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Brief Survey: Mixed Research – Report Paper

Green Manufacturing - Sustainable Practices for Eco-Friendly and Efficient Production Process : A Study

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Abstract: Green manufacturing is a cutting-edge method of production that aims to minimize environmental damage through material recycling, waste reduction, and more effective use of natural resources. It incorporates a "repair, reuse, refurbish, rebuild, and recycle" (5R) method, which extends product lifespan and optimizes resource utilization, going beyond the conventional "reduce, reuse, recycle" strategy. Reducing harmful emissions and reaching "zero waste" are the two main objectives of green production. The beneficial effects of green manufacturing on the standard of the final product as well as the welfare of the workforce and the community are noteworthy. Sustainability and environmental responsibility are emphasized. Even if the Internet of Things (IoT) is becoming more and more popular, green manufacturing is still essential to building sustainable enterprises. Now that it is integrated with the Six Sigma approach, it is an effective instrument for raising operational effectiveness and lowering faults across a range of processes. It has been applied to a case study about the production of rubber weather strips in this instance. Reject rates were significant losses, thus the goal was to reduce them. The rejection rate was greatly decreased by applying Six Sigma's DMAIC technique, which resulted in cost savings and improved product quality. The study shows how Six Sigma can improve manufacturing processes' performance and lower their rejection rates. In conclusion, green manufacturing emphasizes resource efficiency and waste reduction as a sustainable and environmentally conscious approach to production. It enhances the Six Sigma approach in attaining improved product quality and operational excellence.
Keywords: Green Manufacturing, Six sigma, Environment, IoT , Energy.

1. Introduction

A progressive method of production, green manufacturing focuses a major emphasis on reducing its environmental impact. It expands upon the conventional "reduce, reuse, recycle" approach to provide the more all-encompassing 5R framework: "repair, reuse, refurbish, rebuild, and recycle." This strategy attempts to maximize resource utilization and increase product longevity with the ultimate goal of reaching the lofty "zero waste" mark [1]. Reducing harmful environmental effects through waste reduction, recycling, effective use of natural resources, and other relevant methods is one of the main goals of green manufacturing. It also includes actions taken to reduce harmful emissions while the product is being manufactured. Furthermore, green manufacturing places a higher priority on the health of the local community and its workforce [2], demonstrating a larger commitment to sustainability. The significance of green manufacturing has not diminished, even though the Internet of Things (IoT) has attracted a lot of attention lately. IoT might provide more ways for businesses to improve their environmental impact, but green production is still a keystone in the implementation of sustainable business practices. This paper explores the field of green manufacturing and highlights its importance for creating a sustainable environment [3]. It examines several tactical instruments and specialized techniques related to green manufacturing, emphasizing their vital uses in advancing environmental sustainability. Beyond the confines of conventional production techniques, green manufacturing is a complex idea. It stands for an all-encompassing production strategy that supports sustainability and environmental objectives.

This strategy is based on the notion of aiming for product durability while also reducing waste and resource usage. The transition of green manufacturing from the well-known "3R" strategy (reduce, reuse, recycle) to the more comprehensive "5R" approach is one notable feature [4]. The goal of this phase is to maximize product longevity and resource efficiency through repair, reuse, refurbishment, rebuilding, and recycling [5]. The goal of

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"zero waste" production is the pinnacle of green manufacturing. A key component of green manufacturing is the dedication to minimize environmental damage using diverse approaches [6]. This entails reducing the amount of trash produced, actively recycling products, and implementing more effective methods of using natural resources. It also places a strong emphasis on lowering dangerous pollutants during the manufacturing process, which helps to provide safer and cleaner working conditions.

The DMAIC methodology of Six Sigma is a potent technique with many useful applications in the field of green manufacturing [7]. Define, Measure, Analyze, Improve, and Control, or DMAIC for short, offers an organized framework for process optimization and improvement. Within the framework of green manufacturing, DMAIC functions as a methodical and data-driven approach to optimize resource usage, cut waste, and improve environmental sustainability all the while preserving or enhancing product quality. With the use of this methodology, manufacturers can pinpoint the parts of their operations that contribute to environmental inefficiencies, create data-driven remedies, and put long-term enhancements into place. Businesses can integrate their environmental goals with operational excellence and reduce their environmental impact, improve resource utilization, and increase overall sustainability by incorporating Six Sigma's DMAIC methodology into green manufacturing practices.

2. Literature Survey

According to Yang Shen et al. [2023] intelligent manufacturing reduces pollutants and obsolete equipment in enterprises while providing opportunities for green technology innovation at a reasonable cost. Here uses resource optimisation to analyse data from 269 Chinese cities and concludes that intelligent manufacturing considerably reduces environmental pollution and PM2.5 concentrations [8]. This impact is mediated by green tech innovation, which has nonlinear benefits. This effect is especially noticeable in areas with higher environmental quality, highlighting the critical role that digitalized IM plays in encouraging pollution management and environmentally friendly business development.

Green manufacturing creatively reduces environmental impact through waste reduction, recycling, and resource efficiency, according to research by Abid Haleem et al. [2023]. It takes a 5R approach, building on the 3R technique to improve resource efficiency and product lifetime. It's crucial for sustainability and reflects a dedication to ecological responsibility [8], coupled with new trends like IoT. In the field of technology and computing in particular, green manufacturing is essential to improving environmental sustainability [9]. Reducing waste and power consumption through energy-efficient design and responsible product lifecycle management is a possible avenue towards a future that is more environmentally friendly.

Jing Gao et al. [2023] looked into the challenges that traditional development and externalities present to green technological innovation in manufacturing [10]. A system dynamics model that combines conceptual and behavioural logic is used to analyse green tech innovation under environmental regulation in order to address this. Subsystems break down the advantages of willingness, behaviour, and invention. Reducing command-and-control, improving market-based incentives, and encouraging public participation in environmental rules are ways that the manufacturing sector might overcome obstacles. According to the findings, adopting green technology can improve manufacturing's economic, social, and environmental outcomes [11].

According to Binoy Debnath et al. [2023] investigation, Bangladesh's garment industry underutilizes green supply chain management (GSCM), which combines environmental considerations with traditional supply chain management. In order to identify and rank the most important success elements for GSCM, and used a multi-criteria approach, focusing on buyer demand, financial gains, and laws that support sustainable implementation and SDG fulfilment. In order to help achieve the SDGs, it lists 16 essential success elements for GSCM in the apparel business. Industry specificity and method selection are limitations that point to potential directions for future study [12].

The adoption of Six Sigma DMAIC technique to lower the rubber weather strip rejection rate at XYZ Ltd. in Gurugram, India, was covered by Ankesh Mittal et al. [2023]. This strategy reduced rejection rates from 5.5% to 3.08%, saving a substantial amount of money and raising the sigma level from 3.9 to 4.45 in just three months. demonstrates how Six Sigma DMAIC can be used to improve rubber weather strip manufacturing's operational efficiency and quality. Motorola launched the Six Sigma programme in the 1980s with the goal of eliminating manufacturing variances and having zero faults. It explains how XYZ Ltd. reduced the rubber weather strip rejection rate from 5.5% to 3.08% by using the Six Sigma DMAIC approach, which led to considerable cost savings and increased quality [13].

According to research by Dharmendra Hariyani et al. [2023], the rise of Integrated Sustainable Green Lean Six Sigma Agile Manufacturing Systems (ISGLSAMS) in India is fuelled by changing consumer

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preferences and biodiversity loss. highlights market fragmentation, customer needs, and competitiveness as major influencing factors in this analysis of the effects of SGLSAMS drivers on market, operational, and sustainable performance. Significant growth in Integrated Sustainable Green Lean Six Sigma Agile Manufacturing Systems (ISGLSAMS) in India is driven by the loss of biodiversity and changing consumer needs. Peer pressure and laws are not as powerful as the drivers of the market, supply chain, finance, and organisations [14].

According to David Bendig et al. [2023], since the 1990s, green manufacturing (GM) has become more significant in the fight against climate change. exposes a recent rise in research by describing 6,000 publications from three databases, yielding 189 papers. In addition to identifying new research areas in GM performance, people, and interdisciplinary aspects, it provides an organised framework for generalised GM research with thirty subcategories [15]. These three key contributions—tracking the development of GM research, offering a thorough framework, and recommending future research directions are noteworthy. For businesses, striking a balance between economic and environmental objectives is still difficult.

Teresa B. A. Ribeiro et al. [2022] studied that 158 questionnaire responses to examine the application of lean and green practises in Portuguese manufacturing enterprises. Increased Lean-Green adoption highlights the advantages of integrating these practises and enhances operational, environmental, and financial performance. evaluated the application of green and lean practises in Portuguese manufacturing companies and the effects these practises had on financial, environmental, and operational performance. Businesses were divided into three categories based on the 158 responses to an online survey: Low, Medium, and High implementers [16]. The results demonstrate a favourable correlation between execution and outcomes, providing recommendations for businesses looking to improve their Lean-Green programmes.

According to research by Katarzyna Antosz et al. [2022], production businesses want to increase the efficacy and efficiency of their maintenance procedures in order to avert unanticipated failures and the resulting expenses. investigates the use of qualitative and quantitative research in conjunction with the Six Sigma approach to analyse maintenance efficiency. Using the Six Sigma DMAIC methodology, he sought to increase machine availability in the production process by finding factors affecting failure frequency and duration [17]. Statistical analysis identifies important elements and prospective changes for higher production machine availability. Influential aspects were identified using statistical analysis, which resulted in suggested modifications. Benefits were noted in the case study, however not all were adopted. However, the suitability of this strategy may change for various businesses. The bibliometric review of sustainability in manufacturing and production was examined by M. Caterino et al. [2022], who examined 563 pertinent works from SCOPUS spanning a 22-year period (2000–2021). reveals an emphasis on broad sustainable and green themes, with room for further research in fields such as Industry 4.0, human factors, resilience, flexibility, and agility; additionally, a bibliometric analysis on clean, green, and sustainable manufacturing was carried out, underscoring the growing importance of these concepts in both industry and academia [18]. The unproven effects of Industry 4.0 and the absence of clear sustainability goals in the face of shifting paradigms, however, continue to be problems. Research in the underrepresented area of integrating sustainability, human factors, adaptability, and resilience is still needed.

The low adoption of green innovations in manufacturing was examined by Mohsin Shahzada et al. [2022] through an analysis of the GIA model based on UTAUT. SEM and ANN analysis of a survey of Pakistani industries highlight the significance of green facilitating conditions for sustainable development (SD) by revealing important determinants of green behavioural intention (GBI) and the moderating influence of organisational size [19].

Ankur Goyal et al. [2022] looked into how pressure from stakeholders, new rules, environmental challenges, and the rise of global industry influence the adoption of eco-friendly technologies. Funding is a problem for small and medium-sized enterprises in emerging nations. proposes the "Green quality circle" idea, which emphasises the need for management support and training while enabling shop floor workers to improve manufacturing operations ecologically. This proposal is supported by case studies. Productivity is essential to competitiveness and economic progress [20]. Quality circles provide financial rewards for labour intensive, systematic problem-solving. introduces "Green quality circles" to highlight the financial advantages of eco-friendly practises and engage employees at the grassroots level in environmental sustainability at a little cost.

According to Elvis Korku Avenyo et al. [2022], industrialization spurs growth but increases CO2 emissions, which poses a challenge to sustainable development [21]. investigates the relationship between industrial emissions and technology intensity, finding that industries with medium- and high-technology had lower emissions, especially in emerging nations. And emphasise the significance of environmentally friendly industrialization routes, promoting technology advancements for improved international integration and less environmental effect. Understanding the relationship between technology, industrialization,

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and CO2 emissions becomes essential given the urgency of sustainable production, particularly for developing nations striving for progress and societal well-being [22].

According to Nan Jiang et al. [2022] a fractional-order replication dynamic equation to model the learning and modification of strategies in manufacturing enterprises' green and low-carbon (GLC) innovation evolution. Examines the uniqueness, local and global stability, and evolutionary stable strategy (ESS). The discretized model, ESS, and parameter sensitivity are analyzed, revealing insights such as the potential for stable GLC technology adoption with profitable incomes [23]. Additionally, and highlights the impact of fractional order on convergence and system stability. And underscores the continual adaptive process in enterprise strategy formation, emphasizing the significance of accumulated experience for decision-makers.

Izaskun Alvarez-Meaza et al.'s [2021] examined how the necessity to reduce energy use and greenhouse gas emissions motivates factory schedules to adopt green practises [24]. A bibliometric examination of 420 papers published between 2006 and 2020 indicates that energy-efficient algorithms, computational development, and transportation are the main areas of concentration for this expanding field of study, which is largely headed by China.

Manufacturers use lean and green practises to pursue efficiency, profitability, and environmental responsibility, according to Fatima Ezahra Touriki et al. [2021]. This was upset by COVID-19, which highlighted the need for lean, smart, green, and resilient paradigms. furthermore examines current advancements, identifies knowledge gaps, and suggests research frameworks for direction. examines the manufacturing sector's SGRL paradigms from 2011 to 2021, noting any gaps and future opportunities. Integration investigation, strong frameworks, integrated models, difficulties analysis, trade-offs between being lean and green robust, global promotion, technological contributions, renewable resources, resilience methods, and linkages in SGRLM are among the areas that require further research. Research gaps and paradigm integration are outlined in two proposed frameworks [25].

By creating four stages, Compliance-Driven, Eco-Opportunist, Green Innovator, and Green Manufacturing Evangelist Ganesh Prasad Shukla et al. [2021] looked into the inadequacies in green manufacturing maturity models. It presents the idea of "green manufacturing orientation" and uses a case study to support the model by showing how the firm gradually moved towards greater degrees of maturity but saw uneven growth in its GM orientation. In order to overcome the shortcomings in previous studies, he presents a revolutionary Maturity Stage Model of Green Manufacturing Orientation (MSM-GMO). It makes use of ten management dimensions and establishes four maturity levels based on environmental proactivity drivers. A case study illustrates how organizations grow unevenly and at their own speed, highlighting the model's applicability to manufacturing management.

According to research by Xueqi Zhai et al. [2020], fostering the green transformation of manufacturing is essential for both economic expansion and environmental preservation. According to a 2017 study using data from 500 Chinese enterprises, government policy, technology, human capital, and funding are all beneficial to the green transformation. Environmental regulation acts as a moderator, increasing the impact of government power and technology while decreasing the impact of funding. Through these characteristics, it shapes transformation as a mechanism of change. Policies with specific environmental regulations are advised in order to encourage green economic growth. demonstrates the importance of these elements in the green transition and the demand for creative solutions in the green economy.

Using the answers of 36 senior managers, Mahak deep Singh et al. [2020] looked into the critical success criteria for implementing green manufacturing in Indian Small and Medium-Sized Enterprises (SMEs). Statistical tests validate the dependability of the data, enabling additional examination of the eight parameters found in this pilot study.and evaluates the variables affecting the adoption of green manufacturing in Indian SMEs. Based on data from 36 SMEs, the following factors are critical to business performance: customer attributes, green supply chain management, adoption of new technologies, and dedication from top management. These factors are validated by reliability tests, and the distribution of the data looks normal.

According to Huiling Liu et al.'s [2020] research, manufacturing faces two challenges from sustainable development. incorporates enterprise theory, strategic innovation, and sustainable development theory to help manufacturing companies implement green strategies and handle risks, opportunities, value chains, environmental competitiveness, organizational design, and performance evaluation. integrates corporate strategy, green theory, and sustainable development with an emphasis on production companies. In order to improve green manufacturing theory and strategic innovation for Chinese manufacturing enterprises, it examines opportunities and risks, environmental competitiveness, green value chains, organizational design, and performance evaluation. This allows the transition from high-energy and high-pollution models to workable green strategies.

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According to research by Kasinathan Karmugilana et al. [2020], the demand for green products is driven by resource depletion and growing population. Reliable data is available on social media, especially Twitter. focuses on several facets of green products and covers green management, manufacturing, logistics, and marketing. examines debates about green products on Twitter at different points of time. People are generally unbiased and well-informed about these phases, with the exception of green manufacturing, which is not well-trusted. Brand trust is demonstrated by the low negativity associated with green marketing and management. There is potential for more research in this area as the scant data indicates that people are still interested in green trends.

Amine Belhadi et al. [2020] Investigated how Big Data Analytics (BDA) interacts with Green Manufacturing (GM) and Lean Six Sigma (LSS) and how that interaction affects Environmental Performance (EP). and underline their important functions, suggest directions for future study, with a focus on longitudinal studies across various industries and cross-national comparisons. Comprehending these associations can assist professionals and scholars in proficiently handling ecological issues and improving production efficiency.

According to Shuai Mao et al. [2019], integrating new-generation technology in process safety in smart manufacturing addresses challenges in green manufacturing. In the process industry, AI helps with knowledge acquisition, reasoning, data fusion, dynamic risk assessment, and decision-making. emphasizes the importance and difficulties of green manufacturing. It examines artificial intelligence (AI) technologies, including deep learning, Bayesian networks, and knowledge graphs, and offers solutions for the technological difficulties and advancements in process safety.

Researchers Y. Nukman et al. [2017] looked into how sustainability embraces green manufacturing. presents the Green Manufacturing Index (GMI), a tool for assessing environmental and economic efficacy. In order to provide sustainable manufacturing standards that can be applied to any industry's operations, GMI classifies machining practises. putting up a proposal for an automated solution that would interact with current manufacturing systems, compute GMIs on a monthly or annual basis, and update product cycle records. The flexible GMI technique improves manufacturing processes' sustainability and is appropriate for a variety of industries, including those with outdated equipment.

According to G Dilip Maruthi et al. [2015], the energy consumption and emissions of industrialization contribute to environmental degradation in the current competitive scenario. Green manufacturing is a solution that reduces pollution, waste, and resource use. stressing the value of energy-saving and lean manufacturing techniques, with an emphasis on lowering costs and boosting competitiveness. Putting ISO 14000 standards into practice encourages environmental responsibility even more while increasing productivity and competitiveness in the global market. Sustainable practices and waste reduction must be given top priority in the manufacturing sectors.

3. Result and Discussion

Together, the ideas and tactics presented in these declarations form a thorough plan for improving corporate sustainability and efficiency. First off, the process of finding overlaps and classifying characteristics emphasizes how important meticulous waste management is. This methodical approach to waste reduction lowers a business's ecological impact while simultaneously minimizing operating expenses and upholding environmental responsibility. In addition, using renewable energy sources in procurement, manufacturing, and supply chain procedures shows a strong commitment to sustainable and eco-friendly practices. This reduces carbon emissions while also appealing to investors and customers who are becoming more and more interested in eco-friendly companies.

The focus on practices like extended material usage, recycling, and reducing internal waste generation, in addition to waste management and the use of renewable energy, demonstrates a larger commitment to the circular economy concept. This strategy encourages sustainability while fitting in with social expectations for ethical resource management by promoting resource efficiency and waste reduction. In this context, sustainable manufacturing practices are essential since they lower carbon emissions at different points during the production process. This not only shows a dedication to environmental responsibility but may also improve a business's standing and draw in investors and customers that value sustainability.

Furthermore, there is evidence that using green manufacturing practices can enhance both brand reputation and business outcomes. These strategies support operational effectiveness and financial success by drawing in environmentally conscientious clients and optimizing supplier chains. The ability to incorporate digital ecosystems into the supply chain and adjust to new technologies is critical in a market that is always changing. This adaptability makes it possible to make data-driven decisions, improve customer interaction, and optimize operations—all of which are critical for being competitive and relevant in a changing corporate environment. Finally, it becomes clear that proactive supply chain management is essential to maintaining the sustainability and resilience

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of a company. Business continuity and long-term success are improved by foreseeing and successfully handling significant changes and obstacles. All things considered, these integrated strategies promote efficiency, sustainability, and competitiveness while satisfying the needs of the modern market and society for ethical, progressive businesses

4. Conclusion

The expanding importance of green manufacturing and its complex effects on business, the environment, and society are discussed by the researchers. A potent tactic for tackling today's urgent issues, such as resource efficiency, economic competitiveness, and environmental sustainability, is green manufacturing. It not only lowers emissions, waste, and pollutants but also encourages innovation and the uptake of environmentally beneficial technologies. In order to adapt to the changing needs of society, green manufacturing is always changing, ranging from automated and sophisticated analytics to integrated sustainable systems. Since it harmonises corporate operations with environmental responsibility,

it is especially important in meeting the global imperative of sustainability. Green manufacturing provides the path for a more efficient and ecologically responsible future by encouraging green technology, lean and smart paradigms, and the adoption of eco-friendly innovations. The study presented here highlights the growing significance of green manufacturing in this era of resource depletion and climate change, demonstrating that it is not only a choice but also a requirement for a more sustainable and prosperous future.

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