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An Investigating on optimizing Sustainable Remanufacturing in Developing Countries: A Novel Application of Lean Six Sigma

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Abstract

Remanufacturing, a process that restores used products to like-new condition with a matching warranty, offers significant environmental, economic, and social benefits. However, traditional remanufacturing faces persistent challenges, including variability, high logistics cost, lack of standardization, and low consumer trust. These issues are particularly severe in developing countries where lack of infrastructure and policy further hinder remanufacturing's potential. The aim of this research is to investigate the optimization of remanufacturing through the integration and application of Lean Six Sigma tool and techniques, with a focus on addressing the challenges and enhancing sustainability in developing countries particularly Nigeria.

A systematic literature review spanning across 20 years from 2004 to 2024 was conducted, Web of Science and Scopus databases were utilized using the keywords; Remanufacturing, Lean Six Sigma, Sustainability, Challenges, Developing countries and Nigeria. Based on the systematic literature review, this research uncovers lack of studies on Lean Six Sigma (LSS) and remanufacturing, leaving a critical gap in the literature. To address the gap, this study seeks to investigate the application of Lean Six Sigma technique to remanufacturing. The combination of Lean's focus on waste elimination with Six Sigma's emphasis on reducing process variability, the two offer a systematic approach to tackle inefficiencies, reduce waste and defects, and foster customer trust.

The findings from the literature suggest that integrating LSS tools such as DMAIC, Kaizen, and Value Stream Mapping into remanufacturing can significantly mitigate core variability, streamline reverse logistics, enhance process standardization and customer perception.

The novel contribution of this paper is demonstrating the potentials of Lean Six Sigma as a transformative tool for a sustainable remanufacturing particularly in developing countries.

Keywords: Remanufacturing, Challenges, Lean, Six Sigma, Sustainability, Developing countries, Nigeria

1 Introduction

The global transition from linear production to circular economic has highlighted the importance of sustainable manufacturing practices. Among these, remanufacturing has emerged as a critical strategy, offering substantial environmental, economic, and social benefits. It involves the restoration of used products to like-new condition with warranty to match. (Ijomah et al., 2004). Remanufacturing processes typically require less energy and resources compared to original manufacturing procedures. Remanufactured products can save significant amounts of energy and materials, leading to a reduction in net pollutants emission like Green House Gases (Zhang et al., 2023). Remanufacturing can save costs in half, materials in third, and about 40% energy compared to traditional manufacturing (Zhang et al., 2019). Numerous social, economic, and environmental advantages can result from well-executed remanufacturing. Among these advantages, from an economic perspective, are reductions in raw material and recycle costs (Kalverkamp and Raabe, 2018). Energy savings, reduced emissions, less air pollution, and reduced raw material usage are some of the specific environmental benefits that have been highlighted by various authors (Deng, 2020). Since local labour is needed to reprocess returned products, social benefits are largely associated with the creation of jobs. Local job opportunities arise when the need for skilled personnel rises in response to greater recognition and utilisation of remanufacturing services (Matsumoto et al., 2017). Potential savings from remanufacturing can vary from 20% to 80% depending on the industry, product, and procedure (Ijomah and Childez, 2007).

Remanufacturing has gained considerable global attention because of its benefits (Liu et al., 2019). Recognizing these benefits, many original equipment manufacturers (OEMs) have incorporated remanufacturing into their operations to achieve sustainability and maintain a competitive advantage (van Loon and Van Wassenhove, 2018). Remanufacturing is widely carried out in industries such as automotive, aerospace, electronics, and turbines, with companies like Sony, Hewlett-Packard (HP), Apple, Caterpillar, and Emerson leading the way (Copani and Behnam, 2020). While the concept is well-established in developed countries, it remains in its infancy in developing regions like Africa (Nigeria) (Ohiomah and Aigbavboa). Developed nations have broadly adopted remanufacturing, yielding substantial benefits. For example, Europe's remanufacturing industry generated €30 billion in revenue and employed 190,000 people in 2015. Moreover, the global automotive parts remanufacturing market was projected to grow by 6.6% by 2025 (Vafadarnikjoo et al., 2018).

However, despite its potential, the adoption and advancement of remanufacturing remain constrained by challenges such as variability in the process, logistics, supply chain and lack of consumer trust. These challenges are particularly pronounced in developing countries, where regulatory gaps, infrastructure deficits, and limited consumer awareness further impede progress (Yusop et al., 2016, Karuppiah et al., 2023, Chaowanapong et al., 2018).

Table 1 challenges of remanufacturing

Category	Challenges
Operational Challenges	Variability in process Variability in product condition High operational costs Technological and skill deficits
Supply Chain Challenges	Supply chain inefficiencies Inconsistent core availability Core collection and reverse logistics inefficiencies
Quality Assurance Challenges	Ensuring consistent quality. Ambiguity in standards.
Environmental Challenges	Environmental concerns in waste management.

	Unregulated waste handling.
Market and Consumer Challenges	Consumer perceptions and market acceptance. Fragmentation of practices.
Regulatory and Institutional Challenges	Regulatory and institutional gaps. Lack of standardized practices.

In light of the increasing emphasis on operational excellence and sustainability in today's world, it is crucial to thoroughly explore the capabilities of modern tools and techniques. This review aims to systematically gather evidence from prior studies to present a clearer understanding of the support and opportunities. To this effect our research led us to examine the applicability and benefits of Lean Six Sigma tools and techniques. The study delves in to investigate the optimization remanufacturing through Lean Six Sigma.

Lean Six Sigma (LSS) is a business improvement strategy that combines the strengths of Lean and Six Sigma techniques, a concept that has been widely endorsed by industries and scholars for many decades. Lean tools, such as 5S, Just-in-Time, Value Stream Mapping, Kanban, and Poka-Yoke, are rooted in practical experience and focus on enhancing productivity with a clear goal for improvement (Antony et al., 2016, Snee, 2010, Hoerl and Gardner, 2010). While, Six Sigma employs data-driven statistical methods, including Statistical Process Control (SPC) (Hoerl and Gardner, 2010), with the primary aim of reducing variations and defects to boost process performance (Snee, 2010, Antony et al., 2012). The structured DMAIC (Define, Measure, Analyse, Improve, Control) framework is central to Six Sigma, guiding the process toward achieving these objectives. Research frequently highlights the benefits of integrating Lean and Six Sigma, including (1) cost reduction; (2) fewer errors/defects; (3) enhanced product/service quality; (4) elimination of non-value-added steps; (5) shorter cycle times; (6) greater customer satisfaction; and (7) improved employee morale (Albliwi et al., 2015, Rathilall and Singh, 2018, Antony et al., 2019).

2 Methodology

This section outlines the key steps taken to conduct the Systematic Literature Review (SLR). The Research Question (RQ) guiding this study is:

RQ1. What are the current trends in remanufacturing and what challenges do remanufacturing companies face in achieving operational efficiency and sustainability?

The study's data is derived from selected articles available on *Scopus*, a database provided by the scientific publisher *Elsevier*. Article selection was based on a predefined query, with inclusion and exclusion criteria applied to ensure the most relevant results for the research. These criteria include:

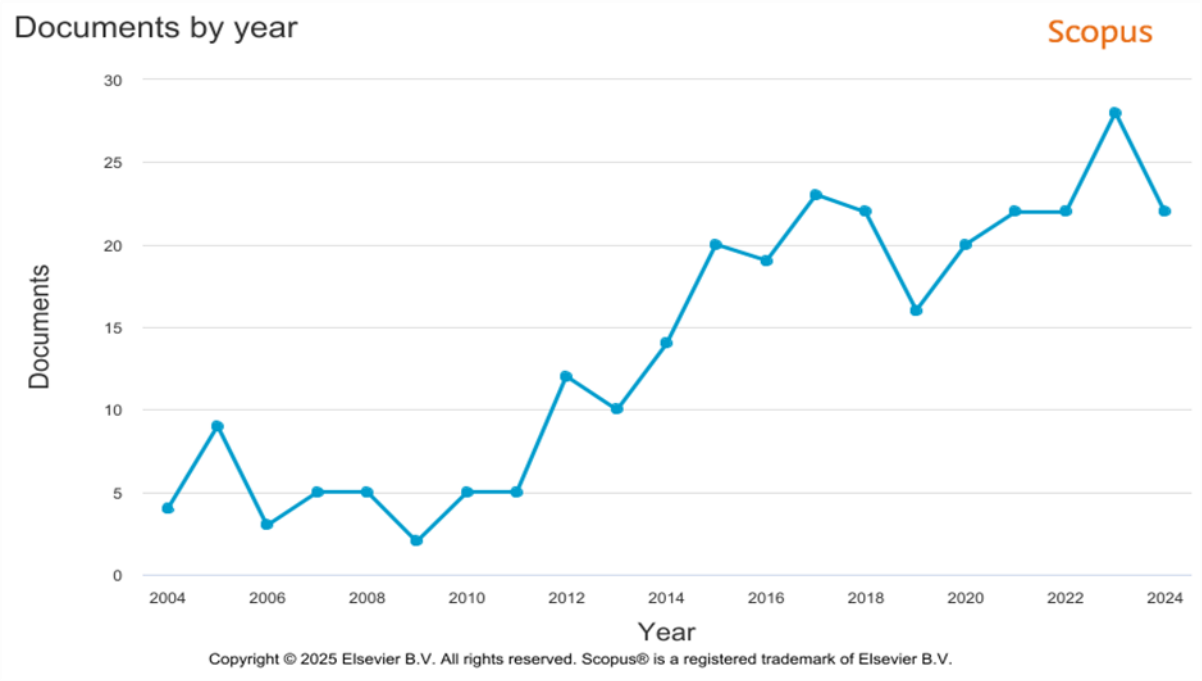
- Timeframe: The search was restricted to the past 20 years, as this period marks the advancement and emergence of different trends in remanufacturing, while its role in the circular economy and sustainability concepts grows stronger.
- Journal Selection: Only journals focused on remanufacturing, lean, six sigma, continues improvement, and sustainability were considered, aligning with the study's specific objectives.
- Language: Only English-language research papers were included, given the language's significance in academic discourse within this field.

- **Keywords:** The selection process prioritized terms related to Lean Six Sigma, Sustainability, sustainable development and Developing countries, particularly in their relation to remanufacturing.

The first phase of our study consists of the creation of a query, that is a string containing Boolean operators and appropriate commands, which allowed to identify a sufficiently large number of articles and results regarding our topic.

The string used in this research paper is as follows: "TITLE-ABS (("Remanufacturing challenges") OR (Remanufacturing AND lean AND six sigma) OR ("Remanufacturing AND Continues improvement") OR (lean "manufacturing") OR ("sustainability remanufacturing") OR (optimisation) OR ("sustainable development") OR ("Developing countries") OR (Nigeria) AND AUTHKEY (quality) OR (") OR (process) OR ("circular economy")) AND AUTHKEY (remanufacturing)". The search string was run in the early 2023.

Figure 1 Number of papers published per year

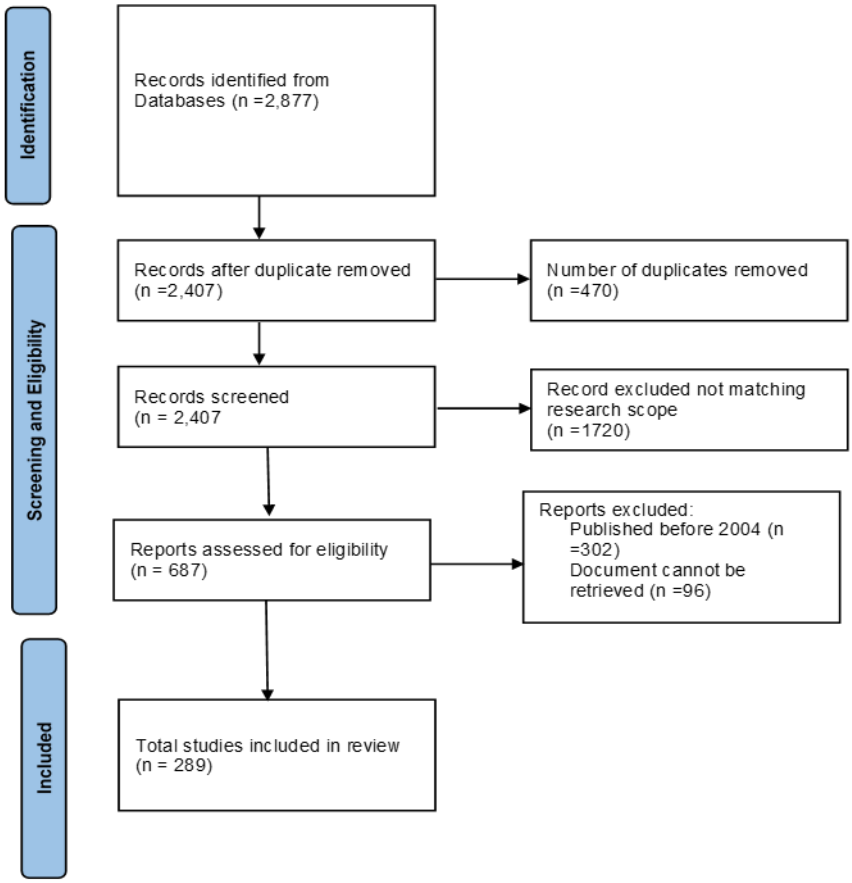


The PRISMA methodology was applied to reduce research bias and ensure reliability and replicability. This approach enables readers to evaluate the review's strengths and weaknesses while demonstrating its quality (Page et al., 2021). PRISMA's four-phase flow diagram facilitates the replication of the review process. Keywords were refined to yield broader and more relevant results. Endnote Reference management software was utilized to organize the collected data and remove duplicates.

The PRISMA methodology involves four key phases: identification, screening, eligibility, and final inclusion of articles (Sarkis-Onofre et al., 2021). In the identification phase, all relevant records from the databases within the research area are collected and compiled into a library. The screening phase focuses on filtering out duplicates from the collected records. During the eligibility phase, the remaining records are carefully read, examined and categorized, with the goal of excluding those that are less relevant to the research topic. Selection criteria play a critical role in narrowing the scope of the

research and focusing on the core topic. For instance, in this context, records that did not relate to the field, as well as other unrelated areas, were deemed out of scope and were excluded. The selected records were chosen for their relevance to the topic. To illustrate the connections between the included references and emphasize the focus on these topics, a map was created using VOS viewer. The map generates a network of bibliographic sources based on the co-occurrence of keywords or tags, meaning the number of times two different bibliographic sources share the same keywords. The map is generated using data exported from a bibliography database file in Excel CSV format. Once the map is created, various visualization features can be used to explore it. In this case, the network visualization is chosen. Keywords are displayed as labelled circles by default, with the size of the label and circle determined by the item's weight the larger the label and circle, the higher the item's weight. Connections between items are represented by lines (Van Eck and Waltman, 2011). After applying the PRISMA method and visualizing the co-occurrence map using VOS Viewer, the findings are analyzed to identify key patterns in the literature related to remanufacturing and Lean Six Sigma.

Figure 2 Prisma flow diagram



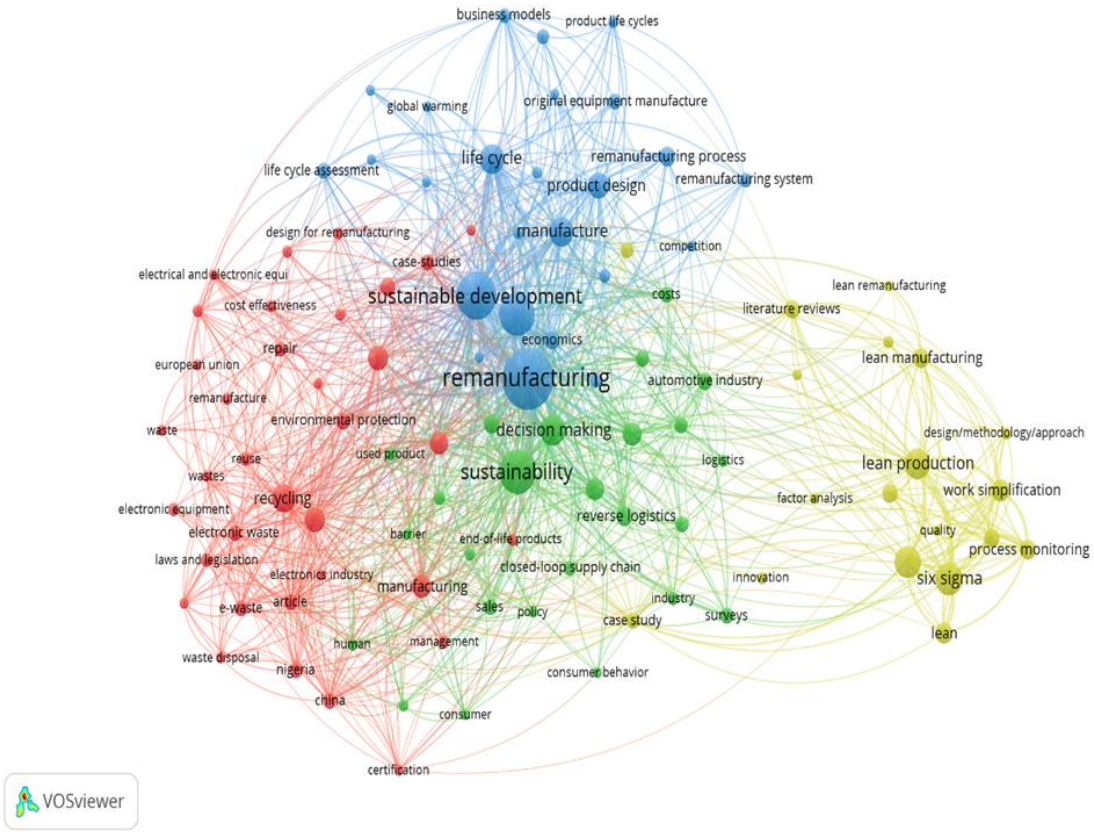
The figure illustrates the process of identifying, screening, determining eligibility, and selecting articles from the literature, emphasizing the significant research interest in this topic. It highlights the extensive background available and the effective alignment of our chosen keywords.

2.1 Findings

The systematic review identified 2,877 papers. After removing duplicates, the number of records decreased to 2,470. Following the exclusion of papers outside the scope, the total was further reduced to 687. After obtaining a substantial number of eligible records, an additional round of filtering is required. The screening process was guided by an extensive reading and analysis of papers related to Remanufacturing, sustainability sustainable development, developing countries, continues improvement and Lean Six Sigma. The literature indicates that emphasis on Remanufacturing gained traction primarily with the advent of circular economy and sustainability, suggesting that the scope of the research should be confined to studies from 2004 onward. Following further reading and screening the of selection, 289 records were ultimately included in the review. Out of the 289 references analysed in our research, the most frequently mentioned keywords were remanufacturing, sustainability, circular economy, sustainable development, challenges, barriers and developing countries. Notably, studies addressing Remanufacturing, sustainability and sustainable development seems to be more dominant.

Additionally, the map generated by VOS Viewer (Fig. 4) highlights the attention these topics have received (Van Eck and Waltman, 2014).

Figure 3 Keyword co-occurrence

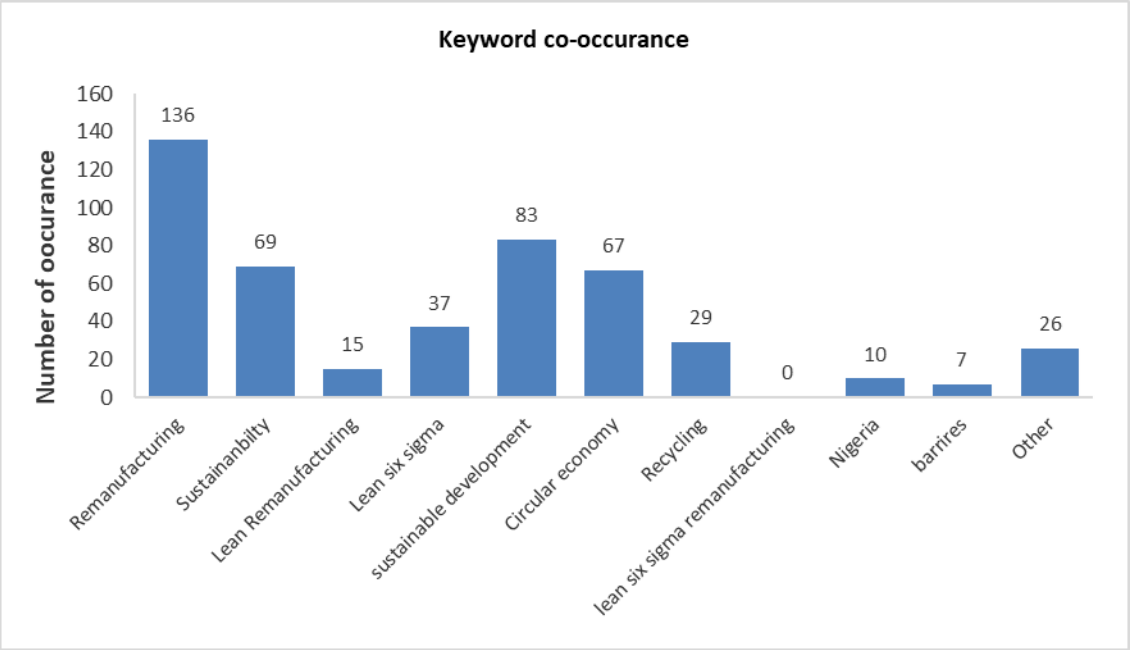


2.2 Gap

Based on the literature review, a new gap is found which is the weak relationship between remanufacturing Lean and Six Sigma. With very few literatures as the lack of co-occurrence of these topics in various references indicated, a need within the research field to explore this area is evident from the bibliography. Therefore, research in areas such as the application, integration and adoption of lean six sigma in remanufacturing are open to be explored.

Bearing in mind that Remanufacturing involves restoring a product to functional state by disassembling, cleaning, inspecting, repairing, reassembling and testing it. The final product is assured to match the quality and performance and warranty of a newly manufactured product (Ijomah and Chiodo, 2010). However, achieving the desired results in remanufacturing comes with significant challenges, including high variability in process and product, high of costs logistics and supply chain, and lack of customer trust in remanufactured products.

Figure 4 Number of papers published by subject area



The application of lean methods in industrial remanufacturing operations (Pawlik et al., 2022), Examining lean production in the remanufacturing industry from organisational and managerial perspectives (Priyono and Idris, 2018). Remanufacturing challenges and possible lean improvements (Kurilova-Palisaitiene et al., 2018). These studies were conducted to highlighting the advantages of adopting lean practices in remanufacturing, by directly linking remanufacturing with lean manufacturing, the model's significance was emphasized, sparking further research interest in the field. Thus, this study has identified a need to study other possible improvements. Which is the concept of Lean Six Sigma in remanufacturing, which to the best of our knowledge so far, it has not been fully and formally been documented into the academic literature (Kurilova-Palisaitiene et al., 2018, Priyono, 2017).

3 Summary

The literature review highlights the growing global recognition of remanufacturing as a key strategy for sustainable manufacturing. It provides substantial environmental and economic benefits, such as reduced energy consumption, minimized waste, and lower production costs. However, it is also affected by a lot of challenges which hinder its advancement, development and wide range adoption.

A systematic literature review spanning 20 years (2004–2024) was conducted using PRISMA methodology, with data sourced from Scopus. The search strategy involved a Boolean query incorporating keywords such as "remanufacturing," "Lean Six Sigma," "sustainability," "developing countries," and "Nigeria." The review process involved identification, screening, eligibility assessment,

and final inclusion of articles, reducing an initial pool of 2,877 papers to 289 highly relevant studies. The selected records were analyzed using VOS Viewer to map keyword co-occurrences and identify research trends.

A critical gap identified in the literature is the limited research on the integration of Lean Six Sigma into remanufacturing. While studies have explored Lean practices in remanufacturing, no one examine the combined effect of Lean and Six Sigma on improving remanufacturing efficiency.

Additionally, existing research identifies several challenges in remanufacturing, including supply chain inefficiencies, high operational costs, and consumer skepticism. Studies suggest that overcoming these barriers requires a structured approach, such as the implementation of Lean Six Sigma, to streamline processes and improve product reliability. However, empirical studies applying LSS in remanufacturing, particularly in resource-constrained settings, remain scarce, presenting an opportunity for further research.

4 Discussion

Lean Six Sigma provides a structured and data-driven approach to addressing inefficiencies in remanufacturing. Lean principles, focusing on waste elimination and process streamlining, align well with the core objectives of remanufacturing, which aims to maximize resource utilization and minimize waste. Similarly, Six Sigma's emphasis on reducing variability and enhancing process control is critical for ensuring consistency and quality in remanufactured products. The integration of tools such as DMAIC (Define, Measure, Analyze, Improve, Control), Kaizen, and Value Stream Mapping can significantly mitigate core variability, enhance process standardization, and foster customer confidence.

Despite its potential, the literature review reveals a significant gap in research exploring the direct application of LSS to remanufacturing, especially in developing countries. Prior studies have examined Lean methodologies in remanufacturing and its benefits, but the combined application both lean and six sigma in remanufacturing remains unexplored. This study, therefore, contributes to the existing literature by proposing LSS as a viable solution for optimizing remanufacturing processes, improving efficiency, reducing costs, and enhancing sustainability in resource-constrained settings.

5 Conclusion

This study underscores the critical need for optimizing remanufacturing practices and highlights Lean Six Sigma as a promising approach to overcoming existing challenges. By integrating Lean principles with Six Sigma methodologies, remanufacturing industries can enhance efficiency, reduce waste, and improve the quality of remanufactured products, ultimately fostering sustainability, greater consumer trust and market acceptance.

The systematic literature review, guided by PRISMA methodology, confirms a significant gap in research concerning the application of LSS in remanufacturing, indicating the need for further empirical investigations.

In conclusion, remanufacturing holds immense potential as a sustainable manufacturing practice, but its success hinges on the adoption of structured continues improvement methodologies such as LSS. Policymakers, industry leaders, and academia must collaborate to promote awareness, build expertise, and create an enabling environment for sustainable remanufacturing. By addressing the challenges identified in this study, companies can unlock the full potential of remanufacturing, contributing to both economic growth and environmental sustainability.

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