Integrating Lean and Green Strategies and Their Effect on Manufacturing Industry Performance: An Empirical Study

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Abstract: This empirical study investigates the integration of Lean and Green manufacturing strategies in 160 Indian manufacturing industries using a structured questionnaire. Reliability analysis confirmed the adequacy of constructs (Cronbach's alpha > 0.65), and correlation analysis showed significant positive relationships between Lean–Green practices and performance parameters. A z-test identified Kaizen, continuous optimisation, material diversity, and green scheduling as the most influential practices. Hierarchical regression analysis further revealed that Total Productive Maintenance (TPM) acts as a significant moderator, improving the explanatory power of the models. Specifically, the inclusion of TPM increased economic performance by 25.8% and environmental performance by 35%, compared to initial regression results. These findings demonstrate that TPM not only enhances operational efficiency but also strengthens sustainability outcomes. The study provides important contributions to Lean–Green literature by offering empirical evidence from the Indian context and quantifying the moderator role of TPM. Practical implications highlight that Indian firms can tailor lean–green adoption according to their size and resources: small and medium enterprises (SMEs) may begin with cost-effective practices such as 5S, Kaizen, and waste segregation, while larger firms can adopt advanced TPM, energy optimization, and green scheduling. Overall, the research underscores that Lean–Green strategies, when supported by TPM, contribute substantially to both cost savings and environmental sustainability, offering a pathway for long-term sustainable development in the Indian manufacturing sector.

Keywords: ANOVA; Cronbach's alpha; hierarchical regression; Lean-Green approach; Survey; TPM

1. Introduction

A sustainable system in environmental management is capable of addressing environmental issues. Environmental needs are addressed through green strategies to meet the demands of the current generation. Ecological balance, economic prospects, and social responsibility are the important parameters for obtaining environmental sustainability in a strategic manner. In the past years, different dimensions of lean–green have been studied to focus on environment management and waste elimination in the operations for building a unified structure. According to the current Sus-VSM, suggestions for enhancing the production process's sustainability performance include cutting down on waiting time and making the workplace better [1)]. Different strategies of the lean green approach aimed at the elimination of unnecessary costs by reducing wastes of environmental waste. It saves the environment from industrial wastes and resource use and addresses environmental dimensions. Social dimensions are addressed by lean–green implementation strategically. Environmental design principles are closely related to the sustainability of the environment. Financial benefits are also seen by reducing resource consumption in the environmental management system. Manufacturing companies are monitoring and strengthening environmental and manufacturing performance parameters. Performance parameters, including environmental design, reflect the performance of lean-green attributes. Environmental goals of the organization are obtained by systematically implementing lean-green strategies [2)]. These companies are closely

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related to enhancing long-term competitiveness. Performance in terms of flexibility, sustainability, reliability, and productivity has been enhanced by implementing lean-green strategies [3]. Manufacturing processes are created by the concept of lean-green, not only from social and ecological perceptive but also from a profit point of view. The integrated lean-green concept is required to enhance production processes and reduce green waste to enhance productivity. There is a continuous need for understanding the lean-green concept for enhancing knowledge of the different benefits of implementing such strategies, including enhanced environmental practices and the enhancement of profit. Organizational and environmental performance has been significantly enhanced by implementing lean and green strategies. Productivity and improved quality of work life are other advantages of implementing lean and green manufacturing strategies. Sustainability attainment through lean and green strategies is the most complex task compared to the mass production paradigm. The thinking of sustainability supports manufacturing practices to obtain environmental, economic, and social benefits. Companies are implementing critical resources of lean-green implementation and are reducing wastes that are sustainable. Environmental emissions and resources creating pollution are critical factors leading towards lean-green implementation. The study was conducted in India's industrial sector to evaluate the advantages of systematically using lean-green practices. A questionnaire has been prepared, containing the filling of the questionnaire and applying statistical and analytical techniques for analysis of the data obtained from industries.

2. Literature Review

The theory of optimizing the performance of a firm has been developed further. Assessed lean and green tools for improving economic, social, and environmental performance, leading towards improvement in business performance. Putri et al. [3] developed a Sustainable Value Stream Mapping (Sus-VSM) method to enhance sustainability performance in feed production by minimizing waiting time and improving workspace efficiency. Agarwal et al. [4] applied a grey DEMATEL approach to reinforce circular economy strategies that significantly reduced greenhouse gas emissions. Anwar et al.[5] conducted an empirical analysis on SMEs, confirming that lean manufacturing adoption directly improves sustainable performance across economic, social, and environmental dimensions. An agenda that thoroughly addresses the potential success factors associated with 14.0 implementation can be built around the technologies found in this study's implementation paths. Bhadu et al. [6] prioritised Industry 4.0 technologies using an Analytic Hierarchy Process (AHP), revealing that digital integration can enhance lean–green outcomes. Bhasin et al. [7] analysed green disclosure practices in Indian companies and found that transparent environmental reporting strengthens stakeholder confidence. Bhaskar [8] proposed the B2Lean methodology, integrating Business Process Re-engineering with Lean principles to achieve long-term quality and efficiency improvements. Each technology's significance can be ascertained based on its AHP rating level. In this regard, businesses have begun informing different stakeholders of their environmental performance and strategies. The goal of this article is to examine how much environmental reporting Indian businesses do. To learn more about the steps these companies have taken to make India a low-carbon economy, a sample of thirty Indian enterprises was selected, and their annual reports were reviewed [9]. The results show that the B2Lean technique greatly increases product quality, decreases cycle times, and improves operational efficiency. The manufacturing industry experiences long-lasting improvements as a result of the combination of Lean's waste minimization and BPR's radical process redesign. Important success criteria and implementation-related difficulties are also noted. For factory managers looking to optimize their operations using a hybrid strategy, the research offers insightful information. Explained that sustainable lean manufacturing is characterized by critical success factors as identified from the literature. It was done before the literature on green HRM from the previous decade. This was the most effective method of disseminating research findings that would be helpful to managers and researchers and further the field's body of knowledge. We have determined the elements, their roles, the level of focus on them, and the gaps[10]. Lean and green have characteristics in common, and combining the two improves organizational production systems' performance results. However, a number of circumstances lessen the overall effect. Although there are conflicting effects of sustainability performance[11]. Surveyed in Morocco in 50 different companies to assess the status of lean green strategies. Environmental performance is greatly affected by these strategies. Results indicated that the correct use of these tools will have a positive impact on profit enhancement[12]. The review's conclusions show that combining lean and green techniques is a successful strategy for addressing the sustainability and operational issues facing SSA's manufacturing sector. Industries must use the appropriate tools and take into account the crucial success criteria to attain operational excellence and reduce environmental problems[13]. We address three key aspects of sustainability in fashion industry operations: corporate social responsibility, supply chain management, and sustainability business approach. In addition to introducing the relevant papers from Sustainability's Issue on the "Sustainability in Fashion Business Operations," we review a few related studies for each topic[14]. In the performance dimension, Lean manufacturing and Industry 4.0 integration largely increase cost-competitiveness, while agile manufacturing primarily increases adaptability. The results indicate that Industry 4.0 is the technology that resolves the trade-off between several conflicting objectives and enables two manufacturing systems to coexist[15)]. These components give manufacturing firms guidance on how to apply Industry 4.0 technology to achieve environmental sustainability and promote the circular economy. By offering a comprehensive understanding of the connections between Industry and economy, their findings pave the way for additional research and practical implementation in the industrial sector[16)]. It was completed. Enhancing social and economic benefits use of lean and green tools and approaches has a direct effect on overall business success. This will help practitioners and academics alike capitalize on their synergistic effects to achieve sustainable development in the manufacturing sector[17)]. In order to extend the production lead time, the study aims to decrease non-value-adding activities associated with different process resources. Both qualitative and quantitative methods are used to collect data. To identify wastes, the process time and floor layout are mapped using Value Stream Mapping using a spaghetti diagram[18)]. Proposed a novel hybrid framework that may effectively evaluate relevant criteria and offer solid support for LCSCM practical implementations[19)]. They explained the integration of lean green production for its importance of synergistic effects for sustainable development and to meet the competitive environment. The relationship between parameters of lean green methodology has been developed [20)]. Due to the actual movement of commodities from raw materials to completed goods, the supply chain process is highly integrated; as a result, there is a greater amount throughout the supply chain. As a result, it is crucial to analyze the growing complexity of the supply chain and comprehend how machine learning is being used to improve the SCM process for the growth and sustainable development of different businesses. To achieve sustainable development. The study is an investigation of the key factors influencing how big Indian companies develop and apply machine learning in the supply chain management process[21)]. Interpretive structural modeling has been employed to find the relationship between various success factors. Top management plays a significant role in implementing critical success factors [22)]. Lean green paradigms for overall improvement in maintenance engineering. The complexity of the manufacturing system and various external and internal factors responsible for maintenance outcomes have been identified [23)]. The author explored and identified lean environmental waste from industrial activities. This technique reduces waste emission and material waste, leading towards resource productivity. Employee training and involvement are highly needed for implementing the Lean and Green concept. The results demonstrate that Lean and Green have a strong synergy and that many Environmental sustainability initiatives can benefit from Lean methods and resources[24)]. They provide innovative techniques for providing environmental solutions resulting in reduced work handling, process automation, cost saving, effluent control, and other operational benefits. It has been observed that the Multi-Criteria Decision technique can be used to check the performance of key performance parameters[25)]. According to the MICMAC study, the primary factors influencing brand management through CSR are CSR planning, the cost of the good or service being provided under CSR, and the individuals participating in CSR [26)]. The favorable results are carefully reviewed and talked about. This study develops an optimal technique for improving defect detection in the textile sector by taking a comprehensive approach that combines simulation modeling, performance evaluation, and real-world deployment. It highlights the efficacy of the suggested IQP by demonstrating notable advancements seen in real-world scenarios using a simulation model [27)]. To improve industry performance and reduce waste without negatively impacting the environment, environmental concerns are taken into consideration[28)]. It was found that 71% of the studies examined carbon management in SC models, whereas 38% of the past studies examined production. Because it identifies areas for further research and offers valuable insights into the body of existing literature, it is expected that this review will be helpful to academics environmental context[29)]. A mathematical model was created to analyze the effects of transportation disruptions. The economic and environmental impact is taken into account while determining the best recovery timeline, which includes judgments on production and shipment quantities. The model specifically calculates the costs of carbon emissions from the refrigerated truck's cooling system and fuel use [30)]. This study emphasizes how crucial it is to apply Six Sigma ideas to industries. The study's contribution seeks to provide businesses in the small-scale transformer industry with valuable information and to bridge the knowledge gap on the application of Six Sigma in this sector [31)]. While Six Sigma concentrates on reducing process variation to increase the quality, Lean Manufacturing emphasizes waste removal to increase operational efficiency. This essay explores the methods and historical development of both systems, emphasizing their distinct yet complementary qualities [32)]. Their motivation and reliance are examined and categorized. The greatest reliance power is seen in the barrier, "Roles and Responsibilities are not defined in Lean Implementation," at level 1. The two biggest obstacles are level 10's "Individual Attitude" (barrier 5) and "Lack of Long-Term Commitment to Change and Innovation" (barrier 4). Generally speaking,

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barriers 4 and 5 exhibit great driving power and modest reliance power. The two obstacles are therefore recognized as "Independent Factors" of the organization's lean used obstacles [33]. Claimed that green manufacturing includes pollution prevention, waste elimination, and affluent treatment. It is viewed as a continuous improvement technique or preventing pollution and is advantageous over competitors in the global economy[34]. The application of the combined lean and agile manufacturing approach is crucial for these industries to get better results and increased performance. Issues about the impact of implementing lean and agile systems have been identified early on in the current paper. Furthermore, common problems (factors) were also investigated later [35]. The weighted interpretive structural modeling (W-ISM) technique was used to examine the common elements of the lean and agile manufacturing system[36]. Customers can use the suggested Collector Vending Machine (CVM) paradigm. According to CVM notifies the closest collector is notified to collect the e-waste when a threshold level of 80% is achieved[37]. Lean manufacturing was created to maximize resource utilization and minimize waste across all manufacturing processes. Conversely, the industrial sector's "green" idea pertains to social and environmental issues. By employing key performance metrics to identify the potential of green-lean ideas of the manufacturing industry, manufacturing companies aim to identify and enhance output performance [38]. They examined and identified key performance parameters of the lean and green approach. Realization of performance has been attained by use of green-lean six sigma [39]. The application of Green Manufacturing (GM) in a variety of business domains, including marketing, information management, can lead to sustainability. Finding and evaluating the Critical Success Factors of sustainable green production in the automobile sector[40]. The best performance evaluation may be significantly impacted by technology and sustainable development practices in a number of ways. In particular, not many studies have been done on sustainable development to find the sustainable development strategies used in Malaysia's industry, especially in the hotel business, and to recommend the most effective strategies used by managers[41].

The idea of the "Green Paradox" has raised questions about those concepts in recent years. The idea is that the introduction of renewable energy speeds up and encourages the production of more dangerous compounds as a result of that use. Due to the small number of articles assessing the Green Paradox and the unreliable evaluation methodology [42]. Three similarities were found in the comparative studies of their study uses a mixed methodology, with an expert revitalization Periods the use of regional tangible and intangible resources developed in the past, the existence of a symbol environment conscious, and an organization that oversees projects with a holistic perspective[43]. They proposed an elimination of waste methodology for food manufacturing industries. Inventory waste has been highlighted in the study throughout the production processes. Cost analysis for monitoring the waste of production processes has been performed[44]. Panel offering insightful opinions and validation during the framework's development and a thorough literature

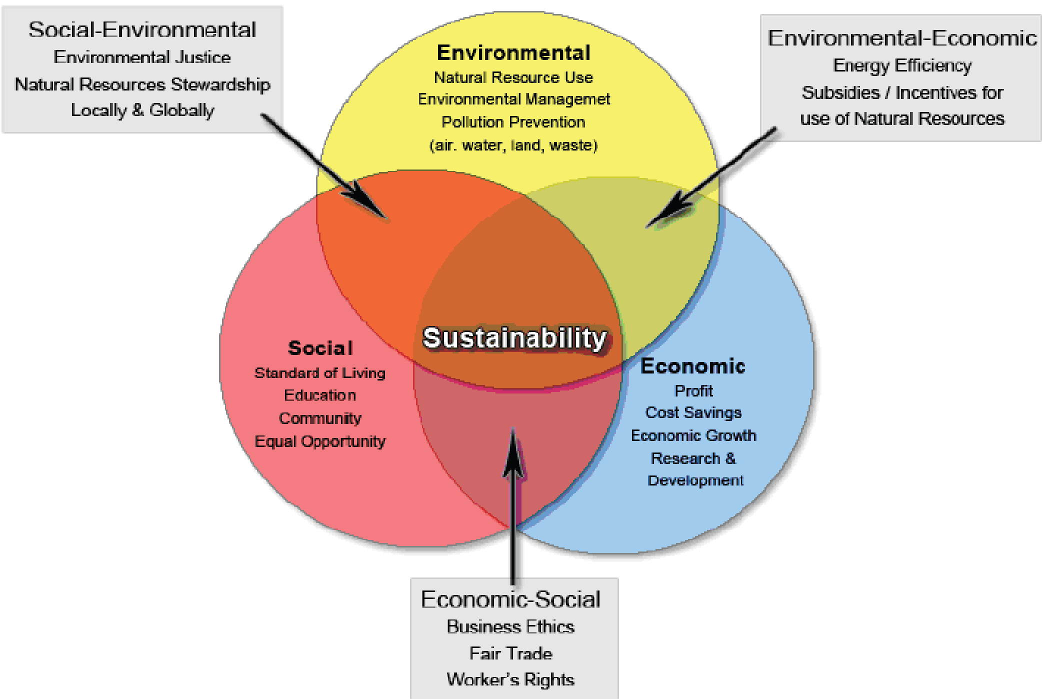

Fig. 1: Sustainability Process in Lean–Green Implementation

analysis to find any gaps in current research[45]. They used ANP (Analytical Network Process) to propose the best combination of performance indicators of sustainable manufacturing. A complex decision-making process for sustainable assessment has been analyzed. Lean manufacturing is less sustainable than green manufacturing[46]. Results indicate a strong linkage between lean and green tools. This will be useful for researchers and academicians for developing sustainable manufacturing in industries. The study explains how artificial intelligence (AI) solutions may improve project teams' productivity and responsiveness by automating repetitive processes, enabling real-time data analysis, and producing actionable insights. Additionally, we discuss the difficulties of integrating AI, such as the need to upskill project managers, data protection issues, and the risk of being overly dependent on technology [47]. Figure 1 shows the elements of a sustainable process, showing different benefits

3. Research Design

A questionnaire survey has been performed based on convenience sampling or based on the simplicity of convenience. The industry database has been created from the Directorate of Indian Industry and the Confederation of Industry. The Northern Indian Industrial Directory has also been utilized for the survey. Snowball sampling has been done by reaching the preceding Industry from the current Industry. Figure 2 shows the methodology used for the proposed research.

The first section of the questionnaire consists of the name and Location of Industry, Characteristics of the respondent, and product manufactured by the company. The questionnaire consists of both open and closed-ended questions. The questionnaire has been sent to peers and academic experts for its content reliability (adequacy of questions). Figure 3 shows different steps to complete the questionnaire. The measurement of other sections consists of five point likert scale (Lean and Green tools on five point: 1=Not at all important, 2= To small extent, 3= To a moderate extent, 4= To a large extent, 5= To an extremely large extent; Impact of TPM on 1=Not at all important, 2= To small extent, 3= To a moderate extent, 4= To a large extent, 5= To an extremely large extent; and benefits for organizational sustainability on 1=Not at all benefit, 2= To small extent, 3= To a moderate extent, 4= To a large extent, 5= To an extremely large extent). A total of 160 industries are surveyed, including Industries manufacturing auto parts, multi-products, sheet metal components, Die Casting, tractor parts, steel rods, fasteners, and Die and Punch. The respondent designations include managing directors, partners, heads of departments, executives, assistant managers, senior engineers, and engineers from different departments.

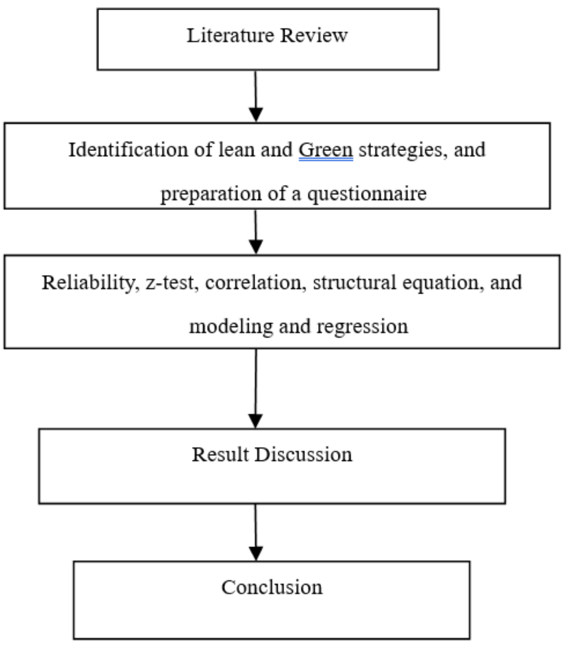

Fig. 2: Research Methodology

Also, the survey covered 160 companies from Northern India, representing a wide array of manufacturing sectors, including auto parts, sheet metal components, die casting, steel rods, fasteners, and tractor components. These companies ranged from small-scale enterprises to large industrial units. Notable participants included M.R.G Auto Ltd, Kamal Cycles & Exports, K.V. International, and Harmeet Forging. The companies were identified using credible industrial directories such as the Confederation of Indian Industry (CII), the Directorate of Indian Industry, and the Northern Indian Industrial Directory. The snowball sampling technique was also employed to reach additional firms through industry referrals. Respondents consisted of senior-level personnel such as managing directors, partners, department heads, assistant managers, senior engineers, and executives, ensuring a rich and diverse set of organizational perspectives on Lean-Green implementation and its outcomes.

3.1. Reliability Statistics

The loading of 0.5 has been used while calculating Cronbach's alpha (reliability statistics) using an online calculator. Reliability statistics of all variables are adequate for operations management research {cronbach's alpha =0.65. Table 1 describes the values of Cronbach's alpha for different constructs.

3.2. Correlation between Lean-Green strategies and performance parameters

The Karl Pearson coefficient is calculated between lean green strategies and performance parameters. The correlation coefficient is tested using single-factor ANOVA for its significance towards performance improvement. Table 2 describes values of Pearson

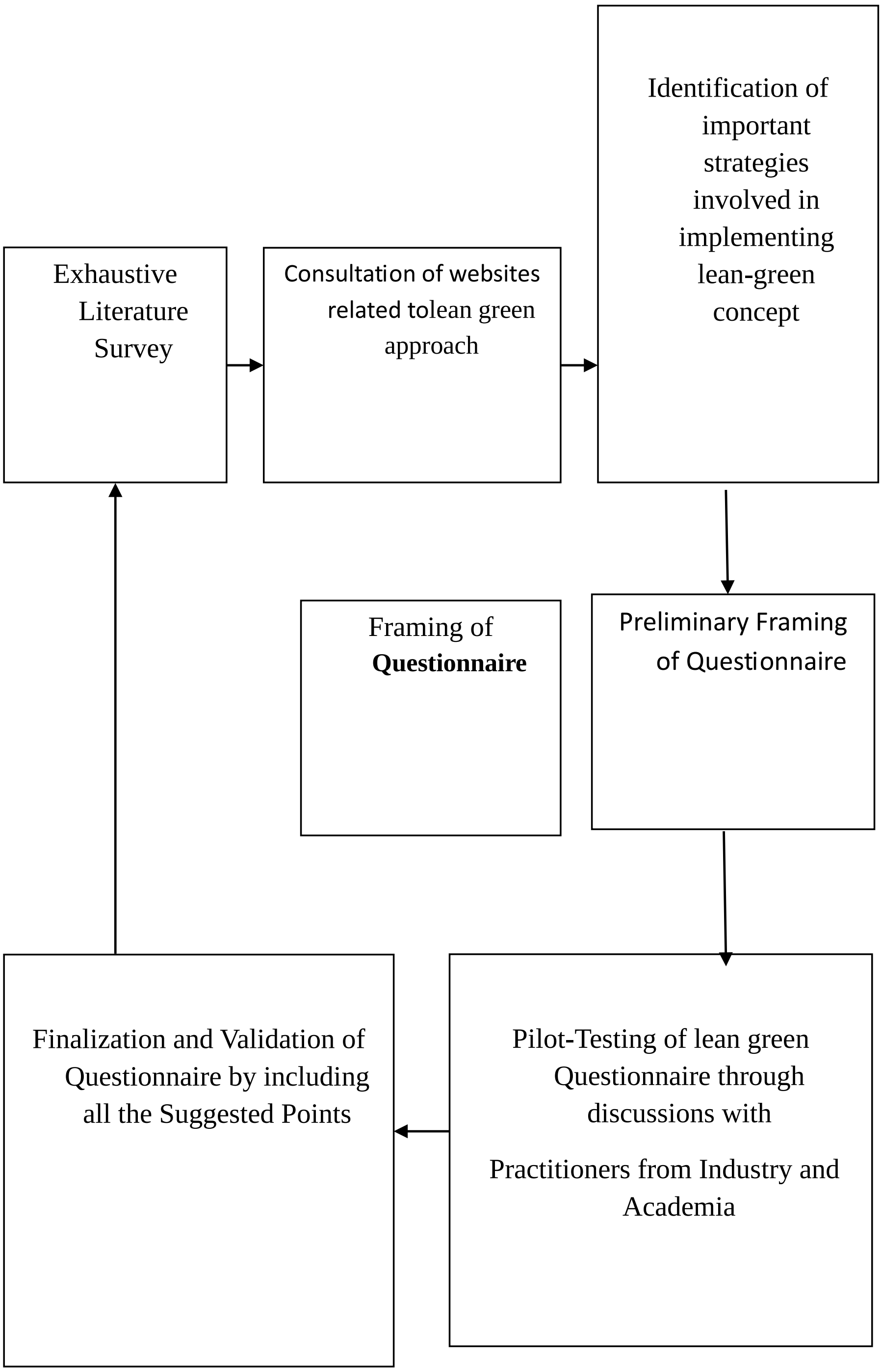

Fig. 3: Framing of Lean-Green Questionnaire

Table 1: Reliability statistics for different constructs

Constructs	Cronbach's Alpha
Lean strategies	
Removal of waste	0.736
Waste Segregation	
Proper utilization of space	
KAIZEN	
5S	
Design of Environment	
Integration of energy and material flows.	
Kanban system	
Single Minute Exchange of Die	
Supply chain involvement	
Technology Modification	
Continuous optimization	

Process Integration	
Green Strategies	
Green purchasing	0.846
Environmental Management System	
Material Diversity	
Recycling	
Green Scheduling	
Impact of TPM	
Unplanned events	0.698
Understanding of the problem	
Less intervention	
Environmental Performance	
Use of natural resources	0.723
Environmental Management	
Pollution Prevention	
Social benefits	
Improved Standard of Living	0.626
Awareness of education	
Equal opportunity for all	
Economic performance	
Profit enhancement	0.862
Economic Growth of the Company	
Research and Development	
Saving in cost	

Table 2: Correlation coefficient between lean green strategies and performance parameters

	EP	**SB**	**ECONP**
Lean Strategies	0.2216*	0.0588*	0.1386*
Green Strategies	0.2267*	0.1316*	0.2081*
*Correlation is significant at 5% level			

Table 3: Validation of correlation with single-factor ANOVA

Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
3.428571	159	547.0714	3.440701	0.049613		
3.4	159	513.2	3.227673	0.1329		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3.607779	1	3.607779	39.53443	1.07E-09	3.871054
Within Groups	28.83709	316	0.091257			
Total	32.44487	317				

correlation measured using MS Excel 2007, and Table 3 shows values calculated in single-factor ANOVA.

3.2.1. Results Discussion of Correlation Analysis

Since the calculated value of F using single-factor ANOVA is more than the critical F, the null hypothesis (There is no significant correlation between lean green strategies before implementing them) is rejected. All correlations are significant at 5% level. Results suggest that Lean manufacturing strategies significantly aimed at improving environmental performance (r=0.2216), followed by improved economic performance (r=0.1386) and attaining social benefits (r=0.0588); Green manufacturing strategies significantly aimed at improving environmental performance (r=0.2267), followed by improved economic performance (r=0.2081) and attaining social benefits (r=0.1316). Waste elimination strategies are highly helpful in getting cost benefits; environmental waste elimination strategies are also aimed at improving the economic performance of manufacturing system processes.

3.3. Importance of different variables

In order to find out important lean green strategies and the benefits of implementing these strategies, z z-test has been applied in Microsoft Excel 2007. The null hypothesis is taken as the mean of the initial population (a five-point Likert scale has been applied, and half of it is 2.5, which is taken as the hypothesized mean). Table 4 shows the z-test applied to all variables.

3.3.1. Result Discussion of the Tests

All z values are significant at 5% level (95% confidence interval). Results claimed that KAIZEN is rated most important (mean=3.73625) in terms of lean strategies followed by Continuous Optimization (mean=3.7125), Single Minute Exchange of Die (mean=3.64375), 5S (mean=3.59375), Kanban System (mean=3.56875), Proper utilization of space (mean=3.55625), Integration of energy and material flows (mean=3.50625), Process Integration

Table 4: z-test applied to all variables

Variables	Mean	Std. Deviation	z-stat
Lean Strategies			
Removal of waste	3.1125	0.513803	15.07889*
Waste Segregation	3.375	0.601361	18.40487*
Proper utilization of space	3.55625	0.557926	23.94694*
KAIZEN	3.73625	0.640331	23.82829*
5S	3.59375	0.694062	19.93333*
Design of Environment	2.95	0.750681	7.582581*
Integration of energy and material flows	3.50625	0.593432	21.44839*
Kanban system	3.56875	0.60002	22.53049*
Single Minute Exchange of Die	3.64375	0.666794	21.69697*
Supply chain involvement	3.24375	0.621895	15.1276*
Technology Modification	3.475	0.603449	20.43732*
Continuous optimization	3.7125	0.565101	27.14034*
Process Integration	3.48125	0.75212	16.50261*
Green Strategies			
Green purchasing	3.1875	0.595449	14.60454*
Environmental Management System	3.0375	0.559509	12.15154*
Material Diversity	3.31875	0.628184	16.48635*
Recycling	3.28125	0.584623	16.90339*
Green Scheduling	3.3187	0.712617	14.533*
Environmental Performance			
Use of natural resources	3.1125	0.560632	13.81937*
Environmental Management	3.2875	0.730189	13.64191*
Pollution Prevention	3.425	0.649625	18.01105*
Social Benefits			
Improved Standard of Living	3.09375	0.569639	13.1845*
Awareness of education	3.3	0.680362	14.87338*
Equal opportunity for all	3.25	0.777029	12.20912*
Economic Performance			
Profit enhancement	3.6	0.528437	26.33054*
Economic Growth of the Company	3.3625	0.639256	17.0665*
Research and Development	3.2	0.767254	11.54034*
Saving in cost	4.15	0.626461	33.3158*
Z critical (0.05) = 1.96 *Significant at 5% level			

(mean=3.48125), Technology Modification (mean= 3.475), Waste Segregation(mean= 3.375), Supply chain involvement(mean= 3.24375), Removal of waste(mean=3.1125), Design of Environment(mean=2.95); Material Diversity and Green Scheduling are rated most important(mean =3.31875) in terms of Green Strategies followed by Recycling (mean = 3.28125), Green purchasing (mean = 3.1875), and Environmental Management System (mean = 3.0375); Pollution Prevention (mean = 3.425) in rated most important environmental benefit followed by Environmental Management (mean= 3.2875), and Use of natural resources(mean= 3.1125); Awareness of Education (mean= 3.3) is rated most in terms of social benefits followed by Equal opportunity to all(mean= 3.25) and Improved Standard of living(mean= 3.09375); Saving in cost is rated most important (mean= 3.09375) in terms of Economic Performance followed by Profit enhancement(mean=3.6), Economic Growth of the Company(mean = 3.3625) and Research and Development (mean= 3.2).

3.4. Importance of main variables

The z-stat has been calculated for the main variables by taking the mean of all variables and preparing an array. This array has been used to measure mean, standard deviation, and z-statistics. Table 5 presents the z-test values for the main variable.

3.4.1. Results Discussion of the importance of the main variables

All respondents are confident (95% confidence level) in their responses to the main variables. Results signify that lean manufacturing strategies are more important (mean 3.440625) than green strategies (mean = 3.22875); Economic performance is rated the most important benefit (mean =3.578125), followed by Environmental Performance (mean =3.275) and social benefits (mean=3.214583).

3.5. Moderator effect of TPM between LM, GS, and Benefits (Hierarchical Regression)

The moderator effect of the impact of TPM on Lean
Green strategies and benefits, including performance parameters viz. economic performance, social benefits
And environmental performance (Figure 4) has been measured using hierarchical regression and expert analysis. The clustering and hierarchical regression process, utilizing SPSS 21v software. Both the ECONP and EVMTLPERF performance parameters have been analyzed. The primary independent variables, Lean and
Tables 6 and 7 show the contrast between the final hierarchical regression and the original multiple regression. Centralization (ECONP and EVMTLPERF), their product (ECONP and EVMTLPERF), and the moderating effect of TPM. (GS), were then presented as a block, followed by their Green Dimensions (LM) and Green Strategies.

3.5.1. Result Discussion of Hierarchical Regression

The study's findings showed that the moderator variable (Impact of TPM) significantly increased the percentage contribution of LM and GS to ECONP. This suggests that the centralization of independent variables has greatly enhanced the companies' economic performance. In the case of EVMTLPERF, the moderator effect is also significant, indicating that the concentrated effect of independent factors has also improved environmental performance. Economic effect has increased by 25.8% and environmental performance has increased by 35%. Additional findings showed that a positive correlation between independent and dependent variables is indicated

Table 5: shows values of the z-test applied to the main variable

Main variable	Mean	Std. Deviation	z-stat
Lean Strategies	3.440625	0.22204	53.58519*
Green Strategies	3.22875	0.363662	25.34783*
Environmental Performance	3.275	0.452572	21.66076*
Social Benefits	3.214583	0.465958	19.39842*
Economic Performance	3.578125	0.38156	35.74101*
Z critical (0.05) = 1.96 *Significant at 5% level			

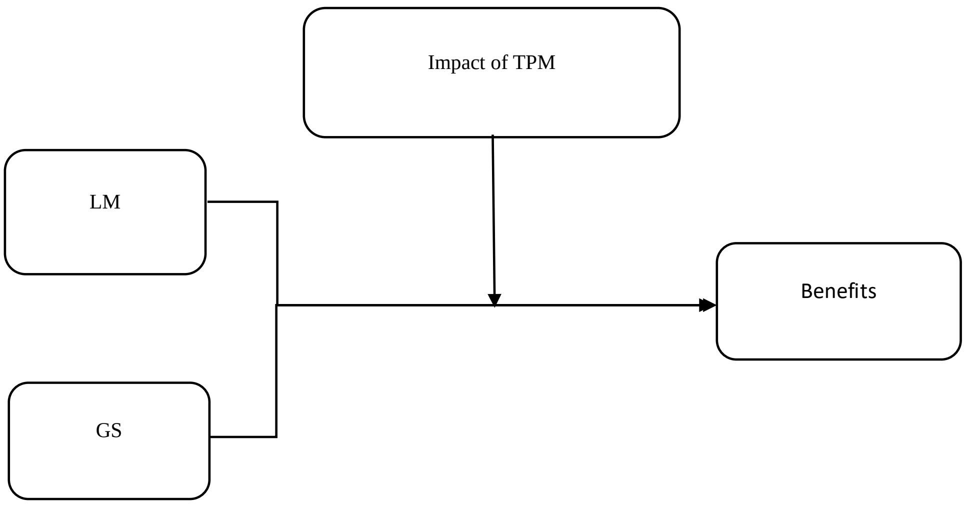

Fig. 4: Moderator Model for measuring the impact of TPM

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Table 6: Results of initial regression and final hierarchical regression (ECONP)

Initial Multiple Regression			Final Hierarchical Regression		
R Square	R Square Adjusted	t value	R Square	R Square Adjusted	t value
0.026	-0.061	LM- -0.032 GS- - 0.144 Constant- 3.504	0.258	0.256	LM-0.076 GS- --0.448 Moderator – 2.627* Constant- 3.6

*Significant at 5%level

Table 7: Results of initial regression and final hierarchical regression (EVMTLPERF)

Initial Multiple Regression			Final Hierarchical Regression		
R Square	R Square Adjusted	t value	R Square	R Square Adjusted	t value
0.066	0.005	LM- 0.206 GS- - 0.144 Constant- 2.892	0.350	0.262	LM-0.549 GS- --0.524 Moderator – 3.422* Constant- 2.9

*Significant at 5%level

by positive R-squared values. Every claim has high statistical stability, as evidenced by the fact that all t-values are significant at the 5% level. Moreover, TPM shows a moderate to very high level, which signifies that economic benefits have occurred after implementing lean manufacturing and green strategies by using TPM as a moderator variable in manufacturing organizations of India.

4. Conclusions, Implications, and Practical Limitations

The findings confirm that small incremental improvement strategies (Kaizen) play a vital role in systematically reducing waste and enhancing sustainability. To achieve manufacturing excellence, organizations must adopt lean and green practices, which significantly contribute to both economic and environmental outcomes. The study highlights the importance of material diversity and green scheduling as key drivers for profit enhancement.

Moreover, Total Productive Maintenance (TPM) as a moderator considerably strengthens the model, improving economic performance by 25.8% and environmental performance by 35%. These percentages refer to the increase in explanatory power (R^2 values) of the regression models after introducing TPM. This demonstrates that TPM not only supports operational efficiency but also fosters long-term sustainability in environmental outcomes, thereby maximizing organizational benefits.

In the Indian context, implementation of lean–green strategies require a tailored approach. Small and medium enterprises (SMEs) can begin with cost-effective tools such as 5S, Kaizen, and waste segregation, while larger industries may implement advanced TPM, energy optimization, and green scheduling practices. In addition, government initiatives such as Make in India and strict environmental regulations. In the Indian manufacturing landscape, the implementation of Lean–Green strategies must be contextually customized. For instance, small and medium enterprises (SMEs) can initially focus on low-investment practices such as 5S, Kaizen, and waste segregation, which require minimal infrastructural change. In contrast, large-scale industries can pursue resource-intensive interventions such as advanced TPM deployment, process automation, and green scheduling integrated with energy optimization. The presence of national initiatives like Make in India and the enforcement of environmental compliance frameworks by the Ministry of Environment and Forests serve as external motivators, thereby aligning these strategies with India's sustainable development goals. In the Indian manufacturing landscape, the implementation of Lean–Green strategies need to be tailored to the specific context. For example, small and medium enterprises (SMEs) can start with low-cost practices such as 5S, Kaizen, and waste segregation, which require little infrastructural change. Meanwhile, large-scale industries can adopt more resource-intensive initiatives such as advanced TPM deployment, process automation, and green scheduling combined with energy optimization. The existence of national initiatives like Make in India and the enforcement of environmental compliance frameworks by the Ministry of Environment and Forests act as external motivators, helping to align these strategies with India's sustainable development goals. Regulations provide external drivers that facilitate adoption. These context-specific insights help Indian organizations implement lean–green strategies in a way that aligns with their resources and challenges.

Despite these contributions, the study has certain limitations. The use of convenience sampling may restrict generalizability, as respondents were not randomly selected. Moreover, while the challenges of implementing lean–green strategies were not quantitatively measured in this study, they were identified through literature review and supported by qualitative feedback from respondents, highlighting barriers such as lack of training, infrastructure gaps, and resistance to change. Future studies may address these limitations by combining survey-based analysis with in-depth case studies.

Environmental performance in this study was measured through indicators such as resource utilization, pollution prevention, and environmental management. The term ‘‘environmental stability’’ therefore refers to improvements in these recognized environmental performance parameters, rather than a novel metric. The term ‘environmental stability’ used in earlier drafts has been replaced with ‘environmental performance improvement.’ This parameter encompasses standard indicators used in sustainability measurement, including efficient resource utilization, pollution prevention, and environmental management system effectiveness. Thus, it represents recognized environmental performance metrics rather than a novel construct.

This study also makes an important contribution to the existing literature. It provides empirical evidence from 160 Indian manufacturing firms on the integration of lean and green strategies, moderated by TPM. Unlike previous works that studied lean or green practices in isolation, this study demonstrates their synergistic effect and quantifies the improvement in economic and environmental performance. By highlighting TPM as a critical enabler, this research extends the lean–green literature in the context of Indian manufacturing. Although the limitation of implementing Lean–Green strategies was not measured through direct quantitative analysis, qualitative insights from industrial respondents and literature review revealed key challenges such as a lack of training infrastructure, limited technological readiness, and employee resistance to process change. These observed challenges emphasize the need for a combined survey–case study approach in future research to measure the intensity of such barriers.

This study extends the existing Lean–Green literature by providing empirical evidence from 160 Indian manufacturing firms, demonstrating how the synergistic integration of Lean and Green practices, when moderated by TPM, enhances both economic and environmental performance. Unlike prior studies that examined these paradigms in isolation, the present work quantifies their combined effects and introduces TPM as a moderator variable within the Indian context, offering a unique contribution to operational sustainability research.

Overall, this research offers strong practical implications. It demonstrates the crucial role of lean and green strategies in promoting competitiveness and sustainability. Industrial professionals can gain actionable insights into how these strategies can be effectively implemented in their organizations to achieve both cost savings and environmental improvements, thereby supporting long-term sustainable development. Specifically, the inclusion of TPM increased economic performance by 25.8% and environmental performance by 35%, referring to the rise in explanatory power (R^2 values) of the regression models after the moderator was introduced.

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Appendix

Lean- Green Questionnaire
General Organizational Information

Name and Address of Company
Name and Designation of Respondent
Products Manufactured by the company

Part A) Please mark tick at the appropriate place to indicate the level of importance of lean–green practices.

Practices	Not at all important [1]	To a small Extent [2]	To a moderate Extent [3]	To a large Extent [4]	To an extremely Large Extent [5]
Removal of waste	1	2	3	4	5
Green purchasing	1	2	3	4	5
Product Redesign	1	2	3	4	5
Waste Segregation	1	2	3	4	5
Proper utilization of space	1	2	3	4	5
KAIZEN	1	2	3	4	5
5S	1	2	3	4	5
Design of Environment	1	2	3	4	5
Environmental Management System	1	2	3	4	5
Material Diversity	1	2	3	4	5
Integration of energy and material flows	1	2	3	4	5
Kanban system	1	2	3	4	5
Single Minute Exchange of Die	1	2	3	4	5
Supply chain involvement	1	2	3	4	5
Technology Modification	1	2	3	4	5
Continuous optimization	1	2	3	4	5
Recycling	1	2	3	4	5
Plan and Design	1	2	3	4	5
Green Scheduling	1	2	3	4	5
Process Integration	1	2	3	4	5

Part B) Please mark tick at appropriate places to indicate important barriers in implementing Lean-Green Strategies.					
Barriers	Not at all Barrier [1]	To a small Extent [2]	To a moderate Extent [3]	To a large Extent [4]	To an extremely Large Extent [5]
Resistance from employees	1	2	3	4	5
Inadequate training programs	1	2	3	4	5
Lack of related infrastructure	1	2	3	4	5
Lack of motivation	1	2	3	4	5
Lack of co-operation and understanding	1	2	3	4	5
Lack of trained professionals	1	2	3	4	5
Lack of knowledge on new technology	1	2	3	4	5
Lack of individual effort,	1	2	3	4	5
Disparity in the pay scales of workers	1	2	3	4	5
Disruptions during implementation	1	2	3	4	5
Problems with the compatibility of equipment	1	2	3	4	5
Organizational rigidities within the company	1	2	3	4	5
Lack of a proper work environment	1	2	3	4	5
Lack of prior planning	1	2	3	4	5
Production management skill deficiency	1	2	3	4	5

Part C) Please mark tick at the appropriate place to indicate different success factors of lean-green strategies.					
Success factor	Not at all Important [1]	To a small Extent [2]	To a moderate Extent [3]	To a large Extent [4]	To an extremely Large Extent [5]
Impact of TPM					
Unplanned events	1	2	3	4	5
Understanding of the problem	1	2	3	4	5
Less intervention	1	2	3	4	5
Impact of Lean Thinking					
Less movement	1	2	3	4	5
Less Clutters	1	2	3	4	5
No overproduction	1	2	3	4	5

Impact of Green Thinking					
Product life cycle management	1	2	3	4	5
Reduction in the use of non-renewable resources	1	2	3	4	5
Higher appreciation of what constitutes internal customer value	1	2	3	4	5

Part D) Please mark tick at the appropriate place to indicate the impact of Lean-Green implementation on performance improvement (sustainability of organization).

Benefits	Not at all Benefit [1]	To a small Extent [2]	To a moderate Extent [3]	To a large Extent [4]	To an extremely Large Extent [5]
Environmental Performance					
Use of natural resources	1	2	3	4	5
Environmental Management	1	2	3	4	5
Pollution Prevention	1	2	3	4	5
Social benefits					
Improved Standard of Living	1	2	3	4	5
Awareness of education	1	2	3	4	5
Equal opportunity for all	1	2	3	4	5
Economic performance					
Profit enhancement	1	2	3	4	5
Economic Growth of the Company	1	2	3	4	5
Research and Development	1	2	3	4	5
Saving in cost	1	2	3	4	5

Name of company	**Product**
Mabesto products	Auto Parts
Kamal cycles &exports	Cycle parts
M.R.G Auto Ltd	Auto Parts
K. V. International	Sheet metal components
K. R. P. Manufacturing Company	Tractor parts, Auto parts
K. K. International	Auto Parts
Joginder Enterprises	Auto Parts
J. K. Indl corporation	Auto Parts
Harmeet forging	Auto Parts
Happy Enterprises	Alloy steel and auto parts
H. K. Products	Auto Parts and Cycle Parts

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