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Analyzing Critical Success Factors of Lean 4.0 Implementation in Small and Medium Enterprises for Sustainable Manufacturing Supply Chain for Industry 4.0 Using PLS-SEM

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Abstract: Lean 4.0 (L4.0) is a transformed form of traditional lean to suit Industry 4.0's (I4.0) requirements. The L4.0 has a great deal of potential to match the I4.0's challenges in terms of speed, dynamics, and efficacy once it has been digitalized. The study aims to identify and model the L4.0 CSFs for successful lean implementations in SMEs to suit I4.0 needs. The thorough analysis of the literature led to the identification of the L4.0 CSFs. The expert panel from SMEs was involved in selecting the relevant 22 L4.0 CSFs that suited the needs of manufacturing SMEs. Based on the feedback of the expert panel, a questionnaire survey was carried out. Further, collected responses were analyzed using an exploratory factor analysis (EFA). The EFA results identified four major groups: 'worker-enabled technologies', 'IT-enabled technologies', 'management', and 'L4.0' related CSFs. Furthermore, the study uses partial least square structural equation modeling (PLS-SEM) to simulate the L4.0 CSFs and identify the influence of each CSF toward successful lean implementation. The PLS-SEM results confirm that the lean CSFs have positive effects on successful lean implementation. The present research contributes to enhancing the knowledge and L4.0 practices of manufacturing SMEs. The results show that successful implementation will promote 'productivity improvements (PI)', 'waste reduction (WR)', 'competitive advantage (CA)', and 'sustainable manufacturing system (SMS)'.

Keywords: critical success factors of Lean 4.0; Industry 4.0; Lean 4.0; sustainable manufacturing supply chain management; PLS-SEM

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1. Introduction

Small and medium enterprise (SME) businesses make a substantial contribution to a nation's sustainable growth [1]. There are several factors, such as factory size, number of employees, annual revenue, fiscal year, size, etc., that differentiate SMEs from large network units [2]. The distinction between SMEs and micro, small, and medium-sized firms (MSMEs) differs from one nation to another [3]. When it comes to the kind of expertise needed, organizational structure, culture, types of resources, total assets involved, etc., SMEs may have varied requirements. SMEs compete with larger companies in building a strong economy by creating jobs, and they are significant economic units on a global scale. Thus, there is a considerable role for SMEs in boosting the country's GDP [4]. However, the increasing production costs, market competition, and product pricing mean that SMEs struggle to maintain sustainable manufacturing supply chain management. Hence, there are many SMEs found performing organizational reforms to accomplish long-term manufacturing sustainability. To assure profitability, resilience, and social and environmental benefits internationally, SMEs employ a variety of business practices and initiatives [5].

The top management of SMEs may plan their investment in infrastructure, technology, and employee building for I4.0. Process innovations have been shown to considerably improve performance efforts, green supply chain management (GSCM), and lean approaches. Process innovation, because of I4.0 technologies, influences performance [6]. SMEs adopt lean manufacturing into their manufacturing systems to avert global challenges [7]. The prevailing global business pressure compels Indian SMEs to adopt lean-based manufacturing practices to survive the global pressure [8]. Lean manufacturing systems help in responding to local and global demand and maintaining sustainability in manufacturing SC. Lean implementation in SMEs must consider the lean barriers to avert lean failures [1]. It is investigated that the performance of I4.0 is influenced by L4.0. Lean also enhances organizational competitiveness to strengthen its readiness for I4.0 [8].

There are several studies investigating the L4.0 CSFs for successful L4.0 implementation in I4.0 [9]. These studies investigated CSFs to help Indian manufacturing industries successfully implement them to obtain manufacturing sustainability. Their studies found that the I4.0 maturity with L4.0, along with workers' skill level and experience, is significantly important in L4.0 implementation. A study based on interpretive structural modeling of lean product life cycle management in I4.0 was carried out [10]. This case-study-based research attempted to explore the I4.0 relationship among L4.0 tools to enhance business performance in a smart and sustainable manufacturing system [11].

Looking at the present research, limited studies are found investigating the lean CSFs' relationship modeling using SEM-PLS with performance outcomes in manufacturing SMEs. As per the above discussion, it is important to investigate the following research questions: What are the various L4.0 CSFs that influence successful lean implementation? What kind of association exists between lean CSFs, successful lean implementation, and organizational performance? What is the role of each CSF in the performance of the organization?

The research layout is drawn as follows: Section 2 gives the literature review that investigates the role of L4.0 CSFs. The research technique used is described in Section 3, along with data collection and SEM model development. Section 4 describes the results obtained. Section 5 narrates the discussion of the present research. Section 6 provides limitations and future research, and Section 7 concludes the research.

2. Literature Review

In contrast to large businesses, lean studies in SMEs are frequently disregarded by academics that study lean implementations [8]. Because of this, the literature on the use of lean in SMEs is not particularly noticeable. It has also come to light that many Indian SMEs have difficulty grasping lean concepts clearly due to their lack of knowledge and awareness of the lean concept. Lean and its fundamental tenets (flow, value, pull, minimizing waste, etc.) are now widely used in a variety of industrial and service industries on a worldwide scale. Thus, lean becomes mandatory for many manufacturing (and service) operations [12]. Lean thinking encourages firms to eliminate waste and generate profit [13]. Lean practices are considered the first choice for management to improve organizational performance, ultimately leading to sustainability. Hence, SMEs are adopting lean principles in their operations [8]. Additionally, businesses should implement lean and eco-friendly approaches in product management as they face new challenges in production processes [14].

A DEMATEL-based study that examined 18 factors concluded that the industrial journey toward excellence is fueled by big data analytics and technology-based talent [15]. Employee motivation has been noted to vary between nations and between companies; hence, they must be motivated towards lean practices using the new technology in I4.0 [16]. A combined approach of fuzzy DEMATEL and fuzzy Delphi was used in deciding the CSFs for I4.0 to achieve organizational excellence [17]. The IoT, AI, 3D printing, robotics, real-time data, cloud computing, predictive analytics, and augmented reality are beneficial for achieving L4.0. Later, the study revealed 14 significant I4.0 applications in manufacturing industries [18]. L4.0 CSFs have been modeled to investigate their internal relationships using a nonlinear fuzzy-based approach [19]. The effect of lean CSFs on lean success in hospital services has been investigated using structural equation modeling (SEM) [20]. The study concluded that CSFs play a moderating role and provide good support in building relationships between implementation factors and lean outcomes.

Worker-enabled technology in I4.0 helps in productively accomplishing the required task. To make employees technology-enabled, employee training, skill, and motivation must provide flexibility to fulfill the work requirement in dynamic conditions. The industrial revolution posed many challenges and demanded a different set of skills and knowledge to work more efficiently than before. According to an exploratory study, knowledge transfer inside a company and cross-training of employees are positively correlated. Further research revealed that lean tools widen employees' knowledge and competencies and assist businesses in managing tacit knowledge [21]. Employee training provides workers with the ability to perform a set of tasks with the required productivity. The I4.0-based changes need changes in employee knowledge, skill, and training to make them adaptable to new challenges [22]. The revolutionary changes due to I4.0 necessitate changes in the general skills of employees due to digitalization [22]. I4.0 relies heavily on employee talents (both general and specialized) to perform challenging tasks based on new technology. Employee skills may be enhanced by adopting a set of dimensions for I4.0 requirements [23]. Another issue to think about is that the advantages of Industry 4.0 technology may be hampered due to a lack of skills. This can affect the operations of the firm.

Less than 30% of digital transformation activities within a business are successful [23]. A successful digital transformation demands a proactive approach from the organization in supporting computer-savvy leaders, systematic workforce nurturing, flexible worker empowerment, an effective incentive-based suggestion scheme to promote digitalization, and continuous evaluation of digital tool usage using a Kaizen approach for continuous improvement. There is a significant role for workers in the successful digitalization-based transformation at the grass-roots level. Employee adaptability will support the digitalization process in I4.0 [23]. The employee must undergo sustained changes in behavior to adapt to the new work environment in I4.0 and meet the performance standard of the task [24]. I4.0 provides the adoption of revolutionizing technologies that dive into a safer workplace. The morale of the employee depends on a safe and sustainable workplace [25]. I4.0 employs a vast range of new technologies and thus necessitates the integration of information technology and data [16].

Wi-Fi-enabled technology such as IoT plays a significant role in I4.0 [26]. Several advanced technologies such as cyber-physical systems (CPS), big data analytics (BDA), virtual reality and augmented reality (VR & AR), machine-to-machine communication (M2M), cloud computing (CC), additive manufacturing (AM), robots in manufacturing (RM), and 'security of data and foolproof cyber security' help in accomplishing quality 4.0 [8] and a sustainable manufacturing supply chain [27]. CSFs related to management consist of 'top management support', 'long-term vision', 'funds/resource availability', and 'I4.0 strategy implementations' which play a significant role in I4.0 [28,29]. L4.0-related CSFs include various CSFs of 'L4.0 awareness', 'employee readiness for change', 'prioritizing the lean tools and practices', and 'competition pressure' [30,31].

Based on the in-depth review of the literature on L4.0, the modeling of L4.0 CSFs has not been found using PLS-SEM; hence, the present research adopts this methodology to provide the quantitative relationship between L4.0 CSFs and successful L4.0 implementations in SMEs.

3. Research Method

The present research used a mixed-methods approach to identify a set of L4.0-based CSFs using a comprehensive review of the literature. First, 26 L4.0 CSFs were identified from the review of the literature. A nine-member expert panel was framed from the SME manufacturing sector, each with more than six years of working experience and a degree in engineering. Three expert panel meetings were carried out at different stages of the studies, beginning with the introduction of the goal of the study and the selection of L4.0 CSFs for the study. The final meeting was held after the analysis of responses using EFA results [32]. The identified L4.0 CSFs were further used for developing the questionnaire [31]. EFA was carried out, and subsequently, PLS-SEM was conducted to develop the model [33]. Table 1 provides the collection of lean CSFs identified from the review of the literature.

Table 1. Lean CSFs.

Sr.No.	CSFs Code	CSFs	Description	References
			Worker-enabled technology-related L4.0 CSFs	
1	WET1	Employee training	Employee training enhances work-enabled technology.	[15,21,22].
2	WET2	Employee skill	It is an ability of a worker that is used in completing the assigned work in the I4.0 environment.	[22,23]
3	WET3	Employee motivations	Workers sustained their behavior to meet the new work requirement in I4.0.	[16,24]
4	WET4	Employees using IT/data integration	Employee ability to integrate information technologies and data in the I4.0 environment.	[16]
5	WET5	Employee morale	Employee morale increases with the safer and more sustainable workplace in I4.0.	[17,25]
			IT-enabled technology-related L4.0 CSFs	
6	ITET1	Internet of Things (IoT)	It helps in linking anything through Wi-Fi for data integration in I4.0.	[18,25–27]
7	ITET2	Cyber-physical system (CPS)	It integrates the multi-functionality of a sensor, internet-enabled machine, or equipment through a network having a computer control in I4.0.	[18,25,27,34]
8	ITET3	Big data analytics (BDA)	It provides a large amount of data revealing significant information for useful decision-making in I4.0.	[18,25,27]
9	ITET4	Virtual reality and augmented reality (VR & AR)	It is the real-time use of information integrated with real-world objects.	[18,27,35]
10	ITET5	Machine-to-machine communication (M2M)	It provides direct communication between machines (wireless or wired) through a communications channel.	[27,36]
11	ITET6	Cloud computing (CC)	It provides access to computer system resources, involving data storage and future computing power.	[18,27]
12	ITET7	Additive manufacturing (AM)	It helps in developing a 3D object, building layer by layer.	[18,27]
13	ITET8	Robots in manufacturing (RM)	It helps in task completion through a computer-driven operation in I4.0.	[18,25,27]
14	ITET9	Security of data and foolproof cyber security	It helps in protecting digital information from unauthorized access, corruption, or theft throughout its entire life cycle.	[27,36]
			Management-related L4.0 CSFs	
15	MR1	Top management support	They are committed to providing strategic and infrastructure support continuously towards the I4.0 needs.	[1,15]
16	MR2	Long-term vision	The long-term vision provides strong long-term planning with a vision for I4.0.	[1,37]
17	MR3	Funds/resource availability	They provide the required resources continuously towards the I4.0 requirements.	[1,37]
18	MR4	I4.0 strategy implementations	They continuously plan and implement strategies toward the I4.0.	[1,38]

Table 1. *Cont.*

Sr.No.	CSFs Code	CSFs	Description	References
			L4.0 related CSFs	
19	LR1	L4.0 awareness	The employees and management create for themselves L4.0-related requirements to realize I4.0.	[1,36]
20	LR2	Employee readiness for change	The mental state of employees who are ready for change, which assists in I4.0.	[1,39]
21	LR3	Prioritizing the lean tools and practices	Employees' ability to visualize the L4.0 tools usage for I4.0 needs.	[1,39]
22	LR4	Competition pressure	The competition pressure arising to cut costs, cut lead time, and increase product quality compels SMEs to become lean-oriented to achieve I4.0.	[1,39]

The internal review board was contacted to obtain the required approval. Participants completed a consent form after a brief presentation, stating their willingness to participate in the study and their right to withdraw at any time. Additionally, respondents might choose not to answer any questions, without any reservations. It was unanimously resolved that the data would be used confidentially without allowing any participants to receive any direct or indirect benefits. Participants approved the audio recording of the interview, their confidentiality, and the authors' entitlement to the preservation of the original data. Additionally, there was total flexibility to contact any participant, and access to the information was permitted whenever it was needed.

3.1. Model Development

L4.0 practices based on digitization and internet-enabled technologies influence the I4.0 working; hence, this must be investigated for its implementations in SMEs. There has been a lot of interest in using partial least square structural equation modeling (PLS-SEM) across a wide range of areas, particularly in lean engineering implementation for I4.0 [6,31]. To model the relationship between L4.0-based CSFs, I4.0, and business performance, the partial least squares method was employed to provide the data analysis for its excellent relationship prediction [40,41]. PLS-SEM generally employs a causal modeling strategy, which is designed to use non-normal data with smaller sample sizes. It can further be used to optimize the explained variance of dependent latent variables [42,43].

3.2. Measurement Model

The association between the items and their original latent structure is described in this section. The convergent and discriminant validity of the measurement model was explored.

Convergent and Discriminant Validity

The level of agreement between two or more measurements (CSFs) of the same concept is referred to as convergent validity (group). It is considered a part of the construct's validity [43]. Three tests may be employed to evaluate the convergent validity of the measured constructs when employing the PLS model. Hence, Cronbach's alpha (α), composite reliability (ρ_c), and average variance extracted (AVE) may be calculated. The use of a Cronbach's alpha and ρ_c value of 0.7 was advised by Nunnally and Bernstein as the threshold value for modest composite reliability [44], whereas values over 0.60 were appropriate for exploratory investigations [45]. It is a normative metric for evaluating the convergent validity of a model's constructs, with values above 0.50 indicating a fair level of convergent validity [45].

The term 'discriminant validity' denotes the empirical distinction of the tested phenomena. It shows that any undetected measurements in the phenomenon are subsequently tested by SEM [46]. It was stated that the degree of similarity between various measurements should not be too high to demonstrate discrimination [47].

3.3. Materials and Methods

An exploratory, cross-sectional study was conducted. The questionnaire was administered to Indian manufacturing SMEs using Google Forms. A questionnaire was sent to identify manufacturing SMEs based on their size. Micro-business investment and turnover (between INR 1 and INR 5 crores), small enterprise investment and turnover (between INR 10 and INR 50 crores), and medium enterprise investment and turnover (between INR 20 and INR 100 crores) were identified. With 1 denoting 'strongly disagree' and 5 denoting 'strongly agree,' a five-point Likert scale was employed.

Using a random selection procedure, a database of 420 Indian SMEs active in the manufacturing sector was created from the Confederation of Indian Industry (CII) directory. The targeted sample was selected using the random selection approach, which served to ensure the necessary unpredictability and an equal probability of selection from the population of SEMs. Manufacturer shop floor managers are often regarded as lean-practicing managers. Consequently, a mixed sample of academicians and working managers was chosen for the questionnaire's pilot testing. Based on the results of the pilot survey, minor modifications in the question format were carried out. Concerns about the ethics of completing the questionnaire were also addressed.

The Google Forms links were sent to 420 SMEs using social media platforms such as WhatsApp, Facebook, emails, and LinkedIn. Follow-up reminders were also sent to respondents. With the help of the acquired information, 280 survey forms were obtained, with a response rate of 66.67 percent. As a result of data filtering, 220 pieces of feedback were deemed appropriate for further analysis. The majority of respondents were from surgical parts manufacturers, casting machining units, machine manufacturers, and gear manufacturers, constituting 77.2% of the total samples. The remaining respondents were automotive parts manufacturers, electrical parts manufacturers, and others, constituting 22.7% of the total samples.

For the data analysis, SPSS 28.0 and SmartPLS 4.0 were employed. Since SmartPLS 4.0 has a graphical user interface (GUI), the variance-based SEM may model latent variables with minimal data requirements [48]. The present research uses PLS-SEM as it needs minimum data, offers simple assumptions, and is capable of modeling multiple variable relationships [48]. Further, the normally distributed data show no compulsion in the PLS. Various data types such as nominal, interval, or ratio data with low sample sizes may be used for the analysis [48]. Table 2 provides the demographic statistics.

Table 2. Demographic information [31].

Variable	Item	Frequency	Percentage (%)
Gender	Male	128	0.582
	Female	92	0.418
Firm size based on employee strength	Micro (1–4)	53	0.241
	Small (5–99)	72	0.327
	Medium (100–499)	95	0.432
Establishment years	<5	41	0.186
	>5 <10	86	0.391
	>10 years	93	0.423

Table 2. *Cont.*

Variable	Item	Frequency	Percentage (%)
Industry type	Casting machining	46	0.209
	Gear manufacturing	30	0.136
	Machines manufacturers	31	0.141
	Surgical parts manufacturers	63	0.286
	Automotive parts manufacturers	19	0.086
	Electrical parts manufacturers	14	0.064
	Other	17	0.077

4. Results

4.1. Factor Analysis

The EFA technique was used to determine the factor structure of the 22 CSF items of a L4.0 implementation. The Kaiser–Meyer–Olkin test provides the measures of sampling adequacy. In the present case, it was found to be 0.771 higher than the suggested value of 0.6. Bartlett's test of sphericity was found to be significant (χ^2 (231) = 2022.716, p = 0.000). Thus, both indications satisfy the minimum limits to use the factor analysis for subsequent data analysis. To enable the factor analysis's elements' encapsulation, each diagonal of the anti-image correlation matrix was ensured to be greater than 0.5. Estimates of the variance, or rather, initial communalities in each variable, were explained by all components. The smaller value of fewer than 0.3 classifies the variables not fitting with the factor. The loading factors all exceeded the value of 0.5, and all initial communalities were higher than the threshold. Table 3 shows the communities of L4.0 CSFs.

Table 3. Communalities of L4.0 CSFs.

Item	Communalities	Item	Communalities
WET1	0.610	ITET7	0.488
WET2	0.679	ITET8	0.768
WET3	0.612	ITET9	0.677
WET4	0.729	MR1	0.639
WET5	0.665	MR2	0.779
ITET1	0.646	MR3	0.835
ITET2	0.548	MR4	0.813
ITET3	0.712	LR1	0.711
ITET4	0.534	LR2	0.818
ITET5	0.586	LR3	0.757
ITET6	0.775	LR4	0.764

Following the analysis of the 22 items with eigenvalues greater than 1, four components have been identified. The eigenvalues and total variance are well-explained by the four factors (68.83%), as presented in Table 4. On a varimax rotation, the first factor linked to 'IT-enabled technology' explained 20.80% of the variance, while the second factor, 'worker-enabled technology', received 14.92% of the variance. The third factor, 'management', can be explained by 13.78% of the variance, and the fourth component, 'L4.0', is explained by 12.81% of the total variance.

The reliability of the questionnaire was tested using the Cronbach's alpha value. Table 5 provides Cronbach's alpha values, which range from 0.843 to 0.870. Thus, all the values are well within the limit of 0.7, which indicates that the questionnaire and the components can be considered reliable [42].

Table 4. Factor loadings L4.0 CSFs (N = 220).

	Components			
Item	1	2	3	4
WET4	0.789			
WET2	0.782			
WET1	0.762			
WET3	0.746			
WET5	0.702			
ITET6		0.820		
ITET3		0.769		
ITET9		0.767		
ITET7		0.529		
ITET8		0.767		
ITET1		0.739		
ITET2		0.711		
ITET5		0.687		
ITET4		0.546		
MR3			0.896	
MR4			0.870	
MR1			0.777	
MR2			0.618	
LR2				0.883
LR4				0.808
LR3				0.738
LR1				0.691
Eigenvalues % of variance	14.925	20.801	13.788	12.806

Table 5. Reliability analysis.

Name of Lean CSFs	Reliability
Work-enabled technology-related CSFs	0.870
IT-enabled technology-related CSFs	0.854
Management-related CSFs	0.849
L4.0-related CSFs	0.843

4.2. Structural Equation Model—Lean CSFs

4.2.1. Measurement Model

Table 6 provides measurement model results. The AVEs needed to be higher than 0.50 to achieve the convergent outcome [42]. The corresponding values of CR and Cronbach's Alpha for various constructs are found to be within the specified ranges [42]. Table 7 shows the measurement model cross-loading.

Table 6. Measurement model results.

Construct	Item	Outer Loading		Cronbach's Alpha	CR	AVE
		Initial	Modified			
Worker-enabled technology-related CSFs	WET1	0.717	0.717	0.852	0.885	0.607
	WET2	0.747	0.747			
	WET3	0.793	0.793			
	WET4	0.856	0.856			
	WET5	0.776	0.776			

Table 6. *Cont.*

Construct	Item	Outer Loading		Cronbach's Alpha	CR	AVE
		Initial	Modified			
IT-enabled technology-related CSFs	ITET1	0.770	0.770	0.896	0.902	0.517
	ITET2	0.680	0.680			
	ITET3	0.798	0.796			
	ITET4	0.646	0.646			
	ITET5	0.728	0.728			
	ITET6	0.742	0.742			
	ITET7	0.321	0.321			
	ITET8	0.833	0.833			
	ITET9	0.815	0.815			
Management-related CSFs	MR1	0.803	0.803	0.881	0.908	0.711
	MR2	0.821	0.821			
	MR3	0.867	0.867			
	MR4	0.879	0.879			
L4.0-related CSFs	LR1	0.841	0.841	0.856	0.897	0.687
	LR2	0.842	0.842			
	LR3	0.776	0.776			
	LR4	0.853	0.853			

Table 7. Measurement model cross-loading.

Items	IT-Enabled Technology-Related CSFs	L4.0-Related CSFs	Management-Related CSFs	Worker-Enabled Technology-Related CSFs
ITET1	**0.770**	0.389	0.192	0.154
ITET2	**0.680**	0.232	0.244	0.156
ITET3	**0.798**	0.172	0.312	0.182
ITET4	**0.646**	0.293	0.074	0.268
ITET5	**0.728**	0.206	0.255	0.161
ITET6	**0.742**	0.192	0.255	0.09
ITET7	**0.321**	0.253	−0.143	0.132
ITET8	**0.833**	0.300	0.366	0.104
ITET9	**0.815**	0.381	0.264	0.242
LR1	0.395	**0.841**	0.217	0.365
LR2	0.299	**0.842**	0.177	0.198
LR3	0.224	**0.776**	0.060	0.437
LR4	0.295	**0.853**	0.061	0.28
MR1	0.193	0.065	**0.803**	0.213
MR2	0.315	0.154	**0.821**	0.357
MR3	0.220	0.098	**0.867**	0.064
MR4	0.296	0.200	**0.879**	0.278
WET1	0.160	0.229	0.055	**0.717**
WET2	0.123	0.239	0.155	**0.747**
WET3	0.248	0.345	0.227	**0.793**
WET4	0.204	0.392	0.261	**0.856**
WET5	0.134	0.268	0.376	**0.776**

4.2.2. Second-Order Test/Path Analysis

Formative latent variables made up the second order for CSFs. The prevailing significance of the path coefficients may be evaluated using the bootstrapping method. Establishing the collinearity of the formative components inspires the assessment of the variance inflation factor (VIF) value. Since none of the VIFs were higher than 3.5, the components independently contributed to the higher-order construct. Table 8 shows the resulting CSFs with four subscales, namely, IT-enabled technology (β = 0.608, *p*-value < 0.000), worker-enabled technology (β = 0.275, *p*-value < 0.000), management related (β = 0.236, *p*-value < 0.000), and L4.0 related (β = 0.288, *p*-value < 0.000). The four subscales' second-order findings that were accepted have a big impact on how L4.0 is implemented.

An examining technique for the research hypotheses as well as establishing the relationship between the construct's path analysis is used. Table 9 shows that the CSFs have a positive and significant influence (β = 0.161, *p* = 0.023) on successful L4.0 implementation.

Table 8. Test of second-order formative models using bootstrapping.

Construct	β	Sample Mean	Standard Deviation	T Statistics	*p*-Value	VIF
IT-enabled technology → CSFs of L4.0	0.608	0.602	0.059	10.271	0.000	2.82
L4.0 related → CSFs of L4.0	0.288	0.287	0.031	9.207	0.000	2.47
Management related → CSFs of L4.0	0.236	0.229	0.043	5.542	0.000	2.43
Worker-enabled technology → CSFs of L4.0	0.275	0.273	0.043	6.331	0.000	2.79

Table 9. Hypotheses and relative paths for the model.

Path	β	Sample Mean	Standard Deviation	T Statistics	*p*-Value
CSFs of L4.0 → Successful L4.0 implementation	0.161	0.177	0.071	2.278	0.023

The coefficients of determination (R^2 values) were used as the assessment criterion for PLS-SEM results once reliability and validity had been verified. The coefficient of determination measures the proportion of an endogenous construct's variation that can be accounted for by its predictor constructs. The R^2 value represents the proportion of the independent variables' variation that they can account for. The structural model's capacity for prediction is therefore increased by a higher R^2 value. Figure 1 provides the results of R^2 for successful lean implementations in the present research model. The R^2 value was found to be 0.026, which implies that the L4.0 CSFs may contribute 26.0% to the success of L4.0 implementations.

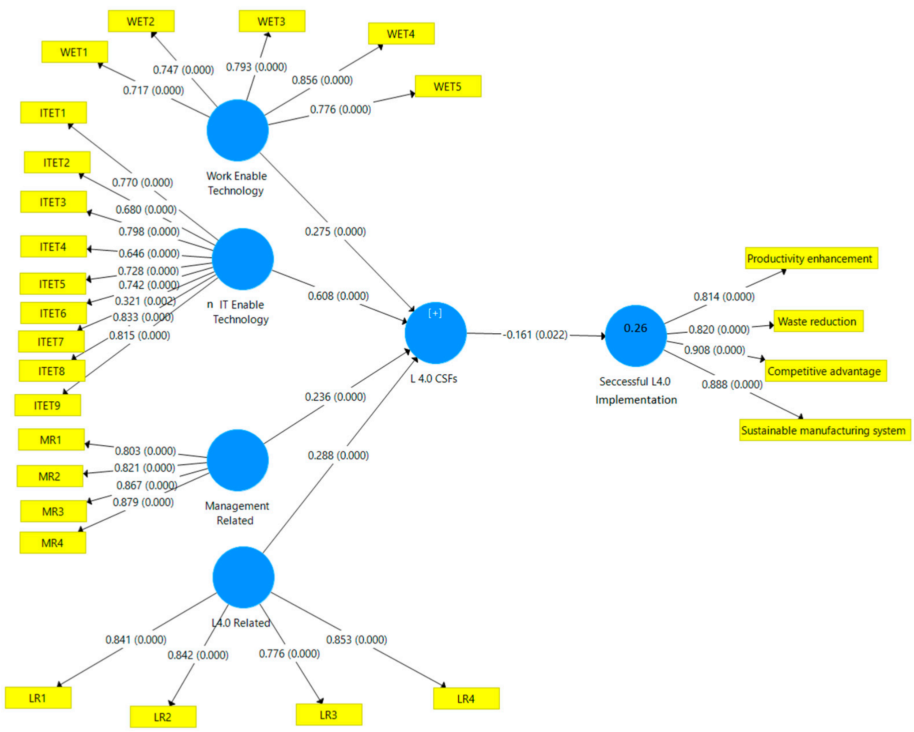

Figure 1. Structural model. Legend: WET = worker-enabled technology, ITET = IT-enabled technology, MR= management related, LR = L4.0 related, CSFs = critical success factors, PI = productivity improvement, WR = waste reduction, CA = competitive advantage, SMS = sustainable manufacturing system.

5. Discussion

The L4.0 CSFs play a significant role in successful lean implementation that benefits SMEs in many ways. SMEs can reduce their process waste and increase production output by increasing their productivity. Thus, lean implementation helps management improve productivity through waste reduction. A successful lean implementation helps SMEs achieve a sustainable manufacturing system. In a nutshell, L4.0 helps to achieve lower levels of stress and exhaustion, cultural transformation, and shortened traceability times, which are some of the unnoticed advantages. In contrast, some common benefits such as waste reduction, financial gains, a decrease in reworking, lower inventory levels, and a shortening of lead times are also delivered by successful lean implementations [29]. The digital transformation of L4.0 towards I4.0 readiness may pose several challenges if the SMEs are not able to visualize the digitization and digitalization processes. Hence, SMEs must take care to create a sound transformation in an appropriate conducive environment so that alignment of L4.0 tools with I4.0 manufacturing takes place effectively [49].

Therefore, the present research investigates the L4.0 CSFs' impact on successful L4.0 implementations. The result obtained in the present study confirms that L4.0 CSFs have a significant relationship with successful L4.0 implementations (path coeffect (β) = 0.161) and selected CSFs can contribute up to 26.8% to lean implementation success. Thus, the study provides a set of CSFs that help in successful L4.0 implementations.

The following sub-sections provide a discussion of the four CSF clusters obtained because of EFA.

Since both L4.0 and I4.0 aim to increase productivity and quality while concentrating on reducing waste and emphasizing customer needs, they share comparable objectives [50]. L4.0 has potential CSFs that influence successful lean implementation and help the company accomplish several objectives. Worker-enabled technology-related CSFs. In L4.0 implementations, worker-enabled technologies play a significant role in enhancing strategic advantages.

I4.0 readiness demands a paradigm shift in the manufacturing process accomplished with the help of Wi-Fi-enabled technologies, thus demanding radical changes in the worker who can cope with state-of-the-art technologies [51]. Workers must face flexibility challenges in the CPS to accommodate the wide spectrum of jobs. Hence, adequate qualification, training, skill, motivation, and morale are required to create a multi-tasking environment with interdisciplinary understanding. The various CSFs identified under this category were 'employee training', 'employee skill', 'employee motivations', 'employees using IT/data integration', and 'employee morale'. I4.0 demands human integration in I4.0 environments with the necessary architecture for further development [52]. The present empirical research establishes that there is a positive association between CSFs of worker-enabled technology-related activities and successful lean implementation, leading to several lean benefits. The finding is in line with past research that indicates that lean adopters stress more hard lean practices (lean tools and techniques) over soft lean practices (human factors and ergonomics), jeopardizing the lean implementation. The use of hard lean practices in the absence of soft lean practices affects worker quality and hampers lean implementation [53].

In I4.0, data integration with fast and trusted communication is very important in decision-making. The IoT plays a significant role in establishing such integration. The use of IoT promotes data sharing among sectors, although there are some concerns over data security and privacy issues. The various CSFs identified under this category were 'IoT', 'CPS', 'BDA', 'VR & AR', 'M2M communication', 'CC', 'AM', 'robots in manufacturing', and 'security of data and foolproof cyber security'. The Wi-Fi-enabled technologies are helping manufacturing SMEs achieve operational efficiency by reducing task errors [54]. The expected benefits from I4.0 technologies were found to be improved product customization and quality, a reduction in operational cost, and increased productivity [55].

Top management support is required in accomplishing the purchasing 4.0 process for IT-enabled tools and equipment [56]. The various CSFs identified under this category were 'top management support', 'long-term vision', 'funds/resource availability', and 'I4.0

strategy implementations'. The transition to I4.0 necessitates company-wide integration encompassing a vast base of Wi-Fi-enabled technologies and value chain digitization. However, the I4.0 transition for SMEs may be planned to begin with the constrained operational area so that the core company strategies are envisaged. In the context of Industry 4.0, the creation of a lean-digitized production system is a workable business strategy for firm survival [57].

L4.0 is supported by digital technology [58]. The various CSFs identified under this category were 'L4.0 awareness', 'employee readiness for change', 'prioritizing the lean tools and practices', and 'competition pressure'. 'Employee readiness' plays a vital role in L4.0 implementation to accomplish I4.0 [39].

A successful lean implementation will promote 'productivity improvement (PI)', 'waste reduction (WR)', 'competitive advantage (CA)', and 'sustainable manufacturing systems (SMS)'. The lean implementation process can enhance the strategic resources to boost the sustainable competitive advantage and sustainable manufacturing systems by cutting down the waste and cost [12].

6. Limitations and Future Research

The present empirical investigation provides the structural equation modeling of 22 constructs representing L4.0 CSFs for successful implementations aimed at achieving sustainability in the manufacturing supply chain. Further, they are grouped into four CSF clusters, which may be assumed to be limited. Hence, future studies may adopt more comprehensive constructs to establish CSFs' relationship for successful L4.0 implementations.

The present study is based on Indian manufacturing SMEs. Employee knowledge, training, skill, etc., differ from country to country when compared globally. The skill level of workers in the prevailing sector is high because there are more IT-enabled manufacturing sectors in SMEs. Hence, some of the present results may be generalized with some exceptions. The L4.0 CSFs identified were based on the small group technique involving experts. Future study may consider a panel of experts covering a large spectrum of SMEs. Further studies may consider expanding CSFs to cover different SME sectors to maximize the benefits of successful L4.0 implementations. The success rate obtained in the present study may be enhanced by including a larger sample size.

7. Conclusions

SMEs struggle to compete with large enterprises in terms of technology; infrastructure; state-of-the-art machines or equipment; workers' knowledge, training, soft skills, and hard skills; etc. There is a need for L4.0 implementation in its digitized form so that manufacturing SMEs obtain the lean benefits in the areas of 'productivity enhancement', 'waste reduction', 'competitive advantage', and 'sustainable manufacturing systems'. SMEs should adopt the L4.0 implementation to achieve I4.0 readiness.

The present study has identified 22 L4.0 CSFs that are contributing to successful L4.0 implementations in manufacturing SMEs. The influence of each L4.0 CSF has been deduced using empirical and structural relationships. A PLS-SEM-based model was prepared based on 22 L4.0 CSFs grouped into four clusters. The identified four clusters of L4.0 CSFs are related to 'worker-enabled technology', 'IT-enabled technology', 'management', and 'L4.0'. Future studies may induct more sets of data while considering lean implementation. Different sectors may adopt a different set of data and replicate this study to gain lean success insights.

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