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Article

An Integrated ISM-MICMAC Analysis for Mapping Key Factors for Lean-Green Integration in Small Scale Manufacturing Systems

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Abstract: The growing demand for sustainable manufacturing has encouraged industries to integrate Lean and Green manufacturing for achieving operational excellence along with environmental sustainability. The implementation is influenced by multiple interrelated factors, particularly in small-scale manufacturing systems where resource constraints and limited technical capabilities exist. The study aims to identify key factors influencing Lean-Green integration and to develop a structured framework to find the interrelationships. An extensive literature survey was performed to identify factors affecting Lean-Green integration, which were subsequently refined to 14 key relevant factors. These factors were validated and ranked based on expert opinions collected. The ISM approach was then employed to establish the relationships among these factors and to develop a hierarchical structural model. The MICMAC analysis was conducted that classifies factors on the basis of driving and dependence power. Results show that management commitment, Lean and Green training, and organizational culture-related aspects act as key driving factors, forming the foundation for successful implementation. Also, factors such as Emission Control and Energy Management are found to be highly dependent on these drivers. The findings of this study provide a valuable insight for practitioners in prioritizing strategies for Lean-Green implementation in small-scale manufacturing systems.

Keywords: Lean Manufacturing; Green Manufacturing; Lean-Green Integration; Sustainable Manufacturing; Interpretive Structural Modelling (ISM); MICMAC Analysis

1. Introduction

In recent years, the small-scale manufacturing industries have been facing increasing pressure to improve their performance in economic terms as well as in environmental and social dimensions. The concept of sustainability has emerged as a critical requirement for organizations to ensure long-term competitiveness and responsible resource utilization. Manufacturing operations contribute significantly to environmental degradation by consuming too many resources, using too much energy, and producing waste and pollution. These concerns have forces firms to rethink their production systems and develop sustainable manufacturing strategies that will reduce the environmental impact while maintaining efficiency and profitability. .

Traditional manufacturing systems were mostly designed for high yield and efficiency, often ignoring environmental consequences. However, increasing global issues such as climate change, resource depletion and stringent environmental standards have led to sustainability as an integral part of industrial operations. Organizations are now expected to adopt practices that can reduce waste, increase the energy efficiency, and promote environmentally responsible production processes. In this context, two major approaches such as Lean manufacturing and Green manufacturing have gained significant attention as effective strategies to address sustainability challenges in manufacturing industries .

1.1 Lean Manufacturing for Sustainability

Lean manufacturing (LM) is the most effective approaches for improving operational efficiency and reducing waste in the manufacturing systems. Lean is about eliminating non-value-added activities and consistently improving processes to increase productivity and customer value. . Lean has been considered as a tool of operational excellence for years, but due to its emphasis on resource efficiency and waste minimization, it has evolved into an important contributor to Sustainability . Lean recognizes seven forms of waste like overproduction, waiting, transportation, excess inventory, motion, defects and over-processing. Elimination of these wastes can significantly reduce material and energy consumption and operational costs of the organizations which indirectly contributes towards environmental sustainability .

The adoption of lean practices not only enhances productivity but also reduces the environmental impact by decreasing resource wastage and emissions . Kaizen is the term for continuous improvement, a core Lean tool that involves all employees and promotes small improvements in processes. Kaizen provides a culture of continuous improvement where all employees are actively involved in identifying process inefficiencies and proposing improvements. The participative approach improves operational performance and promotes sustainability through resource conservation and waste reduction . Continuous improvement initiatives have been identified as successful in achieving long term sustainability goals in manufacturing organizations. Another important tool of Lean is a Value Stream Mapping (VSM) which is used to analyze and optimize the flow of materials and information in the production processes. VSM helps to identify inefficiencies in the process and activities that do not add value. This, in turn, enables organizations to streamline their operations. More recent studies have extended VSM to include environmental parameters, leading to the development of “Green VSM” which integrates environmental performance indicators such as energy consumption and emissions into process analysis .

The integration improves the organizational performance by improving the operational efficiency and environmental performance. There are different phases of 5S such as sort, set in order, shine, standardize, and sustain. 5S is mainly used to improve the workplace. The 5S is a methodology that reduces waste, improves safety and increases productivity by ensuring the workplace is clean and organized. In addition, it helps in sustainability by minimizing the waste of materials and better utilization of resources . The 5S disciplined approach also contributes to the implementation of other Lean and Green practices. Total Productive Maintenance (TPM) enhances equipment reliability and reduces downtime through proactive maintenance strategies. TPM enhances the operational efficiency by reducing thr equipment failures and optimizing performance. From a sustainability perspective, TPM reduces the energy, material waste and emissions by keeping equipment in the optimal condition . Better equipment operation results in less impact on the environment and better use of resources.

Another major Lean practice is Just-In-Time (JIT) in production. This is the art of manufacturing the right amount at the right time in the right amount. JIT reduces inventory, storage needs and helps process flow. JIT also helps in environmental sustainability as it reduces the excess inventory and over production . It helps to save resources and reduce waste. Lean manufacturing principles are a good foundation for sustainability with its focus on efficiency, waste reduction and continuous improvement. However, although Lean has an indirect contribution to environmental performance, it does not directly address environmental issues like pollution, emissions and depletion of resource. This restriction shows the importance of integrating Lean with Green production techniques to reach a total sustainability.

1.2 Green Manufacturing Practices

Green manufacturing (GM) is the process of reducing the environmental impact of the manufacturing processes by utilizing the resources efficiently and by adopting eco-friendly practices. It aims to reduce the creation of waste, the use of energy and to encourage the use of sustainable materials. Green manufacturing has gained importance due to increasing environmental concerns, regulatory pressures and the need for sustainable development . Waste reduction is the major element of green manufacturing. Organizations are increasingly adopting practices like waste minimization, recycling and reuse to mitigate the environmental impact of their operations. Waste reduction helps in resource conservation and also reduces the cost of waste disposal and compliance to regulation . Research has shown that good waste management practices can improve environmental and economic performance.

Energy efficiency is another important aspect of green manufacturing. Production processes require high energy consumption which leads to increased carbon emissions and ultimately degrade environment. Organizations can reduce their energy consumption and carbon footprint by adopting energy-efficient practices and technologies.

The sustainability performance has been found to be improved by the energy efficiency initiatives such as use of renewable energy sources and energy management systems . Recycling and reuse of materials are a fundamental tool of green manufacturing. Recycling decreases the consumption of raw materials and the generation of waste and reuse extends the lifecycle of products. These techniques help in the development of a circular economy which minimizes waste and makes efficient use of resources .

Many organizations are adopting closed-loop supply chains that facilitate recycling and reusing materials. Eco-design, also known as green product design, is the design of products with minimal or no adverse effects on the environment throughout the product life cycle. This includes energy efficient manufacturing processes, use of environmentally friendly materials and designs for recycling and re-use. Eco-design is essential to the sustainability improvement and reduction of environmental impact of products .

Environmental Management Systems (EMS) such as ISO 14001 offer a structured approach to the management of environmental aspects of manufacturing operations. EMS helps organizations to recognize, track and manage environmental impacts, comply with regulations and continually improve environmental performance. . It has been found that the implementation of EMS improves environmental performance and organizational reputation. Green manufacturing practices are successful in solving environmental concerns, but they usually require huge investments and may not directly improve operational efficiency. Thus, combining green practices with Lean manufacturing can assist organizations in obtaining environmental and operational advantages.

1.3 Lean-Green Integration

Recently, the convergence of Lean & Green manufacturing has drawn much attention as firms seek long-term performance. Lean-Green integration incorporates the efficiency-driven principles of Lean manufacturing and the environmental concerns of Green manufacturing into a comprehensive approach to sustainability . The majority of studies have indicated that Lean practices help improve environmental performance by reducing waste, energy consumption and resource usage. For instance, Lean tools such as Value Stream Mapping and Kaizen used to identify inefficiencies and eliminate waste which can reduce the environmental impact . Similarly, Just-In-Time production helps in minimizing the inventory and the use of resources, thus contributing to sustainability .

Research has also shown that the integration of Lean and Green principles leads to a higher sustainability performance. . According to Govindan, K. et. al. the integration of Lean and Green approaches leads to the improvement of supply chain sustainability by increasing efficiency and reducing environmental impact. It has been shown that the Integrated Lean-Green practices improve the organizational performance by increasing the utilization of resources and decreasing the waste . Hines, P. et. al. developed a model to link Lean and Green practices to process innovation and sustainability performance. They found that organizations that have integrated Lean-Green practices have significant improvements in both environmental and operational performance.

Similarly, Gál, T. et. al. highlighted that Lean-Green integration improves sustainable manufacturing by integrating efficiency and environmental responsibility. Although the advantages of Lean-Green integration are considerable, its implementation is complex and it is affected by several factors. The barriers of Lean-Green implementation were identified by Imai, M. including, negligible support from management, inadequate resources and technological challenges. The findings concluded that a systematic approach is needed to identify and analyse the factors influencing Lean-Green integration.

1.4 Research Gap

A detailed literature review shows several gaps in the research on Lean-Green integration. Although many studies have investigated Lean and Green practices independently, the integration of the two has been systematically studied only in a few studies. The majority of the existing research is based on the conceptual framework, case study or performance analysis and lacks a detailed understanding of the relationships between the factors affecting Lean-Green integration . The most significant finding in the research is the structural absence of modeling of Lean-Green integration. Some studies have applied techniques such as ISM to analyze drivers of green supply chain management however, there is limited research in applying these techniques to Lean-Green integration specifically. Knowledge of interrelationships among factors is important for effective implementation, since it helps to identify key driving and dependent factors.

Another major gap is the limited use of hybrid multi-criteria decision-making methods such as ISM and DEMATEL in studies of Lean-Green integration. These strategies can help you make decisions and understand causal linkages between variables. However, their use in this area is still limited. Most of the research is conducted in industrialized countries with less focus on small and medium-sized firms (SMEs) in developing countries such as India. Small and medium sized enterprises (SMEs) have specific difficulties in implementing Lean-Green techniques, such as limited resources and experience. Therefore, research is needed to address these issues and provide actionable solutions for SMEs. Moreover, the main factors responsible for Lean-Green integration should be identified and classified in a systematic way. Existing research usually focuses on a small number of characteristics or is limited to particular areas, and does not provide a complete picture. Systematic approaches like ISM with MICMAC analysis can help in identification of key elements and understanding their hierarchical interrelationships.

1.5 Research Objectives

The objectives of this study are:

- To identify key factors which influences Lean-Green integration.
- To develop a structural relationship model among these factors using ISM.
- To classify the factors using MICMAC analysis.

2. Research Methodology

This study uses the Interpretive Structural Modeling (ISM) approach (Figure 1) to create a structured framework for finding and assessing the interrelationships between Lean-Green integration aspects that influence long-term organizational performance.

Figure 1. Interpretive Structural Modelling (ISM) methodology

ISM is a well-known paradigm for dealing with complex systems that transforms ambiguous and poorly articulated models into observable and well-defined hierarchical structures. It is suitable for this study as it allows to identify contextual interactions between several aspects and it helps in the development of a multi-level structural model.

2.1 Identification of Factors influencing the integration of Lean and Green practices

The factors influencing the integration of Lean and Green practices were identified through an extensive review of existing literature. A total of 42 factors (Table 1) were initially extracted and grouped into five major categories: organizational, operational (Lean), environmental (Green), technological and external factors. These categories represent both internal and external conditions required for successful implementation of sustainable manufacturing practices.

Organizational factors emphasize the internal readiness of firms that includes the management commitment, leadership support, employee involvement, training and organizational culture. These elements are widely recognized as a critical enabler for adopting improvement initiatives. The operational or Lean factors focus on process efficiency through tools such as waste reduction, value stream mapping, 5S, Kaizen and Total Productive Maintenance. The environmental factors address sustainability aspects such as energy management, emission control, and eco-friendly practices. Technological factors highlight the importance of the automation, digitalization, and monitoring systems, while the external factors include regulatory pressure, market demand, and stakeholder influence.

Table 1. Identified Lean-Green Integration Factors and Supporting Literature

Sr. No.	Factor Category	Factor	Key Supporting References
1	A. Organizational Factors	Management commitment	[13] [25] [26] [27] [28]
2		Leadership support	[2] [29]
3		Organizational culture	[30] [21]
4		Employee involvement	[31] [32] [16] [30]
5		Employee training and skill development related to Lean-Green	[33] [26] [27]
6		Continuous improvement culture	[8] [2] [6]
7		Environmental awareness among employees	[14] [27] [13]
8		Strategic planning for sustainability	[29] [16]
9		Performance measurement systems	[34]
10		Cross-functional teamwork	[2] [35]
11		Resource Availability	[24]
12	B. Operational / Lean Factors	Waste reduction practices	[4] [6] [36]
13		Value Stream Mapping implementation	[37] [36] [2] [7]
14		5S workplace organization/ Visual Control	[6] [30] [24]
15		Kaizen culture	[8] [2] [6]
16		Just-In-Time production	[4] [38]
17		Total Productive Maintenance (TPM)	[10] [6] [39]
18		Process standardization	[35] [2] [4] [40]
19		Quality management practices	[31] [33]
20		Inventory reduction	[4] [38]
21		Production efficiency improvement	[6] [2]

22		Poka-Yoke/ Error proofing	[22] [7]
23	C. Green / Environmental Factors	Energy Management	[34] [16] [13] [41]
24		Pollution prevention	[42] [13]
25		Circular Material Usage	[1] [16] [13] [43] [44]
26		Green product design	[29] [13]
27		Emission control	[13] [16] [45]
28		Water conservation practices	[34] [16] [13]
29		Eco-friendly material usage	[29] [14]
30		Environmental management systems (ISO 14001)	[13] [16]
31	D. Technological Factors	Adoption of green technologies	[42] [29]
32		Automation and digitalization	[46] [16] [29]
33		Data monitoring systems	[46] [34] [29]
34		Cleaner production technologies	[14] [42] [45]
35	E. External Factors	Regulatory Pressure	[13] [23] [27]
36		Customer environmental awareness	[16] [1] [27]
37		Supplier collaboration for green practices	[16] [13] [47]
38		Environmental certification requirements	[13] [29]
39		Market pressure for sustainability	[29] [1] [27]
40		Stakeholder pressure	[13] [16] [29]
41		Financial investment capability	[26] [27] [28]
42		Green supply chain integration	[14] [16] [13]

2.2 election of Key Factors for Small-Scale Industries

From the identified factors, 14 key factors were selected (Table 2) specifically for small-scale manufacturing industries based on their relevance, feasibility, and frequency of occurrence in the literature. These factors were considered suitable for small industries due to their practical applicability and lower implementation complexity.

Table 2. Selected of Key Factors for Small-Scale Industries

Management Commitment
Regulatory Pressure
Resource Availability
Employee Involvement
Kaizen Culture
Lean & Green Training
5S & Visual Control
Process Standardization
Value Stream Mapping

Poka-Yoke (Error Proofing)
Total Productive Maintenance
Energy Management
Circular Material Usage
Emission Control

2.3 Ranking of Factors Based on Expert Opinion

A survey was conducted of total 30 industry professionals and academic experts to evaluate the importance of the selected factors. Respondents had varied experience levels, ranging from early-career engineers to senior managers, consultants, and academicians. The diversity of respondents ensured a balanced perspective. The ranking of factors (Table 3) was determined based on the average scores provided by the experts.

Table 3. Ranking of Key Factors for Small-Scale Industries

Factor	Average Score	Rank
Management Commitment	4.6	1
Lean & Green Training	4.6	2
Kaizen Culture	4.53	3
Emission Control	4.53	4
Employee Involvement	4.47	5
Energy Management	4.43	6
Circular Material Usage	4.43	7
5S & Visual Control	4.3	8
Value Stream Mapping	4.17	9
Total Productive Maintenance	4.07	10
Resource Availability	4.03	11
Poka-Yoke (Error Proofing)	3.67	12
Process Standardization	3.6	13
Regulatory Pressure	3.1	14

The results (Table 3) indicate that the Management Commitment and Lean & Green Training received the highest scores (4.6), highlighting their important role in successful implementation. Factors such as Kaizen Culture and Emission Control were also ranked highly, reflecting the importance of continuous improvement and environmental responsibility. On the other hand, Regulatory Pressure received the lowest score (3.1), suggesting that the external pressure alone is not a strong driver for small-scale industries as compared to internal organizational factors. These results indicate that the internal readiness and workforce capability play a more significant role than external forces.

2.4 Development of the Structural Self-Interaction Matrix (SSIM)

A Structural Self-Interaction Matrix (SSIM) (Table 5) was created using expert (Table 4) inputs that captures the contextual interactions between variables. The SSIM uses four symbols to describe the direction of influence between any two factors (i, j):

• V: Factor i affects factor j.

• A: Factor j affects factor i.

• X: Factors i and j influence each other.

• O: Factors i and j are unrelated.

The qualitative matrix is the base for further quantitative analyses and allows the systematic structuring of expert knowledge.

Table 4. Experts Qualification Table

Expert Type	Criteria	Count
Academia	Professor/Researcher	1
Industry Expert	Lean Green Practitioner	3
Industry (Owner)	Owner of an SSMIs with Lean/Green implementation	1
Consultants	Lean Six Sigma Black Belts	1

Once these factors were identified they were removed from subsequent iteration and the process repeated to calculate the following levels.

Table 5. Structural Self-Interaction Matrix (SSIM)

Variables	1	2	3	4	5	6	7	8	9	10
F1: Management Commitment		V	V	V	V	V	V	V	V	V
F2: Lean & Green Training			V	V	V	V	V	V	V	V
F3: Kaizen Culture				V	X	V	V	X	V	X
F4: Emission Control					A	X	X	O	A	A
F5: Employee Involvement						V	V	X	V	X
F6: Energy Management							X	O	A	A
F7: Circular Material Usage								O	A	A
F8: 5S & Visual Control									V	V
F9: Value Stream Mapping										V
F10: Total Productive Maintenance										

2.5 Development of Initial Reachability Matrix

The SSIM was then converted into a binary matrix called as the Initial Reachability Matrix (Table 6). In this step, the symbolic relationships (V, A, X, O) were replaced with numerical values (1s and 0s) based on standard ISM conversion rules.

Table 6. Initial Reachability Matrix

Variables	1	2	3	4	5	6	7	8	9	10	Driving Power
F1	1	1	1	1	1	1	1	1	1	1	10
F2	0	1	1	1	1	1	1	1	1	1	9
F3	0	0	1	1	1	1	1	1	1	1	8
F4	0	0	0	1	0	1	1	0	0	0	3
F5	0	0	1	1	1	1	1	1	1	1	8
F6	0	0	0	1	0	1	1	0	0	0	3
F7	0	0	0	1	0	1	1	0	0	0	3
F8	0	0	1	1*	1	1*	1*	1	1	1	8
F9	0	0	1*	1	1*	1	1	1*	1	1	8
F10	0	0	1	1	1	1	1	1*	1*	1	8
Dependence Power	1	2	7	10	7	10	10	7	7	7	

This matrix represents the direct relationships among factors. A value of “1” indicates the presence of a relationship, while “0” indicates no direct link. The value “1*” represents a transitive relationship means that the relationship is not directly identified by experts but is inferred through the principle of transitivity in ISM.

The driving power and dependence power of each factor were also calculated at this stage by summing the rows and columns, respectively.

2.6 Final Reachability Matrix and Transitivity

After obtaining the initial matrix, the concept of transitivity was applied to develop the Final Reachability Matrix (Table 7). Transitivity ensures that indirect relationships are also considered in the model.

Table 7. Final Reachability Matrix & Transitivity

Variables	1	2	3	4	5	6	7	8	9	10	Driving Power
F1	1	1	1	1	1	1	1	1	1	1	10
F2	0	1	1	1	1	1	1	1	1	1	9
F3	0	0	1	1	1	1	1	1	1	1	8
F4	0	0	0	1	0	1	1	0	0	0	3
F5	0	0	1	1	1	1	1	1	1	1	8
F6	0	0	0	1	0	1	1	0	0	0	3
F7	0	0	0	1	0	1	1	0	0	0	3
F8	0	0	1	0	1	0	0	1	1	1	5

F9	0	0	0	1	0	1	1	0	1	1	5
F10	0	0	1	1	1	1	1	0	0	1	6
Dependence Power	1	2	6	9	6	9	9	5	6	7	

This step improves the completeness and logical consistency of the model by capturing both direct and indirect influences among factors.

2.7 Level Partitioning

Level partitioning (Table 8) is used to establish the hierarchical structure of the factors. For each factor, two sets are identified viz. Reachability set: Factors to consider and Factors influencing the antecedent set.

The intersection of these sets is used to calculate the levels of each factor. Factors with equivalent reachability and the intersection sets are assigned to the highest level of the hierarchy. These elements are then deleted and the process is repeated iteratively to find the next level. At this step, a multi-level hierarchical structure is set up that describes the interaction of factors.

Table 8. Level Partitioning

Elements	**Reachability Set (R)**	**Antecedent Set (A)**	**Intersection Set (R∩A)**	**Level**
1	1,	1,	1,	4
2	2,	1, 2,	2,	3
3	3, 5, 8, 9, 10,	1, 2, 3, 5, 8, 9, 10,	3, 5, 8, 9, 10,	2
4	4, 6, 7,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10,	4, 6, 7,	1
5	3, 5, 8, 9, 10,	1, 2, 3, 5, 8, 9, 10,	3, 5, 8, 9, 10,	2
6	4, 6, 7,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10,	4, 6, 7,	1
7	4, 6, 7,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10,	4, 6, 7,	1
8	3, 5, 8, 9, 10,	1, 2, 3, 5, 8, 9, 10,	3, 5, 8, 9, 10,	2
9	3, 5, 8, 9, 10,	1, 2, 3, 5, 8, 9, 10,	3, 5, 8, 9, 10,	2
10	3, 5, 8, 9, 10,	1, 2, 3, 5, 8, 9, 10,	3, 5, 8, 9, 10,	2

Once these factors were identified they were excluded from subsequent iterations and the process was reiterated to calculate the following levels. This iterative process continued until all factors were assigned to appropriate hierarchical levels.

2.8 Formation of Canonical Matrix

Based on the identified levels, the factors were rearranged to form the Canonical Matrix (Table 9). The matrix is a systematic representation of the system by classifying the factors by their hierarchical positions.

Table 9. Canonical Matrix

Variables	**4**	**6**	**7**	**3**	**5**	**8**	**9**	**10**	**2**	**1**	**Driving Power**	**Level**

4	1	1	1	0	0	0	0	0	0	0	3	1
6	1	1	1	0	0	0	0	0	0	0	3	1
7	1	1	1	0	0	0	0	0	0	0	3	1
3	1	1	1	1	1	1	1	1	0	0	8	2
5	1	1	1	1	1	1	1	1	0	0	8	2
8	1*	1*	1*	1	1	1	1	1	0	0	8	2
9	1	1	1	1*	1*	1*	1	1	0	0	8	2
10	1	1	1	1	1	1*	1*	1	0	0	8	2
2	1	1	1	1	1	1	1	1	1	0	9	3
1	1	1	1	1	1	1	1	1	1	1	10	4
Dependence Power	10	10	10	7	7	7	7	7	2	1		
Level	1	1	1	2	2	2	2	2	3	4		

The canonical form helps in clearly visualizing the dominance and dependence relationships among factors and prepares the data for graphical representation.

2.9 *Development of the ISM Digraph*

After the level partitioning results, a directed graph known as digraph (Figure 2) is created to visually show the relationships between the factors. The digraph shows the directional links and hierarchical arrangement of elements that lack transitive links. This (Figure 2) digraph is then turned into the final ISM model, which gives a clear structural framework. This shows how the different Lean-Green integration elements interact and influence long-term organizational performance.

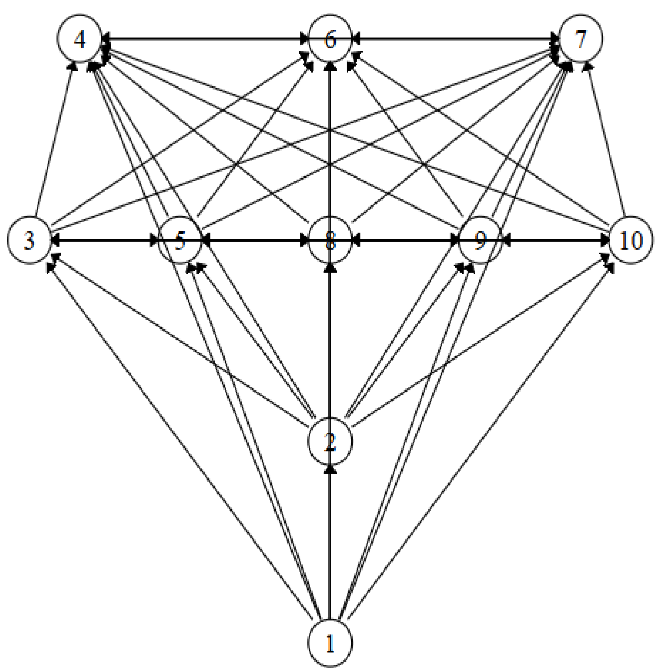

Figure 2. Diagraph

Factors at a higher level (more dependent) were placed at the top position, while those with strong driving power (independent factors) were positioned at the bottom. This graphical representation makes it easier to understand the flow of influence within the system.

2.10 Final ISM Model

In the final step, the diagraph was refined by removing transitive links to improve clarity and readability. The resulting structure represents the final ISM model - conceptual model developed (Figure 3).

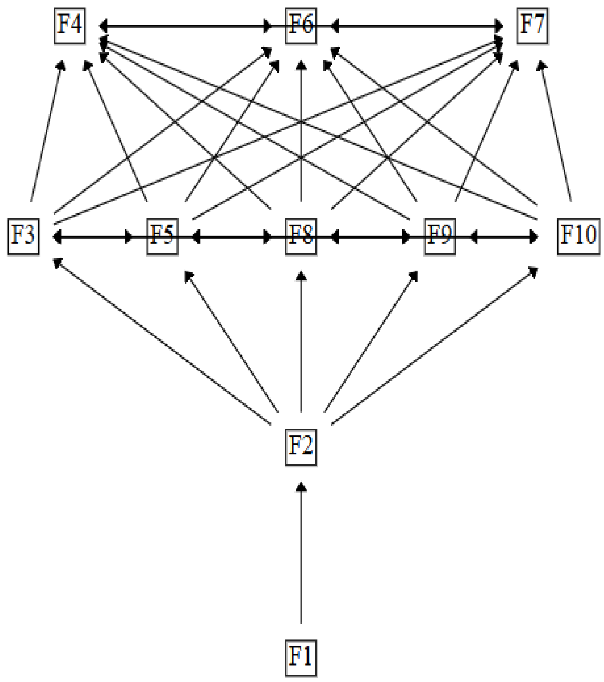

Figure 3. Conceptual Model

This model provides a clear hierarchical framework showing how different factors influence each other. The bottom-level factors act as key drivers for Lean-Green integration, while the top-level factors represent outcomes or dependent variables.

2.11 MICMAC Analysis

After the ISM model, MICMAC (Matrice d'Impacts Croisés Multiplication Appliquée à un Classement) analysis (Figure 4) was carried out to further examine the driving power and dependence power of identified factors. The objective of this analysis is to classify factors into four categories based on the level of influence and dependency within the system. The driving power and dependence power values were obtained from the final reachability matrix. Driving power reveals how strongly one element drives another, whereas dependence power tells how much another factor influences other.

MICMAC

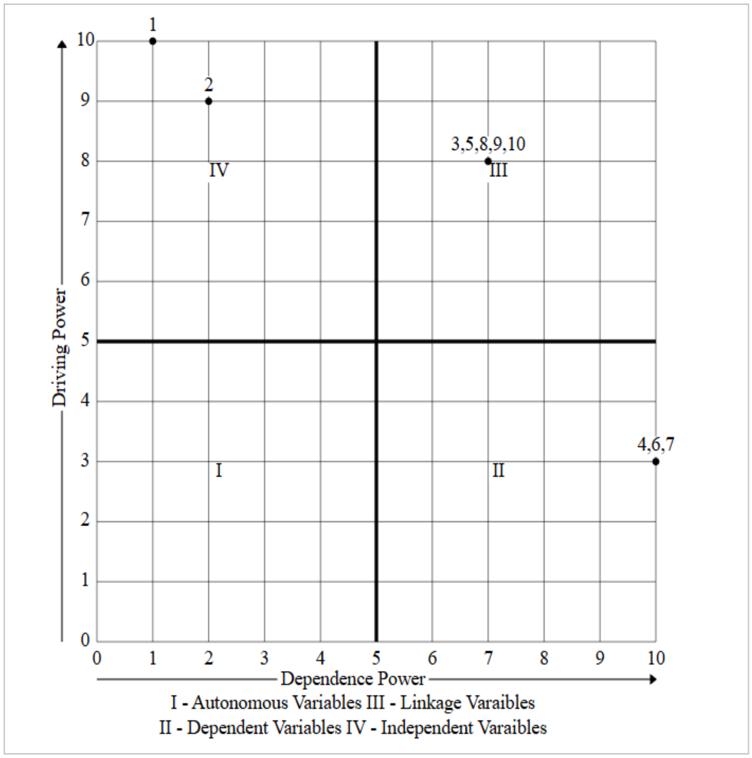

Figure 4. MICMAC Analysis

3. Results and Discussion

The ISM-based analysis provides a systematic understanding of the interaction of Lean-Green integration factors in small scale manufacturing system. The final level partitioning and the reachability matrix clearly demonstrate multi-level hierarchy. Further, the MICMAC classification of different factors based upon the driving and dependence power also support this.

The results of the level partitioning (Table 8) show a hierarchy of four levels. In the base (Level 4), F1: Management Commitment is the most dominant driver, with high driving power and low dependence. This supports the conclusion that leadership intent and strategic direction are the basis for successful Lean-Green implementation. F2: Lean & Green Training (Level 3) is a critical enabling role that translates managerial intent into workforce capability immediately above.

The Level 2 (Middle Layer) consists of F3: Kaizen Culture, F5: Employee Involvement, F8: 5S & Visual Control, F9: Value Stream Mapping, and F10: Total Productive Maintenance. These factors are operational enablers that link strategic intent to execution. Their positioning suggests that continuous improvement practices and workforce participation are significant to embed Lean-Green principles in daily operations.

In the top level (Level 1) the outcome-oriented factors are F4: Emission Control, F6: Energy Management, F7: Circular Material Usage. These are the results of environmental performance following the successful implementation of underlying organizational and operational practices. The high dependence of these suggests that sustainability outcomes are not achieved in isolation, but are the result of a well-aligned system.

The MICMAC analysis (Figure 3) clusters these factors into 4 clusters, which gives more insight into the roles of these factors:

Independent (Driving) Factors F1 (Management Commitment) and F2 (Lean & Green Training) have high driving power and low dependence. These factors are the most important factors and serve as primary enablers. Without strong managerial support and adequate training, the implementation of other practices fails to be effective.

Linkage Factors: F3 (Kaizen Culture), F5 (Employee Involvement), F8 (5S & Visual Control), F9 (Value Stream Mapping), and F10 (Total Productive Maintenance) are included in this category. These factors have high driving and high dependence power which shows their dynamic nature. Any variation of these variables has a significant effect on the system and feeds back into themselves. This makes them critical but sensitive elements, which need to be continuously monitored and aligned.

Dependent Factors: F4 (Emission Control), F6 (Energy Management) and F7 (Circular Material Usage). These factors have high dependence and low driving power. These factors are the measurable environmental outcomes and are highly affected by improvements in organizational and operational practices.

Autonomous Factors: This quadrant indicates no major factors, implying that all the chosen variables are relevant and actively participate in the system.

The results clearly show a cause effect link in the Lean-Green integration. Management Commitment (F1) leads to Training (F2) which improves Kaizen Culture (F3) and Employee Involvement (F5). These human-oriented elements allow to use structured Lean tools like 5S (F8), Value Stream Mapping (F9) and TPM (F10). Successful application of these practices results in better resource utilization and process efficiencies, which leads to improved Energy Management (F6), reduction in emissions (F4) and better Circular Material Usage (F7). This layered relationship means that environmental sustainability in small-scale industries is not achieved directly by green practices alone, but it is the outcome of a strong organizational culture and Lean implementation.

In terms of implementation, the findings imply that small scale industries should focus on top management commitment and structured training programs as a beginning. To just focus on environmental metrics without strengthening these underlying drivers will lead to limited success. Moreover, linkage factors such as Kaizen, TPM and Value Stream Mapping should be carefully managed as they can either strengthen or destabilize the system depending on the way they are implemented. System balance has to be monitored continuously and improved in iterations.

4. Conclusion

This paper provides a systematic and structured way to understand the complex relationships among factors affecting Lean-Green integration in small scale manufacturing industries. The study successfully identifies the key factors and arranges them in a hierarchical framework indicating their relative influence and dependency through the combination of literature review, expert validation, ISM modelling and MICMAC analysis. Results showed that internal organizational factors especially, management commitment and Lean-Green training are the most important drivers for successful implementation. These factors are the base factors of the system as they possess high driving power and low dependence. Similarly, cultural factors such as employee participation and continuous improvement (Kaizen) are very important in reinforcing the implementation process. On the other hand, operational and environmental factors such as process standardization, emission control, and resource efficiency are found to be more dependent in nature, indicating that their successful adoption is contingent upon the presence of strong organizational drivers.

The ISM-based hierarchical model clearly demonstrates that Lean-Green integration is not a stand-alone initiative but a multi-level system where strategic and organizational enablers support operational and environmental outcomes. Furthermore, the MICMAC analysis supports this understanding by classifying factors into driving, linkage, dependent and autonomous clusters, thus helping decision-makers to focus their attention on high-impact areas. In practical terms, the study suggests that small-scale manufacturing industries should develop strong leadership commitment, better training of employees and culture of continuous improvement before implementing advanced Lean and Green practices. These findings can also serve industry persons in developing a targeted support mechanism, training programs and awareness initiatives to promote sustainable manufacturing practices among small enterprises. However, despite its contributions, the study has some limitations. The analysis is mainly based on subjective opinion of the experts which may be subjected to bias. Moreover, the number of factors was limited to keep the model simple and relevant to small-scale industries.

Future work can extend this work by incorporating advanced multi-criteria decision-making techniques like DEMATEL or ANP to further validate the relationships among factors. The proposed model is also empirically validated through case studies or large-scale surveys to find out the applicability of the model in real industrial settings. Moreover, the combination of Industry 4.0 technologies and Lean-Green practices is a promising research area for future study, especially in terms of improving data-driven decision-making and real-time sustainability monitoring.

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