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Original Article

Decoding Lean with Industry 4.0 Transformation: A Model comprising of ROI, Operational Efficiency and Human Capability as Systemic Success Factors in Indian Manufacturing setup

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Abstract *- The production processes can be improved by integrating the Lean Manufacturing principles with Industry 4.0 technologies. It helps an organization to stay competitive in the long run. In this paper, the DEMATEL approach was used to analyze the interrelationships among nineteen Critical Success Factors (CSFs) that affect the optimal integration of Lean and Industry 4.0. The direct-relation matrix estimated from expert evaluation revealed that the ROI and Operational Efficiency are the most critical CSFs. It was observed that the Top Management Support has a greater causal significance. It indicates that the commitment of leadership is paramount in driving strategic orientation and resource deployment in such transformation initiatives. The results show a balanced system with ten causal and nine effect factors. The causality factors primarily comprise considerations of financial and operational performance and innovation capacity as the fundamental motivators for Lean–Industry 4.0 integration. On the contrary, human resource development and organisational culture present themselves as significant effect factors as domains that require constant and active reflection once strategic and operational underpinning have been established. The research presents a practical perspective for manufacturing companies seeking to create clear pathways in their Lean–Industry 4.0 adoptions to align technology development with human resource capability generation.*

Keywords *- DEMATEL, Lean Manufacturing, Industry 4.0, Critical Success Factors, Multi-Criteria Decision Making, Manufacturing Integration, Causal Analysis.*

1. Introduction

The most dominant paradigms that have shaped modern manufacturing have been Lean Manufacturing and Industry 4.0. The Toyota Production System, the source of Lean Manufacturing philosophy, stresses continuous improvement through systematic means of waste elimination. Add to that, these paradigms (considered Lean–Industry 4.0 or Lean 4.0 in practice) enable organisations to double down on operational excellence on one hand and speed their digital transformation journey on the other. While the strategic importance of this convergence is well accepted, there are significant implementation risks for organisations due to a multitude of interlocking factors, such as technology readiness, organisational culture, workforce skills, financial capacity, and long-term strategic orientation. Lean and Industry 4.0 have been analyzed in relation to one another and combined in the same analysis contexts, but there has been little scholarly analysis into the causal linkages and reciprocal responses among the critical success drivers[1-3]. Without a clearer understanding of these interdependencies, organisations face the challenges of considering what enablers to give the most weight, and how certain determinants of enablers in different organizations will support (or detract from) other enablers as part of their commitment to integration of initiatives and programs. To overcome the gap in understanding the causal relations among the Core Success Factors (CSFs) for Lean Industry 4.0 integration, this research study uses the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method to evaluate the influence structure between these CSFs. In contrast, previous studies either have isolated analyses of socio-technical systems or do not have a systematic framework that captures the dynamic and interdependent nature of socio-technical systems, therefore limiting their usefulness in forming a strategic decision. DEMATEL is therefore well suited for complex systems with feedback loops because it considers complex causal relationships [4, 5], and decomposes factors into cause–and–effect clusters. The novelty of this work is that the proposed project goes beyond traditional rank systems or correlation-based methods of comparison by building a systemic causal model that not only specifies major drivers but also determines their impact and relationships in an integrated context. The research furthers through the disentangling of CSFs to causal and effect sets: it explains the structural nature of the factors that structure the model and quantifies the relative power of each in shaping management priorities and process policies, while analyzing their level of importance to process regulation. It enables management to follow the evidence for planning and implementing Lean–Industry 4.0 initiatives. The study contributes to existing literature by providing a causal framework that links the main drivers of Lean and Industry 4.0, which has been largely limited by fragmented approaches. In practice, the results can support manufacturing firms in resource allocation, competency development, and strategic roadmap development for digital–lean transformation. Through targeting the powerful drivers of integration effects, the analysis underpins the construction of coherent and efficient routes to intelligent, high-performing production systems. Collectively, this study has not only filled the identified research gap but also established a strong methodological platform for further studies on socio-technical interaction in Industry 4.0-enabled manufacturing contexts.

2. Literature Review

2.1. Lean Manufacturing Principles

Lean Manufacturing is an established organisational methodology that systematically increases productivity and efficiency by identifying, reducing, and eliminating waste in manufacturing processes through continuous improvement and flow optimisation [6, 7]. Its philosophy is that value is determined from the customer's viewpoint; that is, all activities in the production system must have a direct impact on customer perceived value. Lean functions as a diagnostic and analytic approach that assists organizations in visualising the value from beginning to end process (from raw materials to finished products) and identifying waste, non-value adding actions, and challenges to continuous operations [8, 9]. A second concept, which is core to Lean manufacturing, is ensuring a constant flow whereby materials and information work together without any delays, unnecessary movements, queueing, etc., and supported by pull-based systems in which production is determined by demand and not predictions, which minimizes overproduced goods, inventory, and variability. Continuous improvement (Kaizen) is a systematic approach to improvement based on improvement methods that encourage employees' participation, problem-solving, and the use of evidence-based decision-making to make better operational decisions and improve each aspect of the system. These principles illustrate how Lean Manufacturing goes beyond a toolbox to establish a broader management philosophy to develop value-efficient, responsive, and customer-focused production. In the course of time, Lean Manufacturing has gone into a comprehensive view of the organization that marries cultural change and technical process improvement as a corporate transformation. Successfully applying the Lean model involves a strong organisational interest, meaningful commitment from leadership, and empowerment of staff at all levels, to contribute to a culture of continuous improvement and systematic problem solving. Lean is therefore more successful as an enterprise-wide strategy and less as a collection of individual tools, as incomplete or isolated adoption often has low returns and weak long-term sustainability [10]. Lean thinking is conducive to data-driven decision making, cross-functional work, standard work processes, and more predictable and stable process outcomes. It is in this way that Lean Manufacturing drives operational excellence and provides a necessary basis for digitisation projects and new technologies to be used in Industry 4.0 [11].

2.2. Industry 4.0 Technologies

Industry 4.0 is the fourth phase of its manufacturing corporate paradigm shift[12], integrating digital technologies into and with processes in the real world; such that the end-to-end manufacturing ecosystem becomes highly integrated, intelligent, and flexible [12]. Ultimately, Industry 4.0 is a technological revolution rooted in a suite of technologies that empower smart factories to deliver real-time tracking, autonomous decision-making, and continuous process optimization. As an alternative to IoT, Cyber Physical Systems (CPS) have connected physical machines with Artificial Intelligence (AI) software. This leads to the creation of a closed-loop system that improves the resilience and precision of systems. This enhances the digital aspects of the system, which in turn works well with the physical aspects. In the context of Big Data Analytics, a company can turn the organized, structured, and unstructured data that comes from the whole manufacturing process into decisions that can be acted on. You can use these decisions to improve performance, quality control, and predictive maintenance. AI and ML can help with this skill. Manufacturers' companies have advanced analytics systems that can handle distributed processing and allow for remote monitoring in the cloud without needing to spend a lot of money on IT infrastructure. What also happens is, Additive Manufacturing – a well-established technology through 3D printing processes – has transformed itself as one of the biggest disruption enablers of Industry 4.0, enabling rapid prototyping, customised production, lightweight structures, and design flexibility not otherwise possible without a manufacturing process. Taken together, these technologies offer a complete system of integrated systems at all levels to bring manufacturers out of "real" (linear) production processes and toward "smart, flexible, networked" production systems [13-15].

2.3. Integration of Lean and Industry 4.0

In the literature, it is increasingly being recognised as a relationship that is both cooperative and reciprocal between Lean Manufacturing and Industry 4.0, and a convergence of these two paradigms brings unprecedented operational excellence and organisational agility towards convergence [10]. Industry 4.0 technologies, namely IoT-enabled sensing, cyber-physical automation, and AI-enabled analytics, according to some, can enhance Lean technologies by providing a platform for process transparency, predictive maintenance, intelligent quality control, as well as automate value stream optimisation in real time. For example,[16] found that digital-based technologies support Just-In-Time (JIT) and Total Productive Maintenance (TPM), and that the visibility and prediction for failure caused by changes in the system enable better operational processes as well as greater efficiency. Whereas showed how it is the smart manufacturing system that reduces the waste and variations not only of manufacturing, but also the variability of the manufacturing process in turn, which is one of the problem areas that were normally covered by Lean strategies. In the same vein, [11] defined “Lean Automation” as a hybrid model in which digitalization enables pull production and decreases waiting times, and improves decision-making accuracy across the value chain. In contrast, the literature further emphasises the fact that Lean principles provide the organizational and cultural foundation for Industry 4.0 adoption. Lean focuses on process standardization, waste elimination, employee involvement, and a culture of continuous improvement (Kaizen) to establish the required structural discipline for effective digital transformation. In the International Journal of Production Research, [2], stressed that Lean maturity has a strong impact on a firm’s readiness to exploit Industry 4.0 technologies, with [17] pointed out that without stable, integrated processes, digital solutions usually amplify inefficiency rather than alleviate its presence. From this perspective, Lean enables meaningful digitalization by seeing to it that automation and data-driven tools are applied to well-understood value-adding activities as opposed to simply to processes that are non-value-adding. Regardless of strategic value, recent studies describe a number of important hurdles related to Lean and Industry 4.0 and indicate that the convergence is not an easy process. Such challenges involve technology complexity in digital ecosystems, expensive start-up costs, potential cybersecurity threats, skill- and competency-related gaps of employees, organisational reluctance to change, and lack of clear implementation pathways [11]. [18] observe that the socio-technical character of Industry 4.0 necessitates large upskilling of the workforce and cultural change, and [19] contend that firms may be deficient in the methodological frameworks to effectively connect Lean objectives and digital capabilities. In SMEs, financial constraints are a major concern, which is a barrier for the integration of Lean and Industry 4.0 [20]. Therefore, it becomes necessary to understand the importance of Critical Success Factors (CSFs) for Lean Industry 4.0 integration. Based on the CSFs, a holistic framework is necessary that provides policymakers with an overall benchmark to integrate lean manufacturing with Industry 4.0.

2.4. DEMATEL Methodology in Manufacturing Research

The Decision-Making Trial and Evaluation Laboratory (DEMATEL) is a method used for solving difficult systems with multiple variables that have a direct or indirect effect on the particular component or the whole system. The DEMATEL approach, which was proposed by the Geneva Research Centre, provides a systematic approach for analyzing causal relationships across dimensions for multidimensional problems where there is a need to break up complex relationships that conventional linear analysis might not consider. DEMATEL, by mapping expert opinions out as a visualised structural map, allows for identifying and quantifying cause and effect among variables and the level of prominence (centrality) and relation (causal direction). This feature allows decision makers to rank factors based not only on weight but also on their influence, and not only that, but they also act similarly to or at the same time, depending upon other elements involved in the performance assessment of a system. DEMATEL has been widely used in manufacturing research over the past few years in multiple areas. To illustrate, in another work, used DEMATEL to evaluate interactions among green supply chain management practices. Moreover, [21] used DEMATEL to categorize the key obstacles to adopting Industry 4.0 in emerging markets, suggesting that it is appropriate for analyzing socio- technical systems where there is a combination of technological readiness, human competencies, and organisation structure. The literature pertaining to quality controls, risk assessment, and sustainable manufacturing has also utilized DEMATEL to reveal hidden causes and prioritise paths for improvement [22]. DEMATEL is well designed for the assessment of integrating lean manufacturing with Industry 4.0 since it is able to examine complex, interdependent, and multilevel factors. The Lean I4.0 convergence consists of technical, organisational, environmental, and human-centric dimensions that affect one another non-linearly. DEMATEL shows both the underlying causal systems underlying these dimensions, such as how leadership support leads to employee readiness, or how technological adoption enhances operational output and offers a data-driven base with which to evaluate which Critical Success Factors (CSFs) are likely the most significant. In turn, this makes the methodology particularly well-suited to designing and delivering an evidence-based roadmap for Lean–Industry 4.0 integration.

3. Research Methodology

This research was achieved by applying a mixed research methodology of systematic literature review, expert consultation, and quantitative DEMATEL analysis to examine the interdependencies of Critical Success Factors (CSFs) in Lean & Industry 4.0 integration. The framework of applying this methodology is presented in five consecutive stages. In order to do so, a literature review of extensive scope was conducted in order to incorporate existing studies of possible Critical Success Factors in terms of Lean transformation and Industry 4.0 adoption in corporate change. Second, a representative group of experts in the domain of expert consultation was achieved in order to ensure that some factors are applicable and trustworthy in the research[23]. Third, a systematic approach to data acquisition was achieved in order to analyze the extent to which Critical Success Factors influence each other. Fourth, the direct-relation matrix in the system was computed, and the total-relation matrix was obtained, and causal relationships were established using DEMATEL analysis. Finally, the results were interpreted to separate causal and effect groups. To evaluate factor prominence, they are useful for managers making decisions about what is important to do about their employees.

The CSFs that are chosen represent major dimensions that have been commonly mentioned in recent industrial engineering and digital transformation studies: organisational readiness, technological capability, human skills, strategic alignment, and performance enhancement. The last set of variables should comprise: Top Management Support, Employee Training and Skill Development, Investment in Technology, Data Integration and IT Infrastructure, Organisational Culture and Change Readiness, Supplier Collaboration, Strategic Planning, Leadership Commitment Beyond Support, Cross-Functional Integration, Change Management Capability, Cybersecurity Readiness, Customer-Centric Innovation, Operational Efficiency, Product Quality Improvement, Innovation Capability, Environmental Sustainability, Resource Efficiency, Market Competitiveness, and Return on Investment (ROI). Together, these dimensions depict the multifaceted aspect of Lean–I4.0 Integration and offer a solid basis for analysing the interactions between the organisational, human, and technological components in the process of integration.

3.1. DEMATEL Methodology

The DEMATEL method was selected because it holds great robustness for modelling complex decision environments in which relationships between the parameters are interdependent. It was a four-step process in the approach.

Step 1: Making a Direct-Relation Matrix. Expert respondents assessed the direct effects of each CSF on the others, measured by a four-point language scale, respectively (0=No influence; 1=Low influence; 2=Medium influence; 3=High influence).

A direct matrix $A=[a_{ij}]$ where a_{ij} is produced where factor I influences j. The diagonal elements were set to zero since the factors do not have any effect on themselves.

Step 2: Direct-Relation Matrix Normalization

The normalisation of the direct-relation matrix was done with the parameter $\lambda=1/((\max)_{i} \sum_{j=1}^{n} a_{ij})$. The normalised matrix was then calculated as: $N=\lambda\times A$. Using this rule, the matrix will converge within iterative calculations.

Step 3: Total-Relation Matrix Calculation

In this step, $N=\lambda\times A$ is created, which leads to the introduction of the Total-Relation Matrix. The total-relation matrix T, which captures the direct and indirect effects of CSFs, is: $T = N \times (I - N)^{-1}$ when I is the identity matrix. This matrix tells cascading influence paths through the system with multi-step interactions.

Step 4: Establishing Prominence + Relation

The next index was calculated for all i factors: $R_i=\sum_{j=1}^{n} t_{ij}$ "Total influence given". $C_i = \sum_{j=1}^{n} t_{ji}$ "(Total influence received)". Prominence: This indicates the general importance of a factor. Relation: This tells you if it is overall important for the factors to be considered a net cause, so that they are not known to be a net effect, as stated as positive or negative. Therefore, negative values indicate the effect group, and positive values indicate the factor.

3.2. Threshold Value

In terms of interpreting causality, a threshold value was calculated as the average of all non-zero values in T (total relation matrix). From the calculation, impact values higher than this threshold value were considered significant enough to be retained in the causality influence diagram.

3.3. Data Collection

The methodology used for data collection consisted of manufacturing professionals who have considerable knowledge of lean, Industry 4.0, and new digital trends. Experts used their experience and knowledge to analyze the influence of CSFs. A questionnaire was designed based on factors such as clarity, precision, and reliability of information provided, ensuring clear and concise categories according to the information provided. Instructions were given in writing, and influences and factors were used to reduce a lack of clarity. This method of using multiple experts in DEMATEL analysis helps to obtain a wide range of knowledge.

4. Results and Analysis

4.1. Direct-Relation Matrix

Based on expert evaluation, an initial direct relation matrix was developed to measure the extent of direct influence of each of the 19 Critical Success Factors (CSFs) on others. The 19 x 19 matrix consists of zeros in the diagonal elements, owing to the premise that each factor does not influence itself. The maximum row sum of 53.0 indicates a considerable level of dependence in the system; therefore, integration of Lean and Industry 4.0 is not allowed by a tight network of interactions. This high level of connectivity further validates DEMATEL's capability in investigating a very complex and multi-dimensional issue.

4.2. Normalised and Total-Relation Matrix

A scaling factor of $\lambda = 0.0189$ was used to normalized stability in the calculation process. This led to the derivation of a normalized matrix N, which was used as a basis for deriving the total relation matrix. The total relation matrix (T) considers direct as well as indirect factors. This reflects the extended paths through which a particular factor impacts another. The average influence value of 0.2532 was used as a threshold. This ensured that only significant relationships were considered. The resulting matrix confirms that there are strong interaction patterns as well as a ti-layered causality between the CSFs.

4.3. Prominence and Relation Analysis

The summarized values of R (total influence given), C (total influence received), R + C (prominence), and R – C (relation) are presented in Table 1. The results clearly indicate a defined hierarchy of factor prominence in the respective data sets. The two most prominent factors, Return On Investment (ROI) and Operational Efficiency, have a prominence value of 11.263 and 11.261, respectively. Therefore, they are most closely related to all other factors of importance. These high-prominence determinants play a significant role in creating the integration landscape. Environmental Sustainability, on the other end of the chart, has the least prominence (6.683), indicating that while important, its degree of influence is more indirect, due to other factors. Top Management Support (R – C = 0.735) is the strongest net cause factor of the four variables by causal strength, pointing to its key driver in Lean–Industry 4.0 initiatives. In contrast, Supplier Collaboration (R – C = –0.551) and Employee Training & Skill Development (R – C = –0.437) are both influenced (effect-side) factors, suggesting that they are very sensitive to changes in other parts of the system.

Table 1. Prominence and relation values

Sr No.	Critical Success Factor (CSF)	R + C (Prominence)	R – C (Relation)	Group
1	Return on Investment (ROI)	11.263	Positive	Cause
2	Operational Efficiency	11.261	0.276	Cause
3	Innovation Capability	High	Positive	Cause
4	Market Competitiveness	High	Positive	Cause
5	Strategic Planning	Moderate	Positive	Cause
6	Leadership Commitment Beyond Support	Moderate	Positive	Cause
7	Product Quality Improvement	Moderate	0.208	Cause
8	Investment in Technology	Moderate	Positive	Cause
9	Top Management Support	Moderate	0.735	Cause (Strongest Driver)
10	Resource Efficiency	Moderate	Positive	Cause
11	Change Management Capability	10.483	Negative	Effect
12	Customer-Centric Innovation	Moderate	Negative	Effect
13	Cross-Functional Integration	Moderate	–0.002	Neutral / Bridge
14	Organisational Culture & Change Readiness	Moderate	Negative	Effect
15	Data Integration & IT Infrastructure	Moderate	Negative	Effect
16	Employee Training & Skill Development	Moderate	–0.437	Effect
17	Supplier Collaboration	Moderate	–0.551	Effect (Strongest Dependent)
18	Cybersecurity Readiness	Lower	Negative	Effect
19	Environmental Sustainability	6.683	Negative	Effect

4.4. Cause and Effect Group Classification

The relation index R–C categorizes the CSFs into cause and effect groups. The 10 factors (52.6%) are considered on a cause basis, which confirms that they are the main drivers of integration outcomes as mentioned in Table 2. These include ROI, Operational Efficiency, Innovation Capability, Market Competitiveness, Strategic Planning, Leadership Commitment Beyond Support, Product Quality Improvement, Investment in Technology, Top Management Support, and Resource Efficiency. The other 9 factors (47.4%) represent the effect group, i.e., those affected by the system's causal dynamics. They are Change Management Capability, Customer-Centric Innovation, Cross-Functional Integration, Organisational Culture & Change Readiness, Data Integration & IT Infrastructure, Employee Training & Skill Development, Supplier Collaboration, Cybersecurity Readiness, and Environmental Sustainability. A balanced separation suggests that Lean–Industry 4.0 integration will represent a combination of very strong drivers coupled with equally significant outcomes that are to be managed simultaneously.

Table 2. Aggregate DEMATEL values

Metric	Cause Group	Effect Group
Number of factors	10 (52.6%)	9 (47.4%)
Average prominence (R + C)	10.094	9.094
Mean net relation (R – C)	+0.171	–0.190

4.5. Key Findings

The study indicates that the Return on Investment (ROI) combined with Operational Efficiency is the core lever of the Lean–Industry 4.0 system, and its prominence value is higher than 11.26. They occupy a more central part of feature lists that are the ones that participate by a significant amount in most cases, either affecting and/or being affected by other factors, and, therefore, serving as structural anchoring variables of the elements of Lean–I4.0 integration. The positive or negative trends in these two dimensions have thus spread well throughout the network, thereby highlighting the need to place a strong focus on business financial performance as well as process efficiency for large-scale transformation projects. From a causative point of view, factors such as Top Management Support, which is ranked at only 13th place overall, have the largest positive net relation value at 0.735. This implies that the root cause of the entire system is the devotion of the leadership.

This observation implies that certain (strategic) preferences/resources, as well as the preference of upper management, have strong influences over independent factors, irrespective of whether or not immediate operational directives affect them. Factors such as Operational Efficiency (0.276) and Product Quality Improvement (0.208) have positive net relation values of similar magnitude to each other, thereby emphasizing the fact that strong performance in these two factors is central to technical determinants in Lean I4.0 integration. On the other hand, Supplier Collaboration (-0.551) and Employee Training & Skill Development (-0.437) are part of the effect group as evidenced by negative net relation values. This means that both collaborative supply networks and continuous upskilling cannot be sustained without the leadership support, financial strength, and process capability. Cross-functional integration has a neutral net relation of approximately 0 with a weightage of -0.002, which indicates its neutral influence on both the strong causal and strong dependent models.

The model does not drive or react; it acts as a bridge that helps improvements spread throughout the organization. The relationship matrix is very connected with 185 links that are strong, showing that the factors work well together. The strongest links are between Return on Investment and Operational efficiency, which are 0.344 and 0.342, and this creates a cycle where improving operations helps financial outcomes, and this, in turn, helps the company spend more on making things more efficient. The Return On Investment also has links with Change Management Capability and Innovation Capability, both of which are 0.333, and Operational Efficiency has a strong link with Change Management Capability, which is also 0.333. This shows how the financial and operational sides of a company help shape its ability to be flexible and innovative. The cause-and-effect diagram also helps explain how these things are connected. High prominence positive relation variables (ROI, Operational Efficiency, Innovation Capability) are in the driver quadrant, which represent areas where strategic focus is the most important thing. High prominence negative relation variables are key effect side-effects that will need sustained monitoring and support once the main drivers have established themselves.

The lower prominence factors are a peripheral layer that is less obvious than the core structure in more subtle ways, but does respond to or is responsive to it. This categorization is confirmed by the DEMATEL-based cluster: the average prominence of cause factors (10.094) exceeds that of effect factors (9.094), and the mean net relation of cause factors is positive (0.171), which is compatible with their position as a net influencer. The effect factors have a negative effect on the system. It seems that the factors that affect the system are linked to each other. ROI, which has a value of 11.263, is the most important factor in the cause group. The effect side of Change Management Capability, which is worth 10.483, is also very important for ROI. The simplified model shows that Lean-Industry 4.0 is linked to good leadership, long-term financial health, and organizational excellence. Changes in these areas will be good for innovation, change readiness, supplier partnerships, and workforce development. This will help the group really change and make their plans for the digital world come true. Lean-Industry 4.0 will help the company make this change happen.

5. Theoretical Implications

This study concentrates on how Lean practices and Industry 4.0 work together and how factors like Return on Investment and operational efficiency are connected. The above factors are important because they help to connect the operational parts of a company. Improving the financial performance of a firm is the primary goal of both lean and Industry 4.0. One of the major factors that leads to financial performance is operational excellence. In addition to Operational excellence, Top Management Support also plays an important role in bringing about a cultural shift in an organization.

The role of Top Management is to provide resources. The support of Top Management is an important factor in bringing about change in an organization. It ensures that everyone in the firm is working and slowly moving towards the goals.

Leadership, Employee Training, and Organizational Culture are extremely important in bringing Lean practices and Industry 4.0 together, which will help the organization to shift its goals more towards digitalization. At a ground level Organisation should decide what the key factors are that are necessary for the leadership. The relationship between Return on Investment and operational efficiency shows how financial performance and process improvement work together. This has given us priorities for decision-making. First, organizations should establish the key factors that make change happen, such as committed leadership, clear objectives for Return on Investment, and stable operations. This foundation is essential for follow-up efforts like building employee skills, reinforcing culture, and developing partnerships. Any investments in technology and innovation should have an impact on the business so that they are not wasted.

That linking of strategic and operational or technological choices anchors the direction of transformation in practice. Collectively, the results form the basis of a graduated implementation roadmap for the establishment of leadership involvement and baseline identification as the first step, building the capacity of organizations, learning from one another, and slowly scaling up through partnership with suppliers and the value chain. Over the long term, ongoing monitoring of success and improvements in ROI contribute to sustaining the success of the transformation. In relation to previous literature, it confirms earlier studies that emphasized Leadership as the pillar of the strategy and the essential linkage between Operational effectiveness and financial outcomes, two focal tenets of Lean theory. However, it also introduces a new view because it shows that cultural factors and training factors are, in fact, a part of the later strategic and technological developments and not a prerequisite.

This modest effect of Environmental Sustainability in the current study would appear to be representative of industrial priorities that continue to focus on operational and financial issues in early periods of change. From a methodological development standpoint, the DEMATEL use further validates the interpretation of the findings by permitting one to account for and compare the immediate and indirect causal ties between variables. It is possible to make a direct line between cause and effect relationships and reduce the influence due to subjective bias by applying expert evaluation, which was structured and numerical in nature. However, the scope of industry, expertise size, and context are important factors to consider when interpreting the results. In addition, the four-point rating scale might also reduce sensitivity towards minor variations in influence strength. Future work with larger and more diverse samples, longitudinal data, and cross-industry comparison may yield more validated insights based on this study and provide a comprehensive view of the Lean–Industry 4.0 integration dynamics.

6. Conclusion

The DEMING method is used to analyse how multiple h factors are necessary for the integration of Lean Manufacturing and Industry 4.0. The factors that the DEMATEL method looks for are operational, technological, and people-centric variables. On analysis, it is found that ROI and operational efficiency are the most influencial factors. These factors are the result of integrating lean and Industry 4.0, which leads to improvement of operational excellence and financial perfomance. Another significant factor that is a driving force for integration is Top Management Support. Once the leadership group decides that combining both lean and Industry 4.0 can bring about certain change, they will be motivated to pursue it. The leadership establishes priorities, provides resources, and maintains continuity of strategic direction. We also learn from the study that Employee Training, Skill Development, and Organisational Culture can fall under the effect category, human and cultural maturity has been developed from prior strategic, technological, and operational transformations.

This also suggests that socio-technical shifts in Lean–Industry 4.0 integration develop along a cumulative and iterative trajectory and not one distinct linear trajectory. The presence of significant feedback links, specifically that of ROI with Operational Efficiency, indicates that digital–Lean transformation is self-perpetuating. Because of the performance gains, the better financial performance can be used for the reinvestment in the continuous improvement work, to work more effectively. This, in principle, provides the deepest causal maps for Lean-Industry 4.0 integration and for a better conceptualization of the relationship between leadership behaviour, process excellence, and financial sustainability.

At the managerial level, the findings have acted as a guideline to prioritize implementation. For successful integration to flow from the top with clear leadership intention, operational systems backed by high-level buy-in, and well-defined ROI mapping. Generally, Lean–Industry 4.0 integration is a challenging and complex concept, based on the management of high-stakes drivers, reinforcement of the feedback loops, and the development of the flexible organizational capacity to achieve sustainable competitiveness in the long term.

6.1. Limitation

Although the study adds significant knowledge to the causality structure of Critical Success Factors regulating Lean–Industry 4.0 integration, there are some limitations that need to be acknowledged. In the first place, the size of the expert panel, while in line with previous DEMATEL uses, restricts the statistical generalisability of the results. The findings can thus be viewed as analytically strong, but situation-specific and not universally representative.

Interpretations have to be adopted. Second, the focus of the expert panel is mainly manufacturing-related, as it is the most mature subfield in Lean and the one that is most well-equipped for Industry 4.0 practices. The corresponding causal networks, in turn, might not account for sector-specific interactions in services, healthcare, or hybrid industries. Future research could reinforce the research's external validity by applying it to a range of industrial sectors and organizational contexts.

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