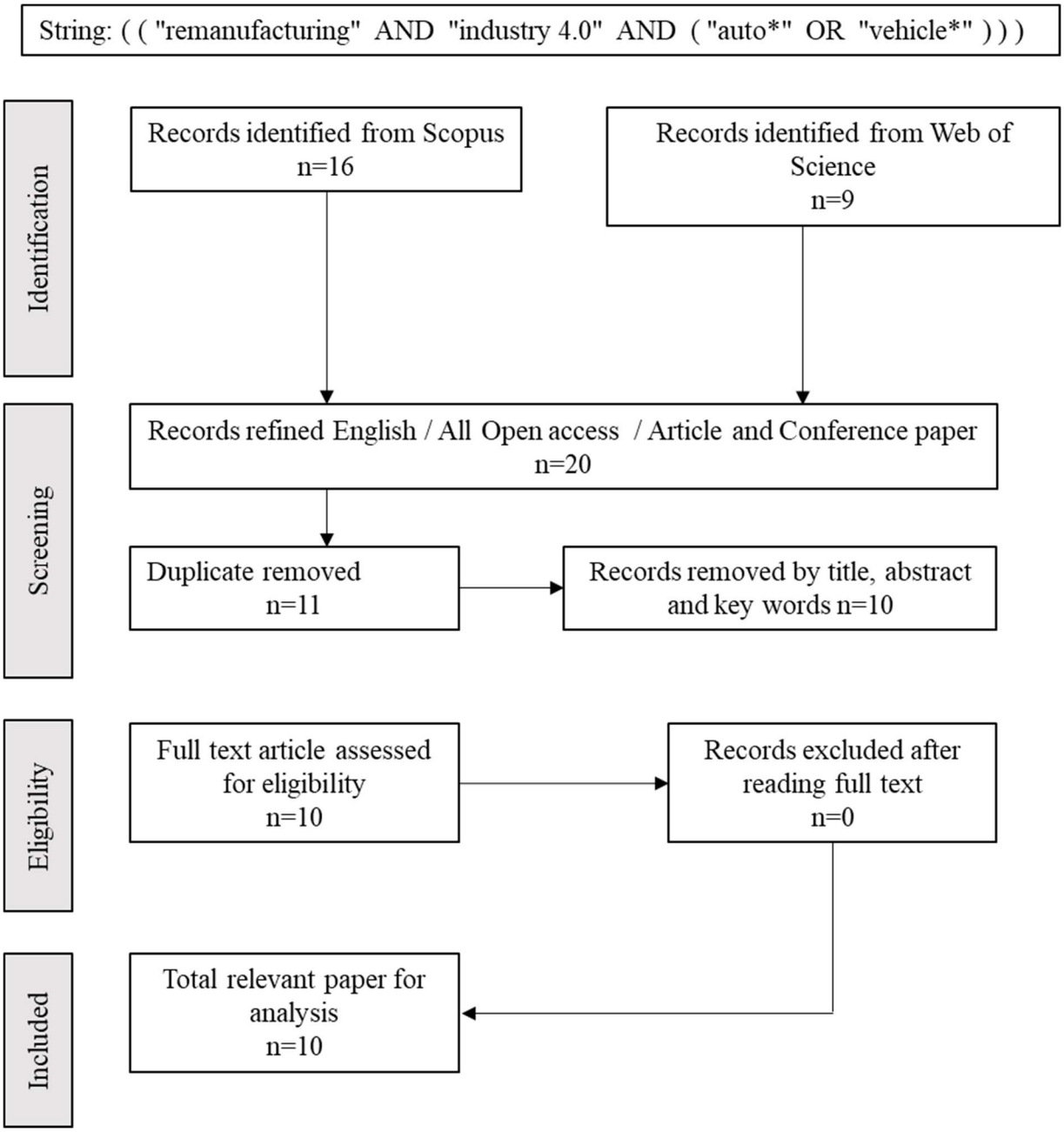
ii Screening

iii Eligibility

iv Included

Considering the duplicates removal, title, abstract and keywords with the inclusion and exclusion criteria, from a total of 25 papers, 10 papers were selected as sample for this article.

Figure 1 - PRISMA full diagram



Source: Adapted from Moher et al. (2009)

3.1 Case study

Through a convenience sample, data collected from a multinational automotive manufacturing company in Brazil was used for comparisons with the result current existing in the literature. The convenience sample method was chosen to be a technique that allows collecting information easily accessible and readily available for studies purposes (ETIKAN et al. 2016).

As a documental research, existing data from internal records were extracted for analysis, through a consultation with the industrial automotive expert. The case study involves a process of a specific remanufacturing component, aiming to design the remanufacturing operation and identify the issues and technologies that are used to mitigate it.

Overall, this remanufacturing process is an exclusive and dedicated operation apart from the main automotive company activity, and it is done manually by professionals trained in inspection, disassembly, and reassembly process.

The result from the data collected shows that:

- There is no technology or automated process used in this remanufacturing operation;
- The state of each part and quality evaluation is checked individually and based on experience;
- In case of uncertainties in information about condition and quality, parts are replaced.
- Remanufacturing is not applied for wearing parts (wearing parts are replaced independently of quality or condition);
- Parts remanufactured are registered manually in a "memorial vehicle service sheet" in the internal system for traceability;
- The final product remanufactured is tested in a vehicle dedicated for this purpose before being released for reassembling;
- The cost savings made from the material recovered is expressive and it is considered to extend the remanufacturing operation to other products that are manufactured by the automaker itself.

Although any technology toward Industry 4.0 is applied in the remanufacturing operation, this company is known to adopt automation and digital technologies in their manufacturing process.

4. Results and Discussion

Based on the review articles a framework was created to summarize, and outcome data analysis (Table 2) to a comprehensive study of the main challenges faced by remanufactures and the potential of Industry 4.0 technologies in their operation. It includes in the first column the respective authors, followed by the challenge scenario that remanufactures face in their operation. "Findings" represent the benefits of Industry 4.0 technologies to solve some of those issues and, then the relevant Industry 4.0 technologies are highlighted.

Table 2 - Detailed analysis result from the literature review

#	Author's	Remanufacturing challenge	Findings	Relevant I4.0 technologies in remanufacturing	Part / Operation
1	Tiwari D. et al. 2021	Lack of information about the condition and quality of returned product.	Industry 4.0 technologies have the potential to solve this challenge by tracking the products in use by utilizing embedded sensors.	Sensors and Machine Vision for Inspection / Robotic Applications for Disassembly / Modelling, Simulation and Digital Twin for the Decision Making Process	Electric motors
2	Wang Z. et al. 2020	Carried out largely by manual process and disturb the production schedules.	Industry 4.0 to improve the efficiency and support optimized production planning / All information of production system integrated / Information and equipment connected to Iot / Sensor data to make an accurate evaluation of current state and prediction of the useful life of equipment.	Sensors / Production System Integrated	Production machinery
3	Okorie O. et al. 2020	Uncertain quality of returned used products, timing and product knowledge.	With Industry 4.0 more data produced as sensor-enabled products enter the remanufacturing shop-floor.	Monitoring tools and robotics / Smart sensors / Additive manufacturing / Simulation modelling	Remanufacturing operation
4	Groß S. et al. 2020	Unknown conditions of the used products.	Scheduling of machines and AGVs to realize flexible material handling / All participants are networked / Cyber-physical system to communicate and find solutions.	Automated Guided Vehicles (AGVs) / Cyber-physical system	Production Planning Control
5	Siddiqi M.U.R. et al. 2019	Remanufacturing is done manually / Labor and training cost are high to perform the disassembly process / High injury rate.	Visual Structure for Motion (VFM), a relatively low cost method, to develop a 3D digital model / Automation of the automotive engine using industrial robots.	Visual Structure for Motion (VFM), 3D digital model	Automotive engine
6	Goodall P. et al. 2019	Uncertain nature of product returns.	Digital manufacturing systems to predict material flow behavior within remanufacturing operations.	Real traceability RFID systems / Data-driven simulation	Remanufacturing operation
7	Huang J. et al. 2019	Uncertainties in the condition of those products and unpredictability in remanufacturing operations.	Effectiveness at increasing flexibility and adaptability by reducing setup efforts / Compliance helps robots to mitigate the effects of position and velocity errors and handle uncertainties in the location, size and shape of the workpiece.	Human-robot collaborative disassembly cell	Automotive water pump
8	French R. et al. 2019	The repair or regeneration is manual welding. Complex geometries and large variety of non-uniform wear and deformation found on individual pieces.	Modular design and interconnection of physical subsystems allow transparent data management and intelligent sensing / The Industry 4.0 allows modular subsystems to perform such decentralized decisions, increasing production speed and assuring quality.	Additive manufacturing	Robotic welding system
9	French R. et al. 2018	Aiming in repairing 100% of the repairable yield of used turbine blades and in eliminating hazardous to human effects.	The robotic concept is aiming to reduce the human impact on the remanufacturing / The combination of independent inspection mechanisms and advanced sensor fusion will assure the quality of the process and eliminates faulty products reaching circulation.	Robots and advanced sensors	Jet engine compressor blades
10	Okorie O. et al. 2018	Combine ecological concerns and economic growth using remanufacturing. Limited literature about.	Within emerging concepts such as Industry 4.0 (I4.0) and the Internet of Things (IoT), understanding decision-making and stakeholders' interaction is important in optimizing manufacturing and post manufacturing processes.	Operations data, design data , RFID, Embedded Sensors	Battery system embedded in hybrid and electric automobiles

Source: Authors (2022)

From the framework above, most of the issues are related to uncertainties about parts condition and quality, remanufacturing operations is done manually, and a lack of skilled professional in remanufacturing operation. Unpredictability in remanufacturing operations due to the complex and variety of parts and high injury rate is also mentioned, bringing also to the fore the importance of Industry 4.0 technology in remanufacturing.

Additionally, according to the literature, Industry 4.0 technologies with sensors, and devices for inspection, evaluation and traceability have the potential to solve the lack of information about the condition and quality of returned products, as well as an Integrated Production System for data exchanging, and Additive Manufacturing and Simulation for decision making are the most technologies applied in the parts and operation aforementioned.

Regarding the case result and the literature review, both bring the remanufacturing operation based on professional expertise. There is also a consent to lack of information about parts condition once all parts are removed and substituted for new ones.

5. Conclusion

Remanufacturing plays a critical role in economic growth. As part of a Circular Economy and due to the high-volume products, automotive industries are being encouraged to adapt their process once it enables to restore of products as new condition, and as consequence, for more sustainable production. However, some uncertainties like quality and conditions of returned products, lack of professional expertise, or cost investment, make organizations resistant in adopt those practices. Nevertheless, the adoption of digital technologies towards Industry 4.0 is presented as a viable practice to overcome some of those issues. Through a systematic review of the literature, this paper presents the challenges in the remanufacturing operations, and the potential of Industry 4.0 technology to solve them.

The case study in an automotive company shows some of the challenges cited in the literature, but even remanufacturing operations being done manually, and all parts being replaced in case of uncertainties, the cost-saving from material recovered is still considerable. In this scenario, any technology toward Industry 4.0 is applied in their remanufacturing operation, however, future studies could consider the application of the current Industry 4.0 technologies used in their manufacturing process in their remanufacturing operation for process optimization.

Furthermore, this article is based on a particular automotive company, and more case-based studies could be included to get additional results. Future studies could also make economic analysis and justify the viability of such technologies.

6. Acknowledgements

The authors wish to acknowledge the assistance of students and mentors from CENPRO (Centro de Pesquisa em Engenharia de Produção) at School of Applied Sciences (FCA UNICAMP) at Campinas University, for their guidance and encouragement. The authors also wish to acknowledge the experts in the automotive field and the company that contributed with this work, who remained anonymous, but always is open and spare no effort to support academic research.

REFERENCES

BENOY, A. M.; OWEN, L.; FOLKERSON, M. Triple win-the social, economic and environmental case for remanufacturing. **All-Party Parliamentary Sustainable Resource Group & All-Party Parliamentary Manufacturing Group, London**, 2014.

BOTENE, Pedro Henrique Ribeiro; DE AZEVEDO, Anibal Tavares; DE ARRUDA IGNÁCIO, Paulo Sérgio. Blockchain as an enabling technology in the COVID-19 pandemic: a systematic review. **Health and Technology**, v. 11, n. 6, p. 1369-1382, 2021.

ETIKAN, Ilker et al. Comparison of convenience sampling and purposive sampling. **American journal of theoretical and applied statistics**, v. 5, n. 1, p. 1-4, 2016.

FRENCH, Richard; BENAKIS, Michalis; MARIN-REYES, Hector. Intelligent sensing for robotic re-manufacturing in aerospace—An industry 4.0 design based prototype. In: **2017 IEEE International symposium on robotics and intelligent sensors (IRIS)**. IEEE, 2017. p. 272-277.

FRENCH, Richard; MARIN-REYES, Hector; BENAKIS, Michalis. Transfer analysis of human engineering skills for adaptive robotic additive manufacturing in the aerospace repair and overhaul industry. In: **International Conference on Applied Human Factors and Ergonomics**. Springer, Cham, 2018. p. 3-12.

GOODALL, Paul; SHARPE, Richard; WEST, Andrew. A data-driven simulation to support remanufacturing operations. **Computers in Industry**, v. 105, p. 48-60, 2019.

GROß, Sebastian; GERKE, Wolfgang; PLAPPER, Peter. Agent-based, hybrid control architecture for optimized and flexible production scheduling and control in remanufacturing. **Journal of Remanufacturing**, p. 1-27, 2020.

HUANG, Jun et al. A strategy for human-robot collaboration in taking products apart for remanufacture. **Fme Transactions**, v. 47, n. 4, p. 731-738, 2019.

KAMPER, Achim et al. Remanufacturing of electric vehicles: Challenges in production planning and control. **Procedia Manufacturing**, v. 33, p. 280-287, 2019.

KERIN, Mairi; PHAM, Duc Truong. A review of emerging industry 4.0 technologies in remanufacturing. **Journal of cleaner production**, v. 237, p. 117805, 2019.

KITCHENHAM, Barbara. Procedures for performing systematic reviews. **Keele, UK, Keele University**, v. 33, n. 2004, p. 1-26, 2004.

MOHER, David et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement (Chinese edition). **Journal of Chinese Integrative Medicine**, v. 7, n. 9, p. 889-896, 2009.

OKORIE, Okechukwu et al. A decision-making framework for the implementation of remanufacturing in rechargeable energy storage system in hybrid and electric vehicles. **Procedia Manufacturing**, v. 25, p. 142-153, 2018.

OKORIE, Okechukwu et al. Towards a simulation-based understanding of smart remanufacturing operations: A comparative analysis. **Journal of Remanufacturing**, p. 1-24, 2020.

SIDDIQI, Muftooh UR et al. Low cost three-dimensional virtual model construction for remanufacturing industry. Journal of Remanufacturing, v. 9, n. 2, p. 129-139, 2019.

STEINHILPER, Rolf. Remanufacturing-The ultimate form of recycling. **Fraunhofer IRB Verlag**, ISBN 3-8167-5216-0 p. 108, 1998.

TIWARI, Divya et al. A review of circular economy research for electric motors and the role of industry 4.0 technologies. **Sustainability**, v. 13, n. 17, p. 9668, 2021.

WANG, Zezhong et al. Towards smart remanufacturing and maintenance of machinery-review of automated inspection, condition monitoring and production optimisation. In: **2020 25th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA)**. IEEE, 2020. p. 1731-1738.

YANG, Shanshan et al. Opportunities for industry 4.0 to support remanufacturing. **Applied Sciences**, v. 8, n. 7, p. 1177, 2018.