

THE ROLE OF DIGITAL TRANSFORMATION IN ENHANCING OPERATIONAL EFFICIENCY AND COMPETITIVE ADVANTAGE IN MANUFACTURING INDUSTRIES

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Abstract

This study examines the role of digital transformation in enhancing operational efficiency and competitive advantage within manufacturing industries. Drawing on the Resource-Based View (RBV) and Porter's competitive strategy framework, the research investigates both the direct and indirect effects of digital transformation, with operational efficiency serving as a mediating variable. Using a quantitative approach, data were collected from managerial-level respondents in manufacturing firms that had implemented digital initiatives within the past three years. The measurement and structural models were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). The results reveal that digital transformation has a significant impact on operational efficiency ($\beta = 0.682, p < 0.001$) and directly contributes to a competitive advantage ($\beta = 0.325, p < 0.001$). Operational efficiency also has a strong positive impact on competitive advantage ($\beta = 0.521, p < 0.001$), confirming its mediating role. The findings highlight that efficiency gains are a key mechanism through which digital transformation delivers strategic benefits, while also generating direct competitive advantages through innovation, agility, and customer engagement. This study offers both theoretical contributions to the digital transformation literature and practical guidance for manufacturing firms and policymakers seeking to maximize the returns on digital investments.

Keywords: *Digital transformation, Operational efficiency, Competitive advantage, Manufacturing industry*

INTRODUCTION

In recent years, the manufacturing industry has undergone a profound transformation driven by rapid advancements in digital technologies. The emergence of Industry 4.0, characterized by the integration of cyber-physical systems, the Internet of Things (IoT), cloud computing, and artificial intelligence (AI), has fundamentally reshaped how manufacturing firms operate. (Favoretto et al., 2022). Digital transformation is no longer a mere technological upgrade but a strategic necessity for firms seeking to remain competitive in an increasingly volatile and complex global marketplace. By leveraging these technologies, manufacturing companies can streamline processes, enhance production flexibility, and improve resource utilization, thereby driving operational efficiency. (De Paz Carmona et al., 2023).

The global manufacturing sector faces mounting pressures from various directions, including fluctuating customer demands, international competition, and the need for sustainability. (Qiang, 2024). Traditional production systems, often reliant on rigid workflows and manual intervention, struggle to cope with these demands. (Chen et al., 2016). In contrast, digitally transformed operations enable real-time data-driven decision-making, predictive maintenance, and seamless coordination across the value chain. This agility allows firms to respond promptly to market changes and optimize performance, creating a competitive edge over rivals who lag in technology adoption. (Felix & Rembulan, 2023).

Furthermore, the COVID-19 pandemic accelerated the urgency of digital transformation in manufacturing. Disruptions in supply chains, labor shortages, and fluctuating market conditions forced firms to rethink traditional business models and embrace remote monitoring, automated systems, and AI-driven analytics. (Skare et al., 2023). These shifts highlighted the crucial role of digital tools in maintaining business continuity and resilience during crises. As a result,

manufacturers have recognized that digital transformation is not only an enabler of efficiency but also a safeguard against operational disruptions.

The benefits of digital transformation in manufacturing extend beyond operational improvements to include strategic advantages such as innovation capacity, market responsiveness, and sustainable development. For instance, smart manufacturing systems can reduce energy consumption, minimize waste, and enable eco-friendly production methods, aligning with global sustainability goals. (Ananda et al., 2023). Additionally, advanced analytics and machine learning facilitate product customization, enabling manufacturers to meet specific customer needs without sacrificing efficiency. This capability strengthens brand differentiation and customer loyalty, key components of long-term competitive advantage (Susanti et al., 2023).

Despite these benefits, the journey toward digital transformation is fraught with challenges. Manufacturers must navigate substantial investments, organizational resistance, and skill gaps to realize the full potential of digital tools. (Felix & Rembulan, 2023). Moreover, the complexity of integrating diverse technologies into legacy systems can hinder progress. These factors highlight the need for a deeper understanding of how digital transformation contributes to operational efficiency and competitive advantage, particularly in the context of manufacturing industries that face unique structural and market challenges.

Digital transformation has been widely defined as the integration of digital technologies into all aspects of a business to fundamentally change operations and deliver value to customers (Vial, 2019). In manufacturing, this transformation often takes the form of smart factories, where interconnected devices and systems facilitate real-time monitoring, predictive analytics, and autonomous decision-making. Studies have shown that such integration can significantly improve operational efficiency by reducing downtime, optimizing supply chain processes, and enhancing product quality. (Berman, 2012).

The link between digital transformation and competitive advantage has also been well-documented. (Skare et al., 2023) Argue that smart, connected products and operations open new avenues for differentiation, enable cost leadership, and create barriers to entry for competitors. Furthermore, digitally mature firms tend to be more agile, capable of introducing innovative products and services faster than their less digitally advanced counterparts (Verhoef et al., 2021). This agility is critical in manufacturing industries where time-to-market and adaptability to customer demands are decisive competitive factors.

However, the literature also indicates that the impact of digital transformation is contingent on several organizational and contextual factors. These include leadership commitment, digital skills, organizational culture, and the ability to manage change (Westerman et al., 2014). Without the necessary alignment of these elements, technology adoption may fail to translate into tangible performance gains. Thus, while digital transformation offers substantial potential, its successful implementation requires a strategic, holistic approach that integrates technology, people, and processes. (Leão & da Silva, 2021; Shehadeh et al., 2023).

Although the advantages of digital transformation in manufacturing are well recognized, there remains a gap in understanding the precise mechanisms by which it enhances operational efficiency and competitive advantage. Many firms invest in advanced technologies without achieving the expected returns, often due to misalignment between digital initiatives and strategic objectives or insufficient organizational readiness. This gap is particularly pronounced in manufacturing industries where technological integration must contend with complex production processes, entrenched operational practices, and a diverse workforce. As such, there is a need for empirical research that explores the interplay between digital transformation, operational performance, and competitive positioning in manufacturing contexts. This study aims to investigate the role of digital transformation in enhancing operational efficiency and competitive advantage in manufacturing industries.

METHOD

This study adopts a quantitative research design to examine the role of digital transformation in enhancing operational efficiency and competitive advantage within manufacturing industries. The quantitative approach was chosen because it enables systematic measurement of relationships between variables and the testing of hypotheses based on statistical evidence (Creswell & Creswell, 2018). The research population consists of manufacturing companies operating in various sectors in Indonesia, including automotive, electronics, and consumer goods. A purposive sampling technique was employed to select firms that have implemented at least one significant digital transformation initiative within the past three years. Respondents were managerial-level employees and decision-makers involved in operations, production, or technology adoption, as they possess relevant insights into both operational processes and strategic competitiveness. Data collection was conducted through a structured questionnaire distributed electronically to facilitate wider reach and timely responses.

The research instrument was developed based on validated scales from previous studies. Digital transformation was measured using indicators such as adoption of Industry 4.0 technologies, integration of digital tools into production processes, and organizational digital maturity (Verhoef et al., 2021). Operational efficiency was assessed through metrics related to production cycle time, defect rates, resource utilization, and cost efficiency (Frank et al., 2019). Competitive advantage was evaluated using dimensions such as product differentiation, market responsiveness, and customer satisfaction (Porter & Heppelmann, 2015). All measurement items were rated on a five-point Likert scale, ranging from 1 (“strongly disagree”) to 5 (“strongly agree”). Before data collection, a pilot test was conducted with 20 respondents to ensure clarity, reliability, and validity of the questionnaire items. Cronbach’s alpha values above 0.70 were considered acceptable for internal consistency.

Data analysis was performed using Partial Least Squares Structural Equation Modeling (PLS-SEM) via SmartPLS software, which is appropriate for exploratory research and complex models with latent constructs (Hair et al., 2019). The analysis followed a two-step approach: first, assessing the measurement model for reliability, convergent validity, and discriminant validity; second, evaluating the structural model to test the hypothesized relationships between digital transformation, operational efficiency, and competitive advantage. The significance of path coefficients was determined using a bootstrapping procedure with 5,000 resamples. Additionally, the coefficient of determination (R^2), predictive relevance (Q^2), and effect sizes (f^2) were examined to provide a comprehensive understanding of the model’s explanatory power and practical significance.

RESULTS AND DISCUSSION

Measurement Model Assessment

The measurement model was evaluated to ensure reliability and validity. Table 1 presents the outer loadings of each indicator on its respective construct. All indicators achieved loadings greater than 0.70, indicating satisfactory convergent validity (Hair et al., 2019).

Table 1. Outer Loadings

Construct	Indicator	Loading
Digital Transformation (DT)	DT1	0.824
	DT2	0.857
	DT3	0.873
	DT4	0.849
Operational Efficiency (OE)	OE1	0.812
	OE2	0.831
	OE3	0.854
Competitive Advantage (CA)	CA1	0.846
	CA2	0.872
	CA3	0.889

Source: Data Processed

All constructs demonstrated composite reliability (CR) above the recommended threshold of 0.70 and Average Variance Extracted (AVE) above 0.50, as shown in Table 2.

Table 2. Construct Reliability and Validity

Construct	Cronbach's Alpha	Composite Reliability (CR)	AVE
Digital Transformation (DT)	0.874	0.910	0.717
Operational Efficiency (OE)	0.845	0.902	0.698
Competitive Advantage (CA)	0.861	0.915	0.781

Source: Data Processed

Discriminant validity was assessed using the Fornell-Larcker criterion, with the square roots of AVE exceeding inter-construct correlations (Table 3).

Table 3. Fornell-Larcker Criterion

Construct	DT	OE	CA
Digital Transformation (DT)	0.847		
Operational Efficiency (OE)	0.682	0.835	
Competitive Advantage (CA)	0.645	0.701	0.884

Source: Data Processed

Structural Model Assessment

The structural model results indicate that Digital Transformation (DT) has a significant positive effect on Operational Efficiency (OE) and Competitive Advantage (CA). Additionally, OE positively influences CA. The R² values indicate substantial explanatory power for OE (0.465) and CA (0.592).

Table 4. Path Coefficients and Significance

Path	β	t-value	p-value	f ²
DT → OE	0.682	14.732	0.000	0.870
DT → CA	0.325	4.891	0.000	0.128
OE → CA	0.521	8.214	0.000	0.352

Source: Data Processed

Table 5. Coefficient of Determination (R²)

Construct	R ²
Operational Efficiency	0.465
Competitive Advantage	0.592

Source: Data Processed

Table 6. Predictive Relevance (Q²)

Construct	Q ²
Operational Efficiency	0.317
Competitive Advantage	0.411

Source: Data Processed

Bootstrapping with 5,000 resamples confirmed the statistical significance of all hypothesized relationships. All paths had p-values below 0.05, supporting the proposed hypotheses.

Table 7. Bootstrapping Results

Path	Original Sample (β)	Sample Mean (β)	Std. Dev.	t-value	p-value
DT → OE	0.682	0.681	0.046	14.732	0.000
DT → CA	0.325	0.327	0.066	4.891	0.000
OE → CA	0.521	0.520	0.063	8.214	0.000

Source: Data Processed

The findings reveal that digital transformation strongly enhances operational efficiency ($\beta = 0.682$, $p < 0.001$), which in turn significantly improves competitive advantage ($\beta = 0.521$, $p < 0.001$). While digital transformation also directly influences competitive advantage ($\beta = 0.325$, $p < 0.001$), the indirect effect via operational efficiency is substantial, suggesting that efficiency gains are a key mechanism through which digital transformation delivers strategic benefits in manufacturing industries.

Discussion

The findings of this study provide compelling evidence that digital transformation plays a crucial role in enhancing both operational efficiency and competitive advantage in the manufacturing industry. The statistical results from the PLS-SEM analysis indicate that digital transformation has a significant impact on operational efficiency ($\beta = 0.682$, $p < 0.001$) and directly contributes to a competitive advantage ($\beta = 0.325$, $p < 0.001$). Furthermore, operational efficiency itself has a strong positive impact on competitive advantage ($\beta = 0.521$, $p < 0.001$), suggesting that efficiency gains serve as a critical pathway through which digital transformation translates into strategic benefits.

Digital Transformation as a Driver of Operational Efficiency

The substantial positive relationship between digital transformation and operational efficiency observed in this study aligns with prior research emphasizing the operational benefits of digital technologies. Industry 4.0 technologies such as IoT-enabled machinery, AI-driven predictive maintenance, and real-time production monitoring have been shown to significantly reduce downtime, optimize resource allocation, and enhance process accuracy (Frank et al., 2019; Tortorella & Fettermann, 2018). The β value of 0.682 suggests that the adoption of these technologies in manufacturing environments creates measurable improvements in cycle times, defect rates, and cost structures.

This finding also reflects the theoretical framework of the Resource-Based View (RBV), which posits that firms gain a competitive edge through the acquisition and deployment of valuable, rare, inimitable, and non-substitutable resources (Barney, 1991). In the digital age, advanced technological capabilities represent such resources. By embedding digital tools into production systems, manufacturing firms effectively transform their operational processes into a strategic resource that is difficult for competitors to replicate. Moreover, the relatively high R^2 value for operational efficiency (0.465) indicates that digital transformation explains nearly half of the variance in efficiency performance. This suggests that while other factors, such as workforce skills, supply chain integration, and organizational culture, also contribute to efficiency, the role of digitalization is dominant and indispensable in modern manufacturing contexts.

Operational Efficiency as a Pathway to Competitive Advantage

The finding that operational efficiency significantly influences competitive advantage ($\beta = 0.521$) underscores the importance of process optimization as a foundation for strategic positioning. This is consistent with Porter's (1985) competitive strategy framework, which identifies cost leadership and differentiation as primary routes to competitive advantage. Enhanced efficiency enables cost leadership by lowering production expenses, while also facilitating faster response to market demands—an important element in product differentiation. In practice, operational efficiency gained through digital transformation allows manufacturers to deliver higher-quality products at lower costs and with shorter lead times. These capabilities not only attract cost-sensitive customers but also appeal to premium segments that value reliability and customization. This dual strategic

benefit reinforces the argument that efficiency is not merely a tactical objective but a critical enabler of long-term competitive positioning in manufacturing industries (Gunasekaran et al., 2017).

The indirect effect of digital transformation on competitive advantage via operational efficiency, implied by the model's mediation pathway, suggests that firms may reap greater strategic benefits when digital initiatives are explicitly aligned with efficiency goals. This insight supports the integration of technology adoption strategies with operational excellence programs such as Lean Manufacturing or Six Sigma, creating a synergistic effect that maximizes returns on digital investments.

Direct Impact of Digital Transformation on Competitive Advantage

While the mediation pathway through operational efficiency is important, the direct effect of digital transformation on competitive advantage ($\beta = 0.325$) cannot be overlooked. This direct relationship likely captures strategic benefits that are not purely operational. For instance, digital tools enable enhanced customer engagement, data-driven product innovation, and greater agility in responding to emerging market opportunities (Porter & Heppelmann, 2015; Verhoef et al., 2021). For manufacturing firms, this could manifest in the form of smart products that provide real-time usage data to customers, predictive analytics that inform personalized offerings, or digital platforms that strengthen supply chain collaborations. Such capabilities extend beyond process efficiency to shape brand image, customer loyalty, and market differentiation—key components of sustainable competitive advantage.

Practical Implications

The practical implications of these findings are significant for manufacturing managers and policymakers. First, managers should recognize that digital transformation is not an isolated IT initiative but a strategic imperative that requires integration into the firm's broader operational and competitive strategies. Investments in technologies such as IoT sensors, cloud-based analytics, and AI-driven decision support systems should be guided by clearly defined efficiency and competitiveness objectives. Second, the strong relationship between operational efficiency and competitive advantage suggests that managers should prioritize initiatives that deliver measurable efficiency gains. For example, implementing predictive maintenance systems can reduce equipment downtime, while advanced quality control analytics can minimize defects and rework. These improvements not only lower costs but also enhance the firm's reputation for reliability and quality. Third, the direct strategic benefits of digital transformation highlight the need for firms to explore customer-facing digital innovations. Digital twin technologies, for instance, can provide customers with transparent insights into product performance, while collaborative platforms can strengthen relationships with suppliers and distributors. These innovations can create differentiation in competitive markets where products alone may be commoditized.

For policymakers, the findings emphasize the importance of supporting digital transformation in the manufacturing sector through targeted initiatives such as technology adoption grants, workforce upskilling programs, and infrastructure development. Facilitating access to affordable cloud computing resources or promoting standards for digital interoperability can lower barriers to entry for smaller manufacturers, enabling them to compete on a more level playing field with larger firms.

CONCLUSION

This study concludes that digital transformation serves as a pivotal driver of both operational efficiency and competitive advantage in manufacturing industries. The empirical results demonstrate that digital technologies—ranging from IoT-enabled systems to AI-driven analytics—not only streamline production processes and reduce operational inefficiencies but also directly enhance a firm’s ability to compete in dynamic markets. Furthermore, operational efficiency emerges as a key mediating pathway through which digital transformation delivers strategic benefits, underscoring the need for firms to align digital initiatives with process optimization goals. These findings reinforce the view that digital transformation is not merely a technological upgrade, but a strategic imperative that integrates people, processes, and technology to create sustainable value in manufacturing.

SUGGESTION

Based on the findings, manufacturing firms are advised to adopt a holistic approach to digital transformation that integrates technological investments with strategic and operational objectives. Managers should prioritize the implementation of Industry 4.0 technologies—such as IoT, cloud-based analytics, and AI-driven decision support—while ensuring these tools are embedded within well-defined efficiency improvement programs. Continuous workforce upskilling is essential to bridge digital capability gaps and maximize technology utilization. Additionally, firms should explore customer-facing digital innovations, such as digital twin solutions or interactive platforms, to enhance differentiation and brand loyalty. For policymakers, targeted incentives, infrastructure support, and standardized digital frameworks can accelerate technology adoption, particularly among small and medium-sized manufacturers, thereby strengthening the sector’s overall competitiveness in the global market.

REFERENCES

- Ananda, A. S., Murwani, I. A., Tamara, D., & Ibrahim, I. I. (2023). Adoption of Digital Marketing Toward Digital Transformation in Indonesian Micro-and Small-Sized Enterprises. *2023 8th International Conference on Business and Industrial Research (ICBIR)*, 877–882.
- Berman, S. J. (2012). Digital transformation: opportunities to create new business models. *Strategy & Leadership*, *40*(2), 16–24.
- Chen, Y.-Y. K., Jaw, Y.-L., & Wu, B.-L. (2016). Effect of digital transformation on organisational performance of SMEs: Evidence from the Taiwanese textile industry's web portal. *Internet Research*, *26*(1), 186–212.
- De Paz Carmona, M. E., De Paz Carmona, H., & EM, C. C. (2023). *Digital Transformation and Education. A Technical Point of View*.
- Favoretto, C., Mendes, G. H. de S., Filho, M. G., Gouvea de Oliveira, M., & Ganga, G. M. D. (2022). Digital transformation of business model in manufacturing companies: challenges and research agenda. *Journal of Business & Industrial Marketing*, *37*(4), 748–767.
- Felix, A., & Rembulan, G. D. (2023). Digital Transformation and The Customer Experience: Enhancing Engagement and Loyalty. *Entrepreneur: Jurnal Bisnis Manajemen Dan Kewirausahaan*, *4*(03), 228–240.
- Leão, P., & da Silva, M. M. (2021). Impacts of digital transformation on firms' competitive advantages: A systematic literature review. *Strategic Change*, *30*(5), 421–441.
- Qiang, X. (2024). Digital Transformation in the Financial Sector Through Fintech. *Advances in Economics, Management and Political Sciences*, *76*, 226–234.
- Shehadeh, M., Almohtaseb, A., Aldehayyat, J., & Abu-ALSondos, I. A. (2023). Digital transformation and competitive advantage in the service sector: a moderated-mediation model. *Sustainability*, *15*(3), 2077.
- Skare, M., de las Mercedes de Obesso, M., & Ribeiro-Navarrete, S. (2023). Digital transformation and European small and medium enterprises (SMEs): A comparative study using digital economy and society index data. *International Journal of Information Management*, *68*, 102594. <https://doi.org/https://doi.org/10.1016/j.ijinfomgt.2022.102594>
- Susanti, E., Mulyanti, R. Y., & Wati, L. N. (2023). MSMEs' performance and competitive advantage: Evidence from women's MSMEs in Indonesia. *Cogent Business and Management*, *10*(2). <https://doi.org/10.1080/23311975.2023.2239423>