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Analysing the Barriers for Implementation of Lean-led Sustainable Manufacturing and Potential of Blockchain Technology to Overcome these Barriers: A Conceptual Framework

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Abstract

Micro- Small and Medium Enterprises (MSMEs) are very significant for a country's economy due to their contribution to manufacturing, sales and Gross Domestic Product (GDP) growth. The global market competition and standards have been compelling MSMEs to improve quality, reduce waste, improve environmental performance and optimize the cost of products by implementing sustainable practices. The combined approach of lean and sustainable practices can help MSMEs to minimize emissions from waste and manufacture low-cost products with energy-efficient technology. However, MSMEs face many challenges while implementing lean and sustainability tools. Therefore, the main aim of this study is to identify the barriers which create obstruction in the implementation of lean-led sustainable manufacturing practices in Indian MSMEs and prioritize them by calculating their weights. The study also proposes a framework for the integration of blockchain technology in the supply chain to overcome the barriers for the implementation of lean and sustainable manufacturing practices. Extensive literature reviews and experts' opinions have been used to identify the critical barriers for the implementation of lean-led sustainable manufacturing practices in manufacturing firms. A total of forty barriers were selected and further categorized under seven main categories of barriers. The main category barriers and subcategory barriers are ranked based on the weight obtained through Best Worst Method (BWM). The ranking results are further analysed to assess the reliability and robustness using sensitivity analysis. The study reveals that economic and managerial barriers, knowledge and awareness barriers and organizational barriers are the most prominent category of barriers for lean and sustainable manufacturing. The study found that 'Lack of awareness among customers towards sustainability', 'initial capital investment and low financial profit', 'lack of knowledge about potential benefits from sustainable products and practices' and 'resistance to change due to past failure' are the most critical barriers for implementation of lean-led sustainable practices in Indian MSMEs. The study has analysed the features of blockchain technology and their effect on the performance of lean-led sustainable supply chain. The findings of the study will help managers and practitioners in Indian MSMEs from certain perspectives to develop an effective and efficient strategy to overcome these barriers and become sustainable. Therefore, this study provides valuable insights for researchers and practitioners.

Keywords- Lean manufacturing, Sustainable manufacturing, Green manufacturing, Blockchain technology, Barriers, Best–worst method (BWM), Sensitivity analysis.

1. Introduction

The Consumption of natural resources is increasing day by day, becoming a cause for concern with regard to finding the best way to manufacture products. The shortage and high cost of resources result in the high manufacturing cost of products. The increase in manufacturing cost can be reduced with improvement in operational strategies and resource efficiency in firms. The current era of globalization is also concerned about the environmental and financial sustainability of the manufacturing organization. Global policies are focusing on sustainability issues and hence customers and stakeholders are demanding green products (Kaswan and Rathi, 2020). Innovation in business, human involvement and environmental performance are the main pillars of sustainable growth in manufacturing firms (Parmar and Desai, 2020). To initiate sustainable growth in a firm requires the adoption of better practices that help to reduce the environmental effect. Lean manufacturing with a sustainability approach can help the organization to minimize their manufacturing cost through waste elimination and improve their environmental performance. The combination of lean and sustainable/green manufacturing is one of the prominent areas of research that helps manufacturing firms to improve their social, environmental and financial performance (Parmar and Desai, 2020). Nowadays the government of developing countries are also promoting such strategies to help their country become green and sustainable (Industrial Development Report, 2020). Government rules and regulations, stakeholder policies and customer demand are creating pressure on manufacturing firms to reduce the consumption of natural resources. It is important to improve the sustainability level of manufacturing firms as it will help to reduce the wastage of resources. In literature, many researchers have supported the combination of lean manufacturing practices with green manufacturing practices to help the organization become sustainable (Ahmad et al., 2020; Kumar et al., 2016; Singh et al., 2020).

MSMEs play a crucial role in the development of a country's economy. MSMEs are also important in the field of manufacturing products, providing a variety of high-quality services to meet consumer demand and the global market. Many studies have analysed the improvement in MSMEs performance in India (Singh et al., 2021). The studies have provided good exposure to the growth, improvement and development of manufacturing companies in specific areas. However, such studies cannot tackle the barriers to manufacturing firms in financial, social and environmental sustainability. Thus, it is important to use such approaches and techniques which can help the firm to improve financial profits with sustainable development. The synergic effect of lean manufacturing with environmental techniques helps to reduce several waste emissions such as gas emissions, wastewater and solid waste in the manufacturing process (Kaswan and Rathi, 2020). Despite the benefits of lean and sustainable techniques, managers are still hesitant to implement such strategies in the manufacturing system due to many barriers such as fear of failure, limited resources and financial crises (Thanki and Thakkar, 2018).

Therefore, it is important for MSMEs to understand their contributions to the environment and social performance through the implementation of lean and green/sustainable practices. The concept of lean and sustainable manufacturing seems easy but changing from traditional manufacturing to advanced (lean-led sustainable practices) manufacturing is an extensive task as in various case studies, it did not succeed at the first phase of implementation (Fatemi and Franchetti, 2016). Thus, to avoid the failure of lean and green/sustainable practices, it is necessary to find and rank the critical challenges/barriers that create difficulty in the implementation of these practices. The barriers for implementation of lean and green/sustainable practices exhibit very much interdependency with each other, therefore it is very important to identify which barriers should be put on the top ranking so that incremental executions lead to a comprehensive implementation. This will help the managers to take appropriate measures to resolve such barriers.

A total of 51 barriers were discovered during the study's early phase through the literature review. After the consultation with experts and literature survey, forty barriers were finalized for further analysis in the study. The selected barriers are related to each other and have interdependency. In this scenario, it is important to use Multi-Criteria Decision Making (MCDM) techniques to rank the barriers. Many researchers have used MCDM techniques such as Decision Making Trial and Evaluation Laboratory (DEMATEL) by Singh et al. (2020), Analytical Hierarchy Process (AHP) by Mittal et al. (2016), fuzzy AHP by Yadav et al. (2018), fuzzy TOPSIS by Gaikwad et al. (2020) etc. The above-mentioned methods have been used by various researchers to prioritize several alternatives in various areas. Best Worst Method (BWM) is an MCDM technique that can use to rank complex decisions with high dependency (Rezaei, 2016). BWM offers competitive advantages such as consistency, less violation and deviation over other MCDM techniques. BWM technique uses the least pairwise comparison among variables/ alternatives which results in more consistent and prominent results as compared to other MCDM techniques (Rezaei, 2016). Therefore, in this study BWM technique is used to rank the barriers for the implementation of lean and sustainable practices in Indian MSMEs.

Many researchers have discussed about the various approaches to deal with the barriers (Malek and Desai, 2019; Parmar and Desai, 2021; Rejeb et al., 2021). Researchers have found number of solutions to counter the barriers for lean and sustainable manufacturing. However, blockchain is such an advanced technology that can help to overcome the barriers faced by firms during the implementation of lean and sustainable manufacturing in the supply chain (Kouhizadeh and Sarkis, 2018). Researchers have developed conceptual frameworks to adopt blockchain technology in a sustainable supply chain (Nandi et al., 2020; Rejeb et al., 2021; Wang et al., 2020). Recent studies have analysed the implementation of blockchain technology to overcome the barriers in the manufacturing supply chain and analysed the importance of environmental performance (Liu et al., 2020). Blockchain is an emerging technology that can help manufacturing firms to become sustainable. Moreover, from the best of knowledge of authors, there is no study that incorporates blockchain technology to overcome the barriers of lean-led sustainable manufacturing in Indian MSMEs. The study will motivate the industrial practitioner and managers from Indian MSMEs to adopt lean and green/sustainable practices in their firm and will guide the way of successful implementation by systematically focusing on the most critical barriers to the comparatively less critical barriers. The adoption of blockchain technology will significantly help the MSMEs to overcome these barriers and create a smooth path for implementation of lean and green/sustainable practices.

The main objective of lean-led sustainable practices is to eliminate waste in the manufacturing process and become sustainable. As MSMEs contribute a major role in the country's economy, it is important to analyse the impact of lean-led sustainable practices with blockchain technology. The conceptual model has been designed and validated by the experts in the study. The present study fills the gap in the literature with the following questions:

(i) Which are the main barriers to the lean-led sustainable manufacturing practices implementation in Indian MSMEs?
(ii) How to prioritize the barriers with the help of the best-worst method?
(iii) To develop a conceptual model to depict the role of blockchain technology to overcome the identified barriers in the supply chain.
(iv) How the ranking of barriers for the implementation of lean and sustainable manufacturing practices and blockchain technology can be helpful for the Indian MSMEs, practitioners, academicians, government authorities and society?

The remaining paper is presented as follows: Section 2 presents the literature related to lean and sustainable/green manufacturing, MSMEs, blockchain technology and BWM. Section 3 consists of the research methodology used in the study. Section 4 highlights the results and discussions of the study. Section 5 discusses the managerial implications. The last sections 6 and 7 present the conclusions and future direction of research for the study.

2. Literature Review

The present study follows a comprehensive literature review to extract barriers for the implementation of lean and sustainable manufacturing practices in manufacturing firms. In the first phase, research articles from the year 2001 to 2022 are selected to find the relation between lean manufacturing, green/sustainable manufacturing, MSMEs, blockchain technology and the best worst MCDM approach. The articles were collected from various sources such as Springer, Emerald, Taylor and Francis, Elsevier and Inderscience. In the next phase, articles with keywords such as lean manufacturing, green manufacturing, sustainable manufacturing, MSMEs, blockchain technology, Best Worst method and barriers were segregated for further study. The research articles published in conferences, reports and books were not considered in this phase. In the last phase, forty prominent barriers of lean and sustainable manufacturing were extracted from the literature.

2.1 Lean and Sustainable Manufacturing

The lean and sustainable manufacturing approach is a business improvement tool that can help organizations to achieve financial stability and environmental sustainability (Singh et al., 2021). It helps the firm to fulfil the customer's demand and deliver the product at a low cost (Mittal et al., 2016). The combined lean and sustainable approach is important for firms to improve operational and environmental performances (Singh et al., 2020). The synergistic impact of the lean and green approaches will inspire the organizations to improve their cost-based system to an environmentally sustainable manufacturing system (Ahmad et al., 2020). Researchers in previous studies have analysed that the adoption of lean and sustainable practices in MSMEs can help to achieve a significant improvement in a firm's performance (Bhattacharya et al., 2019; Garza-Reyes et al., 2018; Kaswan and Rathi, 2020). Studies also show that lean and sustainable approaches can help the firm to reduce manufacturing defects, waste and inconsistencies in the system especially in Small and Medium Enterprises (SMEs) (Ahmad et al., 2020; Gaikwad et al., 2020; Karuppiah et al., 2020). In the current situation, manufacturing companies are becoming more responsible for environmental performance and the carbon emissions reduction process. Sustainability issues are enforcing the manufacturing companies to adopt cost-effective and environmental based practices (Bhattacharya et al., 2019; Garza-Reyes et al., 2018; Sindhwani et al., 2019). Waqas et al. (2022) conducted a study to analyse the impact of lean, green and agile supply chain on sustainability performance, green innovation, competitive advantage and supply chain responsiveness. The study suggested that an integrated approach of lean, green and agile supply chain practices supports the manufacturing firms to improve their sustainability performance.

2.2 Effect of Lean and Sustainable Manufacturing on MSMEs Performance

MSMEs play an important role in any country's economy in terms of annual production, profits and growth (Garza-Reyes et al., 2018). MSMEs help the country to create employment through job creation and help the country to achieve its goals through various sustainability initiatives such as Make in India, Paris Pact 2030 (European Commission, 2018) and National Action Plan on Climate Change (NAPCC-2008) etc. In this scenario, it becomes very essential for MSMEs to adopt such strategies which help to reduce carbon emissions, negative impact on the environment and provides economic results (Garza-Reyes et al., 2018). Lean and sustainable manufacturing approaches can help to reduce the adverse effect of MSMEs on environmental performance (Bhattacharya et al., 2019). Singh et al. (2020) analysed that manufacturing firms have resistance to changing behaviour to new techniques and approaches. Therefore, it is essential to identify and analyse the critical barriers for the implementation of lean and sustainable manufacturing in Indian MSMEs.

Lean and sustainable manufacturing focuses on the reduction of waste activities and implements such green techniques which helps to produce green products. In the era of globalization, it is important to incorporate environmental and social performance with financial stability in manufacturing organizations. Lean and sustainable manufacturing helps to integrate the three pillars of sustainability in manufacturing firms. Gandhi et al. (2021) conducted a study to find the key challenges faced during the implementation of lean, green and six sigma practices in Indian manufacturing firms. The study suggests that barriers such as lack of cooperation between management and employees, scarcity of time, work pressure and lack of cooperation from suppliers are the critical factors which create hurdles in the implementation of lean, green and six sigma practices. Thomas and Khanduja (2021) analysed the critical barriers for implementation of green lean six sigma (GLSS) and found that lack of awareness for green products, lack of top management commitment and involvement as well as lack of funds along with an improper estimation are the top most obstacles for GLSS.

Yadav and Gahlot (2022) analysed the critical barriers for the implementation of green, lean and six sigma (GLSS) in SMEs. The study found that lack of customer involvement, financial constraints and ignorance towards kaizen are the critical barriers for GLSS. The study urges the manufacturers and practitioners to adopt GLSS tools such as 5S, environmental value stream mapping and life cycle assessment approach to improve their sustainability performance. Rajak et al. (2022) suggested that to achieve sustainability, manufacturing firms need to adopt strategies such as reuse, repair, reduce and remanufacturing. The implementation of these strategies requires a closed-loop or circular supply chain to maintain the reverse flow of material. Rajak et al. (2018) illustrated a closed-loop supply chain network design to analyse the impact on optimum cost, time and environmental performance. The study finds that the mode of transportation through the air causes the highest impact on the environment as compared to other modes of transportation. Thekkoote (2022) suggested that the combined approach of lean and green manufacturing can significantly improve the sustainability performance of SMEs. Alayón et al. (2022) suggested that SMEs exhibit certain characteristics which require specific solutions to improve their sustainability performance. The study suggests that technology incompetency is a critical barrier for SMEs in the adoption of sustainable manufacturing.

Bhattacharya et al. (2019) conducted a systematic literature review of lean and green manufacturing on sustainability performance. In comparison to the individual approaches, the study found that combining lean and green has a positive effect on sustainability. The adoption of lean and sustainable manufacturing can lead to several issues which can hinder the implementation process. These issues are called barriers. Mittal et al. (2016) have used the Analytical Hierarchy Approach (AHP) to rank the barriers of the lean and green manufacturing system. Yadav et al. (2018) used the fuzzy AHP method to investigate the obstacles to the implementation of lean six sigma in a case company. Parmar and Desai (2020) analysed the barriers for the sustainable lean six sigma process through BWM. Ahmad et al. (2020) ranked the important enablers for the implementation of lean and green manufacturing process in SMEs through the BWM method.

2.3 Blockchain Technology

Blockchain technology is an emerging disruptive technology that includes two basic features, namely, distributed ledger system and cryptographic tools. The distributed ledger system is used to verify the transactions of partners without the involvement of intermediates auditing authorities (Rejeb et al., 2021). Cryptographic tools help to integrate data security and safety in the database. Blockchain enables firms, suppliers, customers and stakeholders to connect through a common platform in real-time. Such platforms help organizations to extend their business in global markets and link with customers directly (Wang et al., 2020). Blockchain provides a highly secure mode of information storage. The security system helps to protect against the leaking of confidential information and data of organizations, stakeholders and customers (Kshetri, 2018). A study conducted by Bai et al. (2022) shows that blockchain technology can help firms to improve their supply chain transparency which will ultimately improve social and environmental performance. Rejeb et al. (2022) Suggested that blockchain technology plays an important role in the aspect of circular economy activities and further helps to overcome the sustainability issues in manufacturing firms.

Blockchain technology can help all the stakeholders to understand the flow of products in the supply chain and helps to strengthen the relationship and trust among the supply chain partners directly (Wang et al., 2020). Supply chain partners such as customers, manufacturers and suppliers can access the information easily through a common blockchain platform about the details of products, raw materials, product design and process etc. Khanfar et at. (2021) used a systematic literature review approach to analyse the impact of blockchain technology on the triple bottom line-based sustainability performance of manufacturers in the supply chain. The study supports the implication of blockchain technology in the manufacturing supply chain to improve transparency, traceability, information sharing and data security. The adoption of blockchain technology will encourage manufacturing managers to understand how this emerging technology can address the barriers of implementing sustainable practices.

2.4 Best Worst Method

Multi-criteria decision-making (MCDM) techniques have been widely utilized by researchers to choose the most optimum option among the alternatives. MCDM techniques have been applied to solve various problems such as engineering, science and management. MCDM methods help to calculate the optimum weights to prioritize the factors. Researchers have implemented several MCDM techniques for weight calculations such as Decision-making trial and evaluation laboratory (DEMATEL), Technique for order of preference by similarity to ideal solution (TOPSIS), Simple Additive Weighting (SAW), Fuzzy-Analytic Hierarchy Process (Fuzzy-AHP) etc. Fuzzy AHP has been widely used by researchers to calculate the weights of alternatives. Fuzzy AHP requires a large number of pairwise comparisons among alternatives which can create ambiguity in results.

The BWM technique overcomes the pairwise comparison problem and delivers more accurate results (Rezaei, 2016). BWM method is an MCDM technique developed by Razaei to choose the best option among all sets of alternatives. Compared to fuzzy AHP and ANP, the BWM method requires few pairwise comparisons. Many researchers have used the fuzzy AHP approach in the study to calculate the weights of different criteria. Although many researchers have implemented fuzzy- AHP in large studies, the inconsistency in pairwise comparison cannot be neglected as it leads to ambiguous results. This complexity also increases with a large number of alternatives in the problem. Researchers have found that BWM provides better results than fuzzy AHP in four aspects; consistency, minimum violations, deviation and conformity (Malek and Desai, 2019; Rezaei, 2016). In general, the BWM technique requires fewer comparisons and provides more consistent results. Fuzzy AHP requires n(n-1)/2 pairwise comparisons to calculate the weights where n represents the number of factors. On the other hand, BWM requires 2n-3 pairwise comparisons where n represents the number of factors. Since the analysis study requires the ranking of 40 barriers, the BWM method was used to reduce the number of pairwise comparisons. The application of BWM has been found in various research articles to calculate the weights of different factors. Barriers to green innovation in SMEs by Gupta and Barua (2018), barriers for sustainable lean six sigma by Parmar and Desai (2020), ranking the barriers for sustainable manufacturing by Malek and Desai (2019), integrated approach of JIT-lean practices by Talib et al. (2020) etc. have used the BWM approach to calculate the weights. The application of BWM in various research studies justifies the importance and capability of the BWM technique in the research field.

2.5 Research Gaps

From the literature discussed above, the following research gap areas were identified:

- Researchers in the previous studies have identified the barriers for lean-led sustainable manufacturing practices but very few have classified them into groups based on their functions, organizational capabilities and characteristics (e.g., human resources, knowledge and awareness, technology and social performance, etc.)
- Also, very few studies have focused on the prioritization of barriers for the implementation of lean and sustainable manufacturing practices in Indian MSMEs to understand their core problems.
- According to the review of the literature, no study has taken a comprehensive set of implementation barriers for lean manufacturing and green/sustainable manufacturing into account when ranking according to weight calculations.
- Literature suggests that studies related to the integration of blockchain technology in the supply chain have been explored widely. However, studies related to the integration of blockchain technology into lean-led sustainable supply chains to overcome the barrier are limited.

Therefore, the current study concentrated on identifying and ranking the barriers to lean-led sustainable manufacturing adoption in MSMEs using the BWM approach. The study also proposes a framework for the integration of blockchain technology in the supply chain to overcome the implementation barriers of lean-led sustainable manufacturing.

3. Research Methodology

The study has adopted a three-phase method for the identification, selection, ranking and evaluation of the barriers for implementation of lean and sustainable manufacturing practices. In the first phase, fifty-one barriers were extracted from the literature. In the second phase, barriers were discussed with experts from MSMEs and academic professionals. In this process, a total of forty barriers were considered for further study. The barriers also have sub-categorises under seven main headings. The barriers selected for the study with their subcategories are shown in Table 1. In the third phase, the BWM technique was used to calculate the weight of each barrier and rank them according to the global weights. A framework has been developed to incorporate blockchain technology in the supply chain to eliminate the barriers of lean-sustainable manufacturing. Figure 1 depicts the research methodology used in the study.

3.1 Best Worst Method

The Best- Worst method is an MCDM approach that can provide efficient and reliable solutions to multi-criteria decision problems. BWM method needs data collected by a team of experts to choose the best and worst alternatives among all alternatives selected for the study. The alternative selected as most and least important is represented as the best and worst alternative respectively. Using a nine-point likert scale, the experts were asked to compare the best and other alternatives, as well as other alternatives to the worst alternative. The comparisons among alternatives are called Best-to-Others (BO) and Others-to-Worst (OW) vectors. The two vectors were further solved as a linear programming model to calculate the optimal weights for each alternative. The consistency ratio of the vector was also calculated to measure the experts' judgement. The value of the consistency ratio close to zero shows highly consistent and reliable data. The working principle of BWM and AHP is similar in terms of pairwise comparisons. However, BWM requires fewer comparisons (2n-3) compared to AHP (n(n-1)/2). The fewer comparisons help to maintain consistency in the problem solution. More consistency in results helps to get more reliable results.

Talib et al. (2020) used the BWM approach to prioritize the Just in time and lean practices in Indian manufacturing industries. Ahmad et al. (2020) ranked the enablers for the lean green manufacturing process in Indian SMEs through the BWM approach. Singh et al. (2021) prioritized the lean six sigma enablers with environmental thinking in Indian MSMEs through BWM. Malek and Desai (2019) ranked the main barriers to sustainable manufacturing by using the BWM approach. Gupta and Barua (2018) implemented the BWM approach to analyse the barriers to green innovation in SMEs. The following steps have been followed in BWM to calculate the weight for barriers-

Step 1: Determine the set of alternatives (barriers for lean and green manufacturing) i.e. c1, c2, c3….cn required for problem solutions.

Step 2: Select the most important and least important alternatives which will be term as best and worst alternatives respectively.

Step 3: Compare the best alternative with other alternatives through a pairwise comparison using numbers 1 to 9. The resulting BO vector can be written as equation (1):

$$A_b = (a_{b1}, a_{b2}, ...a_{bn}) \tag{1}$$

where, a_{bj} represents the preference of best alternatives over other alternatives j. It is self-explanatory that $a_{bb} = 1$.

Step 4: Similarly compare the worst alternative with all other alternatives using numbers 1 to 9. The resulting OW vector can be written as equation (2):

$$A_w = (a_{w1}, a_{w2}, ...a_{wn})^T \tag{2}$$

where, a_{wj} represents the preference of alternative j on worst alternative w. It is also self-explanatory that $a_{ww} = 1$.

Step 5: This step is used to calculate the optimal weights $(w_1^*, w_2^*, ...w_n^*)$.

The optimal weights of the alternatives can be found by minimizing the maximum absolute differences of $\left|\frac{w_b}{w_j} - a_{bj}\right|$ and $\left|\frac{w_j}{w_w} - a_{jw}\right|$ for all j alternatives.

This difference can be calculated through equation (3)

$$\min \max_j \left\{ \left|\frac{w_b}{w_j} - a_{bj}\right|, \left|\frac{w_j}{w_w} - a_{jw}\right| \right\} \tag{3}$$

Subject to

$$\sum_j w_j = 1$$

where, $w_j \geq 0$, for all *j*.

Equation (3) is transformed into a linear programming model and can be represented as Equation (4):

$$\min \xi^k$$

$$\text{subject to} \quad \left|\frac{w_b}{w_j} - a_{bj}\right| \leq \xi^k, \ \textit{for} \text{ all j}$$

$$\left|\frac{w_j}{w_w} - a_{jw}\right| \leq \xi^k, \ \text{for all j}$$

$$\sum_j w_j = 1 \tag{4}$$

$$w_j \geq 0, \ \textit{for} \text{ all j}$$

Step 6: The linear programming model in equation (4) is salved to get a unique solution for optimal weights $(w_1^*, w_2^*, \ldots\ldots w_n^*)$ and the optimal value of consistency ratio ξ^k. The value of ξ^k close to zero shows a high level of consistency.

3.2 Data Collection for the Best Worst Method

BWM method requires pairwise comparison data to calculate optimal weights of barriers for the implementation of lean and sustainable manufacturing practices in Indian MSMEs. The pairwise comparison was conducted by using numbers from 1 to 9 which indicate the preference of one barrier over the other barriers. The number and relative importance are shown in Table 2. The data for the study was collected from various Indian manufacturing companies located in Telangana, India. The organizations selected in the study manufacture a wide variety of special metals and alloys, forged bars, rings, hot rolled and cold rolled sheets, tubes, fasteners, gears, metal pipes etc. To increase the firms' resource efficiency, the organisations constantly promote new advanced practices with continuous improvement initiatives.

Ahmad et al. (2020) have used the BWM approach with the help of six experts to analyse the performance of lean and green manufacturing in Indian SMEs. Talib et al. (2020) employed a team of six experts to analyse the implementation process of JIT and lean practices in the Indian manufacturing industry through the BWM approach. Malek and Desai (2019) employed a group of five experts in a case organisation to prioritize the barriers for sustainable manufacturing through the BWM approach. Gupta and Barua (2018) employed a team of four members to analyse the barriers for green innovation in SMEs by using the BWM approach. Therefore, in this study, a team of nine experts has been selected to analyse the lean and sustainable barriers. The data for the study was collected following several visits to the manufacturing firms.

Table 1. Lean –sustainable manufacturing barriers.

Barriers	Subcategory	Description	References
Economical and Managerial Barriers	Initial capital investment and low financial profit (EMB1)	The adoption of lean and sustainable techniques in a firm requires an initial investment, which is a risk factor for business management. Initial capital investment may create a hurdle for the lean-sustainable initiatives in the manufacturing firm. The business is always driven by the profit motive. Reduction in financial profit in the early stage of implementation can discourage the organization to use such techniques.	Ben Ruben et al. (2018), Caldera et al. (2019), Dhull and Narwal (2015), Giunipero et al. (2012), Karuppiah et al. (2020), Kumar et al. (2016), Parmar and Desai (2020), Majumdar and Sinha (2018), Singh et al. (2020), Sindhwani et al. (2019).
	Ineffective organization management towards the adaption of lean and green practices (EMB2)	Support from the organization management for the adaption of lean and sustainable manufacturing is essential.	Ben Ruben et al. (2018), Caldera et al. (2019), Dhull and Narwal (2015), Gaikwad et al. (2020), Giunipero et al. (2012), Parmar and Desai (2020), Singh et al. (2020), Sindhwani et al. (2019), Yadav et al. (2018).
	Lack of risk management methods (EMB3)	The implementation process of lean and sustainable program can get disrupted during the execution phase. Hence the managers should know the risk management methods.	Caldera et al. (2019).
	Resistance to change due to past failure (EMB4)	The organization’s management shows resistance to change in the system due to past experiences or due to changes in the work routine.	Gaikwad et al. (2020), Singh et al. (2020), Sindhwani et al. (2019), Yadav et al. (2018).
	Unproductive time management (EMB5)	Unproductive time management can be responsible for the non-utilization of resources in the firm. The implementation process of lean and green/sustainable techniques requires efficient time management which can help to execute the implementation process smoothly and in a timely manner.	Parmar and Desai (2020), Yadav et al. (2018).
	Lack of top-level management consciousness towards sustainability (EMB6)	Management must track the production system and assess the system for environmental sustainability. Lack of consciousness towards the sustainability issue from management is a very crucial barrier for the lean and sustainability manufacturing process.	Kumar et al., (2016), Parmar and Desai (2020).
Human Resource Barriers	Lack of training for employees and management (HRB1)	Employee and management training will play an important role in the development of organisational skills and awareness of lean and sustainability practices. The training of employees and management is necessary for the organization as it helps the industry to become more resource-efficient and sustainable.	Ben Ruben et al. (2018), Dhull and Narwal (2015), Gaikwad et al. (2020), Karuppiah et al. (2020), Kumar et al. (2016), Parmar and Desai (2020), Sindhwani et al. (2019), Yadav et al. (2018).
	Lack of employee empowerment (HRB2)	Involving employee and managers in the decision-making process to have a clear vision.	Ben Ruben et al. (2018), Karuppiah et al. (2020), Yadav et al. (2018).
	Poor team management skills (HRB3)	Sustainable lean manufacturing implementation require multifunctional and multidisciplinary efforts from employees. The efforts can be achieved through proper team management skill.	Kumar et al. (2016), Lamba and Thareja (2020), Majumdar and Sinha (2018).
	Lack of incentive schemes and wage structure for employees (HRB4)	The organization should provide some incentives schemes and wage structure plans for employees to encourage adoption of lean-sustainable practices. The recognition and reward system can motivate the employees to adopt such strategies.	Majumdar and Sinha (2018).
Organizational Barriers	Inefficient resources (Human resource, financial, material, machine etc.) in organization for project execution (OB1)	For the successful implementation of lean and sustainable management, the availability of efficient resources is necessary. Therefore inefficient resources can be a big hurdle for firm management.	Ben Ruben et al. (2018), Dhull and Narwal (2015), Gaikwad et al. (2020), Kumar et al. (2016), Parmar and Desai (2020), Yadav et al. (2018), Sindhwani et al. (2019).

Table 1 continued…

	Poor coordination and cooperation between departments (OB2)	The poor coordination and cooperation of employees with other departments can result in the poor execution of lean and sustainable manufacturing. Coordination is an important parameter in the organization for information and material flow to utilize the resources efficiently and implement new policies.	Ben Ruben et al. (2018), Gaikwad et al. (2020), Kumar et al. (2016), Parmar and Desai (2020), Singh et al. (2020), Sindhwani et al. (2019), Yadav et al. (2018).
	Lack of encouragement from the organization (OB3)	Encouraging behaviour of an organization is important for the implementation of lean sustainable techniques.	Dhull and Narwal (2015), Parmar and Desai (2020), Karuppiah et al. (2020), Singh et al. (2020).
	Poor organizational infrastructure (OB4)	Organizations have to develop advanced infrastructures such as green warehouses, green transportation etc. to implement sustainable organization policies.	Ben Ruben et al. (2018), Lamba and Thareja (2020).
	Lack of recycling and reuse efforts of the organization (OB5)	The organization oriented towards the recycling and reusing techniques for the material is essential for waste reduction and green efforts.	Mathiyazhagan et al. (2013), Parmar and Desai (2020).
	Poor organization culture to adopt green and lean initiatives (OB6)	The organization culture can be explained as the behaviour and rules which covers trust, working environment and hierarchical structures. If the organizational culture does not care about environmental sustainability and not willing to adopt lean-sustainable practices, then it is necessary to change the organization culture. This type of culture can be a crucial barrier for lean and sustainable manufacturing.	Parmar and Desai (2020).
	Poor facility planning and layout (OB7)	The lean-led sustainable manufacturing implementation process requires proper facility planning and layout for optimum utilization of resources and facilities. Poor planning and layout can lead to a non-value-added activity in the firm.	Ben Ruben et al. (2018), Lamba and Thareja (2020), Parmar and Desai (2020), Sindhwani et al. (2019).
Independent barriers	Lack of support from the government to introduce sustainable practices (IB1)	Government support for organizations to introduce new strategies is essential. The government can provide assistance to manufacturing firms to introduce such strategies so that they become environmental and economically sustainable.	Ben Ruben et al. (2018), Caldera et al. (2019), Parmar and Desai (2020), Majumdar and Sinha (2018), Singh et al. (2020), Sindhwani et al. (2019).
	Governmental environmental laws and regulations and deficient enforcement (IB2)	The implementation of government new policies related to environmental safety can mandate the organization to implement lean and sustainable practices. The government can implement such policies, laws and regulations in firms to reduce environmental waste and emissions.	Dhull and Narwal (2015), Parmar and Desai (2020).
	Market competition and uncertainty (IB3)	Uncertainty in the market and competition can create a severe problem in the supply chain such as the bullwhip effect. The global demand for green products can lead to this situation in the market.	Dhull and Narwal (2015), Giunipero et al. (2012), Kumar et al. (2016), Majumdar and Sinha (2018), Parmar and Desai (2020), Sindhwani et al. (2019).
	Lack of cooperation and coordination from suppliers and stakeholders (IB4)	The implementation process of lean-sustainable techniques in the supply chain requires the involvement of suppliers and stakeholders as well. The collective approach of suppliers, stakeholders and manufacturing firms can help to achieve environmental sustainability.	Dhull and Narwal (2015), Gaikwad et al. (2020), Parmar and Desai (2020), Singh et al. (2020), Yadav et al. (2018).
	Lack of customer demand (IB5)	The adoption of lean and sustainable practices can be encouraged by customer demand. The customer willingness to buy green products can motivate the firm to implement such strategies.	Giunipero et al. (2012).

Table 1 continued…

Knowledge and Awareness barriers	Lack of awareness among customers towards sustainability (KAB1)	The efforts towards customer awareness and involvement for sustainability issues can be very crucial for the adaption of lean and sustainable practices.	Ben Ruben et al. (2018), Karuppiah et al. (2020), Kumar et al. (2016), Majumdar and Sinha (2018), Parmar and Desai (2020), Sindhwani et al. (2019).
	Lack of knowledge about environmental impacts (KAB2)	Knowledge and awareness of the environmental impact of the manufacturing process, waste and emission are very important. The lack of knowledge can be an important barrier for lean-sustainable manufacturing.	Ben Ruben et al. (2018), Caldera et al. (2019), Gaikwad et al. (2020), Parmar and Desai (2020), Singh et al. (2020), Yadav et al. (2018).
	Lack of knowledge about Potential benefits from sustainable products and practices (KAB3)	The information and knowledge about the potential benefits that can be achieved from sustainable products are essential for the management and employees. The potential benefits can also encourage the suppliers as well to implement such strategies.	Singh et al. (2020), Sindhwani et al. (2019).
	Lack of awareness of Lean tools integration with environmental techniques (KAB4)	The lack of knowledge towards the integrated approach of environmental strategies with lean practices can create a hurdle in the adoption of such strategies.	Ben Ruben et al. (2018).
Technology barriers	Lack of information technology (IT) implementation (TB1)	Information technology has always been recognised as an important tool at every stage of the implementation of new practices.	Dhull and Narwal (2015), Lamba and Thareja (2020), Parmar and Desai (2020).
	Lack of advanced green technology, process and system design (TB2)	The sustainable manufacturing process requires a lot of advanced practices, technologies, product and system designs. The lack of technology can create a big hurdle in lean-sustainable implementation.	Majumdar and Sinha (2018), Mathiyazhagan et al. (2013).
	Improper selection of Lean and green tools (TB3)	The tool selection for the organization is very important as it can be profitable if it suits the organization's manufacturing policies, techniques and practices. Improper selection of tools can lead to financial losses for the firm.	Ben Ruben et al. (2018), Yadav et al. (2018).
	Lack of project plans, techniques, and standard practices (TB4)	Lean and sustainable practices require standard practices, project plans and techniques to be followed by the organization. The project plan, practices and techniques can be based on the organization's requirements and financial capabilities.	Parmar and Desai (2020), Yadav et al. (2018).
	Lack of defect monitoring analysis and effective visualization (TB5)	Continuous monitoring and visualization can help the organization to reduce its defect rate and implement statistical analysis to reduce the occurrence of errors in the manufacturing firm.	Ben Ruben et al. (2018), Parmar and Desai (2020).
	Ineffective material handling and transportation (TB6)	Lean and sustainable practices require advanced technologies for the storage and transportation of material to reduce waste and release less environmental emissions.	Ben Ruben et al. (2018).
	Lack of process and quality measurements (TB7)	Continuous monitoring and improvement in process and quality measurement is important with the help of advanced technology and tools.	Parmar and Desai (2020), Yadav et al. (2018)
	Lack of technology up-gradation (Poor R&D) (TB8)	The organization should always update their technology with the help of market research. Technology up-gradation can help the firm to utilize the resources efficiently and achieve sustainability in the system.	Caldera et al. (2019), Dhull and Narwal (2015), Lamba and Thareja (2020), Parmar and Desai (2020), Karuppiah et al. (2020), Singh et al. (2020), Sindhwani et al. (2019).
Social and environmental barriers	Difficulty in sustaining the benefits of improvement (SEB1)	The implementation of new practices is costly. The uncertainty in sustainable benefits can act as a barrier to lean and sustainable practices adoption in the organization.	Gaikwad et al. (2020), Sahoo and Yadav (2018).

Table 1 continued…

	Failure in eco-design (SEB2)	The failure in product design based on environmental practices.	Karuppiah et al. (2020).
	Absence of a green disposal system (SEB3)	A waste disposal system is required to treat waste emissions in the manufacturing system.	Karuppiah et al. (2020).
	Unawareness of green energy (SEB4)	Green energy employment can help to lower the dependency on conventional energy sources.	Karuppiah et al. (2020).
	Lack of balance between environment, social and economic benefits (SEB5)	The organization is unable to improve the environmental, social and economic performance of the manufacturing system.	Malek and Desai (2019), Parmar and Desai (2020).
	Lack of ethical standards and corporate social responsibility (SEB6)	The organization must use such practices that can reduce the exploitation of natural resources. The organization should have to operate in compliance with environmental standard policies.	Ben Ruben et al. (2018), Dhull and Narwal (2015), Mathiyazhagan et al. (2013).

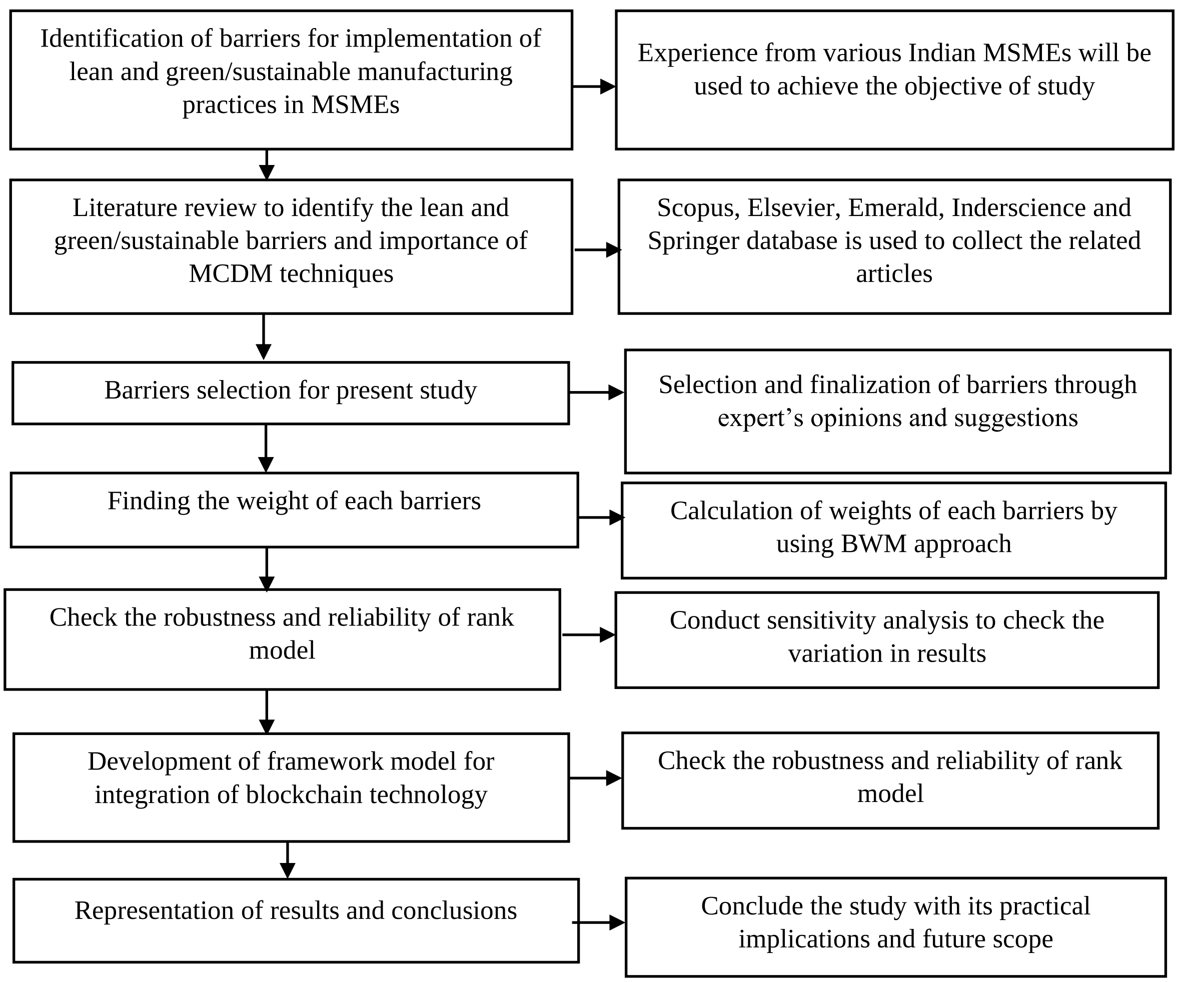

Figure 1. Research framework used in the study.

The expert team includes two senior-level managers, two production managers, two environmental managers, a human resource manager and two academic professionals. The expert who participated in the study had work experience of more than ten years. The experts have participated in the various decision-making process in their firms. To collect the data, experts were asked to fill out a brief questionnaire based on their experience. After the collection of data, weights for the lean–sustainable barriers were calculated through the application of the BWM method.

Table 2. Numbers with the relative importance.

Number	Relative Importance
1	Equal important
2	Between Equal and Moderate important
3	Moderately important
4	Between Moderate and Strong important
5	Strongly important
6	Between Strong and Very strong important
7	Very strongly important
8	Between Very strong and Absolute important
9	Absolutely more important

3.3 Barriers Weight Calculation using BWM

The next step after collecting the data was weight calculation for each barrier. The expert team was requested to select the best and the worst barrier for each category and sub-category barriers. Later the expert team was requested to fill the preference of best barriers over other barriers in the questionnaire. This preference relation was called as best-to-other (BO) vector. Likewise, the expert team provided the preference of other barriers over the worst barrier. The resulting vector was called other-to-worst (OW) vector. The BO vector and OW vector for main category barriers are shown in Table 3 and Table 4 respectively. The final weights for main category barriers were calculated through BWM steps. The average value of weights obtained from each expert's ranking was taken as the final weight. The weight calculated for individual experts and the final average weights are shown in Table 5. The average calculated value ξ^k is 0.0778 (close to zero) which shows the consistency and reliability of the results.

Table 3. Best-to-Others vector.

Expert No.	"Best"	EMB	HRB	OB	IB	KAB	TB	SEB
1	EMB	1	5	4	8	3	5	6
2	EMB	1	5	3	8	2	4	7
3	KAB	2	5	4	9	1	4	6
4	EMB	1	5	3	8	2	4	6
5	EMB	1	4	4	8	2	3	6
6	KAB	2	5	3	7	1	4	9
7	EMB	1	4	5	9	2	6	8
8	EMB	1	3	4	8	2	5	6
9	KAB	2	3	4	9	1	5	7

Table 4. Others-to-Worst vector.

Expert No.	"Worst"	EMB	HRB	OB	IB	KAB	TB	SEB
1	IB	8	3	5	1	6	4	2
2	IB	7	3	6	1	7	5	3
3	IB	9	3	6	1	8	5	2
4	IB	8	4	6	1	7	5	2
5	IB	7	4	5	1	7	7	2
6	IB	8	4	6	1	8	5	3
7	IB	9	2	3	1	5	3	4
8	IB	8	2	3	1	6	2	3
9	IB	8	6	3	1	9	3	4

Table 5. Major criteria weights.

	EMB	HRB	OB	IB	KAB	TB	SEB	ξ^k
Expert 1	0.4032	0.0968	0.1210	0.0403	0.1613	0.0968	0.0806	0.0806
Expert 2	0.3477	0.0862	0.1436	0.0378	0.2154	0.1077	0.0616	0.0831
Expert 3	0.2230	0.0892	0.1115	0.0335	0.3569	0.1115	0.0743	0.0892
Expert 4	0.3521	0.0845	0.1408	0.0352	0.2113	0.1056	0.0704	0.0704
Expert 5	0.3300	0.1061	0.1061	0.0337	0.2121	0.1414	0.0707	0.0943
Expert 6	0.2187	0.0875	0.1458	0.0380	0.3519	0.1094	0.0486	0.0856
Expert 7	0.3872	0.1165	0.0932	0.0343	0.2330	0.0777	0.0582	0.0788
Expert 8	0.3667	0.1288	0.1041	0.0396	0.2081	0.0833	0.0694	0.0496
Expert 9	0.2135	0.1423	0.1067	0.0323	0.3588	0.0854	0.0610	0.0682
Final Weight	0.3158	0.1042	0.1192	0.0361	0.2565	0.1021	0.0661	0.0778

The final calculated weight of each barrier is presented in Table 5 called as the major criteria weights. The local weight of each sub-categories barrier has been calculated through the same steps of the BWM approach. The final global weights and ranking of each barrier are presented in Table 6. The global weights of each barrier are obtained through the multiplication of local weights of barriers with weights calculated in the particular category of barriers. The final rankings are assigned based on the global weights of barriers.

3.4 Role of Blockchain to Overcome the Barriers of the Lean-Led Sustainable Supply Chain in MSMEs

Blockchain technology is distributed database platform that stores the records of data and information in a manner that makes it tamper-resistant. The data stored in the database can be accessed and inspected by many users but cannot be changed or deleted. The data stored in the database cannot be modified which makes blockchain technology a more legitimate and authentic way of storing information such as transaction history, performance history, materials information etc.

The collaboration of blockchain technology in the manufacturing supply chain is significant in view of business performance. Blockchain technology helps the firms to incorporate the active participation from all the stakeholders and customers. The collaboration of stakeholders and customers also depends on trust and mutual understanding with management and business strategies. To achieve that trust from the stakeholders and customers, management should ensure the reliability and safety of information and data shared by the stakeholders (Stefansson, 2002). Blockchain technology is such an emerging technology that can provide several positive features to manufacturing firms and help to overcome the barriers of lean-led sustainable supply chain. Blockchain technology is a distributed system of database that can help firms to store and record the ledgers of digital activities that have been shared among the stakeholders of the supply chain (Crosby et al., 2016). Blockchain technology provides a secured form of data sharing about the transaction history, instantaneous information and product details etc. Blockchain technology with human intervention can be helpful for firms to achieve economic, social and environmental sustainability. Figure 2 shows the integration of blockchain technology to overcome the lean and sustainable manufacturing barriers and shows the improvement in supply chain performance.

Blockchain helps to improve supply chain integration through real-time information sharing. It helps in strategic planning and developing a strong relationship between suppliers, customers, outsourcing partners, contractors etc. Blockchain ensures the safety and security of data that helps to develop trust between firm and supply chain partners and hence improve operational efficiency. Blockchain technology develops a reliable relationship among supply chain partners such as customers, suppliers etc. and helps to implement lean practices such as just in time, outsourcing, total productive maintenance etc. Blockchain technology ensures the safety and security of the confidential data and information shared by the stakeholders in the supply chain. The tamperproof storage of data and information provides an excellent facility for exchanging information, reducing paperwork, reducing data redundancy, support the data validation of the supply chain. Blockchain improves the traceability in the system and provides a transparent and auditable platform for information about materials, processes, products and transactions. Blockchain creates an absolutely transparent system for effective resource planning and inventory management which helps to reduce the cost of products, predict the demand and provide flexibility in the supply chain. Blockchain technology provides a database of data and information that can be easily accessed by supply chain partners. The easy access to information about the product quality, description, availability, transaction status etc. helps to create a strong relationship among supply chain partners.

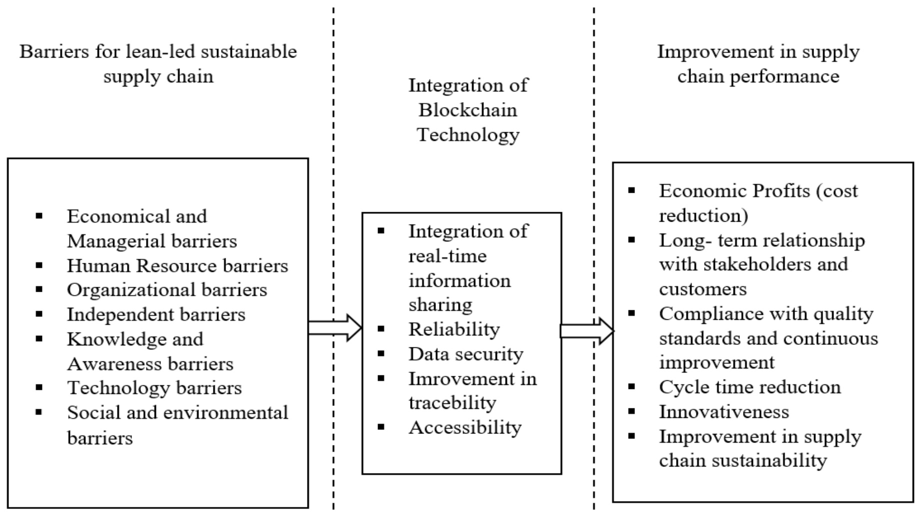

Figure 2. Framework for integration of blockchain technology in lean-led sustainable supply chain (Rejeb et al., 2021; Wang et al., 2020).

The application of lean and sustainable manufacturing in MSMEs can be facilitated by blockchain technology. The advanced platform of data sharing in the supply chain can help to reduce the material cost, distribution cost, and information sharing cost. Blockchain technology also helps to reduce the cost per working hour, risk cost and many intangible costs associated with the production process. Blockchain technology provides a data-sharing platform for manufacturers, suppliers, customers and stakeholders. The confidential information and data about funds transfer, materials information, supplier details etc. can be shared securely through blockchain technology. The transparency in data sharing helps to maintain a long-term relationship among all the stakeholders in the supply chain. Blockchain technology can help the manufacturer to track the number of process intermediaries, productivity, inventory management, compliance with environmental rules and regulations and process automation. The blockchain platform helps to improve the quality standards of products with reduction in process/product errors, reduction in data errors and on-time deliveries to customers. Blockchain technology helps to update the actual data of production and delivery time, lead time, cycle time, product design and development times. The information regarding product availability, fund availability and supplier lead time also helps the manufacturing firms to manage their supply chain accordingly. The updated technology such as blockchain encourages the firms to innovate their product and process and explore new opportunities in the local and global market. Blockchain technology also helps the firm to adopt the life cycle analysis approach of products in the supply chain to analyse the impact of the manufacturing cycle on the environment. The life cycle approach also helps to reduce waste generation such as wastewater, greenhouse gas emissions and solid waste. Blockchain technology helps to improve the sustainability performance of the supply chain with the reduction in waste emissions from the production process.

The information-sharing approach through the blockchain platform helps the firms to develop innovative ideas for product and process improvement, quality improvement and implementation of environmentally friendly practices. Blockchain technology can validate the skills and qualifications of employees and the performance of employees can also be tracked through distributed online ledger system. Blockchain can help in verifying and certifying product quality and service performance. Blockchain helps to create a platform to share information about the manufacturing process, assembly, delivery and maintenance of equipment with suppliers and stakeholders.

4. Results and Discussions

Global market competition and environmental concerns are creating pressure on manufacturing firms to become financial and environmentally sustainable. Manufacturing firms do not only facing the pressure of the global market but also getting pressure from stakeholders and customers to incorporate the environmental sustainability concept in the strategic planning process. It is imperative to examine the ranking of lean-sustainable barriers based on their criticalness and effectiveness so that management can focus on them with utmost priority. Therefore, this study aims to identify the barriers for the implementation of lean and green/sustainable manufacturing practices in MSMEs. The barriers were further ranked based on data collected from the experts' team in the study using the BWM approach. The study reveals that among the main barriers: economical and managerial barriers hold the first rank with the weight of 0.3158. Knowledge and awareness barriers hold the second rank with a weight of 0.2565. Organizational barriers hold the third position with a weight of 0.1192. Human resource barriers hold the fourth position with a weight of 0.1042. Technology barriers hold the fifth rank with a weight of 0.1021. Social and environmental barriers hold sixth and independent barriers hold the seventh position with the weight of 0.0661 and 0.0361 respectively. The organization should remove these barriers with several strategies.

The BWM results show that economical and managerial barriers are the most important barriers while implementing lean and sustainable manufacturing. It indicates that manufacturing firms need to focus on their economical and management performance with continuous improvement strategies. Yadav et al. (2018) analysed the barriers using the fuzzy AHP approach and found that managerial barriers, organizational barriers and information barriers are the three main barriers for lean six sigma. Malek and Desai (2019) showed that economical- managerial barriers and organizational barriers are major barriers to sustainable manufacturing. Knowledge and awareness about the environmental impacts and their significance are also found as the second most important barrier for lean and sustainable manufacturing. Rahman et al. (2020) analysed the barriers for green manufacturing with fuzzy VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje) and found that lack of knowledge about the environmental impact is the most critical barrier for sustainable practice. The organization should encourage the workers and management to include such strategies which can help to reduce carbon emissions and create awareness about environmentally friendly techniques. The organizational barriers hold the third position in the ranking, which suggest that the firm should streamline its organizational activities. If the organizational activities are planned based on lean and sustainable tools adoption then it will not create a hurdle during the implementation process. Yadav and Desai (2017) suggested organizational barriers act as a prolonged procedure that has to be initiated at the early stage of implementation to achieve better results.

Table 6. The final ranking of barriers for lean–sustainable manufacturing.

Main Criteria	Weight of main criteria	Main Criteria Relative Ranking	Sub- Criteria	Weight of Sub Criteria	Sub-Criteria Relative Ranking	Global Weight	Global Ranking
Economical and Managerial Barriers (EMB)	0.3158	1	EMB1	0.3536	1	0.1117	2
			EMB2	0.1182	4	0.0373	9
			EMB3	0.0820	5	0.0259	12
			EMB4	0.2554	2	0.0807	3
			EMB5	0.0394	6	0.0124	23
			EMB6	0.1514	3	0.0478	6
Human Resource Barriers (HRB)	0.1042	4	HRB1	0.4710	1	0.0491	5
			HRB2	0.0613	4	0.0064	30
			HRB3	0.3074	2	0.0320	10
			HRB4	0.1603	3	0.0167	16
Organizational Barriers (OB)	0.1192	3	OB1	0.1139	4	0.0136	22
			OB2	0.1366	3	0.0163	17
			OB3	0.3488	1	0.0416	8
			OB4	0.0818	5	0.0098	26
			OB5	0.0360	7	0.0043	37
			OB6	0.0666	6	0.0079	29
			OB7	0.2163	2	0.0258	13
Independent Barriers (IB)	0.0361	7	IB1	0.0495	5	0.0018	40
			IB2	0.2526	2	0.0091	27
			IB3	0.1702	3	0.0061	33
			IB4	0.0778	4	0.0028	39
			IB5	0.4500	1	0.0162	18
Knowledge and Awareness barriers (KAB)	0.2565	2	KAB1	0.4805	1	0.1233	1
			KAB2	0.0577	4	0.0148	20
			KAB3	0.2901	2	0.0744	4
			KAB4	0.1717	3	0.0440	7
Technology barriers (TB)	0.1021	5	TB1	0.0454	8	0.0046	36
			TB2	0.0626	6	0.0064	31
			TB3	0.0784	5	0.0080	28
			TB4	0.0464	7	0.0047	35
			TB5	0.0991	4	0.0101	24
			TB6	0.3047	1	0.0311	11
			TB7	0.1344	3	0.0137	21
			TB8	0.2290	2	0.0234	15
Social and environmental barriers (SEB)	0.0661	6	SEB1	0.0939	4	0.0062	32
			SEB2	0.0822	5	0.0054	34
			SEB3	0.0445	6	0.0029	38
			SEB4	0.2438	2	0.0161	19
			SEB5	0.1477	3	0.0098	25
			SEB6	0.3878	1	0.0256	14

Human resource is ranked as the fourth most important barrier. Human resource barriers are an internal barrier of the organization which is basically related to poor performance of employees, few incentive schemes, improper training etc. The human resources need to be properly trained, groomed and empowered to adapt environmental techniques with lean tools in the organization. The technology barrier is ranked as the fourth barrier. The lean and sustainable practices require some advanced technology adoption to reduce waste emissions. Lack of technology advancement can negatively affect the green innovation in firms and create a hurdle while implementing the lean practice. Technology barriers are current concerns for firms as they play a vital role in adopting several green practices such as green transportation, green material handling, green energy, green storage and packaging etc. Rahman et al. (2020) found that infrastructure and technology is a critical barrier to implementing green practices in manufacturing firms. Yadav and Desai (2017) revealed that prime use of technology and communication can help the management in the smooth implementation of lean practices. Yadav et al. (2018) suggested that technology barriers and human resource barriers are obstacles to the quality improvement process. The organization should use upgraded technology with skilled employees. Social and environmental barriers and independent barriers were found at lower positions in the ranking of barriers. These barriers can be taken as internal barriers and external barriers to the organization. The independent barriers and social and environmental barriers are basically due to external factors. Independent barriers contain those challenges which affect the organization while implementing new techniques. Social and environmental barriers contain those barriers which need to be removed by the organization to reduce wastage and improve efficiency.

'Lack of awareness among customers towards sustainability (KAB1)' has been identified as the main sub-category barrier in the sustainable lean implementation process in manufacturing firms. The awareness about environmental impact and sustainability among customers can create pressure on the manufacturer to use green and lean practices in the firm. Moktadir et al. (2018) showed that the lack of awareness of customers about the green product is the most influential barrier for the sustainable supply chain in the Bangladeshi industry. 'Initial capital investment and low financial profit (EMB1)' holds the second position in subcategory barriers. The process of implementing lean and sustainable practices requires a large investment in the production system. The initial capital investment and low financial profits are the main challenges for manufacturing firms to adopt lean and sustainable practices. Parmar and Desai (2020) found that inadequate funds management is the main barrier for the implementation of lean and green practices in manufacturing firms. Kumar et al. (2016) analysed the barriers for green lean six sigma product development and found that initial fund investment and fund allocation are important barriers for manufacturing firms. 'Resistance to change due to past failure (EMB4)' holds the third position in sub-category barriers. The organization shows some resistance to adopting new practices/techniques in the production process due to past failure experiences. Reluctance to change is also a major challenge for lean and sustainable manufacturing implementation in the firm. Singh et al. (2020) found that change resistance is a major barrier for green and lean manufacturing.

'Lack of knowledge about potential benefits from sustainable products and practices (KAB3)' holds the fourth position in sub-category barriers for lean and sustainable manufacturing implementation in MSMEs. The organization should have to know about the potential benefits of the sustainability process in the manufacturing system. Knowledge about the financial and environmental benefits can encourage the firm to adopt lean-led sustainable techniques. Singh et al. (2020) revealed that lack of awareness about potential benefits is a 'cause' barrier that can influence the other barrier directly. 'Lack of training for employees and management (HRB1)' holds the fifth position in the ranking. Practical training can enhance the capability of employees and management while implementing lean and sustainable techniques in the firm. Yadav and Desai (2017) found that training of employees is necessary for organization performance as an unskilled worker can lead to failure during the adoption of lean and green practices. 'Lack of top-level management consciousness towards sustainability (EMB6)' holds the sixth position in the subcategory of barriers. The management plays an important role during the adaption and implementation of a new practice in the firm. Management consciousness towards sustainability issues can help to implement lean-led sustainable practices in the firm. The combined approach can help the firm to become financially, environmentally and socially sustainable. Singh et al. (2020) found that top-level management consciousness is an important barrier for lean and green initiatives in manufacturing firms.

'Lack of awareness of lean tools integration with environmental techniques (KAB4)' was placed seventh in the ranking. Organizations find it difficult to implement lean tools with environmental techniques due to the lack of awareness about tool integration and its benefits. 'Lack of encouragement from the organization (OB3)', 'Ineffective organization management towards the adaption of lean and green practices (EMB2)' and 'Poor team management skills (HRB3)' hold the eighth, ninth and tenth positions respectively. The rest sub-category barriers are also ranked based on the global weights obtained through the BWM approach.

Managers and MSMEs' practitioners might benefit from the ranking of lean and sustainable barriers in the decision-making process. The ranking approach will provide flexibility to choose appropriate steps while implementing lean and sustainable practices. This study will help experts to prioritize the main set of barriers that one needs to focus on at the early stage of lean-sustainable implementation. The study will provide a guide to practitioners and academic researchers. The practitioners can achieve the benefits of implementation and the researchers can expand the area of research with other MCDM techniques and tackle many such barriers.

Blockchain integrated supply chain can help the manufacturing firms to mitigate the new process adoption risks, information sharing risks and counterfeiting risks while implementing lean and sustainable practices. Blockchain technology can improve the quality of products with improvement in various activities such as regulatory compliance assurance, secured information sharing, verified transaction process and safety from fraudulent activities. Blockchain technology helps firms to verify the supplier's certifications, licenses and past transaction histories for a smooth flow in production. The blockchain helps the suppliers, customers and firm's management to share information on the same platform and helps to create direct communication. Blockchain technology advancement also helps in process automation which eliminates the bottlenecks in the production process and improves the firm performance (Kshetri, 2018). Information sharing through blockchain technology helps to become supply chain more responsive to customers' preferences and environmental conditions through easy identification of the problem in the supply chain. Blockchain provides a reliable platform for engaging in collaborating interactions among suppliers, stakeholders and customers with high security in the supply chain (Nandi et al., 2020). Blockchain technology helps to improve the performance outcomes with the reduction in cycle time, reduction in the number of intermediaries process, paperwork and information sharing. The reduction in cycle time helps to reduce the cost of the product and achieve financial benefits.

4.1 Sensitivity Analysis

Sensitivity analysis is carried out to check the reliability and robustness of the ranking model of lean-sustainable manufacturing obtained through the BWM approach. Sensitivity analysis was performed to examine the variation in global weights from the main category barrier to the subcategory barriers. Sensitivity analysis was conducted to check the variation of global weights of main category barriers on sub-category barriers (Ahmad et al., 2020). In this analysis, the weights of the barriers in the highest-ranked main category change from 0.1 to 0.9, and the weights of other barriers change proportionally. In this study, the "economical and managerial barrier" is the highest rank barrier with the weight of 0.3158 and therefore, the main category barrier's weight is adjusted from 0.1 to 0.9 with a 0.1 increment, and the weights of other categories are also determined and shown in Table 7. Table 8 shows the variation in global weight of sub-categories barriers with respect to the variations in main category barriers during sensitivity analysis. In Table 9, the sensitivity study reveals the variance in the global ranking of sub-categories barriers in relation to the differences in main category barriers.

Tables 8 and 9 demonstrate that when the weight of the "economical and managerial barrier (EMB)" is changed from 0.1 to 0.3, then the barrier "Lack of awareness among customers towards sustainability (KAB1)" gets ranked 1. But, after 0.3 to 0.9, the barrier "Initial capital investment and low financial profit (EMB1)" get ranked 1. Tables 8 and 9 also show that when the weight is increased from 0.1 to 0.9, then the barrier "Lack of support from the government to introduce sustainable practices (IB1)" gets the 40th position consistently which is the lowest rank in the model. Further, it is also observed from Table 9 that the ranking of barriers such as "Resistance to change due to past failure (EMB4)", "Lack of top-level management consciousness towards sustainability (EMB6)", "Ineffective organization management towards the adaption of lean and green practices (EMB2)" and "Lack of risk management methods (EMB3)" improved with the change in weights.

Table 7. Weights of main category barriers during sensitivity analysis.

Main Category	Normal Weights	Modified Weights								
EMB	0.3158	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
HRB	0.1042	0.1347	0.1198	0.1048	0.0898	0.0749	0.0599	0.0449	0.0299	0.0150
OB	0.1192	0.1569	0.1394	0.1220	0.1046	0.0871	0.0697	0.0523	0.0349	0.0174
IB	0.0361	0.0471	0.0418	0.0366	0.0314	0.0261	0.0209	0.0157	0.0105	0.0052
KAB	0.2565	0.3399	0.3022	0.2644	0.2266	0.1889	0.1511	0.1133	0.0755	0.0378
TB	0.1021	0.1353	0.1202	0.1052	0.0902	0.0751	0.0601	0.0451	0.0301	0.0150
SEB	0.0661	0.0861	0.0766	0.0670	0.0574	0.0479	0.0383	0.0287	0.0191	0.0096
Total	1.000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table 8. Global weight of sub-category barriers during sensitivity analysis.

Sub-criteria	Normal (0. 0.3158)	Run 0.1	Run 0.2	Run 0.3	Run 0.4	Run 0.5	Run 0.6	Run 0.7	Run 0.8	Run 0.9
EMB1	0.1117	0.0354	0.0663	0.0995	0.1326	0.1658	0.1990	0.2321	0.2653	0.2984
EMB2	0.0373	0.0118	0.0245	0.0367	0.0490	0.0612	0.0735	0.0857	0.0979	0.1102
EMB3	0.0259	0.0082	0.0182	0.0273	0.0363	0.0454	0.0545	0.0636	0.0727	0.0818
EMB4	0.0807	0.0255	0.0531	0.0796	0.1062	0.1327	0.1593	0.1858	0.2124	0.2389
EMB5	0.0124	0.0039	0.0082	0.0123	0.0164	0.0205	0.0246	0.0288	0.0329	0.0370
EMB6	0.0478	0.0151	0.0297	0.0446	0.0594	0.0743	0.0891	0.1040	0.1189	0.1337
HRB1	0.0491	0.0634	0.0564	0.0494	0.0423	0.0353	0.0282	0.0211	0.0141	0.0071
HRB2	0.0064	0.0083	0.0073	0.0064	0.0055	0.0046	0.0037	0.0028	0.0018	0.0009
HRB3	0.0320	0.0414	0.0368	0.0322	0.0276	0.0230	0.0184	0.0138	0.0092	0.0046
HRB4	0.0167	0.0216	0.0192	0.0168	0.0144	0.0120	0.0096	0.0072	0.0048	0.0024
OB1	0.0136	0.0179	0.0166	0.0145	0.0124	0.0103	0.0083	0.0062	0.0041	0.0021
OB2	0.0163	0.0214	0.0182	0.0159	0.0136	0.0114	0.0091	0.0068	0.0045	0.0023
OB3	0.0416	0.0547	0.0463	0.0405	0.0347	0.0289	0.0231	0.0174	0.0116	0.0058
OB4	0.0098	0.0128	0.0124	0.0109	0.0093	0.0078	0.0062	0.0047	0.0031	0.0015
OB5	0.0043	0.0056	0.0051	0.0044	0.0038	0.0032	0.0025	0.0019	0.0013	0.0006
OB6	0.0079	0.0104	0.0100	0.0088	0.0075	0.0063	0.0050	0.0038	0.0025	0.0013
OB7	0.0258	0.0339	0.0309	0.0270	0.0232	0.0193	0.0154	0.0116	0.0077	0.0039
IB1	0.0018	0.0023	0.0021	0.0019	0.0016	0.0013	0.0011	0.0008	0.0005	0.0003
IB2	0.0091	0.0119	0.0109	0.0095	0.0082	0.0068	0.0054	0.0041	0.0027	0.0014
IB3	0.0061	0.0080	0.0072	0.0063	0.0054	0.0045	0.0036	0.0027	0.0018	0.0009
IB4	0.0028	0.0037	0.0032	0.0028	0.0024	0.0020	0.0016	0.0012	0.0008	0.0004
IB5	0.0162	0.0212	0.0184	0.0161	0.0138	0.0115	0.0092	0.0069	0.0046	0.0023
KAB1	0.1233	0.1633	0.1293	0.1131	0.0970	0.0808	0.0647	0.0485	0.0323	0.0162
KAB2	0.0148	0.0196	0.0157	0.0138	0.0118	0.0098	0.0079	0.0059	0.0039	0.0020
KAB3	0.0744	0.0986	0.1019	0.0892	0.0764	0.0637	0.0510	0.0382	0.0255	0.0128
KAB4	0.0440	0.0584	0.0552	0.0483	0.0414	0.0345	0.0276	0.0207	0.0138	0.0069
TB1	0.0046	0.0061	0.0050	0.0043	0.0037	0.0031	0.0025	0.0019	0.0012	0.0006
TB2	0.0064	0.0085	0.0076	0.0066	0.0057	0.0047	0.0038	0.0028	0.0019	0.0009
TB3	0.0080	0.0106	0.0092	0.0081	0.0069	0.0058	0.0046	0.0035	0.0023	0.0011
TB4	0.0047	0.0063	0.0067	0.0059	0.0050	0.0042	0.0033	0.0025	0.0017	0.0008
TB5	0.0101	0.0134	0.0117	0.0102	0.0088	0.0073	0.0059	0.0044	0.0029	0.0015
TB6	0.0311	0.0412	0.0351	0.0307	0.0263	0.0219	0.0175	0.0132	0.0088	0.0044
TB7	0.0137	0.0182	0.0160	0.0140	0.0120	0.0100	0.0080	0.0060	0.0040	0.0020
TB8	0.0234	0.0310	0.0290	0.0254	0.0217	0.0181	0.0145	0.0109	0.0073	0.0036
SEB1	0.0062	0.0081	0.0065	0.0057	0.0049	0.0041	0.0032	0.0024	0.0016	0.0008
SEB2	0.0054	0.0071	0.0063	0.0055	0.0047	0.0040	0.0032	0.0024	0.0016	0.0008
SEB3	0.0029	0.0038	0.0036	0.0031	0.0027	0.0022	0.0018	0.0013	0.0009	0.0004
SEB4	0.0161	0.0210	0.0199	0.0174	0.0149	0.0124	0.0099	0.0074	0.0050	0.0025
SEB5	0.0098	0.0127	0.0113	0.0099	0.0085	0.0071	0.0057	0.0043	0.0028	0.0014
SEB6	0.0256	0.0334	0.0290	0.0254	0.0218	0.0182	0.0145	0.0109	0.0072	0.0036

Table 9. Global ranking of sub-category barriers during sensitivity analysis.

Sub-criteria	Normal (0.3158)	Run 0.1	Run 0.2	Run 0.3	Run 0.4	Run 0.5	Run 0.6	Run 0.7	Run 0.8	Run 0.9
EMB1	2	8	3	2	1	1	1	1	1	1
EMB2	9	25	14	9	6	6	4	4	4	4
EMB3	11	30	18	12	9	7	6	5	5	5
EMB4	4	12	6	4	2	2	2	2	2	2
EMB5	23	37	29	23	16	13	10	8	6	6
EMB6	5	20	11	7	5	4	3	3	3	3
HRB1	7	3	4	5	7	8	8	9	9	9
HRB2	34	29	31	31	31	31	31	31	31	31
HRB3	13	6	8	10	11	11	12	12	12	12
HRB4	21	13	16	17	18	18	18	18	18	18
OB1	19	19	20	20	21	21	21	21	21	21
OB2	17	14	19	19	20	20	20	20	20	20
OB3	8	5	7	8	10	10	11	11	11	11
OB4	24	22	23	24	24	24	24	24	24	24
OB5	36	36	36	36	36	36	36	36	36	36
OB6	28	27	27	28	28	28	28	28	28	28
OB7	12	9	10	13	13	14	14	14	14	14
IB1	40	40	40	40	40	40	40	40	40	40
IB2	27	24	26	27	27	27	27	27	27	27
IB3	31	32	32	32	32	32	32	32	32	32
IB4	39	39	39	39	39	39	39	39	39	39
IB5	18	15	17	18	19	19	19	19	19	19
KAB1	1	1	1	1	3	3	5	6	7	7
KAB2	22	17	22	22	23	23	23	23	23	23
KAB3	3	2	2	3	4	5	7	7	8	8
KAB4	6	4	5	6	8	9	9	10	10	10
TB1	37	35	37	37	37	37	37	37	37	37
TB2	30	28	30	30	30	30	30	30	30	30
TB3	29	26	28	29	29	29	29	29	29	29
TB4	32	34	33	33	33	33	33	33	33	33
TB5	25	21	24	25	25	25	25	25	25	25
TB6	10	7	9	11	12	12	13	13	13	13
TB7	20	18	21	21	22	22	22	22	22	22
TB8	14	11	13	15	15	16	16	16	15	16
SEB1	33	31	34	34	34	34	34	34	34	34
SEB2	35	33	35	35	35	35	35	35	35	35
SEB3	38	38	38	38	38	38	38	38	38	38
SEB4	16	16	15	16	17	17	17	17	17	17
SEB5	26	23	25	26	26	26	26	26	26	26
SEB6	15	10	12	14	14	15	15	15	16	15

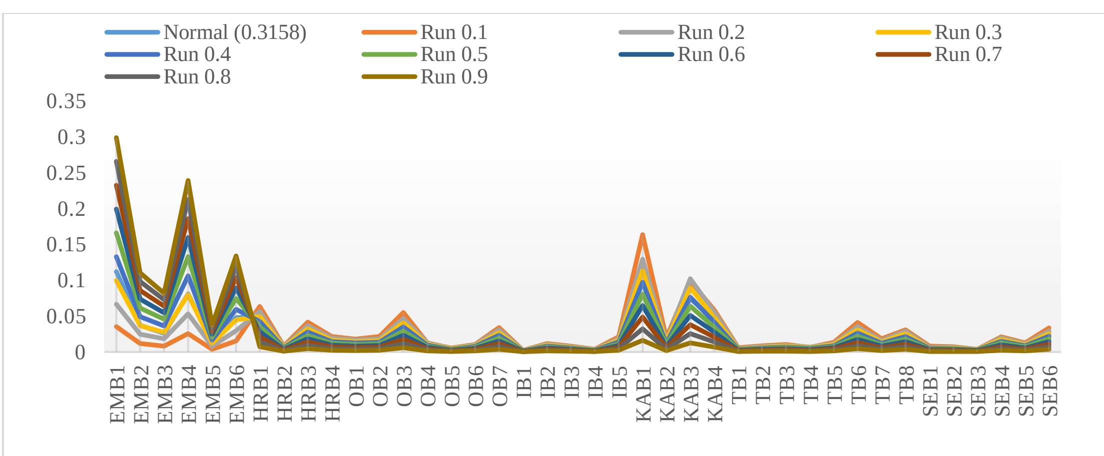

Figure 3. Variation in global weights of sub-category barriers during sensitivity analysis.

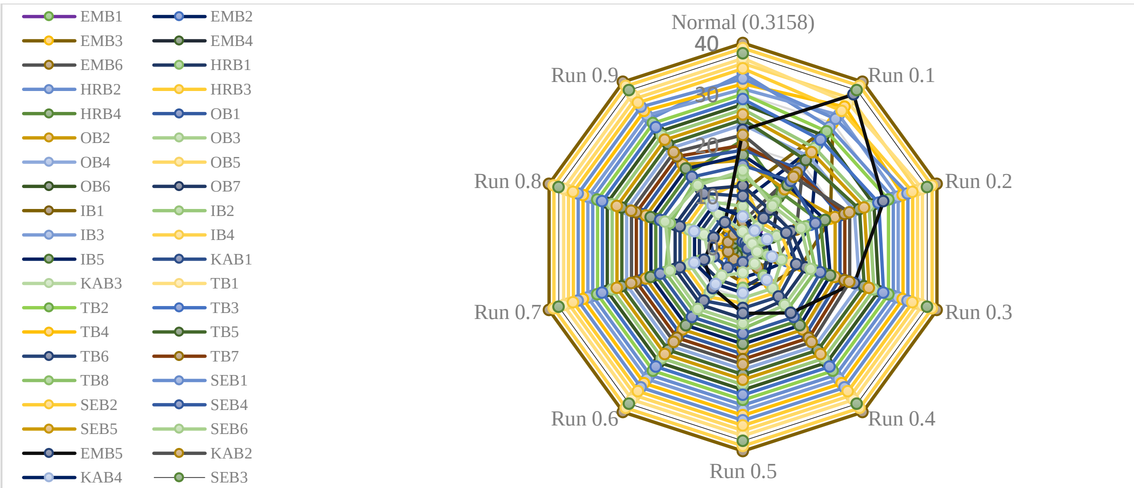

Figure 4. Variation in the global ranking of sub-category barriers during sensitivity analysis.

The sensitivity analysis helps to analyse the sensitiveness of the final global ranking of subcategory barriers due to the changes in weights of main barriers (Table 9). The variation in global weights and global ranks of sub-category barriers are also analysed pictorially in Figure 3 and Figure 4 respectively. It can be observed from Figures 3 and 4, that among the barriers of sub-categories, "Initial capital investment and low financial profit (EMB1)" and "Lack of support from the government to introduce sustainable practices (IB1)" are the most and least important barriers for implementation of lean and sustainable manufacturing. Sensitivity analysis shows that the ranking of sub-category barriers does not vary much even after changing the weights of the main barriers. Hence the results obtained in the study are reliable and the proposed model is robust.

5. Managerial Implications

In developed countries, governments and agencies are promoting the effective use of sustainable tools and lean tools to achieve an environmentally friendly system (Rahman et al., 2020). In developing countries, the adoption and implementations of lean and sustainable manufacturing are still in their early stage (Ben Ruben et al., 2018; Rahman et al., 2020). Studies from previous researchers reveal that many Indian MSMEs are still unaware of the combined approach of environmental and lean tools (Prasad et al., 2020). From this perspective, this study encourages Indian MSMEs managers and practitioners to overcome the challenges of lean and sustainable manufacturing through effective decision-making. The identification and prioritization of barriers will help MSMEs managers to improve the environmental, financial and social performance of the firm. The study will motivate the management to understand the importance of the combined approach of lean-led sustainable practices and promote the techniques among stakeholders, suppliers, customers and practitioners. The management can also create a positive work culture in the organization which helps to implement lean-led sustainable practices in the manufacturing process. The study identified some of the social and environmental barriers connected with organization performance which assess the social and environmental sustainability. The inclusion of lean and sustainable manufacturing will help the firm to make the brand image with sustainable growth. Human resource barriers will help the management to understand the role of employees in team management. The implementation of lean-led sustainable manufacturing will encourage employees participation and commitment to decision making.

The study explores the importance of blockchain technology in the lean-led sustainable manufacturing supply chain to achieve sustainability. The paper attempts to analyse the role of blockchain technology to overcome the barriers for the implementation of lean and sustainable manufacturing practices in Indian MSMEs. Blockchain technology provides several advantages such as transparency, accessibility, security and reliability in the supply chain. The paper presents a conceptual framework to show how can blockchain technology helps firms to counter the barriers and achieve benefits with improvement in supply chain performance. The integration of blockchain technology in the supply chain will help the firms to select, verify and evaluate the potential suppliers and stakeholders for environmental sustainability. The verification and evaluation process based on data history can help the firm in supplier selections as well as lead to maintaining long-term relationships. The continuous auditing and monitoring of supply chain partners for environmental and social sustainability will help the firms to provide necessary training and certification programs for suppliers. The integration of technology will also make the firms more competitive in the global market. Blockchain technology can also play an important role in the life cycle assessment of a product. The technology can help the firm to track the product recycling, reusing and remanufacturing status that finally helps to achieve a circular economy.

6. Conclusions

Globalization and market competition create pressure on manufacturing firms to improve their financial and environmental performance. MSMEs are continuously trying to reduce the waste emissions and defects rate in the production system to improve performance. MSMEs play a significant role in the growth of a country's economy. Thus, it is important to analyse the barriers faced by MSMEs while implementing lean and sustainable manufacturing techniques. The combined approach of lean and sustainable techniques has been recognised as an emerging research area due to concern towards sustainability. The study presents the ranking of barriers for the implementation of lean-led sustainable manufacturing in Indian MSMEs with the help of the BWM approach. The study presents a total of forty barriers that have been selected through literature review and expert opinions. These barriers have been categorized further under seven main categories. The BWM technique was used to rank the barriers with the help of the experts' team. According to the study, the key barriers to the application of lean and sustainable manufacturing include: "economical and managerial barriers' and 'knowledge and awareness barriers'. The barriers under subcategories have also been ranked based on global weight. Lack of awareness among customers towards sustainability, initial capital investment and low financial profit, lack of knowledge about potential benefits from sustainable products and practices and resistance to change due to past failure have been found as the main subcategories of barriers for lean and sustainable manufacturing implementation in MSMEs.

Blockchain technology can be used as a transparent and reliable platform for data storage in a lean-led sustainable supply chain. The barriers associated with the implementation of lean and sustainable manufacturing in MSMEs can be overcome with the implication of blockchain technology. The study proposes a framework of blockchain technology to overcome barriers of lean and sustainable manufacturing and analyse the effect on supply chain performance for Indian MSMEs. It is important for MSMEs to become sustainable as it can help to enhance the economic profit of the supply chain with improvement in social and environmental performance. Blockchain technology can help the supply chain to become more green through the adoption of the 3R (Reuse/ recycle/remanufacture) approach. The study tries to establish a relationship between lean and sustainable manufacturing with blockchain technology features such as integration of real-time information sharing, reliability, data security, traceability and accessibility. The study also analyses the impact of blockchain technology on the performance of lean-led sustainable supply chain.

The comprehensive approach of lean and sustainable/green practices includes concepts of waste reduction, cycle time reduction, cost minimization, 3R approach (reduce, reuse and remanufacture) and sustainable growth. The lean-led sustainable practices help the manufacturing firm to improve their economic, social and environmental performance. However, in developing countries like India, the implementation of lean and sustainable/green practices in MSMEs is difficult due to lack of funding, lack of knowledge, resistance to change behaviour and lack of technology competency. The MSMEs also believe that lean and sustainable practices require a large amount of time investment for developing and implementing sustainable practices. Lack of support from the government to introduce sustainable practices is found as a minor barrier for MSMEs to implement lean and sustainable practices. It is observed that government support with strict regulations is inhibiting MSMEs' ability to adopt new lean and sustainable/green practices, as their main focus is always to abide by the regulations to survive in the market. The experts who participated in the study also suggested that there is a need for support from government bodies to select the proper set of lean and sustainable/green tools to drive sustainable business. If sustainable business practices are to become more than merely examples in a few enterprises, MSMEs and larger enterprises must confront these challenges. In summary, if MSMEs are to implement lean and sustainable/green practices, they need to understand the potential criticality of barriers that arises during the implementation of these practices. The study has analysed the potential barriers for lean and sustainable/green practices so that the MSMEs can strategically overcome these barriers faced in the direction of sustainability growth.

7. Future Research Direction

Every study consists of some limiting factors that constrain the results and scope of the study. It is necessary to highlight these limitations and present them so that future researchers may take care of these constraints. Firstly, the study conducted here focused on manufacturing firms, so the barriers for other industry sectors can be different and need to be analysed with other ranking approaches. Secondly, the barriers ranked here are based on Indian MSMEs. The barriers can differ based on the geographical location of the country, government policies, regulations, customer requirements etc. In future, studies can be carried out in other industries situated in different geographical locations. Thirdly, the data collected in the study was based on the likert scale rating which limits the opinions of experts to a predefined scale rating. In future, researchers can use qualitative data such as direct interviews, open-ended questions and more structured interviews to gain in-depth insight. The qualitative approach can help one to identify practical barriers and their solution in the manufacturing system. Lastly, the study used the BWM approach to rank the barriers for the implementation of lean and sustainable manufacturing practices in MSMEs. Other MCDM techniques such as Fuzzy TOPSIS, WASPS, Fuzzy SAW (Simple Additive Weighting), Fuzzy VIKOR etc. can be used as an alternative approach to compare the results obtained from the BWM approach. The study can also be expanded by the application of the structural equation modelling approach with the inclusion of more experts to analyse the relationship between barriers.

Blockchain technology and its integration in lean-led sustainable supply chain are derived from literature and experts' opinions. This model can be validated with empirical data or actual implementation in case studies firms. The potential risk of data leaks and possibilities of fraud can be considered as future scope of consideration to create a more secure platform for forensic accounting and auditing purposes. Integration of blockchain technology with other technologies such as artificial intelligence, big data analytics and machine learning can also be beneficial for MSMEs' growth.

Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work.

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