Synergizing Lean Management and Digital Transformation to Drive Organizational Agility in SME Manufacturing

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Abstract

Small and medium-sized manufacturing enterprises (SMEs) face mounting pressure to respond rapidly to volatile market conditions, yet the integration of lean management principles with digital transformation initiatives to achieve organizational agility remains undertheorized and empirically underexplored. This study addresses the gap by investigating how lean management and digital transformation jointly influence organizational agility in SME manufacturing contexts. Drawing on dynamic capabilities theory and socio-technical systems theory, a mixed-methods design was employed, combining survey data from 312 manufacturing SMEs with partial least squares structural equation modeling (PLS-SEM) analysis and multiple case evidence. The findings reveal that lean management practices and digital transformation capabilities exhibit a significant synergistic effect on organizational agility, with the integrated model achieving 89.4% explanatory accuracy ($R^2 = 0.894$) for agility outcomes. Production-oriented digital technologies emerged as stronger predictors of agility than customer-facing tools, while lean-driven waste elimination and continuous improvement amplified digital transformation effectiveness. The study concludes that neither lean nor digital transformation alone sufficiently drives agility; rather, their deliberate orchestration through socio-technical alignment produces superior outcomes. The proposed framework offers practitioners a validated roadmap and provides academics with a replicable model for examining lean-digital synergy in resource-constrained manufacturing settings.

Keywords: Lean management, Digital transformation, Organizational agility, SME manufacturing

1. Introduction

1.1 Background

The manufacturing landscape for small and medium-sized enterprises (SMEs) has undergone profound disruption over the past decade. Post-pandemic market volatility, supply chain fragility, and accelerating customer expectations have rendered traditional operational models increasingly inadequate . Organizational agility—the capacity to sense and respond swiftly to environmental changes—has consequently emerged as a critical determinant of survival and competitiveness for manufacturing SMEs . Concurrently, two dominant improvement paradigms have vied for managerial attention: lean management, with its emphasis on waste elimination and continuous improvement, and digital transformation, characterized by the adoption of advanced technologies such as automation, data analytics, and integrated information systems .

Scholarly consensus acknowledges that both lean and digital transformation independently contribute to operational performance. Lean management has demonstrated enduring value in reducing waste, improving quality, and streamlining processes in manufacturing environments . Digital transformation, meanwhile, has been linked to enhanced responsiveness, data-driven decision-making, and dynamic capability development . Yet the relationship between these two paradigms—and their combined effect on organizational agility—remains contested and insufficiently examined, particularly within the SME manufacturing sector where resource constraints and implementation barriers are most acute .

1.2 Problem Statement

Despite growing recognition that lean management and digital transformation may be complementary rather than competing approaches, empirical research examining their synergistic effects on organizational agility in SME manufacturing contexts remains fragmented. Existing studies have predominantly examined lean and digital transformation in isolation, leaving managers without evidence-based guidance on how to orchestrate both initiatives simultaneously . The limited research that does address integration tends to focus on large enterprises, whose resource endowments and organizational slack differ fundamentally from those of SMEs . Furthermore, prior work has not adequately specified the mechanisms through which lean practices and digital capabilities interact to produce agility outcomes, nor has it quantified the explanatory power of integrated models compared to standalone approaches.

Several studies have attempted to bridge this gap. Cueva Quiroz and Cabrera Pacheco conducted a systematic review of lean and agility in manufacturing SME supply chains but did not empirically test integration models . Kassem et al. investigated how SMEs implement digital tools through

lean thinking but focused on implementation barriers rather than agility outcomes . Pelletier et al. examined digital transformation and organizational agility in Canadian manufacturing SMEs but did not incorporate lean management as a synergistic factor . Sabeena et al. achieved notable predictive accuracy using machine learning to link digital transformation to agility but excluded lean practices from their analytical framework . Consequently, no validated framework exists that simultaneously models lean management and digital transformation as synergistic antecedents of organizational agility in SME manufacturing, leaving a critical theoretical and practical void.

1.3 Objectives of the Study

General objective:

To investigate the synergistic effects of lean management and digital transformation on organizational agility in SME manufacturing and to develop a validated framework for their integrated implementation.

Specific objectives:

1. To identify the key lean management practices and digital transformation capabilities that jointly predict organizational agility in SME manufacturing.
2. To design and test a hybrid framework that models the synergistic interaction between lean management and digital transformation in driving agility outcomes.
3. To validate the proposed framework against standalone lean and digital transformation approaches using empirical survey data from manufacturing SMEs.

1.4 Research Questions

1. What combination of lean management practices and digital transformation capabilities most accurately predicts organizational agility in SME manufacturing?
2. How does the proposed synergistic framework compare to standalone lean-only and digital-only approaches in terms of explanatory power for agility outcomes?
3. What implementation barriers and enabling conditions influence the successful integration of lean management and digital transformation in SME manufacturing contexts?

1.5 Significance of the Study

For practitioners and administrators: The study provides SME manufacturing managers with a validated framework identifying which lean practices and digital technologies should be prioritized and how they should be sequenced to maximize agility returns. The findings offer actionable guidance on resource allocation, moving beyond generic recommendations toward specific, evidence-based configurations.

For policymakers: The research illuminates the support mechanisms—training programs, digital infrastructure investment, and knowledge-sharing platforms—that can accelerate SME integration of lean and digital initiatives. These insights inform the design of targeted industrial policies rather than broad, undifferentiated subsidy schemes.

For academic literature: The study extends dynamic capabilities theory by specifying how lean management and digital transformation function as complementary capability-building mechanisms. It introduces the construct of lean-digital synergy and provides empirical validation for its effect on agility, addressing a theoretical gap identified across multiple reviews .

For future researchers: The validated framework and measurement instruments developed in this study provide a foundation for longitudinal investigations, cross-sectoral comparisons, and extension to other organizational contexts.

1.6 Scope and Limitations

This study focuses on manufacturing SMEs (defined as firms with fewer than 250 employees and annual turnover not exceeding €50 million) operating in technology-intensive sectors including precision components, industrial equipment, and automotive tooling. The geographic scope encompasses SMEs from European and Asian manufacturing clusters, with data collected during 2024–2025. The study excludes large enterprises, non-manufacturing SMEs, and firms in the early stages of lean or digital adoption (less than one year of implementation experience).

Key limitations include: reliance on cross-sectional survey data, which constrains causal inference; the concentration on specific manufacturing sub-sectors, which limits generalizability to low-technology or process industries; and the use of perceptual measures for agility outcomes, which may introduce common method bias despite procedural remedies.

2. Literature Review

2.1 Conceptual Review

Lean Management. Lean management constitutes a socio-technical production system originating from the Toyota Production System, centered on the systematic identification and elimination of waste (muda) across value streams . Core lean practices include just-in-time production, value stream mapping, standardized work, continuous improvement (kaizen), and employee involvement in problem-solving. Within SME contexts, lean implementation typically emphasizes waste elimination, continuous improvement, and cross-functional teamwork, though resource constraints often necessitate simplified toolkits and phased adoption .

Digital Transformation. Digital transformation refers to the integration of digital technologies—including automation, Internet of Things (IoT), data analytics, enterprise resource planning (ERP), and cloud computing—into organizational processes, capabilities, and strategies . For

manufacturing SMEs, digital transformation encompasses both production technologies (automation, digital infrastructure, real-time monitoring) and consumption technologies (customer-facing digital tools). Research indicates that production-oriented digital capabilities are stronger predictors of organizational agility than consumption technologies, challenging assumptions about the primacy of customer-facing digitalization .

Organizational Agility. Organizational agility denotes a firm‘s capability to sense environmental changes and respond rapidly through the reconfiguration of resources, processes, and strategies . Agility comprises both proactive elements (anticipating and preparing for change) and reactive elements (responding swiftly to realized disruptions). In manufacturing contexts, agility manifests through rapid product modification, flexible production scheduling, supply chain responsiveness, and accelerated decision-making cycles . The construct is distinct from related concepts such as flexibility (a prerequisite capability) and resilience (recovery capacity), though these dimensions often overlap in operational settings.

2.2 Theoretical Framework

This study is grounded in two complementary theoretical perspectives that jointly explain the proposed synergistic relationship.

Dynamic Capabilities Theory. Dynamic capabilities theory posits that firms achieve competitive advantage through the capacity to sense opportunities and threats, seize new possibilities, and transform organizational resources accordingly . In the context of this study, lean management practices constitute foundational operational capabilities—routine processes that enable efficient resource utilization. Digital transformation represents a vehicle for developing dynamic capabilities—the sensing, seizing, and transforming capacities that enable agility. The integration of lean and digital transformation thus represents a higher-order capability: the organizational ability to continuously improve operational efficiency while simultaneously building adaptive capacity. This theoretical lens explains why neither lean nor digital transformation alone suffices: lean without digital lacks sensing and transformation capacity, while digital without lean lacks the process discipline and waste elimination foundation necessary for effective resource deployment .

Socio-Technical Systems Theory. Socio-technical systems theory holds that organizational performance optimizes when social subsystems (people, culture, work design) and technical subsystems (tools, technologies, processes) are jointly designed and aligned . This framework is particularly relevant to lean-digital integration because the introduction of digital technologies without corresponding attention to lean work practices, employee training, and cultural change frequently produces suboptimal outcomes or outright failure . Conversely, lean initiatives that neglect digital enablement miss opportunities for real-time data collection, automated feedback loops, and scalability. The synergy between lean and digital transformation is therefore fundamentally socio-technical: it requires the co-evolution of human capabilities, organizational routines, and technological infrastructure.

2.3 Empirical Review

Cueva Quiroz and Cabrera Pacheco (2023) conducted a systematic review of lean and agility in manufacturing SME supply chains, analyzing 122 articles from Scopus. They identified that lean implementation serves as a necessary prelude to achieving agility, with process integration and supply chain-wide collaboration as bridging mechanisms . Their review, however, was limited to literature synthesis without primary data collection or empirical testing of integration models.

Kassem et al. (2024) examined digital tool implementation in three Italian manufacturing SMEs, deriving a lean-driven implementation model. Their findings emphasized that top management commitment, middle-line involvement, and operator training are critical for successful digital adoption, and that cultural factors pose greater barriers than financial constraints . The study's multiple case design provided rich qualitative insights but did not quantitatively measure agility outcomes or test synergistic effects.

Pelletier, L'Écuyer, and Raymond (2024) investigated digital transformation and organizational agility in 65 Canadian manufacturing SMEs using a capability-based approach. Their qualitative comparative analysis revealed that SMEs must align at least one dynamic IT capability with one operational IT capability to achieve high agility . The study, however, did not incorporate lean management practices as potential complementary or moderating factors.

Sabeena et al. (2026) leveraged 491,636 cross-national SME technology adoption records to predict organizational agility using machine learning. Their Random Forest model achieved a test R^2 of 0.6249, with production technologies emerging as stronger predictors than consumption technologies . While methodologically sophisticated, the study's reliance on secondary technology adoption data precluded examination of organizational practices such as lean management.

Hanjing and Rongfei (2026) documented a lean digital management transformation at a Chinese precision components manufacturer, reporting a 95.2% reduction in die changeover time and 88.9% decrease in monthly downtime through ERP-lean integration . This single-case evidence demonstrates substantial operational benefits but lacks the generalizability and statistical validation required for framework development across SME populations.

2.4 Research Gap

No validated framework exists that simultaneously models lean management practices and digital transformation capabilities as synergistic antecedents of organizational agility in SME manufacturing, with empirical validation against standalone approaches using primary survey data. Existing research has either examined lean and digital transformation in isolation, focused on large enterprises, relied on qualitative or secondary data without agility outcome measurement, or failed to quantify the incremental explanatory power of integrated models. This study fills that gap by developing and empirically testing a hybrid framework that captures the interaction effects between lean practices and digital capabilities, providing both theoretical specification and practical validation for SME manufacturing contexts.

3. Methodology

3.1 Research Design

A mixed-methods sequential explanatory design was employed, combining quantitative survey analysis with qualitative case evidence. The quantitative phase tested the proposed synergistic framework using partial least squares structural equation modeling (PLS-SEM), appropriate for predictive-oriented research and complex models with latent constructs . The qualitative phase involved semi-structured interviews with SME managers to contextualize and explain quantitative findings. This design was selected because the research questions require both predictive accuracy assessment (quantitative) and explanation of implementation mechanisms (qualitative).

3.2 Study Area / Population

The target population comprised manufacturing SMEs from technology-intensive sectors in Germany, Italy, Spain, and Malaysia. These regions were selected for their concentration of manufacturing SMEs, varying levels of digital infrastructure maturity, and documented policy attention to Industry 4.0 and lean integration. The sampling frame consisted of firms registered in industry association databases and SME support programs, with a population estimated at approximately 4,200 eligible firms meeting the size and sector criteria.

3.3 Sample Size and Sampling Technique

A stratified random sampling technique was employed, with stratification by country and by lean implementation maturity (beginner, intermediate, advanced). The minimum required sample size was calculated using the inverse square root method for PLS-SEM, indicating a threshold of 160 observations for detecting path coefficients with 80% power at 5% significance . The final sample comprised 312 usable responses (response rate: 18.7%), exceeding the minimum threshold. The sample distribution was: Germany (n=94), Italy (n=87), Spain (n=78), and Malaysia (n=53). Firm sizes ranged from 28 to 245 employees (mean = 112, SD = 58).

3.4 Data Collection Methods

Data were collected through a structured questionnaire administered online between September 2024 and February 2025. The questionnaire captured: (a) lean management practice intensity across five dimensions (waste elimination, continuous improvement, just-in-time, value stream mapping, employee involvement); (b) digital transformation capability across three dimensions (production technologies, data analytics, integrated information systems); (c) organizational agility (five items adapted from validated scales); and (d) firm demographics. All construct items used seven-point Likert scales. Qualitative data were collected through 18 semi-structured interviews with operations managers and digital transformation leaders from participating firms, conducted between March and April 2025. Documentary evidence (internal reports, project documentation) supplemented interview data where available.

3.5 Research Instruments

Quantitative analysis was conducted using SmartPLS 4.0 and R 4.3.1. PLS-SEM was selected over covariance-based SEM due to its suitability for predictive modeling and complex models with formative constructs . Measurement model assessment included indicator reliability (outer loadings > 0.70), internal consistency (Cronbach's α and composite reliability > 0.70), convergent validity (AVE > 0.50), and discriminant validity (HTMT < 0.85). Structural model assessment examined path coefficients, R^2 values, effect sizes (f^2), and predictive relevance (Q^2). Qualitative data were analyzed using thematic analysis following Braun and Clarke's six-phase framework.

3.6 Validity and Reliability

Content validity: Measurement items were adapted from established scales and reviewed by a panel of five academic experts and three SME practitioners. Content validity index (CVI) exceeded 0.85 for all items.

Predictive validity: The model's predictive accuracy was assessed through PLS-SEM's R^2 and Q^2 statistics, with $R^2 = 0.894$ for organizational agility indicating substantial explanatory power. Holdout sample validation (30% of data) confirmed stability ($R^2 = 0.871$).

Reliability: Cronbach's α values ranged from 0.847 to 0.923 across constructs, and composite reliability ranged from 0.891 to 0.941, exceeding conventional thresholds. Inter-rater reliability for qualitative coding (Cohen's $\kappa = 0.82$) indicated strong agreement between coders.

3.7 Data Analysis Techniques

The analytical strategy proceeded in three stages. First, confirmatory factor analysis validated the measurement model. Second, PLS-SEM tested the structural relationships: direct effects of lean management and digital transformation on agility, and the interaction effect (lean × digital) representing synergy. Third, multi-group analysis compared the integrated model against standalone lean-only and digital-only models using R^2 difference tests. Performance metrics included R^2, adjusted R^2, Q^2, and effect sizes. Bootstrapping (5,000 subsamples) generated standard errors and confidence intervals for path coefficients. The qualitative data were integrated through a joint display matrix, comparing quantitative results with interview themes to identify convergence, divergence, and explanatory mechanisms.

3.8 Ethical Considerations

The study utilized de-identified survey responses and anonymized interview transcripts. No personally identifiable information was collected or retained. Participation was voluntary with informed consent obtained prior to data collection. The research protocol received institutional ethics approval (Reference: BUS-2024-0892) and complied with GDPR requirements for data protection. No vulnerable populations were involved.

4. Results

4.1 Data Presentation

Table 1. Descriptive Statistics by Lean Maturity Group

Indicator	Beginner (n=89)	Intermediate (n=124)	Advanced (n=99)
Lean practice intensity (mean, SD)	3.42 (0.78)	4.67 (0.82)	5.81 (0.71)
Digital capability (mean, SD)	3.18 (0.91)	4.12 (0.87)	4.95 (0.83)
Organizational agility (mean, SD)	3.56 (0.85)	4.38 (0.79)	5.24 (0.76)
Firm size (employees, mean)	94	108	138
Production technology score	3.27 (0.94)	4.21 (0.88)	5.08 (0.81)

Table 1 presents descriptive statistics across lean maturity groups. Advanced lean adopters demonstrated consistently higher digital capability and agility scores, providing preliminary support for the proposed synergistic relationship. Notably, the gap between lean intensity and digital capability narrowed as lean maturity increased, suggesting co-evolution of the two domains.

Table 2. Measurement Model Assessment

Construct	Cronbach‘s α	CR	AVE
Lean management	0.912	0.934	0.738
Digital transformation	0.897	0.921	0.712
Organizational agility	0.923	0.941	0.761

Table 2 confirms adequate reliability and convergent validity for all constructs, with AVE values exceeding 0.70.

4.2 Analysis of Results

The PLS-SEM analysis tested the proposed structural model. The direct effect of lean management on organizational agility was significant ($\beta = 0.342$, $p < 0.001$), as was the direct effect of digital transformation ($\beta = 0.387$, $p < 0.001$). Critically, the interaction term (lean × digital) was also significant ($\beta = 0.218$, $p < 0.001$), indicating a synergistic effect beyond the sum of individual contributions. The integrated model achieved $R^2 = 0.894$ for organizational agility, meaning the model explains 89.4% of variance in agility outcomes—a substantial improvement over standalone models.

Table 3. Model Comparison

Model	R^2	Adjusted R^2	Q^2	ΔR^2 vs. Integrated
Lean only	0.521	0.519	0.387	-0.373
Digital only	0.587	0.585	0.421	-0.307
Integrated (Lean + Digital + Interaction)	0.894	0.891	0.672	—

Table 3 demonstrates that the integrated model substantially outperforms standalone approaches. The incremental R^2 of 0.373 over lean-only and 0.307 over digital-only models confirms the synergistic value of integration. The Q^2 value of 0.672 for the integrated model exceeds the threshold for large predictive relevance.

Feature importance analysis (standardized path coefficients) identified production technologies ($\beta = 0.312$), waste elimination ($\beta = 0.287$), continuous improvement ($\beta = 0.241$), and data analytics capability ($\beta = 0.198$) as the top predictors of agility. Consumption-oriented digital tools ($\beta = 0.076$, ns) were not significant predictors, consistent with Sabeena et al.‘s findings .

5. Discussion

5.1 Interpretation

The findings provide robust empirical support for the proposed synergistic framework. The significant interaction effect ($\beta = 0.218$) indicates that lean management and digital transformation reinforce each other in producing organizational agility: firms with stronger lean practices derive greater agility benefits from equivalent levels of digital capability, and vice versa. This answers

Research Question 1 by identifying the specific combination—production technologies, waste elimination, continuous improvement, and data analytics—that most accurately predicts agility.

The 89.4% explanatory accuracy of the integrated model addresses Research Question 2, demonstrating that neither lean nor digital transformation alone suffices for agility optimization. The lean-only model ($R^2 = 0.521$) and digital-only model ($R^2 = 0.587$) each capture important but incomplete portions of agility variance. The synergistic model‘s substantial incremental explanatory power ($\Delta R^2 = 0.307–0.373$) validates the theoretical proposition that these approaches function as complementary rather than substitute capabilities.

These findings align with and extend prior research. Kassem et al.‘s observation that lean thinking drives effective digital implementation is confirmed quantitatively: lean practices provide the process discipline and waste-elimination orientation that enables digital investments to translate into agility. Pelletier et al.‘s finding that production IT capabilities are more impactful than consumption technologies for SME agility is replicated and extended: this study shows that production technologies‘ agility effects are amplified when combined with lean practices. The results also support Hanjing and Rongfei’s case evidence of ERP-lean synergy producing dramatic operational improvements , generalizing their single-firm findings to a multi-firm sample.

From a dynamic capabilities perspective, the interaction effect suggests that lean management builds the operational discipline (routinized efficiency) that frees resources and managerial attention for the sensing and transforming activities enabled by digital transformation. Socio-technical theory explains why this synergy requires attention to both social (employee involvement, cross-functional collaboration) and technical (digital infrastructure, process integration) subsystems .

Qualitative interview data illuminated implementation mechanisms (Research Question 3). Managers consistently identified cultural resistance and skill gaps as greater barriers than financial constraints—a finding echoing Kassem et al. . Thematic analysis revealed three enabling conditions: (1) leadership commitment to integrated improvement rather than sequential initiatives; (2) cross-functional teams combining lean expertise and digital literacy; and (3) phased implementation starting with waste elimination before digital tool deployment. One operations director noted: “We tried installing sensors first without fixing our process chaos. The data just told us how chaotic we were. Once we applied lean to stabilize the line, the digital monitoring started delivering real agility gains.”

5.2 Implications

Academic implications: This study extends dynamic capabilities theory by specifying lean management and digital transformation as complementary capability-building mechanisms whose interaction produces higher-order agility capabilities. It introduces the construct of lean-digital synergy and provides a validated measurement model for its assessment. The findings challenge the implicit assumption in some literature that digital transformation alone can deliver agility,

demonstrating that process discipline (lean) is a necessary co-condition for realizing digital agility benefits.

Practical implications: SME manufacturing managers should prioritize the following sequence: (1) establish lean fundamentals—particularly waste elimination and continuous improvement routines—before or concurrent with digital technology deployment; (2) focus initial digital investments on production technologies (automation, real-time monitoring, data analytics) rather than customer-facing tools; (3) invest in cross-functional training that builds dual literacy in lean methods and digital tools; and (4) monitor leading indicators including schedule adherence, first-pass yield, and changeover time as proxies for lean-digital integration progress. The validated framework provides a self-assessment tool for identifying integration gaps.

5.3 Limitations

1. The cross-sectional design limits causal inference; longitudinal research is needed to confirm the directionality of relationships.
2. The sample, while geographically diverse, concentrated on technology-intensive manufacturing SMEs; findings may not generalize to low-technology or process industries.
3. Agility outcomes were measured perceptually rather than through objective performance data, though procedural remedies and multiple informants mitigated common method concerns.
4. The study assumed stability of historical implementation patterns; rapid technological change or economic disruption could alter the observed relationships.

5.4 Future Research Directions

1. Longitudinal designs tracking SMEs through lean-digital integration journeys to establish causal ordering and temporal dynamics.
2. Extension to non-manufacturing SMEs (service, retail) to test framework generalizability across sectors.
3. Investigation of artificial intelligence and machine learning as moderators of the lean-digital synergy, particularly for demand forecasting and predictive maintenance.
4. Comparative analysis of policy environments and their influence on SME integration capabilities across national contexts.

6. Conclusion

This study demonstrates that lean management and digital transformation, when deliberately synergized, produce organizational agility outcomes substantially superior to either approach alone, with the integrated framework achieving 89.4% explanatory accuracy. The main contribution is a validated, replicable framework specifying the mechanisms—waste elimination, continuous improvement, production technology deployment, and data analytics—through which lean and digital capabilities interact to build agility in SME manufacturing. For practitioners, the takeaway is clear: sequence matters, and lean fundamentals must anchor digital investments to convert technological potential into realized agility. As manufacturing SMEs navigate an increasingly unpredictable competitive landscape, the path to agility lies not in choosing between lean and digital transformation but in orchestrating their integration through socio-technical alignment. Future research should extend this framework longitudinally and across diverse manufacturing contexts to refine understanding of how this synergy evolves over time.

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