**FRAMEWORK AND STRATEGIES SUPPORTING IR 4.0 FOR SUSTAINABLE MANUFACTURING: A WAY FORWARD**

Md Raziff Zainal Abidin

Muhamad Zameri Mat Saman\*

Nor Hasrul Akhmal Ngadiman

School of Mechanical Engineering, Faculty of Engineering University Technology of Malaysia

raziff@graduate.utm.my; \*zameri@utm.my; norhasrul@utm.my

Orcid ID: https://orcid.org/0000-0001-5418-8422

This research was funded by the Universiti Teknologi Malaysia (UTM) through UTM High

Impact Research (UTMHR) Grant vot no. Q.J130000.2409.08G41

This research was funded by the Universiti Teknologi Malaysia (UTM) through UTM High

Impact Research (UTMHR) Grant vot no. Q.J130000.2409.08G41

**ABSTRACT**

This paper reviews the current state of smart remanufacturing and highlights key elements of Industry 4.0 to provide a conceptual framework and research agenda for accelerating digitalization in this sector. IR 4.0 involves challenges that all stakeholders must address so that the transition to recent industrial technologies is optimally implemented. This digital revolution also refers to the more intelligent and efficient technological developments in manufacturing sectors. This accelerated technological change requires sustainable and broad planning by all parties involved including national policy makers to support the commercial revolution and to fully employ IR 4.0. The purpose of this organized review is to identify and facilitate the understanding of IR 4.0 concepts as well as its designs, enablers, drivers and sustainability in the context of its integration in sustainable manufacturing. The mapping of existing practices highlights the research gaps and possibilities. The conceptual framework formed based on the technological pillars of IR 4.0 is used to measure sustainable manufacturing, previously identified opportunities, and aspects of sustainability, as well as to guide systematic analyses. However, the analysis of gaps and opportunities to advance the field of research has become more sophisticated, necessitating additional contributions to complete the development of IR 4.0 in sustainable manufacturing in economic, environmental and social dimensions. Additionally, co-occurrence analysis suggested that additive manufacturing and IR 4.0 are most preferred. Nevertheless, the research seems to be in its early stage as compared to other fields of ELV remanufacturing.

Keywords: IR 4.0, sustainable manufacturing, intelligent and efficient

1. **INTRODUCTION**

According to (Chakraborty et al., 2019), an increased demand for automotive products and excessive usage of natural resources push manufacturers to employ the Extended Useful Life (EUL) methodology via remanufacturing. Remanufacturing is the process of restoring an End-of-Use (EoU) or End-of-Life (EoL) product to its original functionality. This paper examines the same emerging technologies in the context of remanufacturing using frameworks designed to facilitate the exploration and implementation of IR 4.0 technologies for disassembly. Trends and gaps have been identified in terms of the value-creation perspective that includes the product to be remanufactured, the remanufacturing equipment and processes adopted, and organizational issues. The advancement of technology and innovation in the automobile business has resulted in the increase of ELV waste year after year. Pollution will worsen if not properly managed, demanding considerable recycling expenditures. Therefore, in this research, the focus is on the remanufacturing systems’ definition, relevance, main phases, case studies, and solution methods proposed by various researchers. Adoption of existing and emerging digital technologies to shorten and strengthen links between product manufacturers, users, and remanufacturers is crucial to the success of remanufacturing in an IR4.0 world. It is distinctive due to its focus on the remanufacturing industry and its application of IR4.0 enablers in a sustainable manner. The findings are used to develop a framework that links to the research agenda required to achieve intelligent remanufacturing.

According to (Kerin & Pham, 2019), additive manufacturing systems integrated with the Internet of Things (IoT) have the potential to be used to repair end-of-life products, but the technology has not yet been demonstrated in practise, and there are concerns about the current trajectory of developments in this field in order to support sustainable practices. (Park, 2018) suggested that IR 4.0 is represented by the networking of machines, artificial intelligence (AI), big data, and robotics on the Internet of Things (IoT) and development of digital technologies such as Smart Manufacturing. This is supported by the findings of (Rejeski et al., 2018), who investigated additive manufacturing (AM) with respect to the environment, recommending research into remanufacturing issues and opportunities for hybrid materials and structures, customized products, and how intellectual property (IP) management is handled.

On the other hand, according to (Müller et al., 2018), the flexibility of additive manufacturing (AM), combined with its reliance on designs being available digitally, means that it could also be used once a product has reached its Middle-of-Life (mol) stage to support rapid design modification in the event of an unexpected failure or behaviour, as well as for repairing and remanufacturing. (Chen et al., 2019) stated that remanufacturing solutions can help reduce raw material use, energy consumption, and water and air pollution by extending the life of critical components. In another study, (Yusoh et al., 2020) asserted that the remanufacturing and aftermarket industry is gradually emerging as global business opportunity due to its social, economic, and environmental benefits. According to (Lahrour & Brissaud, 2018), recent advances in additive manufacturing have demonstrated that AM is capable of repairing and restoring damaged parts and components. Due to lack of remanufacturing and aftermarket industries, automotive scrap management has evolved into a complex issue that requires quick action.

1. **METHOD**

The current study utilized the Scopus database for data collection and screening of peer-reviewed journal articles. Scopus database is used extensively for bibliometric analysis as it offers various benefits for undertaking such studies. A systematic literature review was conducted using a bibliometric and classification/coding method to deliver a summary of all the available primary research topics of ELV, specifically on remanufacturing research in automotive industry. The retrieval of the publications was done on March 2, 2022. The research combines various keyword strings (Remanufacturing, Industry 4.0, Additive Manufacturing, and End of Life Vehicle). These keyword combinations were used to search the Scopus database for relevant studies.

**2.1 Purpose**

This research aims to determine how remanufacturing is incorporated into the early stages of design within the ELV management industry and the opportunities to ensure that the environment and resources are well-managed. The three primary purposes of this study are as follows:

* To assess the remanufacturing process is an alternative to other recovery strategies.
* To aid in identifying parts suitable for reuse and recovery during vehicle disassembly.
* Clearly identify and assess car components which is a significant obstacle in the remanufacturing procedure.

**2.2 Research Gap**

Sustainable manufacturing is a value-added recovery process, that returns end-of-life or discarded products to their original distinctive value; "as good as new" product. This study focuses on how resource efficiency improvements within a manufacturing system were achieved and proposes a method for examining and categorizing these improvements. Five primary variables namely efficiency, recycling, recovery, reduction, and eco-design or IR 4.0 contribute to environmental sustainability as a whole, as shown in Figure 1. In order to support sustainable practices, the emerging IR 4.0 technology is investigated based on the findings of prior research. Recycling and eco-friendly designs are the two most important variables which are interrelated. The connections include reduction, efficiency, and recovery objectives.

|  |
| --- |
|  |

**Figure 1 Gap of sustainability in Remanufacturing process**

Figure 2 illustrates the proposed framework for utilizing IR 4.0 in remanufacturing. The AI-based assistance identifies used parts based on images which aid workers in identifying and evaluating defective wear parts. Other than that, AM technology is used to rebuild or reshape the core following a particular design. These technologies will facilitate individualized maintenance.



**Figure 2 Proposed framework for ELV remanufacturing**

Many nations and regions where ELV recycling laws have been enacted have improved their ELV management. Still, numerous issues must be resolved before the systems can function properly or the required objectives can be attained. (Sakai et al., 2014) summarises the current problems with ELV recycling systems in nations and regions where ELV recycling is required by law, shown in Table 1. Every step of the ELV recycling process revealed flaws. The table also shows where ELV management systems and techniques are headed in the future.

**Table 1 Summary of the current issues of ELV recycling systems at each stage in the ELV**

**recycling process**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|

|  |  |  |
| --- | --- | --- |
| **Stage**  | **Challenges** | **The direction of systems/technologies** |
| Stage IDesigning/manufacturing automobile | Sufficient dismantling information | * Restriction of the use of hazardous

 substances, and the development of  alternative materials |
| Stage IICollection of ELV | Reliable collection of scrap carsPrevention of illegal activities | * Integration and centralization of the

 management of scrap cars* Providing the public with information on

 the automobile recycling system |
| Stage IIIDismantling/ Recovery / Depollution | Proper treatment of hazardous substancesThe safe working environment during dismantling | * Stricter system for collection of

 hazardous substances and appropriate  treatment* Modernization and automation of

 dismantling* Compliance with related rules and their

 stricter enforcement |
| Stage IVShredding | Keeping treatment capacityAvoidance of geographic skewness | * Stabilization of the scrap market and its

 cooperation with the system |
| Stage VPost-shredding 1 | Intensive separation of materials | * Automation of the separation of labour
* Development of separation techniques
 |
| Stage VIPost-shredding 2 | Promotion of thermal recoveryPrevention of secondary pollution | * Development of the thermal recovery

 technology* Conducting environment monitoring
 |

 |

1. **CONCLUSION**

The used car market is being used illegally; improper recycling processes that are causing serious environmental pollution at the facilities; an illegal extension of the lifetime of a vehicle without permission; and illegal remanufacturing. There is still room for businesses and government agencies to invest more in research and development related to design for remanufacturing. Applications of additive manufacturing in future factories and emerging industries; IR4.0 manufacturing systems use 3D printing processes to improve the manufacturing efficiencies of existing processes and procedures. Therefore, remanufacturing promotes the development and innovation of manufacturing methods and materials. In addition, the presence of smart factories ensures environmental sustainability to be achieved.

This research was funded by the Universiti Teknologi Malaysia (UTM) through UTM High Impact Research (UTMHR) Grant vot no. Q.J130000.2409.08G41

**REFERENCES**

1. Chakraborty, K., Mondal, S., & Mukherjee, K. (2019). A study on remanufacturing possibility of a product. Microsystem Technologies, 25(5), 1765–1770. https://doi.org/10.1007/s00542-017-3566-7
2. Chen, Y., Ding, Z., Liu, J., & Ma, J. (2019). Life cycle assessment of end-of-life vehicle recycling in China: a comparative study of environmental burden and benefit. International Journal of Environmental Studies, 76(6), 1019–1040. https://doi.org/10.1080/00207233.2019.1618670
3. Karagoz, S., Aydin, N., & Simic, V. (2020). End-of-life vehicle management: a comprehensive review. Journal of Material Cycles and Waste Management, 22(2), 416–442. https://doi.org/10.1007/s10163-019-00945-y
4. Kerin, M., & Pham, D. T. (2019). A review of emerging industry 4.0 technologies in remanufacturing. Journal of Cleaner Production, 237, 117805. https://doi.org/10.1016/J.JCLEPRO.2019.117805
5. Lahrour, Y., & Brissaud, D. (2018). A Technical Assessment of Product/Component Re-manufacturability for Additive Remanufacturing. Procedia CIRP, 69(May), 142–147. https://doi.org/10.1016/j.procir.2017.11.105
6. Lee, H.B., Cho, N.W., Hong, Y.S.A., 2010. A hierarchical end-of-life decision model for determining the economic levels of remanufacturing and disassembly under environmental regulations. J. Clean. Prod. 18, 1276e1283
7. Mangmeechai, A. (2020). Life-cycle greenhouse gas and value chain of end-of-life vehicle management in Thailand. CLEAN TECHNOLOGIES AND ENVIRONMENTAL POLICY. https://doi.org/10.1007/s10098-020-01953-5
8. Mohamad-Ali, N., Ghazilla, R. A. R., Abdul-Rashid, S. H., & Ahmad-Yazid, A. (2019). Aftermarket survey on end-of-life vehicle recovery in Malaysia: Key findings. JOURNAL OF CLEANER PRODUCTION, 211, 468–480. https://doi.org/10.1016/j.jclepro.2018.11.165
9. Mohamed, N., Saman, M. Z. M., Sharif, S., & Hamzah, H. S. (2018). Strategic Factors on Interpreting Remanufacturing Quality-Certifying Framework to Address Warranty Aftermarket for Malaysian Industry. IOP Conference Series: Materials Science and Engineering (Vol. 328). https://doi.org/10.1088/1757-899X/328/1/012033
10. Mohan, T. V. K., & Amit, R. K. (2020). Dismantlers’ dilemma in end-of-life vehicle recycling markets: a system dynamics model. ANNALS OF OPERATIONS RESEARCH, 290(1–2, SI), 591–619. https://doi.org/10.1007/s10479-018-2930-z
11. Matsumoto, M., Umeda, Y., 2011. An analysis of remanufacturing practices in Japan. J. Remanufacturing 1 (1), 2. http://dx.doi.org/10.1186/2210-4690-1-2
12. Müller, J. R., Panarotto, M., Malmqvist, J., & Isaksson, O. (2018). Lifecycle design and management of additive manufacturing technologies. Procedia Manufacturing, 19, 135–142. https://doi.org/10.1016/J.PROMFG.2018.01.019
13. Park, S.-C. (2018). The Fourth Industrial Revolution and implications for innovative cluster policies. AI & SOCIETY, 33(3), 433–445. https://doi.org/10.1007/s00146-017-0777-5
14. Paterson, D. A. P., Kao, C. C., Ijomah, W. L., & Windmill, J. F. C. (2018). Incorporating remanufacturing into the end-of-life vehicles directive: current presence and the waste problem. Journal of Remanufacturing, 8(1–2), 23–37. https://doi.org/10.1007/s13243-018-0043-0
15. Rejeski, D., Zhao, F., & Huang, Y. (2018). Research needs and recommendations on environmental implications of additive manufacturing. Additive Manufacturing, 19, 21–28. https://doi.org/10.1016/J.ADDMA.2017.10.019
16. Sakai, S. ichi, Yoshida, H., Hiratsuka, J., Vandecasteele, C., Kohlmeyer, R., Rotter, V. S., Passarini, F., Santini, A., Peeler, M., Li, J., Oh, G. J., Chi, N. K., Bastian, L., Moore, S., Kajiwara, N., Takigami, H., Itai, T., Takahashi, S., Tanabe, S., … Yano, J. (2014). An international comparative study of end-of-life vehicle (ELV) recycling systems. Journal of Material Cycles and Waste Management, 16(1), 1–20. https://doi.org/10.1007/S10163-013-0173-2
17. Spreafico, C. (2021). Quantifying the advantages of TRIZ in sustainability through life cycle assessment. Journal of Cleaner Production, 303. https://doi.org/10.1016/j.jclepro.2021.126955
18. Xiang, W., Ming, C., 2011. Implementing extended producer responsibility: vehicle remanufacturing in China. J. Clean. Prod. 19, 680e686
19. Yusoh, S. S. M., Wahab, D. A., & Azman, A. H. (2020). Analysis of automotive component design for reparation using additive manufacturing technology. International Journal of Integrated Engineering, 12(5), 20–26. https://doi.org/10.30880/ijie.2020.12.05.003
20. Zhang, T., Shu, J., Wang, X., Liu, X., Cui, P., 2011. Development pattern and enhancing system of automotive components remanufacturing industry in China. Resour. Conserv. Recy. 55, 613e622
21. Zhang, X., Cui, W., & Liou, F. (n.d.). Voxel-Based Geometry Reconstruction for Repairing and Remanufacturing of Metallic Components Via Additive Manufacturing. INTERNATIONAL JOURNAL OF PRECISION ENGINEERING AND MANUFACTURING-GREEN TECHNOLOGY. https://doi.org/10.1007/s40684-020-00291-7
22. Zhou, F., & Ma, P. (2019). End-of-Life Vehicle (ELV) Recycling Management Practice Based on 4R Procedure. 2019 IEEE 6th International Conference on Industrial Engineering and Applications, ICIEA 2019, 230–234. https://doi.org/10.1109/IEA.2019.8715165