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Justification of Lean-Green Strategies for Performance Enhancement in Manufacturing Industry of India- An Empirical Investigation

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Abstract: Lean Green approach is a way to reduce mud/waste by eliminating unnecessary activities. This study was done to assess the performance of lean green strategies in manufacturing industry of India. Questionnaire survey has been performed followed by application of structural equation modeling and fuzzy TOPSIS. Results indicated that companies are focused on Kaizen improvement approach (small incremental improvements) to a very high extent in terms of lean strategies and green scheduling in terms of green strategies. Five highly significant strategies are ranked based on multi-criteria-decision-making approach namely fuzzy TOPSIS. Continuous optimization of manufacturing processes is ranked to very high extent. Research and Development aspects and pollution prevention are highly improved by implementing lean green approach.

Keywords: Lean-Green approach; Survey; Kaizen; fuzzy TOPSIS

1. Introduction

The Lean-Green approach combines lean manufacturing's efficiency-focused principles with green strategies aimed at environmental sustainability. In this context, the DMAIC (Define, Measure, Analyze, Improve, and Control) technique plays a crucial role in identifying and addressing the drivers and barriers of Lean-Green implementation. In this study, the DMAIC framework was utilized to systematically evaluate key factors influencing the adoption of Lean-Green strategies in Indian manufacturing industries. Specifically, the technique was applied to define critical success factors, measure their impact through data collection, analyze barriers to implementation, propose improvement strategies, and establish control mechanisms for sustained adoption. Lean and Green strategies is a management topic which involves industrial companies in manufacturing. Improvement in efficiency is the main aim of implementing lean green strategies. The solution of reducing waste in supply chain is the major contribution of such strategies. Lesser investment in inventory and reduction in lead time are obtained from lean green implementation by eliminating environmental and industrial wastes. Environmental aspects and waste elimination are major benefits of lean-green implementation they rely that Green lean combination is increase the effectiveness of a manufacturing company. DMAIC technique is used for update the driver and barrier of lean green. Proper implementation of lean and green in manufacturing company. GSCM performance evaluation of industries multi-criteria decision making (MCDM) techniques and fuzzy group decision making methods should be implementation for complex multi-attribute problems in fuzzy environment, green design, green purchasing, green transformation, green logistics[1)]. Growing supply chain has many complexities arises out to implementing lean and green strategies. Environmental benefits and advantages, economic benefits and social benefits are obtained by implementing these strategies. Figure 1 shows different lean green drivers. Combined benefits of Lean-green strategies on quality performance and organization sustainability. Lean and green strategies in support with innovation strategies improve environmental sustainability and reduce cost for achieving economic benefits. According to this study integration and make a framework between Le-Green in manufacturing processes to improve the overall production and improve production technique. Integration of lean production and green production will affect sustainability of production and quality[2)]. Wastes and value are differentiated in organization by lean and green concept. Segregation of non-value-added acts is done by implementing the concept of lean green. Improvement in energy efficiency by eliminating seven wastes is done by Le-Green approach. Sustainability attainment through lean and green strategies is the most complex task as compared to mass production paradigm[3]. Claimed that identifying and eliminating production losses has successfully introduced the approach of lean and green strategies. Rectification of environmental wastes is the main aim of green strategies for enhanced manufacturing performance improvement. Campos and claimed that horizontal deployment of lean strategies leads towards performance improvement in future and only possible in high confidence degree and good knowledge about consequences[4]. This study is an attempt of assess the performance of lean green procedure in manufacturing companies of India. Questionnaire preparation has been done followed by filling them and results are presented.

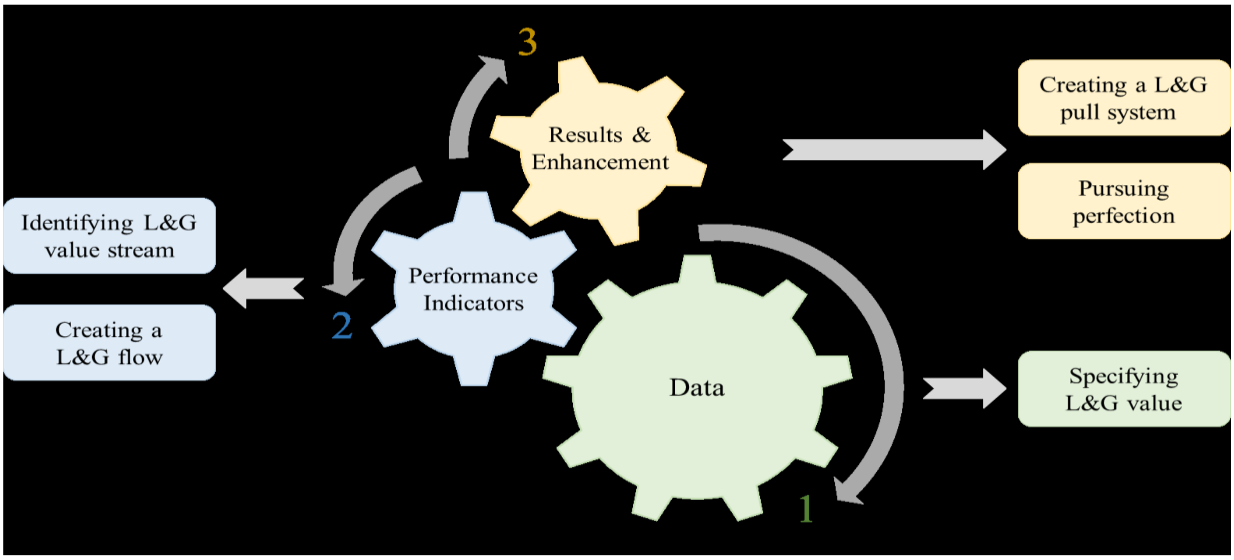

Fig. 1: Lean and Green Drivers. Source (Kuo and Lin, 2020).

The current study builds on and extends the existing body of literature on Lean-Green strategies by addressing notable gaps in both theoretical understanding and practical application within the Indian manufacturing context. Previous studies, such as those conducted in Europe and Southeast Asia, have demonstrated the efficacy of Lean-Green integration in achieving sustainability goals through frameworks like green supply chain management (GSCM) and multi-criteria decision-making (MCDM) approaches such as DEMATEL-ANP-TOPSIS. However, their findings primarily focus on mature industrial settings with well-established sustainability practices. In contrast, the present study uniquely explores Lean-Green strategies in Indian manufacturing, emphasizing incremental improvements (Kaizen), pollution prevention, and waste reduction tailored to the resource and workforce constraints of the region. This research further innovates by applying a combination of fuzzy TOPSIS and structural equation modeling (SEM), enabling precise ranking and validation of the strategies' impact on economic, environmental, and social dimensions. By highlighting these distinctive methodological contributions and demonstrating their practical implications, the study advances the field, providing a foundation for future research in leveraging Industry 4.0 and AI-driven tools for enhanced Lean-Green adoption in emerging economies. This structured approach ensures that the findings are both actionable and aligned with the practical realities of industrial processes.

The present study explores the synergistic impact of Lean-Green strategies on manufacturing performance, emphasizing their economic, environmental, and social dimensions. The revised section now explicitly highlights the application of structural equation modeling and fuzzy TOPSIS to evaluate and rank key strategies. This provides a comprehensive understanding of how these methods contribute to sustainability and operational efficiency in the Indian manufacturing context.

2. Literature Review

Lean and Green strategies is a management topic which involves industrial companies in manufacturing. Improvement in efficiency is the main aim of implementing lean green strategies. The solution of reducing waste in supply chain is the major contribution of such strategies. Value Stream mapping is the main tool of lean manufacturing is used to find the waste and improve the sustainability. Developed the VSM to Sus-VSM. Sus-VSM consists of economic, environmental, and social Benefits. According to this the development of VSM is used to achieved the sustainability[5].

Suggested that a methodically frame work design for six sigma. Lean and Green integrated approach beneficial for economic and sustainable performance of the industry. This Design to reduce cost, improve performance, minimize the energy resources of the Origination[6].

Using the Analytic Network Process, green supply chain management (GSCM) lessens the environmental effects of industrial operations. In six criteria function find the GSCM approach which is most helpful for MCDM Problem. An ANP create the Relationships between criteria and sub-criteria to understand the typical problem easily. To improve the green innovation[7].

According that Dubai city in plastic industry to improve the quality and customer satisfaction with the help of implementation of TQM and Six Sigma. How to cost reduce the Plastic product and maintain the quality so that profitable business. The study result that TQM and Six Sigma policy implication is to improve the environmental benefits[8].

According to Lean Management tools like 5S, Kazein, VSM, TPM and Six Sigma tools is used to eliminate errors and reduce waste and increase the production. In an organization to improve the workmanship, to reduce down time Lean tool to be used to maintain sustainability. But Lean tool proper not used in industries some barrier is coming during implementation like employee involvement, Lack of fund for training, employee fear to take more responsibility, lack of management. So that full utilization of that lean tool increases the quality, reduce the cost of product means increase the all performance of the organization[9].

According to this study integration and make a framework between Le-Green in manufacturing processes to improve the overall production and improve production technique. Manufacturing sustainable productivity and quality will be impacted by the integration of lean production techniques with green production practices[10].

The main objective of paper the combine effect of lean and green is very positive impact for manufacturing industries instead of individual uses of these approaches. Lean and green approaches improving organizational performance like economic, environmental and social dimensions[11].

Six Sigma DMAIC, qualitative and quantitative research method and statistical techniques used for increase the efficiency of the maintenance process. According to this study to find better technology which is used for reduce the failure and improve the maintenance system. In this paper the study of SS project method is used for collected the data from the process and find the factors from the data used for CTQ process performed and analysis the cause of failure. So that to find that failure and improve the maintenance process[12].

According to these paper lean and environmental approaches is beneficial for manufacturing firm. More development of the combination of this lean and green for an industry[13].

Author described a manufacturing industry provide the data of environmental report and various policies. The climate change due to Greenhouse gas emissions. Economic growth of a city due to industrialization but effect on its environment down step. To maintain the environment, it is beneficial to use integrated sustainability development. In which a sample of 30 Indian manufacturing company data collected and find the environment initiatives taken by these company. Information was converted into quantitative information index was calculated on the basis of environmental data based on themes[14].

In Evergreen Journal we learn that GHRM awareness in industry is most important for growing country. Says that Human resource require involvement of employees in environment beneficial program and maintain ecofriendly environment. Organize seminar and training given to the employees for green environment, way of working how to increase production and reduce waste[15].

It was considered for synergies between new innovation and future planning practices are beneficial for an organization. A case study of 162 SME Company finds the observation and applies both integrated approaches after apply both approach and found impact of suppliers and customers' relationship beneficial for company[16].

The purpose of analytic hierarchy process (AHP) Techniques is used for manufacturing company. New technology and supply chain is used in industry for better performance/output. AHP and ANP models is used for the industry 4.0 for better performance[17].

LM implementing involves employees of the organization and good communication for its full implementation. It is an approach that typically aims at uniform and smooth production flow by reducing waste[18].

Described that make a GRI framework for find the sustainability for commercial banks. To prepare the report on 28 commercial bank sustainability by python software and Mann Whitney U test to find the performance of the bank. To develop a benchmark to increase the sustainable performance[19].

Study was done to develop a frame work, and method, driver and barrier for combined approach of lean green and Six Sigma for manufacturing industry sustainability.

Development of three strategies is used for increase the performance and environmental beneficial for an industry. Strategies are Practical implementation social implementation, Originality value is used to reduce waste, reduce pollution and increase the performance of manufacturing industry[20].

Green lean combination is increasing the effectiveness of a manufacturing company. They used DMAIC technique is used for update the driver and barrier of lean green. Proper implementation of lean and green in manufacturing company[21].

Lean production and operational performance on industry 4.0 technologies in Brazil develop country. Total 147 companies surveyed on lean and industry 4.0 technologies on production, quality as performance index for multivariate data analyses. Lean manufacturing used to improve the design of organization, inventory control and performance organization toward the industry revolution[22)].

In the Portuguese area on lean-green supply chain management on sustainability, Data collected and Analysis done. Make a framework model to drive the analysis implementation lean and green practices on supply chain management. Identify the Combined both to eliminate the waste, risk management. Both Approaches is practices at three levels: upstream, organization and downstream used this to increase the sustainability. They study on environment, social, economic lean and green chain management for improvement the sustainability and development of the approaches toward step to an organization[23)].

According to “Low carbon” approaches most important for minimize the carbon emission from environment in a manufacturing company. The techniques for finding ideal solution using fuzzy technology have been developed for selecting low carbon suppliers. Author described that MCDM using fuzzy DEMATEL- TOPSIS-ANP, used to find the cause and effect for better output. LCSCM is used sustain the economic benefits, social benefits better environment benefits. They suggested that combined approaches of DEMATEL-ANP-TOPSIS methodology is used to find the better supplier which have good performance index data and various variable analysis and solve the problem. A MCDM approach is used to improve the low carbon supplier. Many MCDM approach is find by this study solve the problems for best result.[24)]

Examined that lean six sigma technology is used for waste reduction. They find the non-value-added activity in manufacturing company. To reduce the waiting time and improve the overall performance of the manufacturing industries[25)].

Lean and green approaches is used for small and medium enterprises (SMEs), for economic and sustainable performance. They used quantitative and qualitative approaches. And studied 157 articles and review and observed the analysis find the gap. No work on lean and green approaches for sustainability performance for manufacturing industries. They proposed research finding for future performance directions[26)].

Finding the effect of top management leadership and culture transformation on relations between lean-green practices find that Lean and green approach beneficial for SME. Survey and collected the data of 345 Indonesia manufacturing SME and apply SEM. Observed that lean and green effect and increase the sustainability performance of the manufacturing industries. Two factors first are policy makes for Indonesia SME second is integrated decision-making supply chain mechanism for SME. They guide that a framework makes that to more implement the lean and green approaches[27)].

According that lean methodology, non-value-added activities and wastages are removed. Observed that identify the 18 critical lean indicators in manufacturing company from various studies to measure the output of lean implementation for decision making and defined category in three part Financial, operational and human resources with analytical hierarchy model. Training given to the employee regarding lean implementation for best performance of organizations[28)].

System of lean green implementation is devoted to kaizen (continuous improvement) and waste elimination. Lean and green approach to improve the performance sustainability, environmental management system is controlled by lean green approach. It involves integration of investment in supply chain and lean manufacturing system[29)].

It was described that (MCDM) methodology is used to financial increment of bank in India. The ranking cycle is find by used the fuzzy analytical hierarchy process (AHP) approach. They suggested proposed a framework for sustain financial performance of the commercial banks[30)].

They described the relationship XPS production system and lean based programmed. A manufacturing company management system combined with XPS system such as ISO 9001 and 14001 for environment beneficial and improve the improved organization performance[31)].

Study was done on survey of 268 samples in Kaohsiung has been performed to investigate relationship between green operations, lean manufacturing on green performance. A hierarchical regression is also used for performance for an organization[32)].

(MCDM) approach is used to increase the financial performance private sector banks. TOPSIS (IV-TOPSIS) technique has been implemented to assess the performance of the bank. The analysis of this technique to find the financial performance various bank and how to increase the financial health[33)].

Different corporate cultures and process specificities are required in these organizations for strategies implementation of lean manufacturing approach. Environmental, economic and social pillars of sustainability have been copied by implementing lean green concept in systematic approach for enhanced competitiveness[34)].

Corporate social responsibility is very important for industrial management for their good image. Wastes and value are differentiated in organization by lean and green concept. Segregation of non-value-added acts is done by implementing the concept of lean green. Improvement in energy efficiency by eliminating seven wastes is done by lean and green approach[35)].

Combination of Internet of Things and Green Manufacturing is most important for better result. They studied that IoT technology is very important for M.Mgt. The impact of Green Manufacturing in BPM and PLC combined of GM and IoT is beneficial for M. Mgnt[36].

According that LINGO programming software mathematical approach to find the recovery cost for transportation disruptions in a cold chain system in which economic and environmental impact. The developed an inventory model. In this study, operational decision of the cold chain to reduce carbon content, during unexpected stoppage in supply chain process has been implemented. Analyze the developed optimization technique to way for decision makers on the optimal production so that reducing carbon emissions and sustaining the environment[37].

Green supplier is a critical activity in low-carbon supply chain. This study used fuzz-grey multi-criteria decision-making approach and grey rational method to solve the green supplier selection problems. He proposed a study; a questionnaire on fuzzy logic can be used for data collection to prevent bias in information[38].

Sustainable six sigma (SLSS) method is used for reducing defects, economic, cost reduction, economic, environmental and social aspects for manufacturing industries. They study on 129 Scopus data base published paper observed data quantitative study, framework made on the SLSS, to use in various industries for growth overall performance of the manufacturing company[39].

They focused on to increase the productivity and reduce cost of the manufacturing company. To add value adds service by lean manufacturing with 4.0 technologies in SMEs for overall manufacturing performance. They find the 12 (CSF) Factors and combined of Management, technological, organizational, and economics. A hierarchical technique is made based these factors to finding the beneficial technique is used in SMEs to implement lean approaches with industry 4.0 technologies is more effective and standard path for industries benefits[40].

It was performed analyze the model from literature that is focused on green, lean and sustainability related aspects. The bibliometrics analysis was used in this study. They discover that in order to achieve triple bottom line (TBL) progress, a model for lean-green and sustainability practices was put out. They used lean approach with TPM - Total Productive Maintenance - and 6Rto achieve environmental, social and economic benefits for an organization[41].

Study was done on barrier in lean implement used in (SME) manufacturing company. Interpretive Structural Modeling (ISM) methodology is used on 15 identified barriers and make model how to manage the lean barrier. After using both methods (ISM) and (MICMAC) made level 10. Barrier 1, the highest dependence power, Barrier 4, “Lack of Long- Term Commitment to Change and Innovation”. At level 10 “individual attitude” barrier is placed. Strong driving power and dependency power barriers are placed at number 9. So that these 2 barriers are identified as “Independent Factors” of lean implementation barriers within the organization[42].

It was done a framework implementation of lean manufacturing in small-medium companies manufacturing machining industry for increase the economic growth, environment benefits, and social benefits. The aim of LM is to produce high quality product with minimum waste. Many organizations are transformation into lean organization[43].

To generate a performance index numerical value, a mathematical model is subjected to a quantitative evaluation. Impact Matrix Cross-Reference Multiplication (MICMAC) analysis is also used for overcome of lean implementation barrier[44].

Combine effect of GPC and TECH on 1018 European industries after implementation this approaches on manufacturing company show the result on beneficial environment and financial performance increase of the manufacturing industries. The authors find the different level of implementation after we achieved various level of improve environmental and financial performance. So that implementation of technology, that has significant impact on both financial and environmental performance is must for manufacturing organizations[45].

Authors described that develop sustainable-value stream mapping, lean-green principles, and the Manufacturing Sustainability Index (MSI). The AHP technique finds the indicator the sustainable-value stream analysis is used to rate the relevant indication with an efficiency approach after the Delphi technique selects the appropriate indicator. This framework is used for finding the sustainability in the manufacturing process[46].

Cronbach's alpha is used to determine how reliable these parameters. The ranking of CSFs, the Fuzzy- AHP Process compares these factors pairwise. Identify CSFs and determine the weight of GM's detected CSFs in the automotive sector[47].

Author described that RCPES is a five-phase framework that integrates sustainability and green-lean concepts to continuously enhance the economic, social, and environmental performance and operations of manufacturing companies[48].

The application of the combined lean and agile manufacturing approach is crucial for these industries in order to get better results and increased performance.[49]

Lean-Green strategy with a Six Sigma methodology (SLGS). In this study find the benefits of conducting SLGS for waste reduction, energy reduction, and productivity and social improvements[50].

Claimed that green-lean model looks upon synergies of lean green approach and practices systematically. Successful deployment of green-lean strategies is required to fully implement the model in systematic manner. In the current manufacturing scenario, companies are implementing new tools in order to improve company’s competitiveness and efficiency[51].

Author survey and give the finding observation on green environment in japan country. The Green Paradox is the introduction of renewable energy does not have a positive effect. Green Paradox in Japan, it is necessary to needs to establish advanced and sophisticated evaluation method[52].

Analyzed the environmental problems in Japan and Germany for sustainable development for future[53].

According to integrated lean green and value stream mapping technique in plastic manufacturing company. Kaizen and 5S approaches are implemented to assess integrated lean green strategies. Overall performance of the organization has been improved[54].

Green Supply Chain Management (GSCM) preventive negative effects of supply chain operations on the environment. Evaluation of GSCM performance of industries multi-criteria decision making (MCDM) techniques and fuzzy group decision making methods should be implementation for complex multi-attribute problems in fuzzy environment, green design, green transformation, green purchasing. The weights from fuzzy TOPSIS uses ANP to rank alternative organizations' performance in Green Supply Chain Management[55].

Changes in production processes based on a technology-driven strategy have coincided with Industry 4.0. Both approaches to achieve organizational performance competitiveness, LM tools and attributes of Lean 4.0 like Just in Time 4.0 (JIT 4.0), Kanban 4.0, Kaizen 4.0. It is also used for minimizing waste and method of gaining benefits through holistic integration technique[56].

Lean green approach involves integration of manufacturing management and variety of approaches like team work, Just-in–time, cellular manufacturing and supplier development[57].

More than 30 publications were studied, and the results showed that the lean approach and sustainability development addressed the problem of waste reduction from the design phase. Implementing sustainability-lean methods improves the environmental, social, and economic aspects while lowering waste production[58].

In lean and green manufacturing Pollution prevention activities are adding value to standard values of costs and productivity by reducing waste management costs.

Shorter product life cycle is the main characteristic of modern manufacturing organizations to capture resource efficiency and customer demand for making profit in competitive scenario[59].

Using a lean and green strategy improves the production system's efficiency and sustainability. A decision model to get low carbon benefits to maximum extent and dynamic characteristics of sustainable process and carbon benefits in lean manufacturing system was established[60].

3. Research Methodology Framework

Questionnaire has been prepared containing four sections. First section contains information of company, characteristics of respondent and product manufactured. Section two contains importance level of different lean and strategies on (5=Toa extremely large extent, 4=To a large extent, 3=To a moderate extent, 2=To a small extent, not at all important); and section 3 contains benefits on (5=To an extremely large extent, 4=To a large

Extent, 3=to a moderate extent, 2=to a small extent, 1=Not at all benefit). Snowball sampling has been used to select the sample followed by convenience sampling. The methodology for the proposed research has been shown in Fig. 2.

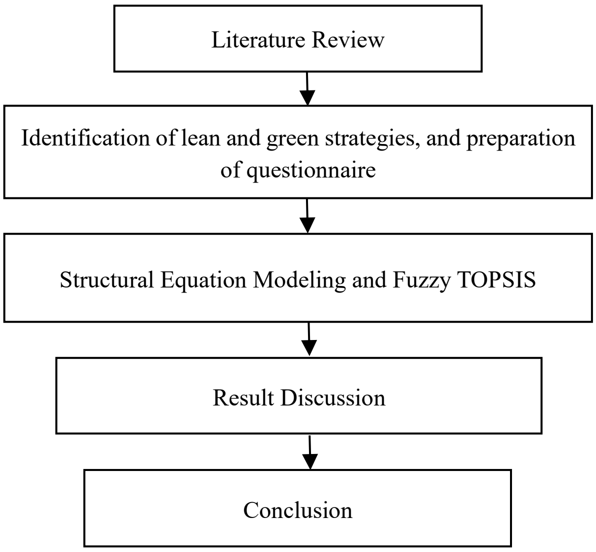

Fig. 2: Research Methodology for the research.

3.1 Justification of Lean Green strategies towards improving performance (Structural Equation Modeling)

Structural Equation Modeling (SEM) has been employed in this study to analyze the relationships between input parameters, referred to as exogenous variables (such as Lean-Green strategies), and output parameters, known as endogenous variables (such as performance improvements). SEM provides a robust framework for assessing and quantifying these relationships, making it possible to understand the direct and indirect effects of various factors on the outcomes. To achieve this, regression coefficients, also known as standard path coefficients (SPC), were computed to represent the strength and direction of the relationships between the exogenous and endogenous variables. Table 1 shows the values of coefficients were calculated using the Data Analysis Tool Pack in Microsoft Excel 2007, which offers a streamlined approach for conducting statistical analyses. The SPC values play a critical role in validating the model by quantifying how changes in one variable (e.g., a Lean-Green strategy) influence another (e.g., operational efficiency or waste reduction). This calculation helps in justifying the hypothesized causal pathways, ensuring that the model accurately reflects the dynamics of the system being studied. For instance, the SPC can illustrate how a specific Lean-Green strategy, such as Kaizen, directly contributes to enhanced productivity or indirectly influences broader sustainability outcomes through intermediate variables. This analytical approach ensures a comprehensive understanding of the interplay between Lean-Green strategies and their impact on performance, providing actionable insights for decision-making in manufacturing environments.

Table 1. shows path coefficients between input variables, latent variables and benefits.

Link	Standard Path Coefficient (SPC) calculated for SEM
LG 1	0.023
LG 2	0.012
LG 3	0.041
LG 4	0.0123
LG 5	0.053
LG 6	0.017
LG 7	0.021
LG 8	0.037
LG 9	0.051
LG 10	0.016
LG 11	0.018
LG 12	0.025
LG 13	0.041
LG 14	0.0137
LG 15	0.0321
LG 16	0.036
LG 17	0.0195
LG 18	0.0288
Benefits....................19	0.041
Benefits....................20	0.052
Benefits....................21	0.0421
Benefits....................22	0.0423
Benefits....................23	0.028
Benefits....................24	0.027
Benefits....................25	0.051
Benefits....................26	0.0358
Benefits....................27	0.0431
Benefits....................28	0.0286

3.1.1 Result Discussion of structural equation modeling applied

Results indicated that the model fit parameters (Chi-Square/Degree of Freedom=1.440; GFI (Goodness of Fit Index) =0.774; CFI (Comparative Fit Index) = 0.694; TLI (Tucker Lewis Index) = 0.174; AGFI (Adjusted Goodness of Fit) = 0.529; Probability level=0.045) lies within limits. Regression coefficients (SPC) for all the constructs are significant at 5% level, signifies claims are justified. Unity improvement in lean green strategies leads towards 2.3% improvement in waste reduction activities, 1.2% improvement in redesign of product, 4.1% segregation of waste activities, 1.23% Improvement in proper utilization of space, 5.3% improvement in kaizen improvement projects, 1.7% improvement in 5S activities, 2.1% improvement in experimental design activities, 3.7% improvement in material diversity, 5.1% enhancement in integration of material and energy flow, 1.6% improvement in kanban system, 1.8 % improvement in die setup time(SMED), 2.5% improvement in supply chain involvement activities, 4.1% improvement in modification of technology, 1.37% improvement in continuous optimization, 3.21% improvement in recycling activities, 3.6% improvement in planning and design activities, 1.95% improvement in green scheduling and 2.88% improvement in process integration used by the manufacturing organizations. Research and development activities are improved by 43.1% with implementation of Lean green strategies in systematic manner.

3.2 Fuzzy TOPSIS

First level of hierarchy justifies the role of lean green strategies; second level explains the application of KAIZEN, Continuous Optimization, Single Minute Exchange of Die, Material Diversity and Green Scheduling towards improvement in current manufacturing system processes, and at third level performance outcomes including improved performance and not improvement have been explained.

They study on the MCDM using fuzzy DEMATEL-ANP-TOPSIS, used to find the cause and effect for better output. LCSCM is used sustain the economic benefits, social benefits better environment benefits. They suggested that combined approaches of DEMATEL-ANP-TOPSIS methodology is used to find the better supplier which have good performance index data and various variable analysis and solve the problem. A MCDM approach is used to improve the low carbon supplier. Many MCDM approach is find by this study solve the problems for best result.

Figure 3 shows the three level hierarchies prepared for the justification of performance improvement. After hierarchy formulation, the application of fuzzy TOPSIS (Technique of Preference Similarity Ideal Solution) has been done in six different standard steps to justify role of lean green approach towards performance improvement. The six-step methodology has been explained below:

Step 1: In this step, the responses from different organization has been ascertained to be converted into the scenario where performance values of decision matrix are not the crisp numeric values but in turn these are linguistic terms which are given by decision maker. In the present study, five-point likert scale (1. Not at all, 2. To small Extent, 3. To a moderate Extent, 4. To a Large Extent, 5. To an extremely large extent) has been applied for both lean green strategies and competences.

Step 2: Now grouping of likert scale into fuzzy numbers that is performed in step 1 has been done. The surveyed organizations are divided into three different categories including those who are in early stages of implementing lean green strategies (category 1), category 2 comes for the organizations who have are in maturity stages of implementation and third category includes those who have completed implemented all lean green and competences (continuous optimization) in their respective organizations. Table 2 to 4 shows the group decision making matrices showing different decision-making matrices.

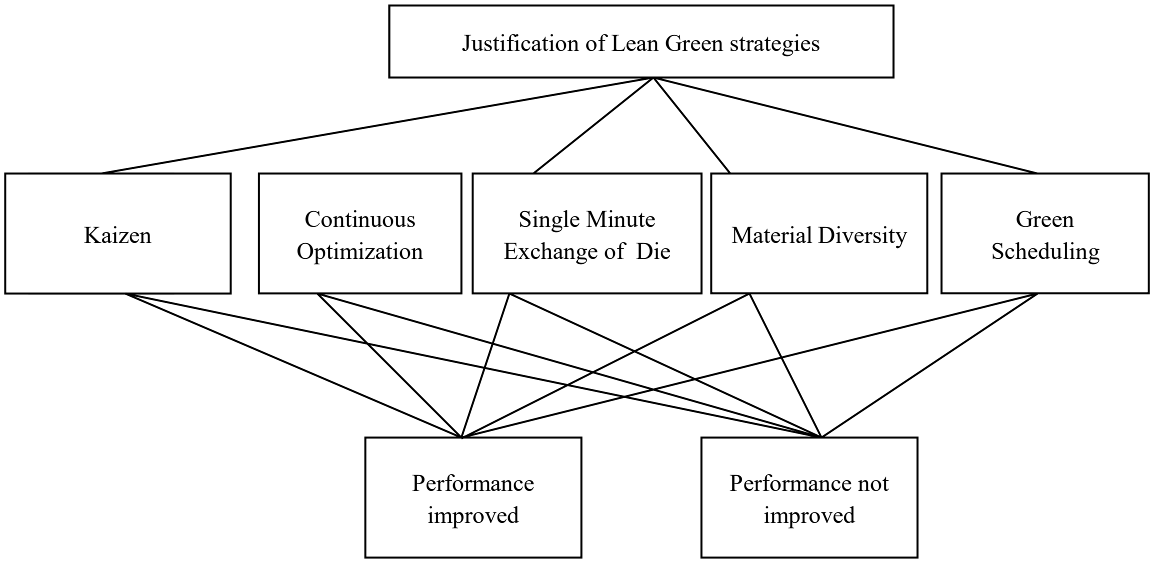

Fig. 3: Three level hierarchy for the justification of performance improvement.

Table 2. Group Decision Matrix (Respondent Category 1).

Attributes/ Criteria	**KAIZEN**	**Green Scheduling**	**Single Minute Exchange of Die**	**Material Diversit**	**Continuous Optimization**
Criteria 1	(3, 5, 7)	(5, 7, 9)	(3,7,9)	(3, 5, 7)	(1, 5, 9)
Criteria 2	(1, 3, 5)	(3,7,9)	(3, 5, 7)	(1, 5, 9)	(1, 5, 7)
Criteria 3	(1, 5, 9)	(3,7,9)	(3, 5, 7)	(5, 7, 9)	(1, 5, 9)

Table 3. Group Decision Matrix (Respondent Category 2).

Attributes/ Criteria	**KAIZEN**	**Green Scheduling**	**Single Minute Exchange of Die**	**Material Diversity**	**Continuous Optimization**
Criteria 1	(5, 7, 9)	(1, 3, 5)	(3,7, 9)	(1, 3, 5)	(1, 3, 5)
Criteria 2	(1, 5, 9)	(3, 5, 7)	(1, 3, 5)	(3, 5, 7)	(1, 5, 9)
Criteria 3	(3,7, 9)	(5, 7, 9)	(5, 7, 9)	(1, 5, 9)	(1, 3, 9)

Table 4. Group Decision Matrix (Respondent Category 3).

Attributes/ Criteria	**KAIZEN**	**Green Scheduling**	**Single Minute Exchange of Die**	**Material Diversity**	**Continuous Optimization**
Criteria 1	(1, 3, 9)	(3, 5, 7)	(1, 3, 5)	(3, 5, 7)	(3,7, 9)
Criteria 2	(1, 5, 9)	(1, 3, 5)	(3, 5, 7)	(1, 5, 9)	(3, 5, 7)
Criteria 3	(3, 5, 7)	(1, 5, 9)	(1, 5, 9)	(1, 3, 5)	(1, 3, 5)

Step 3*:* In this step, group decision matrix is further modified to fuzzy decision matrix by assigning weightage to fuzzy number score using four-point conversion scales. Now in linguistic terms, each decision gives their own weightage to every criterion. To the weightage criteria, crisp numeric values are assigned and matrix is assigned with these values. The two criterions are assigned to every attribute including those who are beneficial and other who

provide cost effectiveness. In the calculation part, KAIZEN, Single Minute Exchange of Die, Material Diversity and Green Scheduling come under criteria of beneficiary and Continuous Optimization comes under cost effectiveness criteria.

Equation (ii) shows the criteria for assigning fuzzy number to weight assigned.

Weightage Numbers are [5, 7, 9]; [1, 5, 7]; [1, 3, 5]

Step 4: This step includes calculation of fuzzy negative ideal solution (FNIS) and fuzzy positive ideal solution (FPIS). The main purpose of calculating FPIS is to maximize the benefit criteria and minimizing the cost optimization criteria. Similarly, FNIS provides maximization of cost criteria and minimization of benefit criteria. Table 7 shows the ideal solution matrix containing the values of FPIS and FNIS.

Table 5 shows normalized fuzzy decision matrix using formula (iii) and Table 6 shows weighted normalized fuzzy decision matrix.

Table 5. Normalized fuzzy decision matrix.

Attributes/ Criteria	**KAIZEN**	**Green Scheduling**	**Single Minute Exchange of Die**	**Material Diversity**	**Continuous Optimization**
Criteria 1	(1/9,3/9, 9/9)	(3/9, 5/9, 7,9)	(1/9, 3/9, 5/9)	(3/9, 5/9, 7/9)	(1/9,1/7, 1/5)
Criteria 2	(1/9, 5/9, 9/9)	(1/9, 3/9, 5/9)	(3/9, 5/9, 7/9)	(1/9, 5/9, 9/9)	(1/7, 1/5, 1/1)
Criteria 3	(3/9, 5/9, 7/9)	(1/9, 5/9, 9/9)	(1/9, 5/9, 9/9)	(1/9, 3/9, 5/9)	(1/5, 1/3, 1/5)

Table 6. Weighted normalized fuzzy decision matrix.

Attributes/ Criteria	**KAIZEN**	**Green Scheduling**	**Single Minute Exchange of Die**	**Material Diversity**	**Continuous Optimization**
Criteria 1	(0.55,2.33, 9)	(1.67, 3.89, 6.99)	(0.55, 2.33, 3.89)	(1.67, 3.89, 6.99)	(0.55,0.99,1.8)
Criteria 2	(0.11, 2.78, 7)	(0.11, 1.67, 3.89)	(0.33, 2.78, 5.44)	(0.11, 2.78,7)	(0.14, 1, 7)
Criteria 3	(0.33, 1.67, 3.89)	(0.11, 1.67, 5)	(0.11, 1.67, 5)	(0.11, 0.33, 1.67)	(0.2, 0.99, 1)

Table 7. Ideal Solution Matrix.

Attributes Criteria	**KAIZEN**	**Green Scheduling**	**Single Minute Exchange of Die**	**Material Diversity**	**Continuous Optimization**
Criteria 1	(0.55,2.33, 9)	(1.67, 3.89, 6.99)	(0.55, 2.33, 3.89)	(1.67, 3.89, 6.99)	(0.55,0.99,1.8)
Criteria 2	(0.11, 2.78, 7)	(0.11, 1.67, 3.89)	(0.33, 2.78, 5.44)	(0.11, 2.78,7)	(0.14, 1, 7)
Criteria 3	(0.33, 1.67, 3.89)	(0.11, 1.67, 5)	(0.11, 1.67, 5)	(0.11, 0.33, 1.67)	(0.2, 0.99, 1)
A^*(FPIS)	(0.55,2.33, 9)	(1.67, 3.89, 6.99)	(0.55, 2.33, 3.89)	(1.67, 3.89, 6.99)	(0.55,0.99,1.8)
A^-(FNIS)	(0.33, 1.67, 3.89)	(0.11, 1.67, 3.89)	(0.11, 1.67, 5)	(0.11, 0.33, 1.67)	(0.14, 1, 7)

Table 8. Distances of alternative solution.

Attributes/ Criteria	**KAIZEN**	**Green Scheduling**	**Single Minute Exchange of Die**	**Material Diversity**	**Continuous Optimization**
Criteria 1	1.21	2.34	1.42	2.24	3.24
Criteria 2	1.96	1.54	1.86	1.64	2.56
Criteria 3	2.42	2.46	2.26	1.88	2.44

After calculating the distance between two fuzzy numbers, the next step is to calculate the closeness coefficient that helps to predict the ranking of different alternatives. CCi (closeness coefficient) has been calculated by below formula:

Table 9 shows values of closeness coefficient measured for each alternative.

Table 9. Values of closeness coefficient measured for each alternative.

Attributes	d_i^*	d_i^-	**CCi**	**Rank**
KAIZEN	2.34	1.97	0.45	4
Green Scheduling	3.64	2.54	0.41	5
Single Minute Exchange of Die	3.27	3.43	0.47	3
Material Diversity	2.35	2.67	0.53	2
Continuous Optimization	2.22	3.45	0.61	1

Percentage contribution has been measured multiplying CCi by the weights measured in Table 8. And taking submission for all the attributes.

Calculation of performance index = 1.13*0.45 + 0.93*.41+.527*47+ 0.907*0.53+0.51*0.61= 0.385

3.2.1 Result Discussion of findings of fuzzy TOPSIS

Results indicated that manufacturing companies are focused on continuous optimization for carrying out lean-green strategic implementation followed by Material Diversity, Single Minute Exchange of Die, KAIZEN and Green Scheduling; Calculation of performance index signifies 38.5% improvement in overall performance by implementing most significant lean green strategies.

A comparative analysis of Lean-Green strategies across different types of manufacturing companies revealed notable variations in their adoption and impact. Sectors such as automotive and electronics, which typically have more structured processes and higher capital investments, demonstrated a higher degree of Lean-Green integration, leveraging advanced tools like green scheduling and continuous optimization. These industries benefited significantly from strategies aimed at waste reduction and energy efficiency due to their scalable operations and established supply chain networks.

In contrast, small and medium enterprises (SMEs) in sectors like textiles and food processing faced greater challenges in implementing these strategies. Limited financial resources, infrastructural constraints, and skill gaps were identified as significant barriers. However, incremental approaches such as Kaizen and 5S activities showed promise in these sectors, enabling gradual improvements in sustainability practices without requiring substantial upfront investment. These findings indicate that while Lean-Green strategies hold universal applicability, their implementation and outcomes are influenced by the unique characteristics of each sector. Future studies could further explore sector-specific adaptations to maximize the impact of Lean-Green strategies across diverse manufacturing contexts.

3.3 Survey Design and Development

The questionnaire used in this study was designed to capture the adoption and impact of Lean-Green strategies in the Indian manufacturing sector. The questions were developed based on an extensive review of prior research in the field of Lean-Green integration, including established frameworks such as Value Stream Mapping (VSM), Kaizen, and green supply chain management (GSCM). This ensured that the survey was grounded in existing literature and reflected best practices in the assessment of Lean-Green strategies. In addition to leveraging prior research, the questionnaire was tailored to the specific context of Indian manufacturing industries. Key input was sought from subject matter experts, including practitioners and academics, to ensure that the questions were relevant and comprehensive. The survey consisted of sections evaluating the importance and implementation level of various Lean-Green strategies, as well as their perceived benefits in terms of economic, environmental, and social outcomes. By combining insights from prior studies and practical expertise, the questionnaire was designed to provide robust and actionable data for this research.

3.4 Social Benefits of Lean-Green Implementation

One of the significant yet often underexplored outcomes of Lean-Green strategy implementation is its impact on improving the standard of living. By fostering resource efficiency and reducing environmental pollution, these strategies contribute to creating healthier work environments and surrounding communities. For instance, reducing emissions and industrial waste through green scheduling and optimized processes not only minimizes the ecological footprint but also directly enhances air and water quality in industrial regions. In addition, Lean-Green strategies like Kaizen and continuous optimization often involve employee engagement and skill development. Workers benefit from training programs that increase their technical expertise, job satisfaction, and career growth opportunities. This empowerment translates into higher productivity and improved socio-economic conditions for employees and their families. For example, organizations implementing Lean-Green principles have reported reduced workplace hazards and better health outcomes for their workforce, further contributing to overall well-being. These social benefits extend beyond the workplace. Communities around industries adopting Lean-Green practices experience improved living conditions due to decreased pollution and resource conservation. In turn, these improvements align with broader sustainability goals, demonstrating how Lean-Green strategies can holistically enhance economic, environmental, and social dimensions of industrial development.

4. Comparative Perspective on Lean-Green Strategy Implementation

A noteworthy avenue for understanding the broader implications of this study is comparing the performance of Indian manufacturing companies with their global counterparts in adopting Lean-Green strategies. Globally, countries with established industrial ecosystems, such as Germany, Japan, and the United States, have leveraged Lean-Green frameworks alongside advanced technologies like Industry 4.0 and Artificial Intelligence (AI). For instance, Germany's Industrie 4.0 initiative integrates green manufacturing principles to optimize resource utilization and reduce emissions across supply chains. Similarly, Japan's Kaizen-driven sustainability practices have demonstrated remarkable success in fostering operational efficiency and environmental stewardship.

In contrast, Indian manufacturing companies, while making significant strides, face unique challenges, including resource constraints, skill gaps, and infrastructural limitations. Despite these hurdles, the adoption of strategies like Kaizen, green scheduling, and continuous optimization has shown potential for transformative change. The findings of this study suggest that Indian industries can achieve comparable performance by integrating Lean-Green principles with emerging technologies, such as predictive analytics and IoT-driven automation. Adding this international perspective highlights the opportunities for Indian manufacturers to learn from global best practices while addressing localized challenges. Future research could focus on cross-country comparative analyses to identify transferable strategies and benchmarks, enabling Indian companies to enhance their competitiveness on the global stage and contribute more effectively to sustainable industrial practices.

5. Conclusions, Implications and Limitations

It is concluded that in order to achieve excellence in manufacturing, companies are highly focused on incremental improvements or kaizen improvement projects for the success of lean green approach. Implementation of lean green strategies leads towards 38.5% improvement in overall performance of manufacturing operations. Research and development activities are highly enhanced by implementing lean green concept in these companies for enhancing economic performance, pollution preventions are highly important environmental activities in these companies and improved standard of living is the most important social benefit achieved after successful implementation of lean-green approach in strategic manner. The study helps line and production managers to understand different aspects of Lean and Green and check how it affects quality, and cost of production of product and Processes. Justification will help industrial professionals to removing barriers in implementing lean-green concept. Practical demonstration is missing in the study which is possible by conducting case study. Method variance may very as there is one respondent.

The findings of this study underscore the immediate economic and environmental benefits of implementing Lean-Green strategies, such as waste reduction, energy efficiency, and improved resource utilization. However, the long-term potential of these strategies extends far beyond these immediate outcomes. By fostering a culture of continuous improvement and sustainability, Lean-Green strategies can drive transformative change in manufacturing systems. Over time, these strategies contribute to creating resilient supply chains, reducing dependency on finite resources, and enhancing corporate social responsibility.

This study highlights the significant role of Lean-Green strategies in enhancing the economic, environmental, and social performance of the manufacturing sector. While the immediate benefits include waste reduction, energy efficiency, and pollution prevention, the long-term potential of these strategies lies in their integration with emerging technologies like Artificial Intelligence (AI) and Industry 4.0. In the Indian context, the adoption of these advanced technologies alongside Lean-Green practices can revolutionize manufacturing systems via facilitating data-driven decision-making, predictive maintenance, and real-time monitoring. For instance, AI-powered analytics can optimize green scheduling and resource allocation, while Industry 4.0 frameworks can integrate Lean-Green principles across supply chains, fostering greater agility and sustainability. While the findings of this study are focused on the manufacturing sector, the principles and strategies identified can be generalized to other industries in India. The Lean-Green approach, with its emphasis on waste reduction, resource optimization, and continuous improvement, is equally relevant to service industries such as logistics, healthcare, and retail. For instance, green scheduling and continuous optimization could be applied to supply chain operations in logistics, enhancing efficiency and reducing carbon footprints. Similarly, Kaizen-driven improvements in resource management and workflow optimization could benefit sectors like healthcare by minimizing operational waste and improving service delivery. By adapting the core strategies to the specific needs and challenges of non-manufacturing industries, organizations can achieve comparable economic, environmental, and social benefits. This generalizability underscores the broader applicability of Lean-Green principles, offering a pathway for industries across India to contribute to sustainable development and improve their competitive advantage in a resource-constrained environment.

The future of Lean-Green strategies in India is particularly promising given the country's focus on industrial modernization and environmental conservation. By leveraging AI and Industry 4.0, Indian industries can achieve a synergistic balance between productivity and sustainability, addressing global challenges such as climate change and resource scarcity. Furthermore, these advancements can enhance India’s competitiveness in global markets and support its transition to a circular economy.

5.1 Limitations of the Study

While this study provides valuable insights into the adoption of Lean-Green strategies in the Indian manufacturing sector, certain limitations must be acknowledged. The data collection relied on a questionnaire-based survey, which, while effective for capturing a wide range of responses, may be subject to response bias. Participants may have overreported their organizations' adherence to Lean-Green principles due to social desirability or underreported due to lack of awareness about the strategies. Additionally, the sample size, although adequate for the methods used, may not fully represent the diversity of the Indian manufacturing sector, particularly small and medium enterprises (SMEs) in rural or less industrialized regions. Future studies should consider employing larger, more diverse samples and integrating mixed-method approaches, such as case studies or on-site observations, to validate and enrich the findings. Addressing these limitations will enhance the robustness and generalizability of the results and provide a deeper understanding of the practical challenges and opportunities associated with Lean-Green strategy implementation.

6. Future Research

6.1 Continuous Process Improvement

One of the primary Lean-Green strategies discussed in this study is the adoption of Kaizen, which emphasizes small, continuous improvements. Industry professionals can implement Kaizen through the identification and removal of non-value-added activities from their processes, leading to waste reduction and enhanced operational efficiency. For instance, regularly assessing and optimizing production workflows can result in incremental improvements in energy usage, material handling, and time management. Implementing Kaizen on the shop floor or in logistics operations can help companies gradually increase efficiency, reduce costs, and minimize environmental impact over time.

6.2 Pollution Prevention

Another key area where industry professionals can apply the study's findings is in pollution prevention. The Lean-Green strategies outlined in this research, such as green scheduling and continuous optimization, can directly contribute to minimizing waste and reducing the environmental footprint of manufacturing operations. By adopting green scheduling, companies can optimize machine and labor schedules to reduce energy consumption and prevent unnecessary waste during idle times. Furthermore, implementing continuous optimization processes can help identify areas where energy consumption, waste generation, and resource use can be minimized. For example, through data-driven decision-making supported by structural equation modeling (SEM) and fuzzy TOPSIS, professionals can assess and prioritize the most effective strategies for reducing pollution in their specific operational context.

By integrating these strategies, professionals can not only improve the sustainability of their operations but also achieve cost savings, enhance productivity, and meet environmental regulations. Future research could focus on case studies that demonstrate how these strategies are practically applied in various manufacturing settings, offering concrete examples of the strategies' impact and providing additional guidance for industry implementation.

References

1) A Choudhary, Alok, Arijit De, Karim Ahmed, and Ravi Shankar. "An integrated fuzzy intuitionistic sustainability assessment framework for manufacturing supply chain: A study of UK based firms." *Annals of Operations Research*) 1-44 (2021).
2) A Fallahpour, Alireza, Kuan Yew Wong, Srithar Rajoo, and Abbas Mardani. "An integrated fuzzy carbon management-based model for suppliers' performance evaluation and selection in green supply chain management." I*nternational Journal of Fuzzy Systems* 22, 712-723 (2020).
3) A. Anwar, Aliya, Khalid Jamil, Muhammad Idrees, Muhammad Atif, and Basharat Ali. "An empirical examination of SMEs sustainable performance through lean manufacturing." *Knowledge and Process Management* 30(3), 289-299 (2023).
4) Ahmad, Shaad, Ahmad Abdullah, and Faisal Talib. "Lean-green performance management in Indian SMEs: a novel perspective using the best-worst method approach." Benchmarking: *An International Journal* 28(2), 737-765 (2021).
5) A.A.A. Putri, S. Hartini, and R. Purwaningsih, "Sustainable value stream mapping design to improve sustainability performance of animal feed production process," *Evergreen,* 8(1) 107–116 (2021). doi:10.5109/4372266.
6) A. Cherrafi, S. Elfezazi, K. Govindan, J.A. Garza-Reyes, K. Benhida, and A. Mokhlis, "A framework for the integration of green and lean six sigma for superior sustainability performance," I*nt. J. Prod. Res.,* 55 (15) 4481–4515 (2017). doi:10.1080/00207543.2016.1266406.
7) Adelina, W., & Kusumastuti, R. D.. "Green supply chain management strategy selection using analytic network process: case study at PT XYZ. IOP Conference Series" *Materials Science and Engineering,* 166, 012026. (2017) doi:10.1088/1757-899x/166/1/012026
8) Alzoubi, Haitham M., Mohammad In'airat, and Gouher Ahmed. "Investigating the impact of total quality management practices and Six Sigma processes to enhance the quality and reduce the cost of quality: the case of Dubai." International Journal of Business Excellence 27(1), 94-109 (2022).
9) Alzoubi, Ali, Muhammad Alshurideh, Iman Akour, and Barween Al Kurdi. "THE IMPACT OF LEAN PRACTICES AND AGILE PRACTICES ON PROCESS QUALITY." I*nternational Journal of Theory of Organization and Practice (IJTOP)* 1(1), 100-117 (2022).
10) Amrina, U. and Zagloel, T.Y.M. (2019), "The harmonious strategy of lean and green production: future opportunities to achieve sustainable productivity and quality", *2019 IEEE 6th International Conference on Industrial Engineering and Applications (ICIEA),* Tokyo, Japan, 187-192

(*2019)*.
11) Ananya Bhattacharya, Alka Nand, and Pavel Castka, "Lean-green integration and its impact on sustainability performance: A critical review",*Journal of Cleaner Production*, 236 117697 (2019)
12) Antosz, K., Jasiulewicz-Kaczmarek, M., Waszkowski, R., & Machado, J.. Application of Lean Six Sigma for sustainable maintenance: case study. IFAC-PapersOnLine, 55(19), 181-186 (2022).
13) Arora, Arun, Vijay Kumar Singh, and Rajeev Rathi. "Sustainable Lean and Green Manufacturing: An Empirical Review of Their Strategies." Advances in Functional and Smart Materials, 1-11 (2023).
14) Bhasin, Niti & Kar, Rabi & Arora, Neha. "Green Disclosure Practices in India: A Study of Select Companies", *Evergreen*, 2(2) 5-13 (2015). doi:10.5109/1544075.
15) B. Shahriari, A. Hassanpoor, A. Navehebrahim, and S. Jafarinia, "A systematic review of green human resource management," *Evergreen*, 6(2) 177–189 (2019). doi:10.5109/2328408.
16) Batra, Safal, Sunil Sharma, Mukund R. Dixit, and Neharika Vohra. "Does strategic planning determine innovation in organizations? A study of Indian SME sector." Australian Journal of Management 43(3) 493-513 (2018).
17) Devashish Nagar, Sudhanshu Raghav, Aman Bhardwaj, Rajender Kumar , Punj Lata Singh, and Rahul Sindhwani, "Machine learning: Best way to sustain the supply chain in the era of industry 4.0" Materials Today: Proceedings, Volume 47(13), 3676-3682 (2021). doi:10.1016/j.matpr.2021.01.267.D.
18) E. Lodgaarda, J.A. Ingvaldsena, I. Gammea, and S. Aschehouga, "Barriers to Lean Implementation: Perception of Top Managers, Middle Managers and Workers". Procedia CIRP 57, 595-600 (2016).
19) Gaba, R.and Sharma,D.,"Benchmarking the sustainable banking performance of Indian commercial banks", *International Journal of Process Management and Benchmarking*, Vol.16(1), 60-80 (2024). doi:10.1504/IJPMB.2022.10051635
20) Gaikwad, Lokpriya M. and Vivek K. Sunnapwar. "An integrated Lean, Green and Six Sigma strategies." *The Tqm Journal* 32, 201-225 (2020).
21) Gaikwad, Lokpriya, and Vivek Sunnapwar. "Development of an integrated framework of LGSS strategies for Indian manufacturing firms to improve business performance: an empirical study." *The TQM Journal* 33(1) 257-291 (2020).
22) G. L. Tortorella, R. Giglio and D. H. van Dun, "Industry 4.0 adoption as a moderator of the impact of lean production practices on operational performance improvement", *International Journal of Operations & Production Management,* Vol. 39(6/7/8), 860-886 (2021).
23) Gupta, Vishal K., and Safal Batra. "Entrepreneurial orientation and firm performance in Indian SMEs: Universal and contingency perspectives." *International Small Business Journal* 34(5), 660-682 (2016).
24) Gupta, Vivek, and Arvind Jayant. "A Novel Hybrid MCDM Approach Followed by Fuzzy DEMATEL-ANP-TOPSIS to Evaluate Low Carbon Suppliers." *Evergreen,* 8(3) 544-555 (2021). doi:10.5109/4491640.
25) Indrawati, S. and Ridwansyah, M."Manufacturing continuous improvement using Lean Six Sigma: an iron ores industry case application", Elsevier Procedia Manufacturing, Vol. 4, *Special issue for Industrial Engineering and Service Science*, 528-534 (2015)
26) J. A. Garza-Reyes, "Lean and green-a systematic review of the state of the art literature", *Journal of Cleaner Production*, Vol. 102 18-29 (2015).
27) J. Bhadu, J. Bhamu and D. Singh, "Critical success factors of lean manufacturing for Indian ceramic industries: Modelling through interpretive ranking process", Indian Journal of Engineering & Materials Sciences, Vol. 28(3), 271-281 (2021).
28) J. Bhadu, P. Kumar, J. Bhamu and D. Singh, "Lean production performance indicators for medium and small manufacturing enterprises: modelling through analytical hierarchy process," *International Journal of System Assurance Engineering and Management,* 13(2), 978-997 (2022).
29) Kosasih, Wilson, I Nyoman Pujawan, and Putu Dana Karningsih. "Integrated Lean-Green Practices and Supply Chain Sustainability for Manufacturing SMEs: A Systematic Literature Review and Research Agenda" *Sustainability* 15(16), 12192 (2023). doi:10.3390/su151612192
30) Kumar, P. and Sharma, D.,"Benchmarking the financial performance of Indian commercial banks by a hybrid MCDM Approach", *International Journal of Process Management and Benchmarking*, Vol. 15(3), 285-309 (2023). doi:10.1504/IJPMB.2023.134147.
31) Kumar, Rajesh, Rajender Kumar, and Ashwini Kumar. "Exploring the challenges of integrating lean green practices in industry 4.0 manufacturing frameworks: an empirical study." In Industry 4.0 Driven Manufacturing Technologies,. Cham: *Springer Nature Switzerland*, 277-292 (2024).
32) Kuo, S.Y., and Lin, P.C. "Determinants of green performance in container terminal operations: a lean management", *Journal of Cleaner Production*, Vol. 275(4), 12-31 (2020).
33) Kumar, P., & Sharma, D,"Prioritising the financial performance of Indian private sector banks by a hybrid MCDM approach" *International Journal of Process Management and Benchmarking*, *16*(4), 490-511 (2024).
34) Kumar, R., and Kumar, R "Impact of Lean and Green Strategies on manufacturing Industry of India-An

Empirical Investigation''. Scope, 13(3), 1413-1429 (2023).

35) Kumar, Rajender, Rahul Sindhwani, Ritu Arora, and Punj Lata Singh. "Developing the structural model for barriers associated with CSR using ISM to help create brand image in the manufacturing industry." International Journal of Advanced Operations Management 13(3), 312-330 (2021).
36) Naim, Arshi, AnandhavalliMuniasamy, Arockiasamy Clementking, and R. Rajkumar. "Relevance of Green Manufacturing and IoT in Industrial Transformation and Marketing Management." *In Computational Intelligence Techniques for Green Smart Cities, Cham: Springer International Publishing*, 395-419 (2022).
37) N.S. Zulkefly, H. Hishamuddin, F.A.A. Rashid, N. Razali, N. Saibani, and M.N.A. Rahman, "The effect of transportation disruptions on cold chain sustainability," *Evergreen*, 8(2) 262–270 (2021). doi:10.5109/4480702.
38) Navamani, G., R. Shanmugapriya, Raman Kumar, Željko Stević, Rajender Kumar, and Sandeep Kumar. "Eternal 1-security number of a fuzzy graph with level J." *International Journal of Knowledge-based and Intelligent Engineering Systems Preprint*: 1-13.
39) P.S. Parmar, and T.N. Desai, "A systematic literature review on sustainable lean six sigma: current status and future research directions," *Int. J. Lean Six Sigma*, 11 (3) 429–461 (2020). doi:10.1108/IJLSS08-2018-0092/FULL/HTML.
40) P. Saraswat, R. Agrawal and M. L. Meena, "An Analysis of Critical Success Factors Using Analytical Hierarchy Process for Implementation of Lean with Industry 4.0 in SMEs," I*n Recent Advances in Smart Manufacturing and Materials: Select Proceedings of ICEM 2020 Springer Singapore*, 255-262 (2021).
41) P. Teixeira, J.C. Sá, F.J.G. Silva, L.P. Ferreira, G. Santos, and P. Fontoura, ''Connecting lean and green with sustainability towards a conceptual model", *Journal of Cleaner Production*, 322, 129047 (2021). doi:10.1016/j.jclepro.2021.
42) R. S. Sakataven, S. A. Helmi, and M. Hisjam. "Lean implementation barriers and their contextual relationship in contract manufacturing machining company." *Evergreen*, 8(2) 499-508 (2021). doi:10.5109/4480735.
43) Sadiku, M.N.O., Ajayi-Majebi, A.J., Adebo, P.O.. Lean Manufacturing. *In: Emerging Technologies in Manufacturing. Springer, Cham.* (2023) doi:10.1007/978-3-031-23156-8_11.
44) Saha, Rajeev Kumar, Raman Kumar, Nikhil Dev, Rajender Kumar, Raul M. Del Toro, Sofía Haber, and José E. Naranjo. "Structural modeling and analysis of fuel cell: a graph-theoretic approach." *Peer J Computer Science* 9 e1510 (2023).
45) Serrano-García, Jakeline, JosepLlach, Andrea Bikfalvi, and Juan José Arbeláez-Toro. "Performance effects of green production capability and technology in manufacturing firms." *Journal of Environmental Management* 330 117099 (2023).
46) Sharma, Sarthak, Manoj Nayak, and Rajender Kumar. "Identification and ranking to the barriers associated to green manufacturing in Indian context." *In AIP Conference Proceedings*, vol. 2962(1), (2024).
47) Singh, Punj Lata, Rahul Sindhwani, Bhupendra Prakash Sharma, Priyank Srivastava, Praveen Rajpoot, Lalit, Rahul, and Rajender Kumar. "Analyse the critical success factor of green manufacturing for achieving sustainability in automotive sector." *In Recent Trends in Industrial and Production Engineering: Select Proceedings of ICCEMME 2021 Springer Singapore*, 79-94 (2022).
48) Siegel, Rebecca, Jiju Antony, Kannan Govindan, Jose Arturo Garza-Reyes, Bart Lameijer, and Ashutosh Samadhiya. "A Framework for the Systematic Implementation of Green-Lean and Sustainability in SMEs." *Production Planning & Control* 35 (1): 71–89 (2022). doi:10.1080/09537287.2022.2052200.
49) Sindhwani, Rahul, Rahul Dev Gupta, Punj Lata Singh, Vipin Kaushik, Sumit Sharma, Rakesh Kumar Phanden, and Rajender Kumar. "Identification of factors for lean and Agile manufacturing systems in rolling industry." *In Advances in Industrial and Production Engineering: Proceedings of FLAME 2020 Springer Singapore,* 367-378 (2021).
50) Sindhwani, Rahul, Punj Lata Singh, Vipin Kaushik, Sumit Sharma, and Rajender Kumar. "An optimised framework for the implementation of hybrid lean and agile manufacturing systems in the rolling industry for India." International Journal of Six Sigma and Competitive Advantage 13(1-3) 289-310 (2021).
51) S.R. Hamid, C.B. Cheong, A. Shamsuddin, N.R. Masrom, and N.A. Mazlan, "Sustainable development practices in services sector: A case of the Palace Hotel from Malaysia." *Evergreen*, 8(4), 693–705 (2021). doi:10.5109/4742113.
52) T. Fujisaki, "Evaluation of green paradox: case study of Japan," *Evergreen*, 5(4) 26–31 (2018). doi:10.5109/2174855.
53) T. Sato, "How is a sustainable society established? A case study of cities in Japan and Germany." *Evergreen*, 3(2) 25–35 (2016). doi:10.5109/1800869.
54) Thekkoote, Ramads. "A Framework for the Integration of Lean, Green and Sustainability Practices for Operation Performance in South African SMEs." *International Journal of Sustainable Engineering* 15 (1): 47–58. (2022) doi:10.1080/19397038.2022.2042619
55) Uygun, Ö.,&Dede, A. ''Performance evaluation of green supply chain management using integrated fuzzy multi-criteria decision making techniques.'' *Computers & Industrial Engineering*, 102, 502–511 (2016). doi:10.1016/j.cie.2016.02.020
56) Valamede, L.S., and Akkari, A.C.S. "Lean 4.0: a new

holistic approach for the integration of lean manufacturing tools and digital technologies", *International Journal of Mathematical, Engineering and Management Sciences*, Vol. 5(5), 851-868 (2020).

57) V. Swarnakar, A.K. Tiwari, and A.R. Singh, "Evaluating critical failure factors for implementing sustainable lean six sigma framework in manufacturing organization: a case experience," *Int. J. Lean Six Sigma*, 11 (6) 1083–1118 (2020). doi:10.1108/IJLSS-05-2019-0050/FULL/HTML.
58) Waheed, Waad, LailaK hodeir, and FatmaFathy. "Integrating Lean and Sustainability for Waste Reduction in Construction from the Early Design Phase." *HBRC Journal* 20 (1) 337–64 (2024). doi:10.1080/16874048.2024.2318502.
59) Yadav, Vishwas, Pardeep Gahlot, Rajeev Rathi, GunjanYadav, Anil Kumar, and Mahender Singh Kaswan. "Integral Measures and Framework for Green Lean Six Sigma Implementation in Manufacturing Environment." *International Journal of Sustainable Engineering* 14 (6) 1319–31 (2021). doi:10.1080/19397038.2021.1970855.
60) Zhu, Xiaoyong, Yongmao Xiao, and Gongwei Xiao. "Decision-Making Model of Mechanical Components in a Lean–Green Manufacturing System Based on Carbon Benefit and Its Application" *Processes* 10, no. 11: 2297 (2022). doi:10.3390/pr10112297.