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Developing integrated framework for Sustainable Manufacturing and Agile Manufacturing for Indian Manufacturing Industries: A Comparative Analysis Approach

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Abstract - The study has been conducted to provide an integrated framework for Sustainable Manufacturing (SM) and Agile Manufacturing (AM) that incorporates a number of important ideas and approaches in order to make their implementation easier and more successful. By comparing and contrasting fifteen frameworks that has been published in scholarly publications, the framework offered a synergic benefit by combining SM principles with agile practices. The framework seeks to balance environmental, economic, and social goals while enhancing adaptability to market dynamics. There are seven main components to the suggested framework for sustainable and agile manufacturing. Foundational support for implementing the proposed framework comes from Top management's support, Energy waste and economic issues, Environmental related issues, Organizational culture related issues, Customer oriented issue, Suppliers related issue, and Human related issues are the seven pillars that will hold up the proposed framework of sustainable and agile manufacturing. This integrated approach not only ensures competitiveness in a dynamic global environment but also positions manufacturing as a catalyst for sustainable development, advancing industry and society toward a more sustainable future.

Keywords: Sustainable Manufacturing, Agile Manufacturing, Framework, Manufacturing Industry.

INTRODUCTION

In the course of time, the constant growth of manufacturing entities all over the globe has resulted in an improvement in the level of life; nevertheless, it has also resulted in a negative impact on the environment [1]. Manufacturing operations are responsible for the production of a significant number of pollutants, which have a direct influence on both the environment and society [2]. These pollutants contaminate both the air and the water. Manufacturing companies are under to pressure from both governmental and non-governmental groups to reduce the negative impacts that they have on the environment and to improve the safety of their workers [3]. According to [17] the implementation of sustainability concepts into industrial processes may be leveraged to reduce the adverse effects on the environment and to strengthen the economic stability of businesses. Numerous firms have taken on the challenge of restructuring their current manufacturing processes in order to bring them into alignment with sustainable practices [4]. This is in response to the viewpoints that have been presented.

Hence, the assessment of sustainability in a manufacturing process and the direction of strategies towards sustainable development are of utmost significance. The assessment of sustainability in the manufacturing process aids in the identification and acknowledgment of prospects for improvement.

The application of sustainability principles in the manufacturing realm serves as a means to diminish the adverse effects on the environment and enhance the economic steadiness of the entity [5]. By employing the sustainable manufacturing (SM) approach, multiple processes are implemented to curtail the negative ecological repercussions, preserve precious resources and energy, and ensure economic viability, safety, and well-being for the organization's personnel, consumers, and society at large [6].

Lean manufacturing, a widely embraced concept in the realm of sustainable manufacturing, encompasses the Triple Bottom Line (TBL) approach [7]. The Triple Bottom Line (TBL) represents the trinity of economic, social, and environmental considerations and stands as a revered framework within the realm of sustainability. Diverse industries have effectively adopted this TBL concept to enhance the performance of sustainable manufacturing [8]. Sustainable manufacturing entails the innovative and conscientious implementation of techniques and processes aimed at metamorphosing raw materials into refined goods, all while significantly diminishing the consumption of energy, the release of harmful greenhouse gases, the generation of waste, and the utilization of non-renewable or hazardous substances.

The phenomenon of globalization has exacerbated competition among manufacturers and has compelled consumers to anticipate increasingly innovative products that boast superior quality while being offered at reduced costs [9]. The situation forces the industrial sector to abandon traditional paradigms like mass production and craft

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manufacturing and has sparked a pressing need to adopt an updated paradigm called "Agile manufacturing" in order to satisfy customers' unmet needs [10]. The intensely competitive business landscape incentivizes manufacturers to implement agile manufacturing; however, they encounter considerable obstacles, including inefficiencies at the top management level, protracted decision-making processes, insufficient technological capabilities, inadequate utilization of information systems within organizations, as well as challenges related to industrial composition and society, and subpar association managing with suppliers [11]. The agile capabilities of an organization significantly influence the development of new products [12].

[13] delineated three salient characteristics, specifically “Agility,” “Adaptability,” and “Alignment,” which empower the industrialized sector to swiftly react to fears within the business landscape and to engage in global competition. The acquisition of agility has increasingly been recognized as paramount for manufacturing entities and has been substantiated as a profit-generating factor in the contemporary business milieu. Agile manufacturing has garnered renewed vigor and objective in enhancing consumer satisfaction and organizational execution, particularly to the heightened focus on SM [14]. The technological innovations witnessed over the past decade have exerted a substantial influence on the manufacturing industry worldwide [15].

2. LITERATURE REVIEW

Before embarking on a literature review, one must give careful thought to the most pertinent articles. Equally crucial is the assurance of the thoroughness and excellence of the gathered articles. Consequently, this current investigation employed a systematic methodology for the literature review, in accordance with the guidance provided by [16], [17], and [18]. Authors have collected data from 16 peer reviewed journals to prepare the framework on SM and AM.

Author [19] presented an alternative approach to comprehensive frameworks for sustainable manufacturing. They conducted a review of existing definitions of sustainable manufacturing, which represented the commonly accepted understanding of the concept. Based on this review, they developed a framework composed of three layers. The first layer, known as the perspective layer, encompasses the most crucial aspects to consider when engaging in sustainable manufacturing practices. The second layer comprises application domains, such as product, process, and technology, which serve as the focal points for actions. Finally, the third layer classifies approaches according to their objectives, specifically whether they aim to enhance or decrease certain aspects.

Many innovative frameworks [20] put forth by scholars in their quest for sustainability have primarily concentrated on the economic and environmental dimensions of organizations; however, they have regrettably overlooked the pivotal contribution of supply chain and logistics in attaining holistic sustainability.

Organizations often face difficulties in attaining sustainability as a result of a lack of awareness regarding societal factors [21]. The implementation of sustainable human resource management and the incorporation of health and safety practices within organizations serve as crucial steps towards achieving sustainability.

A handful of investigations [22-23] have crafted a unique blueprint to empower and propel the integration of sustainability, focusing solely on the domains of Technology, Organization, and Environment (TOE). However, the credibility of these aforementioned constructs remains unverified, thereby casting doubt on their potential applicability.

The manufacturing sector has recognized agile manufacturing as an essential approach to attaining sustainability in a changing business environment and improving responsiveness to varying customer needs [24]. [25] Discussed the use of advanced production flow analysis to identify virtual groups, thus providing the manufacturing industry with effective layouts that improve their manufacturing efficiency. [26] Performed an empirical study on the use of artificial neural networks to identify, differentiate, and measure the influence of agility attributes on competitive capabilities, specifically speed, cost, quality, innovation, flexibility, and proactivity of the organization. [28] Introduced a conceptual framework that connects organizational learning culture to the quality of customer relationships through agility, and examined how the service industry adjusts to the continually changing business landscape. They assessed the effect of organizational learning culture on customer relationship quality, facilitated by agility. [29] Carried out a performance evaluation of an Indian auto component manufacturer using a range of key performance indicators for agile manufacturing, utilizing fuzzy analytic hierarchy process and performance value analysis.

[29] Examined the effects of agile manufacturing on business performance and operational performance aspects, which encompass cost, quality, delivery, and flexibility in the manufacturing industry of Jordan. Their results indicated that agile manufacturing has a favorable and substantial impact on both business performance and operational performance in relation to the dimensions assessed.

3. RESEARCH METHODOLOGY

Manufacturing is a value-added process that transforms raw materials into finished goods through the effective integration of human effort and machines to meet customer expectations [30]. When carried out sustainably, it not only enhances economic performance but also reduces environmental impact and contributes to societal well-being. The global manufacturing sector is increasingly adopting innovative approaches such as agility and sustainability to minimize waste and ensure long-term competitiveness, benefiting all stakeholders [31]. Integrating agility with sustainability improves productivity while reducing negative impacts on the environment, economy, and society, thereby supporting communities, employees, and customers [32].

This study conducts a comprehensive review of Sustainable and Agile Manufacturing literature from the past five years (2018–2024), analyzing 15 research articles published across 16 journals. The proposed integrated framework aims to help manufacturing firms achieve economic sustainability and remain competitive in dynamic markets by enhancing

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responsiveness to changing demand and promoting eco-friendly, efficient, and automated production systems [33].

S. No	Framework studies done by author/year
1	Catherine Maware et.al 2023
2	Shanty Kusuma Dewi et.al 2023
3	Ahmed Ghaithan et.al 2021
4	Mahak Sharma, et al. 2020
5	Jia et.al. 2020
6	Fruchtl et.al. 2020
7	Neto et.al. 2019
8	Mathiyazhagan et.al.2019
9	Malhotra and Sindhwani (2017)
10	Kumar et al. (2017)
11	Sindhwani and Malhotra (2016)
12	Braz and Leite (2016)
13	Samantra et al. (2015)
14	Routroy et al. (2015)
15	Dubey and Gunasekaran (2015)

4. INVESTIGATION OF SM AND AM STUDY

The present study adopts a comparative analysis approach to identify key features from selected literature on Sustainable Manufacturing (SM) and Agile Manufacturing (AM). Previous studies have also applied similar methods, such as [34], which examined the relationships among TQM, TPM, JIT, and agile manufacturing, highlighting that TPM positively influences TQM and JIT, thereby strengthening agility. Likewise, [35] explored the integration of agile manufacturing with TQM and JIT, concluding that their combined application improves overall firm performance.

The SM–AM framework offers multiple benefits, including efficient resource utilization, reduced waste, optimized energy use, and environmentally responsible practices aligned with regulatory requirements. It enhances responsiveness to market changes, supports flexibility in production systems, and balances economic performance with sustainability. Furthermore, it promotes collaboration among employees, suppliers, and customers, fostering innovation and shared goals.

This study reviews 15 frameworks, identifying around 187 constructs related to SM and AM. Similar constructs were grouped based on common meaning, and frequently occurring elements were highlighted as key enablers. Figure 1 presents the comparative analysis and frequency of these elements, illustrating their distribution across different frameworks.

Articles--------->								
Elements	1	2	3		4	5	Frequency	Weightage
Top Management							15	1.00
Energy Waste and Economic issues							13	0.87
Environmental related issues							10	0.66
Organizational Culture related issues							8	0.53
Customer oriented issue				- - -			2	0.13
Supplier related issues				- - -			2	0.13
Human Related issue							2	0.13

Figure 1. Details of the comparison of Frameworks

From the comparative analysis, it was noted that specific constructs had a frequency of 0. 2 or greater, suggesting that 20% or more of the frameworks highlight these constructs. These high-frequency constructs were deemed critical and designated as the "pillars" of the proposed framework for SM and AM.

5. THE STRUCTURE OF SM AND AM FRAMEWORK

A. Roof of the framework

The roof of the framework for SM and AM represents the overarching goals and the unifying vision that binds the pillars together. It serves as the strategic umbrella under which all activities, initiatives, and practices align, ensuring coherence, focus, and direction. This roof not only provides structure to the framework but also establishes the aspirational targets that drive the system forward.

B. Integration of Both Pillars

The integration of the seven pillars of Sustainable Manufacturing (SM) and Agile Manufacturing (AM) creates a unified framework that aligns environmental responsibility with operational flexibility. This synergy drives key outcomes, including economic efficiency, reduced production lead time, environmental sustainability, social well-being, improved customer satisfaction, enhanced flexibility and innovation, and stronger supplier

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collaboration. At its core, the convergence of SM and AM represents a forward-looking manufacturing approach that enables industries to remain competitive while fostering a resilient and sustainable ecosystem.

1. Top Management
2. Energy waste and economic issues
3. Environmental related issues
4. Organizational culture related issues
5. Customer oriented issue
6. Suppliers related issues
7. Human related issues

Top Management: Ensures strategic alignment, resource allocation, and leadership commitment toward sustainability and agility
Energy waste & Economic Factors: Focus on cost efficiency, energy optimization, and long-term financial viability.
Environmental related Issue: Guide eco-friendly decisions, resource conservation, and regulatory compliance.
Organizational culture related issues: Promotes shared values, adaptability, and continuous improvement.
Customer Orientation issues: Drives responsiveness to customer needs and sustainability expectations.
Supplier related issues: Enhances collaboration, supply chain efficiency, and alignment with SM–AM goals.
Human related issues: Emphasize skills, leadership, teamwork, and employee engagement.

C. Significant features of SM and AM framework

- Developed through analysis of 15 research studies, identifying seven core pillars.
- Strong emphasis on active involvement and commitment of top management.
- Built on seven key dimensions: managerial, economic, environmental, cultural, customer, supplier, and human aspects.

Structured design:

- Two foundation walls represent SM and AM outcomes.
- A central wall includes the seven key parameters.
- A roof symbolizes the integration (transfusion) and overall vision of the framework.

Provides a clear roadmap for organizations to achieve sustainable and agile manufacturing through focused implementation and continuous improvement.

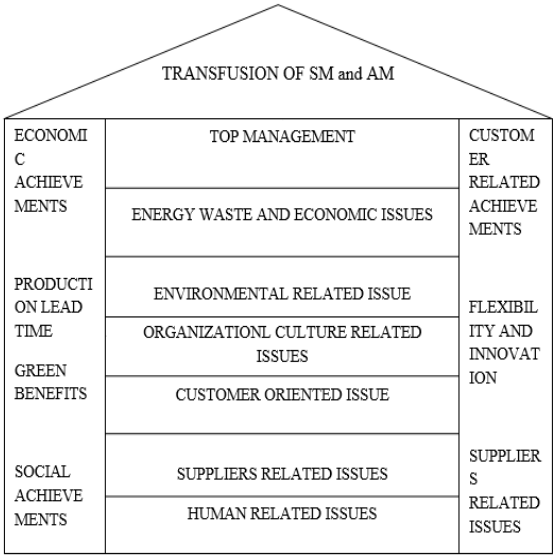

Figure 2 Transfusion of SM and AM frame work

6. CONCLUSION

The integration of Sustainable Manufacturing (SM) and Agile Manufacturing (AM) provides a comprehensive approach to modern manufacturing challenges by combining environmental responsibility with operational flexibility. This framework is built on seven key pillars—top management, energy and economic considerations, environmental factors, organizational culture, customer focus, supplier relations, and human aspects creating a resilient and adaptive system. The convergence of SM and AM ensures alignment toward critical outcomes such as economic performance, reduced lead time, environmental benefits, social well-being, customer satisfaction, innovation, and effective supplier management. Emphasizing collaboration, technological advancement, and continuous improvement, the framework supports scalable and future-ready operations. This study analyses 15 peer-reviewed articles, examining 182 constructs that were grouped based on similarity. Constructs with a frequency of 0.2 or higher were identified as core pillars, providing valuable insights for both academic research and industrial practice.

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