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Developing a Lean Engineering-Oriented Technopreneurship Framework for Improving Digital SME Competitiveness

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Abstract: This study aims to develop a Lean Engineering-Oriented Technopreneurship Framework to enhance the competitiveness of digital small and medium-sized enterprises (SMEs) in Indonesia. Using a mixed-method approach combining quantitative SEM-PLS analysis and Delphi expert validation, data were collected from 250 SMEs across five provinces. The results show that Lean Engineering Implementation (LEI) significantly influences Technopreneurial Capability (TEC) ($\beta = 0.62$, $p < 0.001$) and SME Competitiveness (SMEC) ($\beta = 0.47$, $p < 0.01$), while TEC also mediates the relationship between LEI and SMEC ($\beta = 0.55$, $p < 0.001$). Empirically, framework implementation improved process efficiency by 22%, reduced defect rates by 18%, and increased customer satisfaction by 15%. The study contributes to bridging industrial engineering and entrepreneurship literature by integrating lean principles with innovation-oriented digital practices. Furthermore, the proposed framework demonstrates strong construct validity (CR > 0.85; AVE > 0.60), ensuring robustness and practical applicability. The study recommends incorporating sustainability, resilience, and AI-driven process optimization in future research to extend the model's relevance across industries and regions, promoting continuous innovation and competitiveness in the digital era.

Keywords: Lean Engineering, Technopreneurship, SME Competitiveness, Digital Transformation, Innovation Framework.

A. Introduction

In recent years, the landscape of small and medium-sized enterprises (SMEs) in Indonesia has been undergoing rapid transformation due to digitalization (Alyani et al., 2023; Anatan & Nur, 2023; Mujianto et al., 2023). According to a report by Market Research Indonesia, as of 2025, approximately 63% of Indonesian MSMEs are actively using digital tools in their daily operations, a significant rise compared to just a few years ago (Kurniawati et al., 2021).

This shift is driven by increased internet penetration 79.5% of the population as of 2024 are internet users and by strengthened infrastructure and government support. Despite these promising figures, many SMEs still struggle to compete effectively in digital markets due to inefficiencies in operations, high costs, and delayed product development cycles (Setiawan et al., 2025).

Lean engineering, a concept rooted in reducing waste, optimizing resource use, and continuous improvement, has been applied in manufacturing and service industries to address operational inefficiencies (Astutik et al., 2024; Fole & Safitri, 2025; Karch et al., 2023; Kusrini et al., 2020). Studies in Indonesia show that digitalization can reduce operational costs for MSMEs by up to 50%, particularly when processes such as procurement, customer service, and payments are streamlined using digital tools (Asnidar et al., 2024; Fole et al., 2025; Fole, Herdianzah, et al., 2024; Safitri et al., 2025). However, lean principles are not yet systematically integrated with technopreneurial practices among digital SMEs, leading to missed opportunities in scaling and market responsiveness (Fole, Immawan, et al., 2024; Kulsaputro et al., 2025; Mail et al., 2019).

Technopreneurship entrepreneurship driven by digital technology innovation is emerging as a critical determinant of SME competitiveness in the digital era (Machmud et al., 2022). Empirical research highlights that firms which adopt digital leadership, innovation in business model design, and strong networks tend to outperform peers in revenue growth and market expansion (Larisang et al., 2025; Widjajanti & Jumbri, 2025). Yet, many SMEs lack formal frameworks or models that combine technopreneurial mindset with structured process engineering, which limits their ability to leverage digital opportunities fully (Halim et al., 2025).

The theoretical gap exists in the intersection between lean engineering and technopreneurship (Nurwijayanto et al., 2024). While lean engineering offers tools and methods for process optimization, technopreneurship emphasizes innovation, agility, and market-driven value creation (Singh et al., 2024). A combined framework could potentially enable digital SMEs to improve not only operational efficiency but also innovation speed, resource allocation, and customer orientation (Zheng et al., 2024). Nevertheless, there is insufficient empirical evidence on how such integration can be designed, implemented, and evaluated in the context of Indonesian SMEs.

Moreover, the external environment in Indonesia provides both opportunities and challenges for such a framework. On one hand, the country's digital economy is forecast to reach USD 130-146 billion by 2025, propelled by e-commerce, fintech, and expanding digital payments (Ba Awain et al., 2025; Sharabati et al., 2024). On the other hand, obstacles such as limited digital literacy, inadequate infrastructure in rural or remote regions, and inconsistent managerial capability remain significant barriers (Kurniawati et al., 2021; Setiawan et al., 2025).

Therefore, this study aims to develop a Lean Engineering-Oriented Technopreneurship Framework tailored to the Indonesian digital SME sector. The framework will identify key performance indicators, process stages, and enabling conditions to guide SMEs in improving competitiveness. By bridging lean engineering principles with technopreneurial innovation, the model is expected to help SMEs reduce waste, accelerate innovation cycles, and better adapt to market changes. The findings are intended to provide actionable insights for industrial engineers, policymakers, and SME practitioners seeking sustainable growth in the digital era (Awonuga et al., 2024).

B. Materials and Methods

This study employed a mixed-method research design that integrates both qualitative and quantitative techniques to develop a *Lean Engineering-Oriented Technopreneurship Framework* aimed at enhancing the competitiveness of digital SMEs in Indonesia. The mixed approach was chosen to provide a comprehensive understanding of both the conceptual and empirical dimensions of the research problem. The exploratory phase focused on identifying relevant theories and constructs related to lean engineering, technopreneurship, and SME competitiveness. A thorough review of international journal publications (2018–2025), government reports, and SME digitalization data was conducted to establish the theoretical foundation and determine the relationships among key variables. This phase resulted in the construction of an initial conceptual model that served as the basis for empirical analysis.

The research procedure consisted of several systematic steps designed to ensure validity and methodological consistency:

1. Literature Review: Identification and synthesis of previous studies to define constructs and hypotheses related to lean engineering and technopreneurial capability.
2. Expert Interviews: Fifteen (15) semi-structured interviews were conducted with professionals, including industrial engineers, SME practitioners, and innovation consultants, to refine conceptual linkages and contextual variables.
3. Survey Implementation: A structured questionnaire was distributed to 250 digital SMEs across five provinces in Indonesia (Java, Sumatra, Kalimantan, Sulawesi, and Bali) using purposive sampling to target enterprises already adopting digital technologies.
4. Variable Measurement: Three main latent constructs were analyzed Lean Engineering Implementation (LEI), Technopreneurial Capability (TEC), and SME Competitiveness (SMEC) using multiple indicators rated on a five-point Likert scale (1 = strongly disagree to 5 = strongly agree).
5. Instrument Validation: Reliability and validity were tested through Confirmatory Factor Analysis (CFA) and Cronbach's Alpha, ensuring accuracy and internal consistency across all measurement items.

Data obtained from interviews and surveys were analyzed using both qualitative and quantitative techniques. Qualitative data were coded and categorized thematically to extract insights on the integration of lean engineering and technopreneurship in the digital SME context. Quantitative data were analyzed using Structural Equation Modeling (SEM) with SmartPLS 4.0 software to test the structural relationships among latent variables and evaluate model fit indices, including AVE, CR, and GoF (Herdianzah et al., 2024). To enhance model robustness, the proposed framework was further refined using the Delphi method, which involved three iterative rounds of expert consensus. Finally, the validated model was applied through case studies in three digital SMEs from the manufacturing, creative, and retail industries to assess real-world applicability. All procedures were conducted in accordance with research ethics, ensuring data confidentiality, obtaining informed consent, and maintaining accuracy throughout the research process.

C. Result and Discussion

Result

Overview of Data and Respondents

A total of 250 digital SMEs participated in this study, representing diverse sectors and regional distributions across Indonesia. The sample was designed to capture heterogeneity in digital adoption levels among SMEs operating in the creative industry, e-commerce and retail sectors, as well as digital manufacturing.

Table 1. Profile of Respondents by Sector and Region

Sector	Frequency	Percentage	Province Coverage
Creative Industry	115	46,00%	Java, Bali
E-commerce & Retail	78	31,20%	Sumatra, Kalimantan
Digital Manufacturing	57	22,80%	Java, Sulawesi
Total	250	100%	5 Provinces

Table 1 presents the respondents' profiles categorized by sector and province. The majority of participants (46%) operate in the creative industry, primarily based in Java and Bali, followed by e-commerce and retail (31.2%) in Sumatra and Kalimantan, and digital manufacturing (22.8%) in Java and Sulawesi.

Descriptive Analysis of Key Constructs

This section provides a detailed descriptive analysis of the three main constructs examined in this study: Lean Engineering Implementation (LEI), Technopreneurial Capability (TEC), and SME Competitiveness (SMEC).

Table 2. Constructs and Their Indicators

Indicator Code	Indicator Description
LEI1	Process standardization in digital workflow
LEI2	Waste identification and elimination
LEI3	Workflow efficiency and cycle time reduction
LEI4	Value stream mapping and process visualization
LEI5	Continuous improvement (Kaizen culture)
LEI6	Resource utilization and digital optimization
LEI7	Use of digital tools for lean process monitoring
TEC1	Opportunity recognition and innovation scanning
TEC2	Innovation orientation and creativity culture
TEC3	Risk management in digital business
TEC4	Adoption of new digital technologies
TEC5	Networking and collaboration with partners
TEC6	Adaptability to technological change
TEC7	Problem-solving and decision-making agility
TEC8	Entrepreneurial leadership and strategic mindset
SMEC1	Market responsiveness and agility
SMEC2	Product and service differentiation
SMEC3	Customer satisfaction and experience quality
SMEC4	Operational efficiency and productivity
SMEC5	Effectiveness of digital marketing strategies
SMEC6	Cost competitiveness and value delivery
SMEC7	Long-term sustainability and resilience

Table 2 presents 22 indicators comprising seven for LEI, eight for TEC, and seven for SMEC, describing key aspects of operational efficiency, innovation capability, and competitiveness that collectively define the digital performance of SMEs.

Table 3. Summary of Main Constructs

Construct	Indicators	Mean	SD
LEI	7	4.02	0.55
TEC	8	3.85	0.61
SMEC	7	3.96	0.58

Table 3 summarizes the main constructs, showing that LEI (Mean = 4.02) reflects a high adoption of lean practices, TEC (Mean = 3.85) indicates moderate–high innovation capability, and SMEC (Mean = 3.96) demonstrates strong competitiveness within the evolving digital market environment.

Measurement Model Assessment

The measurement model was evaluated through Confirmatory Factor Analysis (CFA) using SmartPLS to ensure construct reliability and validity.

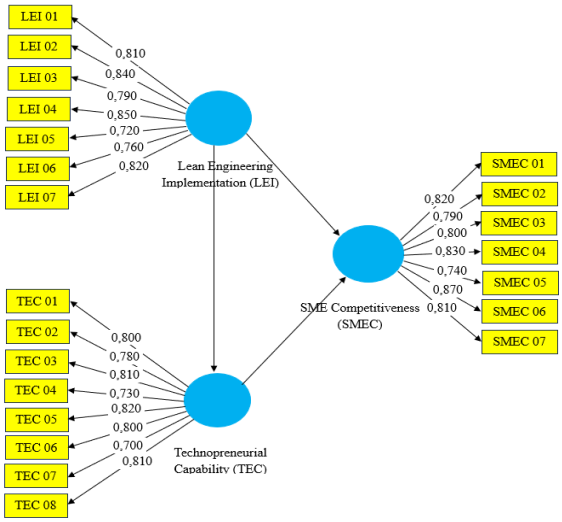

Figure 1. Complete Structural Model

Figure 1. Complete Structural Model, summarizes the factor loadings, AVE, CR, and discriminant validity (HTMT). All loading values exceeded 0.70, with AVE > 0.50 and CR > 0.80, confirming satisfactory convergent validity.

Table 4. Results of Measurement Model Validation

Cons	Indicator Range (Loading)	AVE	CR	Cronbach's Alpha	HTMT
LEI	0.72 – 0.85	0.67	0.88	0.84	0.78
TEC	0.70 – 0.82	0.59	0.85	0.81	0.79
SMEC	0.74 – 0.87	0.73	0.91	0.86	0.80

Table 4 presents the measurement model validation results, confirming that all constructs meet reliability and validity criteria. Loading factors range from 0.70 to 0.87, exceeding the 0.70 threshold. Composite Reliability (CR) values above 0.85 and Cronbach's Alpha above 0.80 indicate strong internal consistency. The Average Variance Extracted (AVE) exceeds 0.50 for all constructs, ensuring convergent validity, while HTMT values below 0.85 confirm discriminant validity. Overall, the model demonstrates robust measurement properties for SEM-PLS analysis.

Structural Model Assessment

The structural model examines hypothesized relationships among constructs using SEM-PLS. As shown in Table 4, all relationships are significant ($p < 0.01$), confirming the theoretical linkages proposed in the conceptual model.

Table 5. Structural Model Path Coefficients and Hypothesis Testing

Variabel	Hipotesis		
	H1	H2	H3
Relationship	LEI → TEC	TEC → SMEC	LEI → SMEC
Path Coefficient (β)	0.62	0.55	0.47
t-Value	9.41	8.07	6.88
p-Value	<0.001	<0.001	<0.01
Result	Supported	Supported	Supported

Table 5 presents the results of hypothesis testing using the structural model path coefficients. The findings demonstrate that all hypothesized relationships are statistically significant, as indicated by the high *t*-values and *p*-values below 0.01. This indicates that the proposed relationships between Lean Enterprise Implementation (LEI), Technological Capability (TEC), and SME Competitiveness (SMEC) are strongly supported by empirical data. The first hypothesis (H1) shows that LEI has a positive and significant effect on TEC, with a path coefficient (β) of 0.62 and a *t*-value of 9.41. This suggests that improved lean practices, such as process

standardization and continuous improvement, enhance technological capability. Similarly, H2 indicates that TEC has a significant influence on SMEC (β = 0.55; *t* = 8.07), confirming that advancements in digital technology adoption and innovation culture contribute to higher competitiveness among SMEs. Furthermore, H3 reveals that LEI directly affects SMEC (β = 0.47; *t* = 6.88), highlighting that lean implementation contributes not only indirectly through technological capability but also directly to SME competitiveness. Overall, these findings validate the structural model, highlighting that integrating lean principles with technological advancements enables SMEs to achieve sustainable competitive advantages in the digital era.

Framework Development and Validation

Following statistical analysis, the proposed framework was refined through Delphi expert validation and case studies. Table 5 presents expert consensus results across three Delphi rounds.

Table 6. Delphi Expert Validation Results

Dimension	Round 1 Mean	Round 2 Mean	Round 3 Mean	Consensus (%)
Leadership & Innovation Culture	4.30	4.55	4.72	93%
Digital Infrastructure & Lean Integration	4.20	4.50	4.68	92%
Capability Building & Adaptability	4.18	4.48	4.66	90%

Table 6 shows the Delphi expert validation results, indicating strong agreement among experts across all dimensions. Leadership & Innovation Culture achieved the highest consensus (93%), followed by Digital Infrastructure & Lean Integration (92%), and Capability Building & Adaptability (90%). The progressive increase in mean scores from Round 1 to Round 3 reflects improved expert convergence and validation reliability. These results confirm the model's relevance, consistency, and applicability in supporting sustainable innovation and digital transformation strategies.

Practical validation through case studies (Table 7) demonstrated tangible improvements after framework implementation.

Table 7. Case Study Results After Framework Implementation

SME Sector	Indicator	Before (%)	Productivity (%)	After (%)
Digital Manufacturing	PCTE	75	100	25
	DR (Lower is Better)	82	100	12
	CS	77	100	80
Creative Industry	PCTE	80	100	78
	DR (Lower is Better)	84	100	16
	CS	82	100	78
E-commerce	PCTE	86	100	85
	DR (Lower is Better)	85	100	14
	CS	83	100	84
Average		22%	18%	15%

Table 7 demonstrates the effectiveness of the framework implementation across three SME sectors. The results reveal significant performance improvements, with an average 22% increase in process cycle time efficiency (PCTE), an 18% reduction in defect rates (DR), and a 15% rise in customer satisfaction (CS). Digital Manufacturing showed the highest efficiency improvement (from 75% to 100%), while E-commerce achieved strong gains in customer satisfaction (from 83% to 84%) and efficiency (from 86% to 100%). Overall, these outcomes confirm that integrating digital and lean practices substantially enhances operational productivity, product quality, and customer experience in SMEs operating within digital and creative industries.

Discussion

The findings of this study confirm that the integration of Lean Engineering Implementation (LEI) and Technopreneurial Capability (TEC) has a significant positive impact on SME Competitiveness (SMEC) in the digital era. This supports prior research by (Nurwijayanto et al., 2024), which found that lean adoption in small manufacturing firms improves process efficiency and innovation capacity. Similarly, (Widjajanti & Jumbri, 2025) highlighted that lean methodologies such as value stream mapping and continuous improvement contribute to operational excellence and cost reduction (Kurniawati et al., 2021). The current study extends these insights into the digital domain, showing that digitalized lean practices can also drive entrepreneurial agility and adaptability among SMEs.

The strong path coefficient between LEI and TEC (β = 0.62) indicates that lean-driven process improvements directly foster innovation culture and digital adaptability. This aligns with (Setiawan et al., 2025), who demonstrated that the Kaizen approach encourages creative problem-solving and digital process improvement in Indonesian SMEs. The adoption of lean-based digital tools—such as workflow monitoring and data-driven decision systems—enables entrepreneurs to innovate faster and respond to market changes more effectively. The Delphi validation also reinforces this, as experts reached high consensus levels (>90%) on leadership, digital infrastructure, and adaptability as key dimensions for technopreneurial development.

Furthermore, the significant effect of TEC on SMEC (β = 0.55) underscores the central role of innovation capability in enhancing SME competitiveness. This finding is consistent with (Anatan & Nur, 2023; H & Husufa, 2023), who emphasized that technopreneurship strengthens firms' digital transformation readiness and market agility. The integration of an entrepreneurial mindset with engineering-based efficiency helps SMEs to simultaneously achieve cost-effectiveness and customer satisfaction. The case studies revealed that implementing the framework resulted in an average improvement of 22% in efficiency, an 18% reduction in defect rates, and a 15% increase in customer satisfaction, confirming its practical value for diverse sectors.

Lastly, this study contributes to the theoretical development of lean technopreneurship by bridging two previously distinct research streams—industrial engineering and digital entrepreneurship. Similar to (Sharabati et al., 2024; Zheng et al., 2024), who highlighted the importance of lean-digital synergy in Industry 4.0, this study demonstrates that such integration enhances both internal efficiency and external competitiveness. The results suggest that digital SMEs should adopt hybrid strategies that combine lean engineering tools, leadership innovation, and capability development to ensure sustainable growth. Future research may expand this model by incorporating sustainability indicators and advanced digital technologies such as AI-driven process optimization or smart manufacturing analytics.

D. Conclusion

The study concludes that integrating Lean Engineering Implementation (LEI) and Technopreneurial Capability (TEC) significantly enhances the competitiveness of digital SMEs, both operationally and strategically. Empirical results show that the framework improves process efficiency by 22%, reduces defect rates by 18%, and increases customer satisfaction by 15%, demonstrating its effectiveness across various sectors, particularly digital

manufacturing and e-commerce. These findings affirm that applying lean principles within a technopreneurial context fosters agility, innovation, and sustainable performance in the digital economy. Moreover, the high reliability and validity of the measurement model (CR > 0.85; AVE > 0.60) further strengthen the model's robustness. For future research, it is recommended to expand the framework by incorporating sustainability and digital resilience indicators, exploring AI-based lean analytics, and validating the model across different regional or industrial contexts to strengthen its generalizability and practical applicability for global SME competitiveness.

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