Journal of International Conference Proceedings (JICP)
Vol. 9 No. 4, pp. 315-331, November, 2026
E-ISSN: 2621-993X P-ISSN: 2622-0989
https://ejournal.aibpmjournals.com/index.php/JICP/index

Building Successful Lean 4.0 Implementation: An Integrated Model of Technological, Managerial, Human, and Organizational Factors

Alvian Alvin Mubarok[1]*, Muhammad Gibran Vitra Al Ardhan[1], Budi Purnomo Saputro[1], Ryan Setya Budi[2]
[1]Department of Management, Faculty of Economics and Business, Universitas Pembangunan Nasional "Veteran" Yogyakarta, Indonesia
[2]Department of Economic Development, Faculty of Economics and Business, Universitas Pembangunan Nasional "Veteran" Yogyakarta, Indonesia
Jl. SWK No. 104, Ngropoh, Condongcatur, Depok, Sleman, Special Region of Yogyakarta 55283, Indonesia
*Corresponding Email: alvian.alvinmubarok@upnyk.ac.id

ARTICLE INFORMATION

Publication information

Research article

HOW TO CITE
Mubarok, A. A., Ardhan, M. G. V. A., Saputro, B. P., & Budi, R. S. (2026). Building successful Lean 4.0 implementation: An integrated model of technological, managerial, human, and organizational factors. *Journal of International Conference Proceedings (JICP), 9*(4), 315–331.

DOI:
https://doi.org/10.32535/jicp.v9i4.5164

Copyright @ 2026 owned by Author(s). Published by JICP

This is an open-access article.
License:
Attribution-Noncommercial-Share Alike (CC BY-NC-SA)

Received: 7 September 2026
Accepted: 10 October 2026
Published: 13 November 2026

ABSTRACT

Lean 4.0 integrates lean principles with Industry 4.0 technologies, requiring technological, managerial, human, and organizational support for successful implementation. This study examines factors influencing Lean 4.0 critical success factors (CSFs) and their impact on implementation success in technology-based startups. A quantitative explanatory approach involved 113 respondents from startups in Yogyakarta and Central Java, Indonesia. Data were collected using five-point Likert questionnaires and analyzed through partial least squares structural equation modeling (PLS-SEM) using SmartPLS 4. Results indicate that worker-enabled technology, IT-enabled technology, management factors, Lean 4.0 factors, employee well-being, organizational culture, and digital readiness positively and significantly influence CSFs. Digital readiness demonstrates the strongest effect (β = 0.261). Furthermore, CSFs significantly influence successful implementation (β = 0.808, p < 0.001), explaining 65.3% of its variance. These findings highlight the importance of prioritizing digital readiness alongside employee capabilities, organizational culture, managerial support, and lean-digital integration to achieve sustainable Lean 4.0 implementation.

Keywords: Critical Success Factors; Digital Readiness; Lean 4.0; PLS-SEM; Startups; Successful Implementation.

INTRODUCTION

Digital transformation has changed the logic of operational improvement. Organizations are no longer expected to choose between efficiency-oriented management systems and digital technologies; instead, they are increasingly required to combine disciplined process improvement with data visibility, automation, connected systems, and rapid learning. Lean 4.0 has emerged from this convergence by integrating lean principles such as waste elimination, value creation, flow, standardization, and continuous improvement with Industry 4.0 technologies. Recent research portrays this integration as a shift from isolated digital tools toward an interconnected operating system in which digital technologies enhance process transparency and decision speed while lean principles prevent technology investments from becoming detached from value creation (Cifone et al., 2021; Gil-Vilda et al., 2021; Kassem et al., 2024). Empirical and framework-oriented studies similarly show that the integration can improve productivity, flexibility, quality, and sustainability when the technological and managerial elements are aligned (Bueno et al., 2023; Hossain & Purdy, 2025; Kabzhassarova et al., 2021).

The implementation challenge, however, is substantial. Lean 4.0 is not a technology acquisition project; it is an organizational transformation that requires the simultaneous development of digital infrastructure, employee capabilities, managerial commitment, learning routines, and a culture that supports continuous improvement. Studies on Lean 4.0 repeatedly identify implementation barriers associated with skills, leadership, strategy, resource availability, data integration, and organizational readiness (Qureshi et al., 2023; Qureshi & Mewada, 2025). Recent evidence also suggests that the determinants of Lean 4.0 adoption are multidimensional. In a study of small and medium-sized enterprises (SMEs), Qureshi et al. (2025) found that process, organizational, human, technological, external, and environmental factors jointly structure the adoption problem. Likewise, Ibrahim and Kumar (2025) emphasize that successful digitally enabled improvement systems depend on clear goals, skilled employees, monitoring, and coordinated organizational support rather than technology in isolation.

These issues are particularly important for technology-based startups. Startups operate under resource constraints, market uncertainty, short learning cycles, and intense pressure to scale while preserving cash and operational discipline. At the same time, digital knowledge and skills are central to the creation and growth of innovative startups (Colombelli et al., 2024). Digital transformation can strengthen organizational resilience through learning and innovation (Awad & Martín-Rojas, 2024), but digital growth does not automatically produce operational excellence. For a startup, the value of connected tools, data analytics, cloud platforms, and automation depends on whether those resources are translated into repeatable routines, employee problem-solving capabilities, and disciplined decisions. From a resource-based view (RBV), technological and human resources create advantage only when they are effectively combined and deployed as organizational capabilities (Barney, 1991; Ahn et al., 2022). Recent Indonesian evidence also indicates that digital transformation is an important mechanism through which firm resources contribute to competitive advantage (Firdaussiah et al., 2026).

A useful starting point for understanding successful Lean 4.0 implementation is the critical success factor (CSF) model developed by Qureshi et al. (2023), which identifies worker-enabled technology (WET), IT-enabled technology (ITET), management-related factors (MR), and Lean 4.0-related factors (LR) as major domains supporting implementation. Nevertheless, a model centered on technology and management can be strengthened by explicitly incorporating the human and organizational conditions that make digital transformation sustainable. Employee well-being (EWB) matters because

technologically intensive change can create additional cognitive demands, uncertainty, and technostress; employees who experience supportive working conditions are more likely to engage constructively with change. Recent studies in Indonesia connect well-being with stronger employee outcomes and emphasize supervisor and organizational support as important resources in digitally changing work environments (Ariawaty et al., 2026; Ismawanti et al., 2025). Organizational culture (OC) is equally important because digital and lean practices require experimentation, learning, collaboration, and openness to process discipline. Earlier Industry 4.0 research shows that innovative culture is associated with readiness for technological transformation (Ziaei Nafchi & Mohelská, 2020).

Digital readiness (DR) provides another missing element. Digital transformation involves not only the possession of software or infrastructure but also strategic orientation, leadership, digital human capital, governance, and the organizational ability to use data and technology consistently. Digital readiness has been conceptualized as a multidimensional capability that is especially consequential for resource-constrained SMEs in emerging markets (Pingali et al., 2023). Readiness assessments also demonstrate the importance of strategy, employees, and supply-chain integration (Lassnig et al., 2021; Silva et al., 2022). In Indonesia, SMEs show heterogeneous levels of digital transformation readiness, underlining the need to view readiness as a managerial and organizational capability rather than a binary state of technology adoption (Anatan & Nur, 2023). More recent evidence from Indonesian creative industries further links digital readiness to agility, creativity, and competitiveness (Aryanti & Christianingrum, 2026).

Despite these advances, three gaps remain. First, much of the Lean 4.0 literature has been developed in manufacturing and SME settings, whereas technology-based startups have received limited empirical attention. Second, prior work frequently examines technological, human, managerial, or cultural conditions separately, leaving limited evidence on their simultaneous contribution to a higher-order configuration of Lean 4.0 CSFs. Third, the pathway from an integrated CSF configuration to successful implementation needs additional validation in emerging-economy startup contexts. These gaps are important because startups differ from established manufacturers in structure, resource availability, workforce composition, and the speed with which digital tools and operating routines change. A model that is useful for startups must therefore combine technological enablers with managerial direction, employee conditions, culture, and readiness.

Accordingly, this study examines the effects of WET, ITET, MR, LR, EWB, OC, and DR on Lean 4.0 CSFs and evaluates the effect of those CSFs on successful Lean 4.0 implementation (SI) among startups in the Special Region of Yogyakarta and Central Java, Indonesia. The study offers three contributions. Theoretically, it extends a Lean 4.0 CSF model by integrating technological, managerial, human, and organizational factors into one empirical framework. Empirically, it tests the framework in a startup setting in a developing economy using partial least squares structural equation modeling (PLS-SEM). Managerially, it identifies the relative strength of the seven factors, allowing startup leaders to prioritize interventions rather than treating Lean 4.0 as an undifferentiated digitalization project. The study is novel in positioning digital readiness, employee well-being, and organizational culture alongside established Lean 4.0 success domains and in assessing their combined role before successful implementation is achieved.

Journal of International Conference Proceedings (JICP)
Vol. 9 No. 4, pp. 315-331, November, 2026
E-ISSN: 2621-993X P-ISSN: 2622-0989
https://ejournal.aibpmjournals.com/index.php/JICP/index

LITERATURE REVIEW

Lean 4.0 and Critical Success Factors

Lean 4.0 represents the systematic integration of lean management and Industry 4.0. Lean management provides a process logic centered on customer value, waste elimination, standardized work, flow, and continuous improvement, whereas Industry 4.0 provides digital capabilities such as the Internet of Things (IoT), cyber-physical systems, cloud computing, big data analytics, automation, and real-time connectivity. The value of integration lies in complementarity. Digital technologies can improve visibility, precision, feedback, and responsiveness, while lean logic helps organizations select and use those technologies in ways that improve value streams rather than merely increase technical complexity (Buer et al., 2018; Cifone et al., 2021). Reviews and implementation-oriented studies of Lean 4.0 likewise emphasize that Industry 4.0 tools should be aligned with lean principles and process-improvement priorities rather than deployed as isolated technologies (Najwa et al., 2022; Kassem et al., 2024).

The literature has moved from conceptual descriptions toward implementation frameworks and empirical validation. Schumacher et al. (2023) identify guidelines for the digital transformation of lean methods and tools, while Bueno et al. (2023) develop a multi-method implementation framework that combines synergy elements, barriers, CSFs, and benefits. Komkowski et al. (2025) show that integration requires operational practices related to initiating, sensing, seizing, transforming, resources, and capabilities. Indonesian readiness research also indicates that Lean 4.0 implementation depends on the alignment of technological capability, human resources, and organizational conditions (Sarjono et al., 2025). Consequently, CSFs can be understood as the set of conditions that must be sufficiently developed and coordinated for Lean 4.0 to move from a technological aspiration to a repeatable operating system.

Qureshi et al. (2023) provide an empirically tested basis for this view by grouping Lean 4.0 CSFs into WET, ITET, MR, and LR domains and linking the combined CSFs to successful lean implementation. Subsequent work continues to identify human, organizational, and process factors as central to Lean 4.0 success (Qureshi & Mewada, 2025; Qureshi et al., 2025). The present study therefore conceptualizes Lean 4.0 CSFs as a higher-order, formative configuration: different domains contribute distinct content to the overall construct and need not be interchangeable. This specification is appropriate because high performance in one domain, such as technology, cannot automatically substitute for severe deficiencies in leadership, employee readiness, or culture.

Theoretical Grounding: Resources, Leadership, and Socio-Technical Alignment

The integrated model is grounded primarily in the resource-based view and complemented by leadership and socio-technical reasoning. RBV argues that competitive advantage depends on the possession and deployment of valuable organizational resources and capabilities (Barney, 1991). In digital contexts, technology alone rarely satisfies this requirement because hardware and software can often be acquired by competitors. More defensible capabilities emerge when digital infrastructure is combined with employee knowledge, managerial routines, organizational learning, and process-specific know-how. Research on technology-based startups similarly shows that technological capabilities and entrepreneurial resources contribute to innovation when they are orchestrated effectively (Ahn et al., 2022). Digital transformation research reinforces this argument by treating transformation as an organizational change involving resources, structures, processes, and capabilities rather than a purely technical upgrade (Kraus et al., 2021; Verhoef et al., 2021).

Managerial commitment provides the direction and resource allocation through which such capabilities are developed. Lean 4.0 transformation requires leaders to articulate priorities, secure resources, coordinate functions, and reduce resistance to new working methods. Evidence from digitally transforming organizations suggests that leadership and organizational values remain important even when technology becomes a prominent performance driver (Purbiyati & Andrew, 2025). Socio-technical reasoning further explains why the human and technical systems must be jointly optimized. Sony and Naik (2020) argue that Industry 4.0 integration should be designed as a socio-technical system in which technology, people, work structures, and organizational processes are mutually aligned. These perspectives justify an integrated model that treats technological, managerial, human, and organizational conditions as complementary contributors to Lean 4.0 success.

Hypotheses Development

Worker-Enabled Technology and Lean 4.0 CSFs

Worker-enabled technology refers to the capabilities that allow employees to use digital tools effectively in problem solving, decision making, data interpretation, and continuous improvement. It includes training, digital skills, motivation, employee use of integrated information, and morale. Lean 4.0 depends on employees who can translate real-time data into process improvements; otherwise, digital technology remains disconnected from lean routines. The socio-technical perspective indicates that technology produces value when users have the competence and discretion to use it in operational improvement (Sony & Naik, 2020). Qureshi et al. (2023) identify worker-enabled technology as a core Lean 4.0 success domain, while later evidence continues to emphasize skills and human factors in adoption (Qureshi et al., 2025). Therefore, stronger WET should reinforce the overall configuration of Lean 4.0 CSFs.

H1: Worker-enabled technology positively affects Lean 4.0 critical success factors.

IT-Enabled Technology and Lean 4.0 CSFs

IT-enabled technology reflects the availability and effective use of digital infrastructure such as IoT, cyber-physical systems, big data analytics, cloud computing, machine-to-machine communication, immersive technologies, and cybersecurity. These technologies improve process visibility and enable faster detection of deviations, waste, bottlenecks, and quality problems. Cifone et al. (2021) show that digital technologies can augment lean execution and decision making, while Lean Production Systems 4.0 research indicates that digital tools can strengthen the design and operation of lean methods when integrated systematically (Schumacher et al., 2023). Because startups are already technology-intensive, the decisive issue is not simple adoption but the degree to which IT is integrated into operating processes. ITET is therefore expected to make a positive contribution to Lean 4.0 CSFs.

H2: IT-enabled technology positively affects Lean 4.0 critical success factors.

Management-Related Factors and Lean 4.0 CSFs

Management-related factors include top-management support, a long-term transformation vision, adequate resources, and a clear Industry 4.0 strategy. Lean 4.0 requires cross-functional coordination and investment decisions that exceed the authority of individual employees. Management also determines whether experimentation is linked to strategic priorities and whether improvement efforts are maintained after initial enthusiasm. Bueno et al. (2023) identify management-related conditions among the central elements of Lean 4.0 implementation, and Purbiyati and Andrew (2025) show that leadership-related organizational conditions remain relevant in digitally transforming settings. Thus, managerial commitment should strengthen the organization's CSF configuration.

H3: Management-related factors positively affect Lean 4.0 critical success factors.

Lean 4.0-Related Factors and Lean 4.0 CSFs

Lean 4.0-related factors represent the organization's specific understanding and operational alignment of lean and Industry 4.0. The construct includes awareness of Lean 4.0, employee readiness for change, prioritization of lean tools and practices, and recognition of competitive pressure. A digital tool that is not connected to lean objectives can automate waste instead of removing it; conversely, lean initiatives that ignore digital possibilities may be unable to achieve the required responsiveness. Recent reviews and implementation frameworks emphasize that the integration itself must be intentionally designed (Kassem et al., 2024; Hossain & Purdy, 2025). Qureshi et al. (2023) similarly treat Lean 4.0-related factors as a distinct CSF domain. Accordingly, greater lean-digital alignment should strengthen Lean 4.0 CSFs.

H4: Lean 4.0-related factors positively affect Lean 4.0 critical success factors.

Employee Well-Being and Lean 4.0 CSFs

Employee well-being refers to positive psychological, social, and workplace conditions that enable employees to function effectively and sustainably. Digital transformation can increase flexibility and access to information, but it can also generate technology overload, role ambiguity, and anxiety. A Lean 4.0 system that seeks continuous improvement requires employees who are willing to experiment, learn, report problems, and participate in change. Indonesian studies show that work resources and supportive conditions are associated with employee well-being and performance (Ariawaty et al., 2026; Ismawanti et al., 2025). By reducing resistance and preserving engagement during technology-enabled change, EWB should strengthen the human foundation of Lean 4.0 CSFs.

H5: Employee well-being positively affects Lean 4.0 critical success factors.

Organizational Culture and Lean 4.0 CSFs

Organizational culture shapes how members interpret change, share knowledge, collaborate, and respond to failure. Lean 4.0 requires a culture that supports learning, process discipline, experimentation, and data-based problem solving. A culture that is rigid or defensive can weaken both lean practices and digital adoption even when technology is available. Ziaei Nafchi and Mohelská (2020) show that innovative organizational culture is relevant to Industry 4.0 readiness, while Qureshi et al. (2025) identify organizational factors and change management as influential in Lean 4.0 adoption. Therefore, a culture that supports innovation, empowerment, and continuous learning should make the broader CSF system stronger.

H6: Organizational culture positively affects Lean 4.0 critical success factors.

Digital Readiness and Lean 4.0 CSFs

Digital readiness is the organization's preparedness to undertake and sustain digital transformation across strategy, leadership, technology, human capital, culture, governance, and customer orientation. It differs from IT availability because it reflects the organization's ability to mobilize digital resources coherently. Research on emerging-market SMEs defines digital readiness as a multidimensional capability and shows that resource constraints make readiness particularly consequential (Pingali et al., 2023). Empirical assessments highlight strategy and employee readiness as key dimensions (Lassnig et al., 2021; Silva et al., 2022), while Indonesian studies confirm that SMEs vary substantially in their readiness for digital transformation (Anatan & Nur, 2023). Aryanti and Christianingrum (2026) further show that digital readiness contributes to agility, creativity, and competitiveness. Because Lean 4.0 depends on the routine use of digital technology within improvement systems, DR is expected to strengthen Lean 4.0 CSFs.

H7: Digital readiness positively affects Lean 4.0 critical success factors.

Journal of International Conference Proceedings (JICP)
Vol. 9 No. 4, pp. 315-331, November, 2026
E-ISSN: 2621-993X P-ISSN: 2622-0989
https://ejournal.aibpmjournals.com/index.php/JICP/index

Lean 4.0 CSFs and Successful Lean 4.0 Implementation

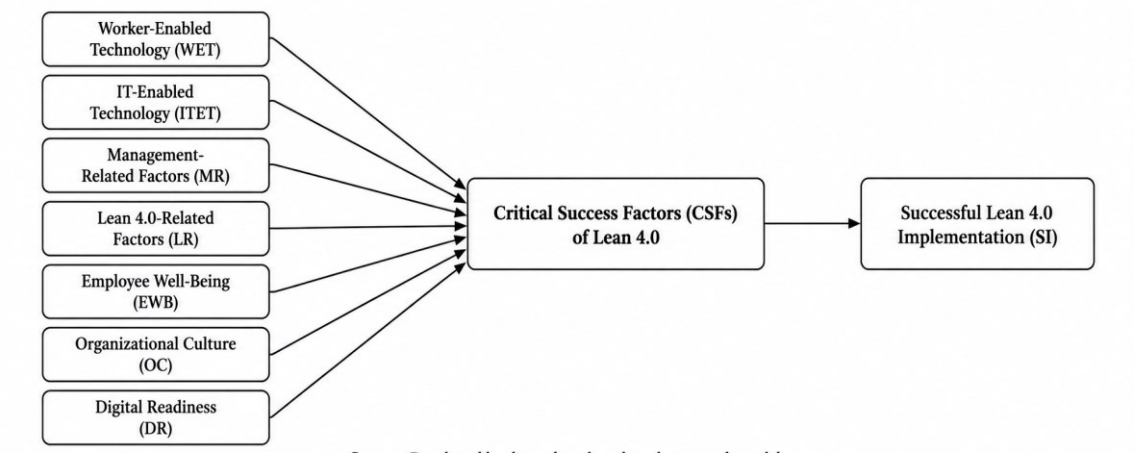
Successful implementation refers to the extent to which Lean 4.0 generates desired operational and strategic outcomes, including productivity improvement, waste reduction, competitive advantage, sustainable operating practices, and profitability. CSFs are meaningful only if their combined presence increases the probability that implementation succeeds. Qureshi et al. (2023) report a positive relationship between Lean 4.0 CSFs and successful lean implementation, while newer studies show that successful adoption depends on integrated combinations of process, organizational, human, and technological factors (Qureshi & Mewada, 2025; Qureshi et al., 2025). The same logic is visible in current integrated Lean–Industry 4.0 frameworks, which emphasize coordinated practices rather than isolated tools (Komkowski et al., 2025). Therefore, a stronger CSF configuration is expected to produce more successful implementation.

H8: Lean 4.0 critical success factors positively affect successful Lean 4.0 implementation.

Conceptual Framework

The research framework is presented in Figure 1. The seven antecedent domains represent technological, managerial, human, and organizational conditions that strengthen the higher-order Lean 4.0 CSF configuration, which subsequently drives successful Lean 4.0 implementation.

Figure 1. Research Framework



Source: Developed by the authors based on the research model.

RESEARCH METHOD

This study used a quantitative explanatory, cross-sectional design to test the proposed relationships among Lean 4.0-related constructs. The research context comprised technology-based startups operating in the Special Region of Yogyakarta and Central Java, Indonesia. The units of analysis were individual organizational members who had direct knowledge of digital technology use and operational processes, including employees, managers, and owners. The target startups had operated for at least one year and had adopted digital technology in their business processes. This context was selected because startups combine high digital intensity with resource limitations and rapid organizational change, creating a relevant setting for examining the conditions required for Lean 4.0 implementation.

Purposive sampling was applied because respondents needed sufficient exposure to organizational operations and digital transformation activities to evaluate the constructs meaningfully. The final sample consisted of 113 respondents. The sample included

participants from e-commerce, financial technology, creative industries, health technology, logistics, education technology, and software-as-a-service/information technology businesses. Data were collected through a structured online questionnaire distributed using Google Forms. All substantive items used a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Participation was voluntary and responses were analyzed at the aggregate level.

The measurement model was adapted from the constructs used in the thesis and the core Lean 4.0 CSF framework of Qureshi et al. (2023). WET captured employee training, skills, motivation, IT/data use, and morale. ITET covered technologies such as IoT, cyber-physical systems, big data analytics, virtual or augmented reality, machine-to-machine communication, cloud computing, and cybersecurity. MR represented top-management support, long-term vision, resource availability, and Industry 4.0 strategy. LR captured Lean 4.0 awareness, employee readiness for change, prioritization of lean tools and practices, and competitive pressure. EWB captured life, workplace, and psychological well-being. OC represented supportive and innovative cultural conditions, bureaucracy, and employee empowerment. DR assessed strategic, leadership, technological, human-capital, cultural, governance, and customer-oriented readiness. SI was measured through productivity improvement, waste reduction, competitive advantage, sustainable operations, and profitability. Lean 4.0 CSFs were modeled as a higher-order formative construct represented by the seven lower-order domains.

The analysis proceeded in two stages. First, preliminary factorability was assessed in SPSS 27 using the Kaiser–Meyer–Olkin (KMO) measure and Bartlett's test of sphericity. Second, PLS-SEM was conducted using SmartPLS 4. Reflective measurement quality was evaluated using indicator loadings, Cronbach's alpha, composite reliability, average variance extracted (AVE), and cross-loadings. Following Hair et al. (2022), loadings near or above 0.70 and AVE above 0.50 were used as primary convergent validity criteria, while reliability values were interpreted in light of the exploratory nature of the model. The higher-order formative CSF construct was evaluated using redundancy analysis and variance inflation factors (VIFs) to assess convergent validity and collinearity. Structural relationships were evaluated through path coefficients, t-statistics, and p-values obtained from bootstrapping, using $p < 0.05$ as the significance criterion. Predictive performance was assessed through R^2 and PLS-Predict, while standardized root mean square residual (SRMR) was reported as a supplementary model-fit diagnostic.

RESULTS

Respondent Profile

The study obtained 113 usable responses. The sample was relatively young, consistent with the workforce profile of technology-based startups: 64.6% of respondents were 20–25 years old and 24.8% were 26–30 years old. Women accounted for 73.5% of the sample and men for 25.7%, with one respondent preferring not to state gender. Regarding education, 44.2% held a bachelor's degree and 38.9% had completed senior high school or vocational education. The most represented sectors were e-commerce (31.9%), financial technology, creative industries, health technology, logistics, education technology, and SaaS/IT. Respondents held permanent, internship, contract, freelance, and owner roles, providing perspectives from different positions within startup operations.

Table 1. Selected Respondent Characteristics (N = 113)

Characteristic	Category	n	%
Gender	Male	29	25.7
Gender	Female	83	73.5
Gender	Prefer not to say	1	0.9

Age	20–25 years	73	64.6
Age	26–30 years	28	24.8
Age	Below 20 years	6	5.3
Education	Bachelor's degree	50	44.2
Education	Senior high/vocational	44	38.9
Education	Diploma	12	10.6
Education	Master's degree	7	6.2
Employment	Permanent employee	40	35.4
Employment	Internship	29	25.7
Employment	Contract employee	26	23.0
Employment	Freelance	17	15.0
Employment	Owner	1	0.9
Sector	E-commerce	36	31.9
Sector	Financial technology	23	20.4
Sector	Creative industry	16	14.2
Sector	Health technology	11	9.7
Sector	Logistics	9	8.0
Sector	Education technology	7	6.2
Sector	SaaS / IT	7	6.2

Source: Primary data processed by the authors (2026).

Preliminary and Measurement Model Assessment

The preliminary factorability assessment supported multivariate analysis. The KMO value was 0.864 and Bartlett's test of sphericity was significant (χ^2 = 2,548.953, df = 780, $p < 0.001$), indicating that the correlation matrix was adequate for factor analysis. During the first measurement-model evaluation, several indicators with loadings below 0.70 were removed. The final model retained indicators with loadings above 0.70 across the reflective constructs. AVE values ranged from 0.532 to 0.583, exceeding the 0.50 threshold. Most reliability coefficients exceeded or approached conventional benchmarks. WET showed lower internal consistency (Cronbach's α = 0.631; CR = 0.634), but was retained because its three remaining indicators loaded from 0.735 to 0.782 and AVE was 0.574. Given the exploratory startup context, this marginal reliability is reported transparently and considered a limitation rather than concealed.

Table 2. Reflective Measurement Model Summary

Construct	Retained loading range	Cronbach's α	CR	AVE
WET	0.735–0.782	0.631	0.634	0.574
ITET	0.736–0.761	0.803	0.804	0.559
MR	0.742–0.783	0.762	0.764	0.583
LR	0.705–0.755	0.719	0.719	0.543
EWB	0.717–0.779	0.800	0.802	0.556
OC	0.721–0.801	0.760	0.762	0.582
DR	0.702–0.755	0.854	0.855	0.532
SI	0.725–0.773	0.806	0.810	0.563

Source: Primary data processed by the authors (2026).

Cross-loading analysis indicated that every retained indicator loaded more strongly on its intended construct than on the other constructs, supporting discriminant validity. For the formative higher-order CSF construct, redundancy analysis produced correlations of 0.922 for DR, 0.882 for EWB, 0.878 for OC, 0.867 for LR, 0.861 for MR, 0.804 for ITET, and 0.694 for WET. WET was slightly below the conventional 0.70 guideline, but its value was close to the threshold and its structural contribution remained statistically significant.

Collinearity was not critical because all VIF values were below 5, ranging from 1.909 for WET to 4.380 for DR.

Table 3. Formative Assessment of the Lean 4.0 CSF Construct

Dimension	Redundancy correlation	VIF	Assessment
WET	0.694	1.909	Near threshold; retained
ITET	0.804	2.586	Acceptable
MR	0.861	4.085	Acceptable
LR	0.867	3.804	Acceptable
EWB	0.882	3.567	Acceptable
OC	0.878	3.529	Acceptable
DR	0.922	4.380	Acceptable

Source: Primary data processed by the authors (2026).

Structural Model and Hypothesis Testing

The hypothesis tests show that all seven domains make positive and statistically significant contributions to Lean 4.0 CSFs. DR has the largest coefficient (β = 0.261, t = 10.823, p < 0.001), followed by EWB (β = 0.187), ITET (β = 0.167), OC (β = 0.156), MR (β = 0.153), LR (β = 0.144), and WET (β = 0.097). Thus, H1 through H7 are supported. The magnitude ordering is substantively important: the model indicates that readiness is more influential than any single technology or management domain, while the positive significance of every path confirms that successful Lean 4.0 preparation is multidimensional.

Table 4. Hypothesis Testing Results

Hypothesis	Relationship	β	t-statistic	p-value	Decision
H1	WET → CSFs	0.097	5.176	< 0.001	Supported
H2	ITET → CSFs	0.167	7.734	< 0.001	Supported
H3	MR → CSFs	0.153	8.970	< 0.001	Supported
H4	LR → CSFs	0.144	9.938	< 0.001	Supported
H5	EWB → CSFs	0.187	10.339	< 0.001	Supported
H6	OC → CSFs	0.156	9.176	< 0.001	Supported
H7	DR → CSFs	0.261	10.823	< 0.001	Supported
H8	CSFs → SI	0.808	21.560	< 0.001	Supported

Source: Primary data processed by the authors (2026).

The effect of Lean 4.0 CSFs on SI is strong and positive (β = 0.808, t = 21.560, p < 0.001), supporting H8. The R^2 for SI is 0.653 (adjusted R^2 = 0.650), meaning that the integrated CSF construct explains 65.3% of the variance in successful implementation. PLS-Predict results also show positive Q^2predict values for all SI indicators, ranging from 0.195 to 0.450, and the PLS-SEM prediction errors for SI were lower than the corresponding linear-model benchmark errors. These results provide evidence of predictive relevance. The SRMR value was 0.102 for both the saturated and estimated models. This value is slightly above the commonly used 0.10 tolerance and therefore

indicates marginal rather than strong global fit. Because PLS-SEM emphasizes prediction and component-based explanation, the finding does not invalidate the structural results, but it warrants caution and is explicitly considered in the limitations.

Table 5. Structural and Predictive Model Summary

Indicator	Result	Interpretation
R^2 for SI	0.653	65.3% of SI variance explained by CSFs
Adjusted R^2 for SI	0.650	Substantial explanatory power
SRMR	0.102	Marginal global fit; interpret cautiously
Q^2predict for SI indicators	0.195–0.450	All values positive; predictive relevance
PLS vs. LM prediction error	PLS RMSE lower for SI1–SI5	PLS model outperforms the linear benchmark for SI

Source: Primary data processed by the authors (2026).

DISCUSSION

The purpose of this study was to explain successful Lean 4.0 implementation through an integrated set of technological, managerial, human, and organizational factors. The results support the central argument: Lean 4.0 success is systemic. All seven dimensions contribute significantly to the CSF configuration, and the combined CSFs have a very strong relationship with successful implementation. This pattern extends the original four-domain Lean 4.0 CSF model by demonstrating that employee well-being, organizational culture, and digital readiness add meaningful explanatory content in a startup context. The findings also reinforce recent literature that frames Lean 4.0 implementation as a coordinated transformation rather than an isolated technology program (Bueno et al., 2023; Komkowski et al., 2025; Qureshi et al., 2025).

Technological Factors and Lean 4.0 CSFs

WET has a positive and significant contribution to CSFs, but its coefficient is the smallest among the seven dimensions. This finding is theoretically meaningful. Technology-enabled work is necessary, yet training, skills, motivation, and access to digital information do not independently guarantee a strong Lean 4.0 system. Employees require an organizational context in which digital skills are connected to problem solving, standardized processes, and continuous improvement. The result is consistent with socio-technical reasoning that digital systems work best when human roles, technical tools, and work design are jointly aligned (Sony & Naik, 2020). It also supports Qureshi et al. (2023), who place worker-enabled technologies among the major Lean 4.0 CSFs. For startups, the managerial implication is that digital literacy initiatives should be tied directly to operational use cases, such as interpreting process dashboards, identifying waste from transaction data, or using collaborative tools to support problem-solving routines.

ITET has a larger positive contribution than WET, confirming that integrated digital infrastructure is an important Lean 4.0 foundation. The result aligns with Cifone et al. (2021), who identify mechanisms through which digital technologies improve the speed, precision, visibility, and feedback of lean practices. It is also compatible with Lean Production Systems 4.0 research showing that the transformation of lean tools increasingly depends on digital integration (Schumacher et al., 2023). In the startup context, cloud platforms, analytics, cybersecurity, system integration, and connected

data can provide a level of process visibility that small organizations often lack. However, ITET is not the dominant factor in this study. This supports the argument that buying or developing technology is insufficient without readiness, culture, human capability, and managerial support.

Managerial and Lean 4.0-Related Factors

MR has a significant positive contribution to the CSF configuration. Lean 4.0 requires management to commit resources, communicate a long-term direction, and ensure that digital initiatives serve operational priorities. This finding is consistent with implementation frameworks that position management support, governance, and resource commitment as necessary conditions for integration (Bueno et al., 2023; Qureshi & Mewada, 2025). It also supports RBV logic: resources become strategically valuable when managerial processes coordinate and deploy them rather than leaving them fragmented. For resource-constrained startups, this role is particularly important because investment decisions are highly selective. Management must decide which digital technologies remove real bottlenecks, which processes should be standardized before automation, and which capabilities should be developed internally.

LR also has a positive effect, indicating that organizations need an explicit understanding of how lean and digital technologies fit together. This result is consistent with recent systematic reviews demonstrating that Lean 4.0 is characterized by specific interactions between lean pillars and Industry 4.0 technologies rather than a generic combination of two management trends (Kassem et al., 2024). Hossain and Purdy (2025) similarly emphasize systemic design when validating a Lean 4.0 framework. The implication is that startups should avoid technology-first implementation. A lean-digital roadmap should begin with value streams and customer value, identify waste and variability, and then select digital enablers that improve visibility, standardization, flow, or problem prevention.

Human and Organizational Factors

EWB emerges as the second-strongest contributor to CSFs, which is an important extension of technology-centered Lean 4.0 models. The result suggests that employees' psychological and workplace conditions are not peripheral benefits of implementation; they are part of the capability required to implement change. Lean 4.0 can intensify data visibility, performance monitoring, and learning demands. When employees experience adequate support and well-being, they are more likely to participate in experimentation and improvement rather than interpret digital systems as threats. This interpretation is consistent with Indonesian evidence linking employee well-being to performance-related outcomes (Ismawanti et al., 2025) and with research showing that supervisor support and work-life conditions shape well-being in technology-intensive work arrangements (Ariawaty et al., 2026). Accordingly, managers should evaluate the human impact of digital process redesign and provide training, workload management, communication, and psychological safety alongside technical implementation.

OC also contributes significantly to CSFs. Lean and digital transformation both require changes in routines and assumptions. A culture that encourages collaboration, learning from problems, employee empowerment, and evidence-based decisions helps convert isolated technology use into organization-wide capability. The finding is consistent with research linking organizational culture to Industry 4.0 readiness (Ziaei Nafchi & Mohelská, 2020) and with recent Lean 4.0 adoption evidence highlighting organizational factors and change management (Qureshi et al., 2025). Startups are often assumed to be naturally innovative, but an entrepreneurial identity does not automatically create a disciplined improvement culture. As startups grow, leaders need mechanisms that

preserve openness while strengthening standardized learning, process accountability, and cross-functional collaboration.

Digital Readiness as the Dominant Driver

DR is the strongest contributor to Lean 4.0 CSFs. This is one of the most important findings of the study. It indicates that successful Lean 4.0 preparation depends less on any single technology than on the organization's broad readiness to mobilize digital strategy, leadership, infrastructure, human capital, culture, governance, and customer orientation together. The finding supports Pingali et al. (2023), who conceptualize digital readiness as a multidimensional capability for SMEs in emerging markets. It also aligns with Anatan and Nur (2023), who show the importance of readiness in Indonesian smaller firms, and with Aryanti and Christianingrum (2026), who link digital readiness to agility, creativity, and competitiveness. Readiness checks in European SMEs likewise show that strategic and employee dimensions are central to Industry 4.0 progress (Lassnig et al., 2021).

From an RBV perspective, this dominance is logical. Digital readiness reflects the organization's ability to combine different resources into a coherent capability. Such capability is more difficult to imitate than the possession of an individual software application. Firdaussiah et al. (2026) similarly demonstrate that digital transformation can serve as a pathway through which company resources are converted into competitive advantage. For startups, the result suggests a sequencing principle: before scaling investment in advanced technologies, management should assess whether strategy, data governance, employee capability, leadership, and process ownership are ready to support them. A digital-readiness audit can therefore serve as an entry point for Lean 4.0 planning.

Lean 4.0 CSFs and Successful Implementation

The strongest structural result is the effect of CSFs on SI ($\beta = 0.808$). The magnitude confirms that successful implementation is strongly associated with the collective strength of the critical conditions included in the model. This result directly supports Qureshi et al. (2023) and is consistent with newer CSF prioritization studies (Ibrahim & Kumar, 2025; Qureshi & Mewada, 2025). It also complements the evidence of Qureshi et al. (2025), which shows that Lean 4.0 adoption in SMEs is shaped by multiple interacting factor groups. The R^2 of 0.653 indicates that the integrated CSF construct explains a substantial share of implementation success. In practical terms, the result argues against fragmented transformation: a startup that invests in cloud systems but neglects employee well-being, management commitment, or lean-digital alignment is likely to leave much of the potential value unrealized.

The predictive results strengthen this conclusion because all SI indicators have positive Q^2predict values and the PLS model produces lower prediction errors than the linear benchmark for the implementation indicators. At the same time, the SRMR of 0.102 suggests that the model should not be treated as a final or exhaustive representation of Lean 4.0 implementation. The remaining 34.7% of unexplained variance and marginal global fit indicate that other variables may matter, including financing constraints, external ecosystem support, customer pressure, platform dependence, cybersecurity maturity, business-model characteristics, and organizational learning. This interpretation is also consistent with contemporary digital transformation research, which views transformation as a broad and evolving organizational phenomenon (Kraus et al., 2021; Verhoef et al., 2021).

Managerial Implications

The findings provide a practical sequence for startup leaders. The first priority should be digital readiness because it has the largest contribution to the CSF configuration. This involves clarifying the digital strategy, strengthening data and system integration, assigning governance responsibilities, and assessing whether employees possess the required digital capabilities. The second priority should be the human system: employee well-being and worker-enabled technology need to be designed together so that new tools reduce friction rather than simply increase monitoring or workload. Third, leaders should build an organizational culture that treats data as a resource for learning and treats problems as opportunities for improvement. Fourth, management should connect investments to a Lean 4.0 roadmap that specifies the operational waste, quality issue, delay, or customer problem each technology is expected to address. Finally, implementation should be evaluated through operational outcomes such as productivity, waste, process stability, and sustainable performance instead of the number of technologies adopted.

CONCLUSION

This study develops and tests an integrated model of successful Lean 4.0 implementation in technology-based startups. Using data from 113 respondents in the Special Region of Yogyakarta and Central Java, the study demonstrates that WET, ITET, MR, LR, EWB, OC, and DR all make positive and significant contributions to Lean 4.0 CSFs. Digital readiness has the strongest contribution, followed by employee well-being, while worker-enabled technology has the smallest but still significant contribution. Most importantly, the integrated CSF configuration has a strong positive effect on successful Lean 4.0 implementation. The model explains 65.3% of the variance in implementation success, providing substantial empirical support for a multidimensional perspective.

Theoretically, the study extends prior Lean 4.0 CSF research by bringing technological, managerial, human, and organizational factors into a single startup-oriented framework. It shows that digital readiness, employee well-being, and culture are not secondary contextual issues but integral components of the conditions that enable Lean 4.0. The findings are compatible with RBV and socio-technical reasoning because implementation success depends on the coordinated use of technology, human resources, managerial routines, and organizational values. Practically, startups should begin Lean 4.0 transformation with a digital-readiness assessment and then align technology investment with employee capability, well-being, management commitment, organizational culture, and lean process priorities. This integrated approach can help prevent fragmented digitalization and increase the likelihood that digital technologies translate into productivity, waste reduction, competitiveness, sustainable operations, and profitability

LIMITATION

This study has several limitations. The sample is restricted to 113 respondents from startups in the Special Region of Yogyakarta and Central Java, which limits generalization to other regions, countries, and organizational types. The cross-sectional design captures perceptions at one point in time and cannot establish how readiness and implementation capabilities evolve. The WET construct shows marginal internal consistency, and the SRMR value of 0.102 indicates that the overall model fit is not optimal. In addition, the model explains 65.3% of successful implementation, leaving meaningful variance for other organizational and environmental factors. Future research should use larger multi-region samples, longitudinal designs, and mixed methods to examine implementation processes over time. Comparative research between startups, SMEs, and established manufacturers would also clarify whether the relative importance

of digital readiness, culture, and employee well-being changes with organizational maturity. Future models could incorporate external ecosystem support, financial readiness, organizational learning, cybersecurity maturity, and environmental pressure.

ACKNOWLEDGMENT

The author expresses appreciation to the startup employees, managers, and owners who participated in the study and to the academic community of the Faculty of Economics and Business, Universitas Pembangunan Nasional "Veteran" Yogyakarta, for supporting the research process.

DECLARATION OF CONFLICTING INTERESTS

The authors have declared no potential conflicts of interest concerning the study, authorship, and/or publication of this article.

REFERENCES

Ahn, S., Kim, K.-S., & Lee, K.-H. (2022). Technological capabilities, entrepreneurship and innovation of technology-based start-ups: The resource-based view. Journal of Open Innovation: Technology, Market, and Complexity, 8(3), Article 156. https://doi.org/10.3390/joitmc8030156

Anatan, L., & Nur. (2023). Micro, small, and medium enterprises' readiness for digital transformation in Indonesia. Economies, 11(6), Article 156. https://doi.org/10.3390/economies11060156

Ariawaty, R. R. N., Soemarayani, I., & Kosasih, K. (2026). Employee wellbeing in hybrid work environments: The role of work-life balance and supervisor support in Indonesia. International Journal of Applied Business and International Management, 11(1), 366–384. https://doi.org/10.32535/ijabim.v11i1.4552

Aryanti, A. N., & Christianingrum, C. (2026). Digital readiness, agility, and creativity as drivers of competitive advantage in the creative industry. International Journal of Applied Business and International Management, 11(1), 400–417. https://doi.org/10.32535/ijabim.v10i3.4629

Awad, J. A. R., & Martín-Rojas, R. (2024). Digital transformation influence on organisational resilience through organisational learning and innovation. Journal of Innovation and Entrepreneurship, 13, Article 69. https://doi.org/10.1186/s13731-024-00405-4

Barney, J. (1991). Firm resources and sustained competitive advantage. Journal of Management, 17(1), 99–120. https://doi.org/10.1177/014920639101700108

Buer, S.-V., Strandhagen, J. O., & Chan, F. T. S. (2018). The link between Industry 4.0 and lean manufacturing: Mapping current research and establishing a research agenda. International Journal of Production Research, 56(8), 2924–2940. https://doi.org/10.1080/00207543.2018.1442945

Bueno, A., Caiado, R. G. G., de Oliveira, T. L. G., Scavarda, L. F., Godinho Filho, M., & Tortorella, G. L. (2023). Lean 4.0 implementation framework: Proposition using a multi-method research approach. International Journal of Production Economics, 264, Article 108988. https://doi.org/10.1016/j.ijpe.2023.108988

Cifone, F. D., Hoberg, K., Holweg, M., & Portioli Staudacher, A. (2021). 'Lean 4.0': How can digital technologies support lean practices? International Journal of Production Economics, 241, Article 108258. https://doi.org/10.1016/j.ijpe.2021.108258

Colombelli, A., Paolucci, E., Raguseo, E., & Elia, G. (2024). The creation of digital innovative start-ups: The role of digital knowledge spillovers and digital skill endowment. Small Business Economics, 62(3), 917–937. https://doi.org/10.1007/s11187-023-00789-9

Firdaussiah, S. N., Sutjipto, M. R., & Hidayat, S. (2026). Optimizing company resources for sustainable competitive advantage: The mediating role of digital transformation in Indonesian MSMEs. International Journal of Applied Business and International Management, 11(1), 224–241. https://doi.org/10.32535/ijabim.v11i1.4524

Gil-Vilda, F., Yagüe-Fabra, J. A., & Sunyer, A. (2021). From lean production to Lean 4.0: A systematic literature review with a historical perspective. Applied Sciences, 11(21), Article 10318. https://doi.org/10.3390/app112110318

Hair, J. F., Jr., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2022). A primer on partial least squares structural equation modeling (PLS-SEM) (3rd ed.). SAGE Publications. https://us.sagepub.com/en-us/nam/a-primer-on-partial-least-squares-structural-equation-modeling-pls-sem/book270548

Hossain, M. M., & Purdy, G. (2025). Design and empirical validation of Lean 4.0: A systemic approach to smart lean production. International Journal of Lean Six Sigma, 16(7), 1587–1611. https://doi.org/10.1108/IJLSS-01-2025-0017

Ibrahim, A., & Kumar, G. (2025). Identification and prioritization of critical success factors of a Lean Six Sigma–Industry 4.0 integrated framework for sustainable manufacturing using TOPSIS. Sustainability, 17(3), Article 1331. https://doi.org/10.3390/su17031331

Ismawanti, R., Komariyah, I., & Suwandi, Y. W. (2025). Work engagement, psychological capital, and employee performance: The mediating role of employee well-being in the banking industry. International Journal of Applied Business and International Management, 10(3), 758–778. https://doi.org/10.32535/ijabim.v10i3.4618

Kabzhassarova, M., Kulzhanova, A., Dikhanbayeva, D., Guney, M., & Turkyilmaz, A. (2021). Effect of Lean4.0 on sustainability performance: A review. Procedia CIRP, 103, 73–78. https://doi.org/10.1016/j.procir.2021.10.011

Kassem, B., Callupe, M., Rossi, M., Rossini, M., & Portioli-Staudacher, A. (2024). Lean 4.0: A systematic literature review on the interaction between lean production and Industry 4.0 pillars. Journal of Manufacturing Technology Management, 35(4), 821–847. https://doi.org/10.1108/JMTM-04-2022-0144

Komkowski, T., Sony, M., Antony, J., Lizarelli, F. L., Garza-Reyes, J. A., & Tortorella, G. L. (2025). Operational practices for integrating lean and Industry 4.0: A dynamic capabilities perspective. International Journal of Production Research, 63(4), 1517–1537. https://doi.org/10.1080/00207543.2024.2381127

Kraus, S., Jones, P., Kailer, N., Weinmann, A., Chaparro-Banegas, N., & Roig-Tierno, N. (2021). Digital transformation: An overview of the current state of the art of research. SAGE Open, 11(3), 1–15. https://doi.org/10.1177/21582440211047576

Lassnig, M., Müller, J. M., Klieber, K., Zeisler, A., & Schirl, M. (2021). A digital readiness check for the evaluation of supply chain aspects and company size for Industry 4.0. Journal of Manufacturing Technology Management, 33(9), 1–18. https://doi.org/10.1108/JMTM-10-2020-0382

Najwa, E., Bertrand, R., Yassine, M., & Fernandes, G. (2022). Lean 4.0 tools and technologies to improve companies' maturity level: The COVID-19 context. Procedia Computer Science, 196, 207–216. https://doi.org/10.1016/j.procs.2021.12.007

Pingali, S. R., Singha, S., Arunachalam, S., & Pedada, K. (2023). Digital readiness of small and medium enterprises in emerging markets: The construct, propositions, measurement, and implications. Journal of Business Research, 164, Article 113973. https://doi.org/10.1016/j.jbusres.2023.113973

Purbiyati, Y. S., & Andrew, R. (2025). The moderating role of digital transformation on the influence of workplace spirituality and sustainable leadership on school organizational performance. International Journal of Applied Business and

International Management, 10(3), 445–463. https://doi.org/10.32535/ijabim.v10i3.4237

Qureshi, K. M., & Mewada, B. G. (2025). Assessing Lean 4.0 critical success factors (CSFs) for implementing in small and medium-sized enterprises (SMEs). Frontiers in Engineering and Built Environment, 5(2), 125–138. https://doi.org/10.1108/FEBE-12-2024-0085

Qureshi, K. M., Mewada, B. G., Buniya, M. K., & Qureshi, M. R. N. M. (2023). 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. Sustainability, 15(6), Article 5528. https://doi.org/10.3390/su15065528

Qureshi, K. M., Mewada, B. G., Yadav, A., Almakayeel, N., Alghamdi, S. Y., & Qureshi, M. R. N. M. (2025). Analysing Lean 4.0 adoption factors towards manufacturing sustainability in SMEs: A hybrid ANN-Fuzzy ISM framework. Scientific Reports, 15, Article 17265. https://doi.org/10.1038/s41598-025-01076-1

Sarjono, S., Hastuti, P., Utomo, S., Soehadi, G., Sadikin, B. S., Zubair, M., Mahmud, J., Purnama, R. A., Hardono, H., & Fifianny, H. (2025). Modelling dimensions and indicators of readiness for Lean 4.0 implementation in Indonesian industries. International Journal of Advanced Computer Science and Applications, 16(12). https://doi.org/10.14569/IJACSA.2025.0161275

Schumacher, S., Hall, R., Bildstein, A., & Bauernhansl, T. (2023). Lean Production Systems 4.0: Systematic literature review and field study on the digital transformation of lean methods and tools. International Journal of Production Research, 61(24), 8751–8773. https://doi.org/10.1080/00207543.2022.2159562

Silva, R. P., Saraiva, C., & Mamede, H. S. (2022). Assessment of organizational readiness for digital transformation in SMEs. Procedia Computer Science, 204, 362–369. https://doi.org/10.1016/j.procs.2022.08.044

Sony, M., & Naik, S. (2020). Industry 4.0 integration with socio-technical systems theory: A systematic review and proposed theoretical model. Technology in Society, 61, Article 101248. https://doi.org/10.1016/j.techsoc.2020.101248

Verhoef, P. C., Broekhuizen, T., Bart, Y., Bhattacharya, A., Dong, J. Q., Fabian, N., & Haenlein, M. (2021). Digital transformation: A multidisciplinary reflection and research agenda. Journal of Business Research, 122, 889–901. https://doi.org/10.1016/j.jbusres.2019.09.022

Ziaei Nafchi, M., & Mohelská, H. (2020). Organizational culture as an indication of readiness to implement Industry 4.0. Information, 11(3), Article 174. https://doi.org/10.3390/info11030174