

How Digital Transformation Enhance Supply Chain Management Efficiency? A Panel Data Analysis of Indonesia Listed Company

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ABSTRACT: This study examines the impact of digital transformation on supply chain management efficiency among Indonesian listed firms, using a panel dataset of 381 companies listed on the Indonesia Stock Exchange (IDX) from 2015 to 2024. The empirical results show that digital transformation significantly enhances supply chain efficiency, as evidenced by improved inventory turnover and higher order fulfillment rates. This finding remains robust after addressing endogeneity concerns and conducting a series of robustness checks. Further analysis reveals that information transparency serves as a partial mediator in this relationship, suggesting that digital transformation boosts supply chain performance largely by improving the visibility and sharing of real-time operational data across the value chain. Heterogeneity test reveals the positive impact of digital transformation is notably stronger in large firms, firms located in regions with high internet coverage, and manufacturing enterprises. Based on these findings, the study offers practical implications across three dimensions: corporate strategy, policy support, and technology implementation. It also identifying for future research, including broadening the data scope beyond listed firms, refining digital transformation metrics with more direct measures, and conducting cross-national comparisons to explore how institutional contexts shape digitization outcomes.

KEYWORDS: Digital Transformation; supply chain management efficiency; Indonesian listed company

I. INTRODUCTION

Firms play a pivotal role in Indonesia's economic development, serving as the primary engines of innovation, employment generation, and growth. Yet, many enterprises rely on traditional operational models and remain vulnerable in the face of persistent structural challenges—such as low productivity, limited access to finance, high firm exit rates, and insufficient coverage banking services (Srikalimah et al., 2021). Despite their importance, Indonesian firms—particularly listed companies—still lag significantly behind both large domestic counterparts and firms in advanced economies in terms of overall performance (Hariastuti et al., 2018). To overcome these challenges and seize emerging global opportunities, Indonesian firms urgently need to enhance operational efficiency and competitiveness. In this context, digital transformation emerges as a critical strategic pathway—not merely a technological upgrade, but a fundamental reconfiguration of how firms operate, collaborate, and create value in an increasingly digital global economy.

Digital transformation refers to the systematic integration of digital technologies into a firm's core operations—spanning production, supply chain management, marketing, and customer relationship management (Slamet et al., 2021). This transformation enables multiple strategic benefits: it enhances operational efficiency, reduces costs, improves customer satisfaction, and strengthens innovation capacity. By leveraging digital tools, firms can streamline business processes, automate routine tasks, and generate actionable insights through data analytics—thereby accelerating response times to market changes and customer demands (Kothapalli, 2022). Empirical evidence also suggests that Indonesian firms are increasingly aware of the performance-enhancing potential of internet access and digital devices, recognizing them as key enablers of competitiveness and growth (Islami et al., 2021).

This study aims to contribute to both academic and practical fields in the following three ways: (1) By empirically examining the relationship between digital transformation and supply chain management efficiency, it enriches the literature on digital transformation and deepens our understanding of the underlying mechanisms through which digitalization enhances operational performance. (2) By investigating the specific context and impacts of digital transformation among Indonesian firms, it provides evidence-based insights to inform the design of locally relevant policies, support programs, and implementation strategies tailored

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to Indonesia's institutional and infrastructural realities. (3) By clarifying the benefits and challenges associated with digital transformation, the study offers actionable guidance for firm managers, policymakers, and technology providers in Indonesia—helping them align investments, manage risks, and prioritize initiatives that maximize the strategic value of digitalization.

II. LITERATURE REVIEW

Digital transformation is poised to bring about a fundamental reconfiguration of supply chain management. By deploying digital technologies such as the Internet of Things (IoT), big data analytics, and cloud computing, firms can significantly enhance the efficiency, transparency, and responsiveness of their supply chains (Seppänen et al., 2025). For enterprises, integrating digital technologies into supply chain management not only improves operational performance but also enables the creation of sustainable competitive advantage (Ning et al., 2023). Specifically, digital technologies facilitate end-to-end tracking and real-time monitoring of logistics and materials, thereby enhancing supply chain visibility and reducing delivery delays; big data analytics helps identify patterns and trends in operational data, supporting better inventory optimization, demand forecasting, and risk mitigation; and cloud computing provides a scalable and cost-efficient platform for data storage and management, fostering inter-organizational collaboration and seamless information sharing (Zhang et al., 2024).

Research indicates that digital transformation can also positively influence corporate environmental, social, and governance (ESG) performance (Radicic et al., 2023), enhancing operational sustainability by improving energy efficiency, reducing waste, and advancing circular economy practices (Jin, 2021). Recent studies further confirm that the adoption of digital technologies—such as artificial intelligence and the Internet of Things—can optimize resource efficiency and strengthen firms' overall sustainability outcomes (Putri et al., 2025).

However, firms continue to encounter a range of distinctive challenges in advancing digital transformation, including limited awareness and technical knowledge, constrained financial resources, and concerns regarding cybersecurity and data privacy (Li et al., 2023). A recent systematic literature review (Rawindaran et al., 2025) explicitly identifies these barriers as manifesting in insufficient cybersecurity literacy, scarce economic resources, and the absence of tailored security guidelines. Similarly, another study reveals that many firms allocate severely inadequate resources to cybersecurity due to budget constraints and often lack dedicated cybersecurity teams (Ang et al., 2025). Consequently, firms require support from governments, industry associations, and technology providers to fully recognize the strategic value of digital transformation and to access the necessary resources and expertise for successful implementation (Ngo et al., 2022). Addressing these challenges enables firms to unlock the full potential of digital transformation and significantly enhance the efficiency and effectiveness of their supply chain management (Buntak et al., 2021).

III. THEORETICAL HYPOTHESES

A. The Impact of Digital Transformation on Supply Chain Management Efficiency

Digital transformation exerts a significantly positive influence on supply chain management efficiency, enhancing operational performance and productivity through multiple synergistic mechanisms (Radicic et al., 2023). This effect operates primarily through the following pathways:

First, the deployment of sensing technologies—such as the Internet of Things (IoT)—enables real-time data collection and transmission across the entire supply chain. This allows firms to precisely track shipment status and monitor environmental conditions, substantially improving supply chain visibility and control (He & Fan et al., 2024). Such enhanced visibility serves as a foundation for inventory optimization, process automation, and stronger inter-organizational collaboration, thereby reducing costs, shortening delivery lead times, and increasing customer satisfaction (Liu, 2021).

Second, demand forecasting and inventory optimization powered by big data analytics and advanced modeling constitute a core channel through which digital transformation improves efficiency (Ning et al., 2023). By analyzing historical sales patterns and market trends, firms can dynamically adjust inventory levels using predictive models, effectively mitigating both overstocking and stock out risks (He & Fan et al., 2024).

Third, process automation represents another critical mechanism. Technologies such as Robotic Process Automation (RPA) can be applied to repetitive tasks—including order processing and invoice reconciliation—reducing human error while increasing speed and accuracy (Stroumpoulis et al., 2024). These digital tools also facilitate seamless data exchange across the value chain, breaking down information silos and fostering trust-based collaboration, which further refines end-to-end supply chain planning (Zhang et al., 2024).

In sum, digital transformation systematically enhances operational effectiveness across all supply chain functions through technological integration and process reconfiguration, ultimately strengthening firms' profitability and market responsiveness

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(Zhang et al., 2024). Fundamentally, it represents not merely incremental improvement but a holistic reconfiguration of supply chain architecture—driving it toward greater intelligence, platform-based coordination, and resilience. Based on this theoretical discussion, we propose the following hypothesis:

H1: Digital transformation positively affects supply chain management efficiency in Indonesian firms.

B. The Role of Information Transparency in the Relationship Between Digital Transformation and Supply Chain Management Efficiency

Digital transformation significantly enhances information visibility and transparency across the supply chain through technologies such as IoT sensors, blockchain, and advanced data analytics (Zhou et al., 2023). Research shows that the integration of IoT and blockchain enables end-to-end product traceability, breaks down information silos across the value chain, and strengthens inter-firm trust through the immutability of distributed ledger records (Rejeb et al., 2019). For instance, in temperature-controlled logistics, IoT devices can continuously monitor cargo conditions in real time, while blockchain ensures the integrity and authenticity of the recorded data (Hellani et al., 2021). Building on this, Huang et al. (2022) propose an “IoT + blockchain” business model that facilitates seamless data sharing across procurement, production, and distribution stages, thereby improving the accuracy of supply chain forecasting.

In terms of operational efficiency, the traceability enabled by digital platforms has been shown to significantly improve inventory turnover and warehouse space utilization (Khan et al., 2023). Moreover, the convergence of Industry 4.0—driven vertical integration with blockchain technology allows for cross-tier data interoperability, effectively reducing demand forecasting errors (Ghobakhloo et al., 2023). Regarding inter-organizational collaboration, smart contracts can automatically execute agreements between firms, minimizing negotiation delays, while blockchain’s auditability enhances accountability among supply chain partners (Sabeti et al., 2018). Empirical evidence further indicates that IoT-enabled platforms can accelerate supply chain responsiveness by up to 40% and reduce coordination costs by approximately 35% through real-time data sharing (Udeh et al., 2024). Additionally, digital tools involving multiple stakeholders have been found to simultaneously enhance compliance and collaborative efficiency (McGrath et al., 2021).

From a risk management perspective, blockchain’s transparency helps mitigate fraud and enables rapid traceability in the event of quality failures (Francisco et al., 2018). Case studies demonstrate that combining IoT with blockchain can reduce raw material traceability time from an average of 72 hours to near real-time, improving risk detection capability by 60% (Tijan et al., 2019). Notably, while information sharing is critical, data privacy and security concerns must be addressed. Techniques such as differential privacy and secure multi-party computation offer promising pathways to enable effective collaboration while safeguarding sensitive information (Zhang et al., 2024).

Overall, digitally enabled supply chains alleviate information asymmetry—a key source of operational disruption—thereby enhancing efficiency, sustainability, traceability, and customer responsiveness. Based on the above discussion, we propose the following hypothesis:

H2: Information transparency mediates the relationship between digital transformation and supply chain management efficiency among listed firms in Indonesia.

IV. DATA SOURCES AND VARIABLE MEASUREMENT

A. Estimation Model

$$Perform_{it} = \alpha_0 + \alpha_1 Digi_{it} + \alpha_2 Control_{it} + \delta_i + \mu_t + \varepsilon_{it} \quad (1)$$

In Equation (1), i denotes the firm and t denotes the year. The dependent variable, $Perform_{it}$ represents firm inventory efficiency, measured as the ratio of cost of goods sold to average inventory balance. The main explanatory variable, $Digi_{it}$ captures the firm’s level of digital transformation, proxied by the ratio of total R&D expenditure to operating revenue. The model also includes a vector of control variables ($Control_{it}$), firm fixed effects (δ_i) to account for time-invariant unobserved heterogeneity, year fixed effects (μ_t) to control for common temporal shocks, and a random error term (ε_{it}).

B. Estimation Model

This study uses listed firms on the Indonesia Stock Exchange (IDX) as the initial sample, covering the period from 2015 to 2024. To enhance the robustness and reliability of the empirical analysis, we apply the following standardized data screening and cleaning procedures. First, we exclude firms that were suspended from trading for extended periods during the sample window to eliminate potential distortions caused by abnormal or non-operational statuses. Second, we remove observations with consecutive missing values for key variables. Finally, to mitigate the influence of outliers, we winsorize all continuous variables at the 1st and 99th percentiles.

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C. Variable Definition

a. Dependent Variable

Following Li et al. (2023), this study employs the inventory turnover ratio—defined as the ratio of cost of goods sold to average inventory balance (denoted as Perform)—as the primary measure of supply chain management efficiency. This metric captures a firm's ability to manage inventory and utilize working capital effectively. Specifically, it reflects the volume of sales generated per unit of inventory investment. A higher ratio indicates that a firm sells and replenishes its inventory more frequently within a given period, implying faster conversion of inventory into revenue, stronger inventory management capability, and greater efficiency in capital utilization. Conversely, a lower ratio suggests weaker inventory liquidity, higher capital tied up in stock, and potential issues such as inventory overstocking or inefficient turnover.

For robustness and complementary analysis, we further adopt order fulfillment rate as an alternative proxy for supply chain efficiency, following Li (2024). This indicator is calculated as:

$$\text{Order Fulfillment Rate} = \left(\frac{\text{Total Quantity Actually Delivered}}{\text{Total Quantity Required Delivered}} \right) \times 100 \quad (2)$$

It directly measures a firm's responsiveness to market demand and the operational effectiveness of its supply chain. A higher fulfillment rate signifies greater efficiency in inventory allocation and order execution, as well as superior coordination across supply chain functions—from procurement and production to logistics and distribution.

b. Independent Variable

Following Meng, Wang, et al. (2023), this study measures digital transformation as the ratio of total R&D expenditure to operating revenue. This metric captures the intensity of a firm's resource commitment to digital technologies and innovation activities, thereby reflecting its strategic orientation and depth of implementation in pursuing R&D-driven digital transformation. From a causal perspective, a consistently high R&D intensity not only signals that digitalization occupies a central role in the firm's strategic agenda but also facilitates the development of internal technological capabilities and the creation of proprietary knowledge barriers. These, in turn, increase the likelihood of achieving profound digital transformations in operational processes, business models, and organizational structures. Hence, a higher value of this indicator typically suggests a more proactive, foundational, and internally driven approach to digital transformation.

For robustness and complementary analysis, we further adopt the textual-based approach of Taufani et al. (2023). Specifically, drawing on publicly available annual reports and disclosure documents from firms listed on the Indonesia Stock Exchange (IDX), we apply text mining techniques to identify and count the frequency of keywords associated with digital transformation—such as “digitalization,” “artificial intelligence,” “Internet of Things (IoT),” “big data,” “cloud computing,” and “Industry 4.0.” We then construct a firm-level digital transformation intensity index by taking the natural logarithm of (total keyword count + 1). This measure reflects the visibility and strategic emphasis a firm places on digital technologies; a higher value indicates a stronger public commitment to—and greater articulation of—digital initiatives, serving as a proxy for its stated digital orientation and implementation intent.

c. Control Variables

Following the previous frameworks by Liang et al. (2022) and Zhang et al. (2024), this study includes a set of control variables to account for firm-level characteristics that may influence supply chain management efficiency. Specifically, we control for: firm size (natural logarithm of total assets), leverage (total liabilities divided by total assets), firm age (natural logarithm of [observation year – establishment year + 1]), fixed asset intensity (net fixed assets as a share of total assets), liquidity position (current assets over current liabilities), and investment opportunity set (Tobin's Q, calculated as [market value of equity + total liabilities] / total assets).

Table 1 Descriptive Statistics

Variables	Obs	Mean	Std. Dev.	Min	Max
Perform	3810	1.109	0.087	0.954	1.229
Digi	3810	3.983	0.869	2.808	5.294
Size	3810	28.95	1.851	24.62	33.55
Lev	3810	0.913	0.135	0.705	1.110
Age	3810	1.440	0.076	1.331	1.586
Fix	3810	0.469	0.281	0.004	0.995
Cash	3810	0.091	0.106	0.001	0.567
Tobin's Q	3810	1.394	2.269	0.088	18.74

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V. RESULT AND ANALAYSIS

A. Benchmark Regression

The baseline regression results are reported in Table 2. Column (1) of Table 2 indicates that in the model without control variables, year-specific effects, and firm-specific effects, in which the coefficient on digital transformation (Digi) is positive and statistically significant at the 1% level. Column (2) showing the specification by including firm and year fixed effects, and the coefficient on Digi remains positive and highly significant at the 1% level. These consistent findings indicate that digital transformation exerts a robust and significantly positive effect on supply chain management efficiency, thereby providing empirical support for Hypothesis 1.

Table 2 Baseline Regression

Variables	Perform (1)	(2)
Digi	0.059*** (0.004)	0.041*** (0.007)
Size		0.013 (0.008)
Lev		-0.281*** (0.031)
Age		-0.049 (0.079)
Fix		0.001 (0.001)
Cash		-0.005** (0.003)
Tobin's Q		0.003 (0.002)
Constant	0.249*** (0.025)	1.180*** (0.113)
Firm and Year	Yes	Yes
Observations	3,810	3,810
R-squared	0.497	0.510
Number of ID	381	381

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

B. Robustness Test

a. Replace the dependent variable

The baseline analysis employs the ratio of cost of goods sold to average inventory balance as the primary measure of supply chain management efficiency, which primarily captures a firm's inventory turnover capacity and working capital utilization. However, this metric may be subject to potential measurement bias arising from firm-specific accounting policies, cost structures, and inventory valuation methods, all of which can influence the reported values of cost of goods sold or inventory balances independently of actual operational performance. To address this limitation and provide a more operationally grounded assessment, we follow Li (2024) and introduce order fulfillment rate (OFR) as a complementary proxy for supply chain efficiency. OFR—computed as the percentage of ordered items successfully delivered—is a direct, outcome-oriented measure that reflects a firm's real-time responsiveness to customer demand and the execution effectiveness of its supply chain. Crucially, it emphasizes the dynamic role of inventory allocation and logistics coordination in fulfilling actual sales commitments, thereby offering a more behaviorally and operationally valid indicator than purely accounting-based ratios.

As shown in Column (1) of Table 3, the coefficient on digital transformation with respect to OFR remains positive and statistically significant at the 1% level, consistent with the baseline findings. This robustness check reinforces the conclusion that digital transformation meaningfully enhances supply chain performance—not only in terms of internal inventory efficiency but also in delivering tangible outcomes to customers.

Table 3 Roboustness Test

Variables	OFR (1)	Perform (2)
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Digi	0.041*** (0.007)	
Digi_2		0.293*** (0.016)
Constant	1.180*** (0.113)	2.266*** (0.104)
Control Var	Yes	Yes
Firm and Year	Yes	Yes
Observations	3,810	3,810
R-squared	0.740	0.510

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

b. Replace the dependent variable

The primary measure of digital transformation used earlier—total R&D expenditure as a share of operating revenue—captures the financial intensity of a firm's investment in digital innovation. While informative, this metric primarily reflects input-side resource allocation and may not fully reflect the actual adoption, integration, or operational implementation of digital technologies. Consequently, it risks underrepresenting firms that adopt ready-made digital solutions without large in-house R&D, or overlooking the depth of digital embedding across business functions.

To address this potential measurement limitation, we follow Taufani et al. (2023) and construct a complementary proxy based on textual analysis of corporate disclosures. Specifically, we identify and aggregate the frequency of keywords related to digital transformation—in annual reports and official filings from firms listed on the Indonesia Stock Exchange (IDX). This textual indicator (denoted as Digi_2) directly captures how firms describe and frame their use of digital technologies across production, management, marketing, and strategic planning, thereby offering a more nuanced view of digital adoption breadth and integration depth.

As reported in Column (2) of Table 3, the coefficient on Digi_2 with respect to supply chain efficiency (perform) is positive and statistically significant at the 1% level, aligning closely with the baseline results. This consistency across measurement approaches strengthens the validity of our core finding: digital transformation—whether gauged by financial investment or strategic disclosure—robustly enhances supply chain management efficiency in Indonesian listed firms.

C. Endogeneity Test

To address potential endogeneity arising from reverse causality and omitted variable bias, this study employs an instrumental variable (IV) approach grounded in a high-dimensional fixed effects framework. Specifically, recent studies indicate that government subsidies for digital infrastructure can significantly lower the marginal cost of digital transformation and thereby accelerate firm-level digitization (Yao, 2025; Bo et al., 2025). Building on this insight, we follow Yang et al. (2024) and construct an instrumental variable: digital infrastructure subsidy (Subsidy), measured as firm-level receipt of government support explicitly designated for digital infrastructure development. The validity of this instrument rests on two key conditions: (1) Relevance: Subsidies directly incentivize digital investment, ensuring strong correlation with firms' digital transformation intensity; (2) Exclusion restriction: Such subsidies influence supply chain efficiency only indirectly—through their effect on digital adoption—and not via other channels, especially after controlling for firm, industry, and year fixed effects.

Table 4 Endogeneity Test

Variables	First Stage Digi	Second Stage Perform
Subsidy	0.017*** (0.006)	
Digi		0.046*** (0.015)
Constant	-0.342*** (0.747)	0.904 (8.362)
C-D Wald F statistic		273.231
K-P rk LM statistic		122.714***
Control Var	Yes	Yes
Firm and Year	Yes	Yes
Observations	3,810	3,810
R-squared		0.433

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Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

As showing in Table 4, the first-stage regression (Column 1) shows that the subsidy variable has a positive and highly significant coefficient on digital transformation, confirming strong instrument relevance. The second-stage results (Column 2) indicate that, after correcting for endogeneity, the effect of digital transformation on supply chain management efficiency remains positive and statistically significant, reinforcing the robustness of our core finding. The Cragg–Donald Wald F statistic result is 273.231, far exceeding the Stock–Yogo critical value (e.g., 16.38 at the 10% significance level for weak identification), decisively rejecting the presence of a weak instrument. The Kleibergen–Paap rk LM statistic is also significant at the 1% level, strongly rejecting the null hypothesis of underidentification. From the finding we conclude these results confirm that the estimated relationship between digital transformation and supply chain efficiency is unlikely driven by endogeneity, thereby strengthening the causal interpretation of Hypothesis 1.

D. Heterogeneity Test

a. Firm Size

Following Andreas et al. (2022), we divided the sample into large and small firms based on the median of Total Assets. Columns (1) and (2) of Table 5 present the subsample results. The coefficient on digital transformation is positive and statistically significant at the 1% level for large firms, indicating that they are better able to translate digital investments into tangible improvements in supply chain efficiency. This heightened effectiveness likely stems from several advantages: large firms typically possess greater financial resources to fund digital initiatives, benefit from more standardized and mature operational systems, and have the organizational capacity to implement and scale digital tools across complex operations. These conditions facilitate smoother integration of technologies such as IoT, cloud platforms, and data analytics into core supply chain processes. This heightened effectiveness likely stems from several advantages: large firms typically possess greater financial resources to fund digital initiatives, benefit from more standardized and mature operational systems, and have the organizational capacity to implement and scale digital tools across complex operations. These conditions facilitate smoother integration of technologies such as IoT, cloud platforms, and data analytics into core supply chain processes. In contrast, smaller listed firms often face significant constraints—including limited capital, weaker digital infrastructure, and lower absorptive capacity—that hinder their ability to fully leverage digital transformation. Additionally, the high fixed costs of digital adoption and the complexity of system integration can disproportionately burden smaller firms, limiting both the scope and impact of their digital efforts. Consequently, while digital transformation holds promise for all firms, its efficiency-enhancing effects appear to be more pronounced and statistically detectable among large enterprises in the current Indonesian context.

Table 5 Heterogeneity Test

Variables	Large Firm	Small Firm	High Development area	Low Development area	Manufacturing	Non-Manufacturing
	(1)	(2)	(3)	(4)	(5)	(6)
Digi	0.035*** (0.011)	0.017 (0.031)	0.037*** (0.009)	0.023 (0.024)	0.038*** (0.008)	0.022 (0.027)
Constant	1.145*** (0.188)	1.135*** (0.269)	1.154*** (0.138)	0.799*** (0.282)	1.260*** (0.137)	1.286*** (0.263)
Control Var	Yes	Yes	Yes	Yes	Yes	Yes
Firm and Year	Yes	Yes	Yes	Yes	Yes	Yes
Fisher's Test	0.027		0.041		0.035	
Observations	1610	2,200	2,140	1,670	1,890	1,920
R-squared	0.423	0.577	0.573	0.485	0.471	0.543

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

b. Development Area Level

Following Kilay et al. (2022), we divide the sample into two subsamples based on the median of regional internet penetration rate, classifying firms as located in either high or low-development area regions. Columns (3) and (4) of Table 5 explain the results of this heterogeneity analysis.

For firms in high-development regions, the coefficient on digital transformation is positive and statistically significant at the 1% level, indicating that digital transformation more effectively enhances supply chain management efficiency in areas with advanced digital infrastructure and high internet coverage. This is likely because such regions offer a conducive external ecosystem—

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characterized by reliable broadband connectivity, a skilled digital workforce, mature cloud and data services, and stronger institutional support—which enables firms to seamlessly adopt, integrate, and scale digital technologies across their supply chains. In contrast, for firms in low-development regions, the effect of digital transformation on supply chain efficiency is positive but statistically insignificant. This limited impact can be attributed to constraints such as underdeveloped ICT infrastructure, shortages of digital talent, and inadequate policy or institutional support. In these settings, even if firms invest in digital tools, the lack of complementary regional capabilities may hinder effective implementation, data utilization, and inter-organizational connectivity, thereby limiting or even suppressing the potential gains from digital transformation.

In contrast, for firms in low-development regions, the effect of digital transformation on supply chain efficiency is positive but statistically insignificant. This limited impact can be attributed to constraints such as underdeveloped ICT infrastructure, shortages of digital talent, and inadequate policy or institutional support. In these settings, even if firms invest in digital tools, the lack of complementary regional capabilities may hinder effective implementation, data utilization, and inter-organizational connectivity, thereby limiting or even suppressing the potential gains from digital transformation. These findings underscore that the success of firm-level digital transformation is not solely determined by internal decisions but is deeply contingent on the quality of the local digital environment—highlighting the critical role of regional infrastructure and ecosystem maturity in shaping digital dividends.

c. Industry Characteristic

Following Azemi & Khairunnisa (2025), we divide by industry characteristic of the Indonesia Stock Exchange (IDX), this study divides the full sample into manufacturing and non-manufacturing firms. Columns (5) and (6) of Table 5 present the subsample regression results. The coefficient on digital transformation is positive and statistically significant at the 1% level for manufacturing firms, indicating that they derive significantly greater supply chain efficiency gains from digital transformation compared to their non-manufacturing counterparts. This difference stems from structural differences between the two sectors. Manufacturing operations are typically characterized by highly standardized production processes and complex, multi-tier material flow systems, which create fertile ground for digital technologies—such as IoT-enabled tracking, AI-driven demand forecasting, and integrated ERP platforms—to optimize production scheduling, enable real-time inventory control, and facilitate end-to-end supply chain coordination.

In contrast, non-manufacturing firms—often operating in service-oriented or trade-based industries—tend to rely more heavily on human capital, interpersonal interactions, and context-specific decision-making, with lower levels of process standardization. These features make it more challenging to systematically apply digital tools to achieve measurable improvements in operational efficiency across the supply chain. Consequently, their digital investments may yield greater returns in non-efficiency dimensions, such as service quality enhancement, customer experience personalization, or brand engagement, rather than in inventory turnover or order fulfillment metrics. Thus, the effectiveness of digital transformation in boosting supply chain efficiency is sector-contingent, with manufacturing firms currently better positioned to translate digital adoption into tangible operational gains in the Indonesian context.

E. Mechanism Test

To further investigate the underlying mechanism through which digital transformation enhances supply chain management efficiency, this study follows Kim et al. (2024) and introduces information transparency (Trans) as a mediating variable. This variable captures the clarity, accessibility, and symmetry of information exchange among supply chain partners, thereby reflecting the extent to which digital transformation mitigates information asymmetry and improves visibility across the value chain. The core idea is that digital technologies—such as IoT, blockchain, and cloud-based platforms—enable real-time data sharing and mutual monitoring, which in turn foster coordination, reduce operational uncertainty, and accelerate responsiveness. To empirically test this mediating channel, we estimate the following set of regression models:

$$Trans_{it} = \beta_0 + \beta_1 Digi_{it} + \beta_2 Control_{it} + \delta_i + \mu_t + \varepsilon_{it} \quad (3)$$

$$Perform_{it} = \phi_0 + \phi_1 Digi_{it} + \phi_2 Trans_{it} + \phi_3 Control_{it} + \delta_i + \mu_t + \varepsilon_{it} \quad (4)$$

In Equation (2), i denotes the firm and t denotes the year; the dependent variable $Trans_{it}$ represents information transparency. This equation examines how digital transformation influences the level of information transparency within a firm's supply chain. In Equation (3), $Trans_{it}$ is included as a mediating variable to assess whether the effect of digital transformation on supply chain management efficiency operates partially through enhanced information transparency. Both equations control for a vector of firm-level covariates ($Control_{it}$), incorporate firm fixed effects (δ_i), to account for time-invariant unobserved

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heterogeneity, and include year fixed effects (μ_t) to absorb common macroeconomic or temporal shocks. The error term is denoted by (ε_{it}).

Column (1) of Table 6 shows that the coefficient of digital transformation (Digi) on information transparency (Trans) is 0.046 and statistically significant at the 1% level, indicating that digital transformation significantly enhances the transparency of information flows within the supply chain. Column (2) reports the results of the mediation model, in which Trans is included as an intermediate variable. The direct effect of Digi on supply chain management efficiency (Perform) declines to 0.038—still significant at the 5% level—but notably smaller in coefficient compared to the baseline estimate. This pattern is consistent with a partial mediation effect: digital transformation improves supply chain efficiency not only through direct operational enhancements but also indirectly by increasing information transparency, which in turn facilitates better coordination, reduces uncertainty, and supports more responsive decision-making across the supply chain. These findings provide empirical support for Hypothesis 2, confirming that information transparency serves as a significant mechanism through which digital transformation exerts its positive impact on supply chain performance.

Table 6 Mechanism Test Result

Variables	Trans (1)	Perform (2)
Digi	0.046*** (0.013)	0.038*** (0.011)
Trans		0.022*** (0.008)
Constant	0.363 (0.840)	1.188*** (0.112)
Control Var	Yes	Yes
Firm and Year	Yes	Yes
Sobel Z value	2.523***	
Goodman-1	2.421***	
Goodman-2	2.633***	
Observations	3,810	3,810
R-squared	0.458	0.517

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

CONCLUSION

This study examines the impact of digital transformation on supply chain management efficiency among Indonesian listed firms, an annual panel dataset of 381 companies listed on the Indonesia Stock Exchange (IDX) from 2015 to 2024. The analysis systematically investigates both the underlying mechanisms and contextual boundaries of this relationship. The key findings are summarized as follows:

First, digital transformation significantly enhances supply chain management efficiency in Indonesian listed firms, as evidenced by improved inventory turnover and higher order fulfillment rates. This result provides robust empirical support for Hypothesis 1. The finding remains consistent even after addressing endogeneity concerns through an instrumental variable approach, confirming the reliability and causal plausibility of the positive effect of digital transformation on supply chain performance. Second, the impact of digital transformation exhibits notable heterogeneity across firms. The efficiency gains are significantly stronger among large firms (with greater financial and organizational resources), firms located in high-development regions with advanced digital infrastructure, and manufacturing firms characterized by standardized and data-rich operational processes. These results highlight that the effectiveness of digital transformation is jointly shaped by firm-level capabilities, regional digital ecosystems, and industry-specific operational structures. Third, mechanism analysis confirms that information transparency serves as a partial mediator in the relationship between digital transformation and supply chain efficiency. By enhancing the visibility, accessibility, and symmetry of information across supply chain partners, digital technologies reduce information asymmetry and foster real-time coordination—thereby indirectly strengthening overall operational responsiveness and efficiency.

These findings carry practical relevance. Listed firms should treat digital transformation as a long-term strategic priority, focusing on improving information transparency, optimizing internal processes, and deepening supply chain collaboration to build competitive advantage. Policymakers ought to accelerate the roll-out of regional digital infrastructure, offer targeted incentives (e.g., subsidies for SME digitization), and promote industry-wide coordination to create an enabling environment for digital adoption. Technology providers are encouraged to develop lightweight, modular, and secure digital solutions tailored to the

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operational realities and resource constraints of Indonesian firms—particularly those in non-manufacturing or less-digitalized regions.

This study also have some limitations. (1) The sample is restricted to listed firms, excluding a large population of unlisted and informal enterprises. Future studies could complement quantitative data with surveys or in-depth interviews to broaden generalizability. (2) Our measures of digital transformation—based on R&D intensity and textual disclosures—capture technological input and strategic intent but may under-represent “softer” dimensions such as organizational redesign, digital culture, or workforce ups-killing. A more holistic index integrating technology, talent, and process change would enrich measurement validity. (3) The study is context-specific to Indonesia and does not account for cross-national institutional differences. Comparative studies across emerging markets could illuminate how regulatory frameworks, market structures, and cultural norms moderate the digital transformation—performance nexus.

ACKNOWLEDGMENT

I would like to express my deepest gratitude to all the individuals and groups whose generous support, insightful guidance, and steadfast encouragement made this research possible. Their wisdom, patience, and unwavering belief in me were instrumental in helping me overcome challenges and bring this project to completion.

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