

REMANUFACTURING AND INDUSTRY 5.0 WITHIN THE AUTOMOTIVE INDUSTRY

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Abstract

The automobile sector is one of the emerging sectors in the Indian economy. It accounts for a large share of exports and contributes to millions of jobs in India. Today, this sector is facing new challenges due to climate change, increased international competition, and emission norms. Additionally, due to the limited availability of natural resources, the government has started implementing a scrap policy in India. The answer to this scarp policy is to implement remanufacturing activities effectively. Remanufacturing presents a significant challenge for Indian automobile manufacturing, necessitating the resolution of inherent remanufacturing barriers or challenges. Poor product life cycle information (PLCI) is the key barrier to remanufacturing and has a negative impact on it. Industry 5.0 has the capability to tackle these issues by recovering, processing, and analyzing Product Life Cycle (PLC). In fact, ongoing research is focusing on implementing remanufacturing strategies using I5.0, aiming to address remanufacturing barriers and develop new remanufacturing business models. The current research focuses on identifying the challenges and opportunities for remanufacturing, as well as improving the existing remanufacturing practices, particularly in the automotive industry within Industry 5.0. We conducted an extensive literature survey to map problems and success factors for remanufacturing, and investigate whether the sector can use Industry 5.0 to reduce these hindrances and their impact.

The findings demonstrate that Industry 5.0 can help remanufacturing achieve incremental gains. Technology advancements such as IoT, digital twins, RFID, and IIoT, among others, enable us to gather and access more information about remanufacturing parts and components. Remanufacturing operations can reduce uncertainty, leading to improved planning for remanufacturing. Therefore, we can conclude that Industry 5.0 will bring about a shift in the way we think about remanufacturing, potentially leading to incremental improvements. This study will help reduce the waste management of components and products, especially in the automobile industry, and promote remanufacturing. These technologies will also assist developing countries in formulating and implementing scrap policies more effectively.

Keywords: Automobile industry, remanufacturing, RFID, digital twin, IoT, IIOT, Industry 4.0, Industry 5.0

1. Introduction:

Remanufacturing is the most popular strategy to reduce the consumption of natural resources through industrial processes, and it involves using end-of-life (EoL) products to create similar or even better ones (Sundin, 2019). According to Liu et al. (2014), remanufacturing products and components can increase resource efficiency by reducing waste. The automobile industry is playing a significant role in the Indian economy. Solid innovation ability and skill in adapting design and production enable the Indian automobile industry to maintain competitiveness despite

numerous challenges, contributing to its success. Industry 5.0 and digital transformation will lead to more resource-efficient and sustainable manufacturing, helping India to stay competitive and benefit from high revenues and the adoption of technologies. Willen (2016).

The remanufacturing model has emerged as a substitute to the conventional linear economic model that formed the first industrialization and today's consumer society. While the linear economic model uses "take, make, dispose," the cornerstones of the circular economy are reusing, remanufacturing, and recycling. If restoring these products to new conditions for re-use is not possible, we use all remaining materials for one or another product. This necessitates significant changes in the company's product design, production systems, and well-adapted business models, as noted by Wiktorsson et al. (2018).

Remanufacturing reinstates end-of-life products to their pristine state (Zhang et al., 2021; Paterson et al., 2017). It involves many industrial processes, such as inspection and assessment of the degree of wear, disassembly, component restoration, and reassembly of the product (Wu et al., 2024). Remanufacturing engages many SMEs worldwide, yet the market remains small compared to its potential. According to Asif and Mohammad (2011), a leading hypothesis suggests that there is currently a disconnect between scholarly research and its industrial implementation (Sierra-Fontalvo et al. 2024).

This research explores potential changes in information management while also addressing the logistical challenges associated with acquiring obsolete products. The concept of Industry 5.0 focuses primarily on digital twins and radio frequency identification (RFID). The neo-industrialization strategy and circular economy concept serve as the foundation.

This study carried out a thorough evaluation of the literature on Industry 5.0 and remanufacturing. While individual research on these two areas of industrial production is well-established, there is a dearth of studies on their coexistence. The literature narrows down and specifically focuses on the automotive industry, studying manufacturing and Industry 5.0. The issues revolve around Industry 5.0 and its technical concept, with the aim of exploring potential opportunities for remanufacturing within the automotive industry. Yu and Sun (2024) discovered that although initial technologies expenditures may appear high, these could result in long-term cost and emission reductions in Industry 5.0. This research is mapping the existing challenges in remanufacturing and exploring if the automobile industry can utilize Industry 5.0 technology to reduce its manufacturing impact on the environment. This research aims to study the readiness level of companies and their plans for remanufacturing. This article is an attempt to provide a summary of the challenges Indian automobile manufacturers encounter in Industry 5.0. Additionally, it discusses design and the manufacturing from the perspective of remanufacturing. A summary of case studies from the Indian automobile manufacturing sector highlights the potential for remanufacturing in this sector following the implementation of the scrap policy. It also assesses the attitudes of the industry toward remanufacturing following the implementation of the scrap policy.

2. Literature Review:

Remanufacturing motivations are closely associated with the country's economic sustainability. According to Östlin (2008), one of the most common reasons companies remanufacture is financial profitability. Toffel (2004) proposed that leveraging standard manufacturing processes can lead to cost reductions in product manufacturing. Östlin (2008) and Li et al. (2023) believe

that cost reduction is the main economic advantage of remanufacturing compared to new manufacturing. Research has demonstrated that remanufacturing can yield in a 40–60% savings when compared to the creation of brand-new products (Chen and Chang, 2012). Its eco-efficiency is further demonstrated by the fact that the processes involved lead to a reduction in energy use (Gutowski et al., 2011). New spare parts will not be available all the time; remanufactured parts may be the only way to meet spare parts demand. OEM companies might have a duty to supply spare parts for products they have already delivered. In the automotive industry, such obligations can amount to fifteen years. Remanufactured spare parts result in cost savings because they eliminate the need for extensive manufacturing, as noted by Richter et al. (2023). Additionally, the production of these spare parts is expensive because the volume is low.

At the core of the production and manufacturing systems, Industry 5.0 emphasises a sustainable adoption cycle and more activities that are focused on society at large (Yang, 2023). Industry 4.0 is giving way to Industry 5.0 in the automotive industry, which goes beyond efficiency and productivity as its primary goals. This revolutionizes supports together green transformation using the CE paradigm and digital transformation using I4.0 technologies. (Madsen & Berg, 2021; Xu et al., 2021). Smart manufacturing facilities of today emphasise innovation and knowledge-driven operations. Consequently, the increasing adoption of I5.0 technologies enables it easier to track resources regardless of how they are being used and gives sufficient information about the equipment's lifetime, such as the severity of deprivation and remaining useable life, to support decision-making (Atif, 2023).

Östlin (2008) points out that a common reason companies do not want to carry out remanufacturing is the risk of cannibalism. Research further underscores that marketing the remanufactured products through other distribution channels to other markets need not pose a problem. Another strategy involves shifting the focus from product sales to service sales. According to Pesce et al. (2024), this allows for the optimisation of a product's usage throughout its whole life cycle and streamlines the company's options for remanufacturing while a manufactured goods hits end-of-life (EoL). The customer can continue to use the remanufactured product, or the company can resell it (Stlin 2008).

Insufficient information about the product in question during remanufacturing makes it difficult to determine the condition of a frame at EoL, necessitating disassembly, testing, and inspection to determine if remanufacturing the product is profitable (Erdmann et al., 2023; Harris et al., 2023). The risk lies in concluding that remanufacturing the product is not profitable, thereby wasting resources on collection, transport, and evaluation. Abdullah and Mohammed (2011).

Nasr and Thruston (2006) proposed the use of Design for Remanufacturing (DfRem) as a solution to this problem, incorporating it into future remanufacturing considerations during product development. They also suggested applying DfRem at the strategic level of the product. Through their knowledge of these processes and product design, OEMs can reap the most significant benefits of the recovery of the products at EoL Lu et al. (2024). One aspect that affects a product's appropriateness meant for remanufacturing is the possibility of non-destructive disassembly. One issue arises from the frequent contradictions between the model's design for assembly (DFA) and design for disassembly (DFD), necessitating careful balancing during product design, as noted by Shahhoseini et al. (2023) and Ramzan et al. (2023). Fang et al. (2016) propose that designers

can utilize this balance to determine the most suitable design for product disassembly. Kerin and Pham (2019) examined the gaps in the value-creation perspective, concentrating on remanufactured products. They came to the conclusion that we need to learn more about the importance of cyberphysical systems in the Internet of Things (IoT) to make smart remanufacturing possible.

To facilitate remanufacturing, it assumes that the operator dismantling the product has access to the information. Asif and Mohammad (2011) highlight the issue of lost or altered criteria and requirements specifications for a product during its life cycle, which can complicate disassembly planning. Service and product upgrades can have similar effects. Fang et al. (2016) anticipated a framework to dismantle plans related to remanufacturing. The framework includes identifying factors that affect the possibility of remanufacturing frames. The proposal then suggests tweaking the design process to facilitate easier remanufacturing of the product. Finally, the framework includes software support, which assesses the appropriateness of manufactured goods for remanufacturing. Investigators investigate the disassembly and necessary measures to accomplish this. It uses CAD models to support this process, providing information on materials, tolerances, and dimensions. The review of the literature leads to the conclusion that an array of challenges still surrounds the use recent technologies in remanufacturing, such as interoperability and advancement in technology issues, the effects of contemporary technologies on the environment over the course of their life cycle, and more. The works of Sun et al. (2023) and Yu and Sun (2024) shed light on these issues. Therefore, advance research is necessary to present ample decision support for more effective planning of the smart remanufacturing transition in the Industry 5.0 era.

India has a large population base that means there is a lot of room for growth in the remanufacturing sector. The assessment of the demand for remanufactured goods takes into account a steadily growing middle class, a market-driven economy, the affordability of nearly all raw materials locally, the availability of skilled labor at a fair wage, reasonably developed credit and financing facilities, and a stable economy. Indian customers place a high value on low ownership and maintenance expenses (Sinha, 2013). For the vast majority of Indian consumers, these are the most important factors when making a purchase.

3. Remanufacturing

3.1 Remanufacturing Processes

Remanufacturing reinstates end-of-life components to original conditions, serving as sustainable alternatives to new production. The most advanced process, remanufacturing, treats each component to accomplish the identical quality and condition as a newly manufactured product. Therefore, it differs from recycling or repair, which aims to dispose of materials or repair broken products to a functional condition (Wang et al., 2023).

Complex mechanical or electro-mechanical products are utilised for remanufacturing, as stated by Cetin and Zaccour (2023). Remanufacturing products offers both economic and environmental benefits. For a product to undergo remanufacturing, it must first undergo disassembly, possess a defect-free frame, and continue to exist after it ceases to function, rather than dissolving or disintegrating. Secondly, a cheaper remanufacturing process provides the opportunity to sell remanufactured product at a lesser cost, which may give an additional selling point.

Matsuto et al. (2013) state that remanufacturing involves seven steps, the first of which involves inspecting the acquired frames. Then sort out and discard any product whose condition is so poor that remanufacturing is not economically profitable. Select only those frames that are easily repairable or recyclable. Disassemble the products to the component level and clean them in the second step. Apply different forms of surface treatment, such as increasing abrasion resistance, if necessary. During the cleaning process, inspect and sort the parts based on their condition. Use those components which are in good condition without further treatment, while sort out components in poor condition from the lot. Remanufacture the remaining parts using techniques like turning, milling, and grinding. Next, reassemble the products using the remanufactured components. Brand new parts replace remanufactured components and units. Finally, test the product quality to ensure it meets the exact requirements of a newly manufactured product. Figure 1 depicts the entire process.

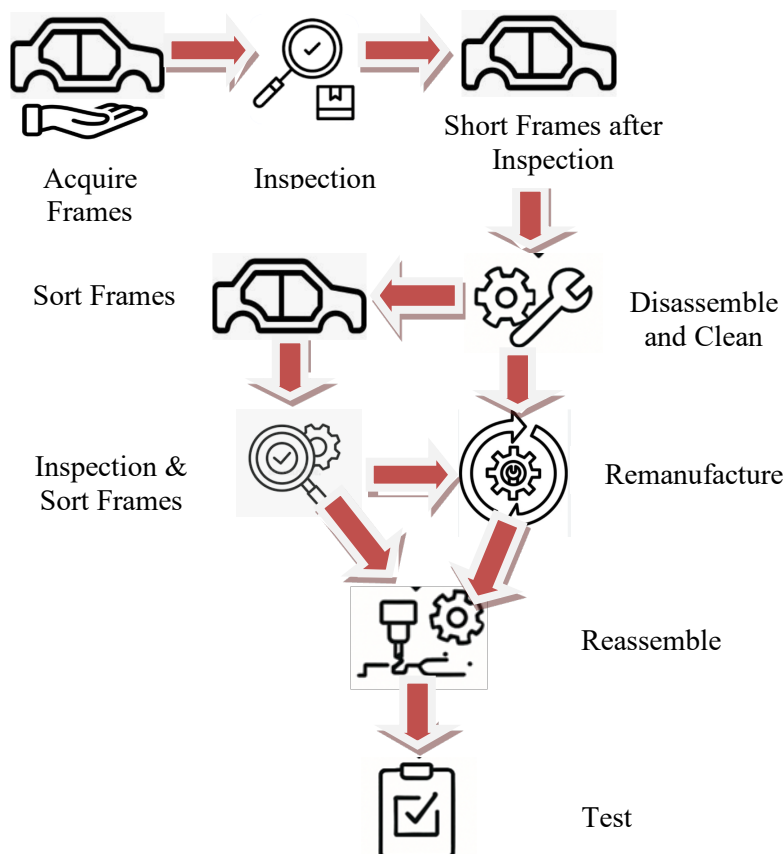


Figure 1: Processes used for acquiring and remanufacturing of frames

3.2 Remanufacturing for Environmental Sustainability

Remanufacturing is one of the most environmentally beneficial alternatives after EoL. According to Östlin (2008), this is supported by Greadel and Allenby (1996), Ryding et al. (1995), Jacobsson (2000), Steinhilper (1998), and Matsumoto and Ijomah (2013). According to Östlin (2008), where a product has a suitable characteristic for remanufacturing, it can be recycled very easily, and the energy consumption of the remanufacturing process is significantly lower than the actual manufacturing. Chen and Chang, 2012, found that remanufacturing consumes 40 to 60 percent less energy as compared to newly built products. According to Sundin (2004), relevant features mean that Lund (1996) summarized that a product meets the following conditions:

- i. The product has a body that is not consumed, confiscated, or has a malfunction.

- ii. Existing technology can restore the product to its original state.
- iii. Industrial production allows for the mass production of the product.
- iv. A refurbished product's value equates to that of the equivalent newly created one.
- v. Purchasing an outdated or defective product is inexpensive when weighed against the cost of the same refurbished goods.
- vi. A lack of quick technical advancement for a product category since mass-producing remanufactured goods that are constantly changing is difficult.

Remanufacturing offers several environmental benefits over new manufacturing and recycling, but extends the utilizing of elderly products can also have adverse effects. The findings of Nikseresht et al. (2023) and Modak et al. (2023) support this. Remanufacturing increases material reuse, which in turn reduces the need for newly recovered materials. It's significant to consider that end-of-life products might contain antiquated and polluting technology that, when used further, can have a greater negative impact on the environment than utilising and production of new products (Stlin 2008; Chaudhari et al., 2023). Sundin, 2004.

3.3 Regulatory Requirements

Legal requirements are an essential driver for resource competence in manufacturing components in automobile industry. Two directives that significantly contribute to reducing environmental impact are the End-of-Life Vehicles Directive (ELV) and the Waste Electrical and Electronic Equipment Directive (WEEE Directive), as noted by Alsheikha and Pakshad (2023) and Asif and Mohammad (2011). The ELV Directives are the directives within the EU that aim to make the managing of end-of-life vehicles more environmentally friendly. It consists of quantitative targets for re-use, remanufacturing, recycling, and requirements for reduced use of toxic substances in new production (Gensch et al., 2023). Today's cars comprise 85% recycled material as a result of these directives. The studies by Maury et al. (2023), Alsheikha and Pakshad (2023), Borthakur (2023), and Gerrard and Kandlikar (2007) demonstrate this. However, the WEEE Directives aim to create more sustainable production and consumption of electronic products. The primary goal is to counteract the accumulation of waste from products and enhance the use of end-of-life products through reuse and recycling. These directives have led to the electronics industry adopting a higher rate of remanufacturing and recycling compared to other sectors. Tortarolo (2023); Milosavljević et al. (2012).

As environmental regulations for the automobile industry become more stringent, the legal requirements for Original Equipment Manufacturers (OEMs) will intensify. The main reasons for this are society's growing awareness of environmental challenges and the depletion of natural resources. Abel & Groth (2023), Abedsoltan (2024). Furthermore, they believe that OEMs are experiencing a significant delay in adapting to new legal requirements. Companies that proactively address these issues, or those that can quickly adapt to new ones directly, will thus reap strategic benefits. Asif and Mohammad (2011). Automotive product remanufacturing accounts for two-thirds of all remanufacturing and is a 53-billion-dollar industry in the USA alone and an at least 100-billion-dollar sector worldwide. 10% of all cars and trucks require an engine replacement during their lives. Both OEMs and independent remanufacturers restore worn-out or damaged engines to original equipment performance criteria, as noted by Choudhary et al. (2011) and Israr et al. (2013). Indian OEMs and remanufacturers are far behind global performance standards. We discuss issues related to Indian remanufacturing in the next section.

3.4 Issues with Remanufacturing in India

The National Green Tribunal (NGT) has already banned diesel-powered cars more than 10 years and gasoline automobiles more than fifteen years in Delhi and the surrounding areas. This implies that the National Green Tribunal (NGT) will declare additional automobiles unfit for travel and dispose of them (Arora et al., 2021). Vehicle Scrapping Programs (VSP) would be established by the Ministry of Road Transport and Highways (MoRTH) under the proposed Motor Vehicles Registration and Functions of Vehicle Scrapping Facility Rules, 2021. This law would require the registration of private cars older than 20 and commercial vehicles older than 15 that fail the required fitness tests to be cancelled. It would go into effect gradually beginning in October 2021 (Arora et al., 2021).

The announcement of the new VSP has prompted both the federal and state governments in India to take action. Karnataka has estimated that, of the 2.8 million registered automobiles, 0.8 million will be scrapped if they are judged unfit. The next years will see the impact of the approach, which has already been embraced by other states such as Gujarat, Bihar, and Assam (Times of India, 2022). In a similar vein, the Uttar Pradesh government has decided to remove unsafe cars from circulation in an effort to reduce effluence in the National Capital Region (NCR) (India.com, 2022).

New car scrap and recycling facilities are creating additional capacity through infrastructure development to complement governmental efforts. The Indian National Capital Region already has one such facility, and plans are underway for more in other parts of the nation (Times of India, 2022a, Times of India, 2022).

Rapid changes in technology and product features have led to a rapid increase in remanufactured products. Remanufacturing is labor-intensive, so the cost of it is high. Adopting innovative technology can significantly reduce the remanufacturing cost. Guide and Daniel (2000) compiled seven main aspects, such as complicated remanufacturing:

1. There is uncertainty about the state and timing of returning used products. This arises because of the uncertainty in a product's service life.
2. A balance among the quantity and diversity of frames and the demand. Problems arise when the company needs a different product than the ones it has already acquired. This adds to the complexity by requiring the company to balance the risk of not meeting demand against growing inventories and the potential need for disinvestment, which could result in increased costs.
3. Later steps in the remanufacturing process, including the acquisition of new assembly components, need to coordinate with the disassembly and condition assessment at the component level. Disassembly can damage components, and significant variations in time consumption pose challenges in assessing lead times.
4. There is uncertainty about the material that can be recovered from the frames. The proportion of remanufactured components can vary between two identically received products.
5. Coordination is necessary for the return of used products. Reverse logistics introduces additional complexity, as it necessitates the procurement of frames from various locations, actors, and acquisition types. In this area, procuring end-of-life products can be linked to the problems surrounding aspects; Guide and Daniel (2000). Kurilova Palisaitiene et al.

- (2018) agree that one of the problems is long and uncertain lead times for remanufacturing. They also conclude that between 83% and 99% of the total lead time is comprised of time spent in stock (before, during, and after the process), waiting for spare parts, and awaiting information on available end-of-life products.
6. The degree to which the product demand aligns with the frame type is a crucial factor. When the customer demands that the remanufactured product meets the exact specifications of the submitted one, coordination between disassembly and reassembly is necessary to ensure the final product meets the required specifications.
 7. There is uncertainty regarding which processes are required to process the product and the time required to process it. Each given product requires a maximum number of processes to meet the desired specification. Reviewing all these processes is only necessary in the worst-case scenario, and in most cases, only one lower number is required. We calculate the probability of a given incoming product undergoing an inevitable process to facilitate planning. The remanufacturing process may experience bottlenecks due to varying frame conditions and diverse method needs over time, leading to increased complexity. Furthermore, the varying conditions may necessitate adapting the machine rigging between frames of the same type.
 8. New manufacturers only need to adapt their business to one product generation. For mass production, manufacturers can dedicate entire production lines to a single product. On the other hand, retailers need to adapt their operations accordingly in small batches with variations between product type and generation, which means that the production systems used by new manufacturers are not suitable for this business. Sundin (2004).
 9. Yeo et al. (2017) summarize the remanufacturing problem by categorizing four factors that enhance the likelihood of success. The product has a high value; its technological life is longer than the life of the product. We have access to efficient technologies for restoration and repair, which we can lease or deliver as services instead of goods.

4. Supply Chain for Reproduction

4.1 Problems in Remanufacturing in Supply Chain

For remanufacturing, the manufacturer needs to acquire frames. Two main terms describe the collection and logistics of these frames: reverse supply chain (RSC) and closed-loop supply chain (CLSC). RSC refers to when a product is disposed of by the customers and taken back by remanufacturers. The remanufacturers check the condition of the frames, and remanufacturers then distribute and market it through different channels other than an ordinary newly manufactured product. A closed-loop supply chain collects the old frames and remanufactures products one or more times. After remanufacturing, it distributes and markets the product in the same way as a newly manufactured item. In this case, either the OEM Company or a third-party player is a subcontractor to the OEM manufacturing company (Abdullah and Mohammad, 2011).

4.2 Acquisition of Frames

In the automotive industry, there are several types of relationships and agreements for acquiring frames. According to Sundin and Dunbäck (2013), below are the main procedures:

- ❖ **Direct Order:** Suppliers and customers of these frames are the same parties. A frame is let in, and the corresponding remanufactured product is desired back. This usually occurs

for complex products such as engines, and the customer/suppliers are often responsible for transporting the frame to the reseller.

- ❖ **Remanufacturing Contract:** Suppliers and customers of the frame are again the same parties, but unlike the direct order, the purchaser/supplier retains possession of the frame and the remanufactured product. Usually, such a contract spans over a more extended period, includes a larger quantity of frames, and often collaborates with an OEM company, where the OEM company is the customer/supplier.
- ❖ **Deposit-Based:** When buying a remanufactured product, the customer pays a deposit. When the customer returns the corresponding frame to the reseller, the customer receives the return of the original deposit. Common for cheaper parts replaced during product service. Sundin and Dunbäck (2013) exemplify this with the calliper in the case of vehicles.
- ❖ **Credit:** Since the customer and supplier of the frame are the same parties. At the submission of a frame, the supplier receives, for example, a discount on a remanufactured product.
- ❖ **Repurchase:** The reseller buys frames. Usually does not involve any additional commitment from either the manufacturer or the supplier. The supplier and customer of the frame are rarely the same parties. Östlin (2008) lists two more types of framework acquisitions: ownership of the product: The manufacturer/reseller owns the product, and the customer uses it through leasing or service provision. It provides high control over the product, and contracts often govern the relationship. In the second type of acquisition, there will be a form of partnership based on a remanufacturing service contract between a manufacturer and a customer.
- ❖ **Voluntary Handover:** The supplier supplies or donates frames to the reseller and can be, but does not have to be, a customer. These relationships are usually not applied individually but rather in combination with each other. Most resellers use repurchases, but they are rarely the primary way to acquire frames. Instead, it is used to develop more inaccessible frameworks or strategic reasons, such as protecting itself from competing manufacturers and receiving more attractive frames. Östlin (2008) discusses how most factors affect the choice of a type of relationship. The more important the product is to the customer, the greater the interest in close collaboration with the remanufacturer. Voluntary handover occurs in the same way, for example, for newspaper recycling, but can also be governed by laws and directives. Examples of this are WEEE, ELV, and RoHS directives. As the financial motives for the customer do not exist in this case, they contribute instead perceived environmental benefits as motivation (Östlin, 2008).

4.3 Reverse Logistics

Reverse logistics involves retrieving products from the end customer and reintegrating them into the product value chain. In many cases, companies withdraw used products from customers for remanufacturing or recycling. However, it may also involve the return of defective products or the filing of claims in cases where the customer has regretted their purchase. The purpose of reverse logistics is to advantage over the residual value that end-of-life products have in many cases or dispose of waste properly. The process includes planning, implementation, and cost control when disposing of products from the customers (Tibben-Lembke and Ronald, 1998).

The design of reverse logistics needs to consider the type of product being handled. The plan has two main strategies: the efficient, which aims for low logistics costs, and the responsive, which should mean fast logistics. Sundin (2004) refers to Blackburn, who suggests that the review should be centralized to reduce expenses for efficient reverse logistics. Conversely, in one responsive strategy, the evaluation should be decentralized to minimise logistics lag. This requires the opportunity at these decentralised locations to technically and cost-effectively carry out the assessment.

5. Industry 4.0 and Industry 5.0

A wide definition of Industry 4.0 is the digitalisation of the industrial sector. Since many expect a change in industrial output comparable to that of earlier industrial revolutions, they also call it the fourth industrial revolution. Cyber-physical systems (CPS), smart factories, and the Internet of Things (IoT) are the ideas that are linked to Industry 4.0 (Kumar et al., 2024; Kagermann et al., 2013). A comprehensive system that manages communication between computers and industrial equipment is called a CPS. Using feedback systems, they can communicate with each other in both directions, unlike before technology, where the communication took place only in one order from computers to machines, Wang et al. (2015). According to Kagermann et al. (2013), factories where CPS has been implemented and the entire production is connected are referred to as smart factories.

Industry 4.0 is about integrating technology both vertically and horizontally into organisations. An example is how to streamline the inventory of a warehouse using drones. An important aspect is also the possibility of decentralising production. A century ago, a single factory produced everything; thirty years ago, there was a significant increase in production outsourcing. Nowadays, the Internet of Things enables control over manufacturing at all levels. We constantly use this capability to control even third-party suppliers.

Industry 5.0 offers the most significant opportunity to significantly enhance remanufacturing through the establishment of creative, technologically advanced, and remanufacturing facilities in many industries (Neights, 2022). Intelligent and sustainable production systems are made possible by Industry 5.0. According to Nahavandi (2019) and Longo et al. (2020), Industry 4.0 focusses mainly on the role of automation and digitisation through connecting physical objects with the real world to enhance manufacturing productivity, intelligence, and flexibility, while Industry 5.0 is focused on the human-centric transformation in the era of automation.

Industry 5.0 emphasises human elements, which complements Industry 4.0's strong emphasis on technology. As an illustration, Industry 5.0 in the supply chain preserves the advantages of Industry 4.0, including mass customisation, while also integrating the benefit of cobots, which keeps people as crucial process participants. Another aspect of Industry 4.0 was data breaches brought on by piracy, which might be fixed using blockchain middleware.

5.1. The Internet of Things

The Internet of Things (IoT) is a collective term for connected products and the infrastructure for communication between such physical devices and the virtual world. More concretely, this means that data is accessible for reading and writing regardless of time and place. Any computer, human, and connected products can access and transfer it. Connected products include physical effects, such as industrial robots and goods, and virtual products, such as media or software. More advanced variants can also collect data using sensors and processes, Series (2012). In principle,

everyone believes that IoT is important for industry or business, including the energy sector and the automobile sector. Deficient competence is a problem, and companies do not know how to implement IoT solutions in their activities (Johansson and Göthe, 2017). The IoT trend is also proving to be strong worldwide, especially in major world economies such as the United States, China, and India (Mumtaz et al., 2017).

As previously mentioned the manufacturing industry is experiencing a paradigm shift due to the possibility of collecting data on the entire life cycles of products, from the design phase and manufacturing to their use by the end customer. At the same time, this poses a challenge in managing extensive data, so-called big data, which are collected. At present, there is often a lack of convergence between physical products and their virtual copies. In many cases, data saving is isolated and fragmented, rendering it unusable in practical applications. Tao et al. (2018), like Islands' problem, is collected and isolated instead of being analysed and integrated. Fei et al. (2017) propose islands as digital twins to address this information.

Rachakatla & Garrepalli (2024) found that the strategic importance of remanufacturing in the context of Industry 5.0 can be acquired by taking advantage of emerging technologies like artificial intelligence (AI), the Internet of Things (IoT), and the industrial Internet of Things (IIoT) in terms of increasing productivity and reducing waste (Kumar et al. 2024).

5.2 Digital Twins

Digital twins, or digital replicas of physical assets that function as their counterparts, are another advantage of Industry 5.0 (Zafar et al., 2024). A digital twin represents the design and function of products in an identical way to a physical product. There are several intended uses of digital twins. One important use is to replace expensive prototypes in product development, provide data on product conditions simultaneously as they are used, and transfer information between physical and virtual products, Larsson (2017). The goal of digital twins is to use their collected data as the foundation for statistics on the life cycles of identical components, thereby enabling the prediction of the service life of both individual components and composite products, Li et al. (2015).

A roadmap for the human-centric transition that emphasises mainly the social and environmental aspects of sustainable growth has been presented by the developing idea of Industry 5.0. Businesses are being forced to change their business strategies to become more sustainable by several of Industry 5.0's cutting-edge technologies (Rosa et al. 2020; Xu et al. 2021). To provide better and more comprehensive decision support and system management, this procedure necessitates the integration of linked smart components, real-time monitoring and control devices throughout the whole production network, and logistics systems. This could potentially lead to the creation of virtual products and the planning of virtual processes (Kritzinger et al. 2018). Industrial practitioners and academics are increasingly focusing on digital twins as one of the key accelerators of Industry 5.0. (Shift to digital twins) Artificial intelligence (AI) is another key element of Industry 5.0, since it holds the potential to develop a manufacturing process that is more intelligent and efficient.

A digital twin consists of three parts: a physical and a virtual product and data that connects them. Fei Tao et al. (2017) summarise the following three characteristics of digital twins:

1. The virtual copy represents the physical product in real time.

2. There is interaction and convergence between both historical data and real-time data; the physical and virtual worlds are physical data generated from different phases of the product life cycle.
3. Parallel comparisons between the virtual and physical worlds can continuously update virtual models.

A general method for developing a digital twin is that a simulated model based on the transmission of the current state of a physical component or based on the drawing of a planned feature is designed. The digital model is then compared with the physical part to verify its accuracy. The digital twin then requires data to be stored in the cloud so that its access should not be dependent on the physical product and that data should continually be updated in real-time. Common problems identified with digital twins are that the quality of collected data is not high enough and that there is no standardised way of collecting data. Slow standardisation also hinders the implementation of agile and adaptive systems in production facilities, Uhlemann et al. (2017). Figure 2 shows the structure of digits twins.

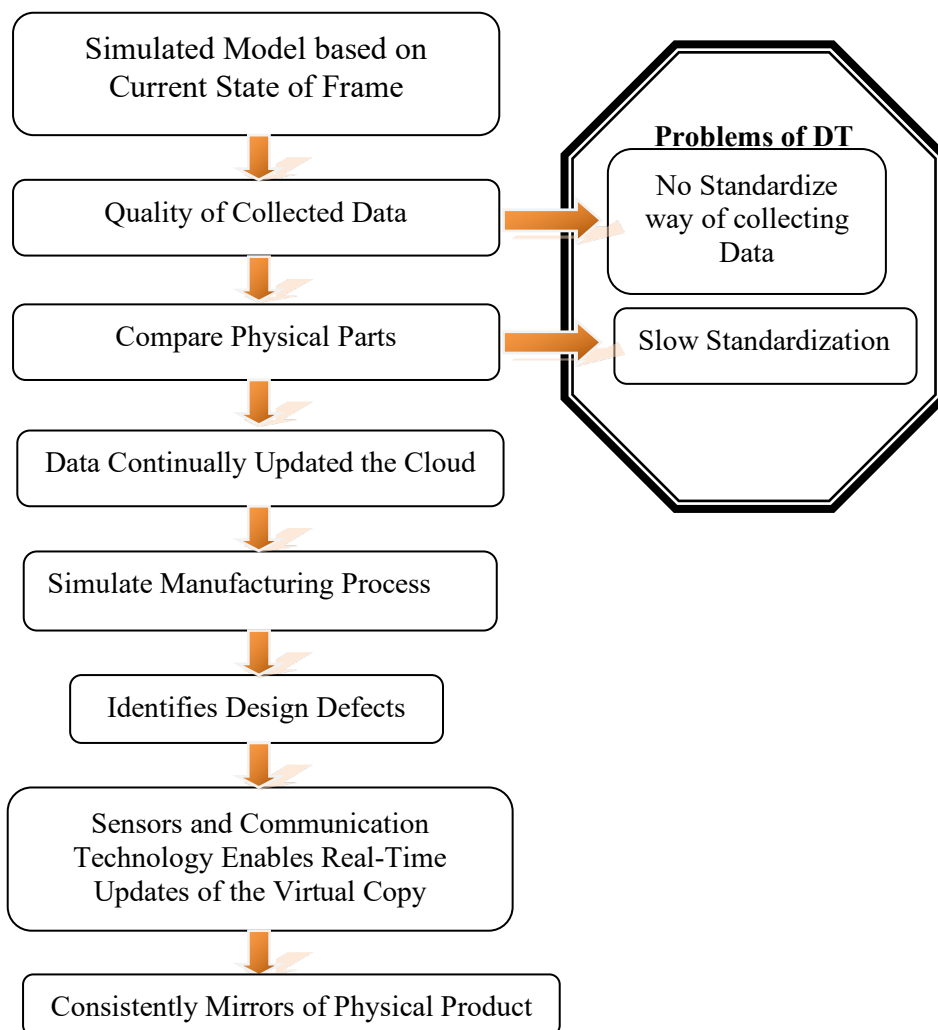


Figure 2: Digits twins and its functioning in Industry 5.0 environment

Digital twins in product development can simulate the manufacturing process to predict and test a product's performance before manufacturing. We can also use historical data on produced products to accurately predict the actual product's performance. This method not only identifies

design defects but also pinpoints their cause and proposes potential solutions. This method enhances the efficiency of maintenance and the utilisation of the product during maintenance and service. Advanced sensors and communication technology enable real-time updates of the virtual copy, ensuring it consistently mirrors the physical product.

5.3 Radio Frequency Identification

Radio Frequency Identification Technology (RFID) uses a tag for identification and tracking. For instance, RFID uses radio waves to identify and track products, people, and animals. FID allows storage of a more significant amount of data than barcodes and may also include sensors to measure temperature (Kim and Park, 2013). Vehicle manufacturing uses this as an example. If you request two identical vehicles, RFID can identify individual vehicles at different stages of production. All vehicles, for example, get the right equipment mounted and painted in the right colour. It is reliable and simple to update real-time information. To constantly update information, for example, at different stations in one manufacturing process, enables the creation of an information flow between other stations, increasing the system's flexibility (Finkenzeller et al., 2010).

Kim and Park (2013) conducted a study on the use of RFID to enhance remanufacturing operations, aiming to gather information about a product's lifetime. This information can then serve as a foundation for decision-making at the end of life (EoL). The stored information includes data related to manufacturing, inspection, service, repair, and disassembly. Zhou and Selwyn (2013) proposed a framework for product information and tracking through RFID. This model aims to learn based on the collection of information from products previously returned, disassembled, and remanufactured to recommend an action plan for a given product. Utilizing machine learning and RFID can reduce the costs and lead time for the diagnosis. Additionally, we use RFID and machine learning to enhance the quality of remanufactured components.

Ilgın and Gupta (2013) and Ilgın and Gupta (2011) have proposed a framework to streamline remanufacturing based on products having embedded sensors. They refer to these products as Sensors Embedded Products (SEPs), as they incorporate built-in sensors that can monitor external influences such as temperature, pressure, and vibration. We suggest RFID tags as the most suitable option when combined with various sensor types, as they can store both static data and dynamic data related to driving processes, working temperature, vibration, and shocks. They consider that the remaining life of a given component is an appropriate way to quantify its quality. The Remanufacturing-to-Order System (RTO) framework scans products using RFID readers upon arrival at the remanufacturing plant to gather component information. The system then utilizes remaining life information to classify a component as functional or non-functional and to determine if a product is missing any components. The system will then use this to determine whether to remanufacture a product as a whole or to supply individual parts (Ondemir and Gupta, 2012).

All vehicles today use inexpensive RFID tags to track them through production. One of the challenges today is positioning the tag on the product without causing obstructions. The RFID tags have a limitation in that they cannot withstand elevated temperatures, such as being placed in one oven during manufacture. Painting can also be problematic for RFID tags.

RFID-based production monitoring (Guo, et al. 2015), digital twin-based cyber-physical fusion, etc., are some examples of applications that remanufacturers can use to improve the intelligence

of their manufacturing process and ultimately achieve lower manufacturing costs. Remanufacturing suggests that intelligent manufacturing can decrease costs by reducing ambiguity in remanufacturing choices. Using intelligent technologies like sensors and RFID tags integrated into the product, the producer can intuitively monitor vital components throughout a product's economic life and provide the gathered lifecycle information.

According to Alqahtani et al. (2019) and Fang et al. (2016), manufacturers may use this comprehensive information to assess the state and remaining life of end-of-life items. This helps them avoid the need for expensive initial disassembly and inspection procedures, which lowers the cost of remanufactured goods. The manufacturer often holds these smart technologies privately, but the approved remanufacturer may have access to them to reduce ambiguity in remanufacturing decisions (Zhang et al., 2024). IoT solutions facilitate more effective collaboration and information sharing across CE stakeholders, which enhances decision-making. The Internet of Things encompasses RFID technologies and wireless sensor networks. Original Equipment Manufacturers (OEMs) can effectively manage returned or damaged products in the supply chain by enhancing recommerce activities and maximising the total recovered value through the use of RFID and IoT sensors (de-Souza et al., 2021; Geissdoerfer et al., 2018).

6. Problems and Suggested Solutions

The problems identified in remanufacturing and suggested solutions are based on the technology for Industry 5.0.

6.1 Problems with Remanufacturing

The biggest problem stems from uncertainty and lack of information, which are caused by numerous unknown factors in daily operations. These factors include uncertainty about the availability and condition of end-of-life products, as well as the timing of their submission. Product type affects the wearing type, the difference in the use environment, and how much a product has been used before it is considered obsolete. In addition, there is a need for remanufacturing companies to determine how well demand matches supply in terms of number and type of frames. This necessitates the acquisition of frames that can meet demand at a reasonable cost. A short life cycle is a contributing factor, as it creates a delay between the launch of a product and the emergence of wear and defects that prompt remanufacturing. Suppose this time delay is significant and the technical development is fast. In that scenario, there is a risk that the frames and the underlying technology become obsolete when the price of available end-of-life products increases significantly. The wear on the edges makes the price of remanufacturing profitable. Products with warranty defects receive an exception to acquire a frame earlier in the product life cycle. This is, however, more about cost-effectively handling exceptional cases than about a circular economic model.

A reseller's operational business must continuously address issues such as disassembly of frames and uncertainty about which components and materials are recoverable from the frameworks. In both scenarios, the state of a frame significantly influences the design handling process. The extent of defects, damage, and wear directly dictates the necessary processes to restore the frame to its original state. The difficulty in deciding in advance what procedures are required makes it difficult to plan to remanufacture. Simultaneously, executing unnecessary processes poses a risk. This leads to inefficient remanufacturing with longer lead times and higher costs.

Defects, damage, and wear and tear pose another challenge when it comes to product disassembly.

Insufficient knowledge about this risk could lead to further damage to the components during disassembly, as corrosion, deformation damage, and damaged key grips could necessitate different disassembly procedures for identical frames. Proponents have proposed DFD and DfRem as aids to promote design solutions that facilitate disassembly. However, this does not resolve the uncertainty surrounding recovered parts and unexpected discoveries that impact the manufacturer's planning. The history of the product type, the use of the individual unit, and wear and tear are more relevant for assessing what can be recovered and how to do it. We will return to opportunities to obtain this information later in the discussion.

6.2 Implementation of Industry 5.0 in Remanufacturing

The issue of uncertainty poses the greatest challenge for remanufacturing companies. At the same time, Industry 5.0 and the digitalization of industrial processes present significant opportunities for increased information collection and analysis. This section will explore whether the implementation of Industry 5.0 can effectively address the identified challenges in remanufacturing.

Recently improved capacity and lower costs for industrial digitization processes create enormous opportunities. The lack of skills and imagination for integrating these solutions into the business are the biggest limitations for companies. The literature study examines two closely interconnected technologies: digital twins and RFID. Sensors are needed to read how manufacturing processes and other external factors affect the manufactured product and help establish a digital twin. Maintaining a current virtual copy of the physical device requires tracking the product in real time.

In addition, data must be transferred in both directions between the virtual model and physical product to verify accuracy. RFID tags meet these requirements. A problem with the construction of digital twins and information tracking with RFID tags is that this should happen during the product's manufacture. In the case of digital twins, it is in principle impossible with today's technology to establish an exact virtual copy of a physical product. Similarly, if a product receives a different RFID tag at a later stage of its life cycle than it did at the beginning; there is a risk that valuable data may not be registered, resulting in an incomplete product. This means that creating digital twins and RFID tags from the outset is a prerequisite for the future.

As mentioned in the literature study, the combination of machine learning and RFID technology can aid in diagnosing end-of-life products. This can also present opportunities to address the issue of uncertainty when submitting end-of-life products to resellers. The combination of digital twins, RFID, and machine learning means that technology exists to predict longevity based on the actual use of each product. If there is a close relationship between users and resellers, the latter can access this information. Better production planning and the creation of opportunities to meet reseller demand can benefit from its use. The collected information about each individual product can also be used to streamline disassembly and remanufacturing processes because the availability of data on each component facilitates determining which procedures are necessary. Furthermore, the disassembly can be visualized before it is performed on the physical product, and thus, damage during disassembly to a higher degree is avoided.

The last identified problem with remanufacturing is the remanufacturing of remanufactured products to market. One challenge lies in how remanufacturers can ensure the product's condition and quality. There are also opportunities for implementing technology in this context. Industry

5.0 encounters the challenge of information requirements. Regarding the remanufacturers, once they restore a product, they can simulate its use and predict its remaining service life, thereby ensuring the product's quality with greater certainty. The next section will address cannibalism, a problem that this approach does not solve.

Another issue that we have yet to find a solution for is the short life cycle of Industry 5.0 products. In situations where technological advancements are occurring at a rapid pace, we do not believe that digitization can resolve the associated issues for manufacturers.

6.3 The market for Remanufactured Products

Remanufacturing has a significant impact on companies, their products, and the opportunities to maintain or strengthen their competitiveness in the automotive industry. We need to discuss technology, customer adaptation, and brand profiling to complement the discussion and effectively address the question at hand. It necessitates numerous compromises and adjustments to the factors that currently define competitiveness.

Customers' views on and willingness to buy a remanufactured product are crucial for a vehicle manufacturer to remanufacture or not. The literature study highlights several environmental benefits of remanufacturing, which incentivize environmentally conscious consumers to choose a remanufactured product. Price differences could be another incentive to buy. The marketing of newly manufactured and remanufactured products separately can result in unintended cannibalism, where the remanufactured products overtake the sales of the newly manufactured ones, particularly when they must provide the same quality and functionality as the newly manufactured ones.

Service provision, where customers pay for a single transport service instead of a vehicle, is one approach to this problem. This approach allows a vehicle pool to consist entirely of remanufactured vehicles or a combination of new and remanufactured vehicles. However, further investigation is necessary to understand the impact of both service provision and the risk of cannibalism on the products marketed through the same channels.

Vehicle type also impacts the customer's propensity to buy. When selling vehicles for professional use, rational motives regarding function and cost can weigh heavier than in consumer purchases, for example, more exclusive passenger cars. In the first scenario, we hypothesize that the rational justification of a remanufactured product's benefits, such as lower cost or less environmental impact, gives it a greater weight than the subjective perception of the product. In the second case, where the customer is likely to be more subjective, remanufacturing can be both advantageous and a disadvantage, depending on how relevant the target group is to possible environmental benefits versus remanufactured components in their vehicle. However, this reasoning only identifies a few factors that can influence a customer's decision to purchase a remanufactured product, necessitating further research to more accurately map buying behaviours.

A significant variation among frameworks and demand contributes to the increased complexity of products for resellers. Customization contributes to such increased variety, while it is a way to meet customers' varying needs and a selling point. This conflicting relationship could be a reason to opt out of remanufacturing if customization weighs heavier. Standardization and modularization allow for the joint use of a larger proportion of components, units, and modules across various products, while replacing the more specialized types. By changing the

specification during remanufacturing, we can reduce the consequences of customer adaptation. However, this will affect the possible scope of the transformation. Thus, it is not a solution but a compromise.

A primary incentive for companies to engage in remanufacturing is that this type of business is profitable or contributes positively to the company through a strengthened brand. Remanufacturing should not focus on by-products with rapid technological development, as it poses a challenge to mass-produce constantly evolving remanufactured products. In this context, rapid technical development should be determined by the product's service life. Most vehicles of a particular product type have a lifespan of ten years, for example, a time lag for a high supply of frames of the same order of magnitude. Has the technical development been significant during the same period? Can the original product be considered outdated? The effects of this will depend on which areas have been developed, but from a sustainability perspective, improvements in safety and environmental impact will do more to extend the use of the older product. A factor that further affects this is that laws and regulations are constantly changing. Older products are at risk of not living up to strict environmental requirements. Remanufacturing can update the product to a later specification, making it a reasonable solution to this problem. To implement this, it is assumed that the product is designed to allow the update to be practically feasible in terms of time, cost, and technical. Simultaneously, a significant update could lead to a decrease in the benefits of remanufacturing as the amount of material recovered from the frames decreases. This conflicting relationship is another aspect that must be considered when deciding whether to remanufacture. Designing the product in a way that allows evaluation of the treated parts is also necessary to better understand the impact.

7. Conclusion

The current study aims to investigate whether Industry 5.0 can establish new incentives for remanufacturing in the Indian automotive industry, and if so, how. The primary drivers of remanufacturing are economic and environmental incentives. The article identified several challenges for the remanufacturer that impact economic and environmental factors, with the most significant being the uncertainty in accessing the frames and their condition. This turns out to be a problem that digital twins and RFID can help solve in a variety of ways as part of Industry 4.0. We also conclude that Industry 5.0 does not bring about a paradigm shift in remanufacturing but rather facilitates incremental improvements. For companies at present considering remanufacturing, this may be a sufficient incentive.

8. Improvement and Future Scope

The work primarily draws from literature studies on two distinct subject areas and aims to integrate them through reasoning about remanufacturing and potential technical solutions. The present work on Industry 5.0 for use in remanufacturing is immature, and its practical application is at an early stage. This complicates the choice of orientation for the work. We could have illustrated more significant benefits by focusing on technologies other than digital twins and RFID. Based on the conclusion, it appears that Industry 4.0 presents opportunities for improvement in remanufacturing. Thus, this application should be considered by companies currently operating remanufacturing, and it is included in the decision documents of companies that are considering remanufacturing. To better understand and value remanufacturing with the support of Industry 5.0, its effects are quantified. Thus, it is suggested that case studies should be

done on activities such as conduct remanufacturing with the help of technology in Industry 4.0 to investigate the value of increased availability of reliable information at an earlier stage. Then the practical application of remanufacturing and Industry 5.0 in combination is low-can pilot projects, and small-scale use is an appropriate first focus area.

Furthermore, this work has not sufficiently studied the challenges associated with Industry 5.0 implementation to draw conclusions about the cost of introducing and establishing the technology, nor the need for cooperation among actors throughout the product's value chain.

Funding: Not Applicable

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