The Strategic Role of Digital Operational Efficiency in Mediating Green Logistics and Carbon Footprint Reduction: A Study of Thai SMEs

Sompong Punlaptavee[1], Phenphak Manotham[2] and Chanicha Moryadee[3]

[1]DBA. Student, College of Logistics and Supply Chain, Suan Sunandha Rajabhat University, Bangkok, Thailand

[2]Doctor of Business Administration Student, Sripatum University, Bangkok, Thailand

[3]Advisor, College of Logistics and Supply Chain, Suan Sunandha Rajabhat University , Bangkok, Thailand

E-Mail: [1]s65584923011@ssru.ac.th, [3]chanicha.mo@ssru.ac.th

Abstract

As the global economy transitions toward a low-carbon future, Small and Medium Enterprises (SMEs) face intensifying pressure to align their operations with Environmental, Social, and Governance (ESG) standards. This research investigates the strategic nexus between Green Logistics Management (GL) and Carbon Footprint Reduction (CF), specifically examining the mediating role of Digital Operational Efficiency (DE). Utilizing a quantitative research design, empirical data were collected from a purposive sample of 500 SME representatives across Thailand's manufacturing and service sectors. The data were analyzed using Structural Equation Modeling (SEM) to test the hypothesized causal relationships.

Data were analyzed through Structural Equation Modeling (SEM). The results indicate that while Green Logistics has a significant direct impact on Carbon Footprint Reduction ($\beta = 0.308$, $p < .001$), its effectiveness is substantially amplified through Digital Operational Efficiency, which acts as a partial mediator (Indirect Effect = 0.132). The model achieves a predictive power of 26.6% ($R^2 = 0.266$).

Discussion of the results suggests that digitalization—including ERP systems, Cloud computing, and Big Data Analytics—functions as a "transparency bridge," allowing SMEs to provide traceable and verifiable carbon data to international stakeholders. The study concludes that for SMEs to remain resilient in the face of mandates like CBAM, they must adopt a "Digital-Green Integration" strategy. Managerial and policy recommendations focus on incentivizing digital adoption and upskilling human capital to foster long-term corporate sustainability.

Keywords: Green Logistics, Digital Operational Efficiency, Carbon Footprint Reduction, Sustainability, SMEs, D-ESG, Structural Equation Modeling.

1. Introduction

The global business landscape is currently undergoing a paradigm shift driven by the dual imperatives of environmental sustainability and digital transformation. For Small and Medium Enterprises (SMEs) in Thailand, this transition is no longer a matter of corporate social responsibility but a critical determinant of survival within the global value chain. As international trade frameworks, such as the European Union's Carbon Border Adjustment Mechanism (CBAM), become more stringent, SMEs are mandated to provide verifiable evidence of their environmental performance. Consequently, reducing the Carbon Footprint (CF) has evolved into a strategic "License to Operate" for businesses seeking to maintain their presence in competitive international markets.

Logistics activities constitute the "nervous system" of SME operations; however, they are also a primary source of greenhouse gas emissions due to fuel consumption and inefficient supply chain processes. While the adoption of Green Logistics Management (GL)—such as route optimization, energy-efficient warehousing, and eco-friendly packaging—is essential, SMEs often face significant barriers, including limited financial resources and a lack of specialized expertise. To overcome these constraints, the integration of Digital Operational Efficiency (DE) is proposed as a vital "Leverage" (คันโยกเชิงกลยุทธ์). Digital innovations, ranging from Enterprise Resource Planning (ERP) and Cloud Computing to Big Data Analytics, do not only streamline operational processes but also provide the "Transparency Bridge" required for accurate carbon monitoring and reporting.

Despite the growing importance of these factors, there remains a significant gap in understanding how digital efficiency specifically functions as a mediator that converts green logistics intent into measurable sustainability outcomes. Therefore, this research focuses on the "Digital-ESG" (D-ESG) nexus to provide an empirical framework for SMEs.

2.Objectives of the Study

This research aims to achieve the following academic and practical objectives:

1. To investigate the current implementation levels of Green Logistics Management, Digital Operational Efficiency, and Carbon Footprint Reduction among Thai SMEs.
2. To examine the direct influence of Green Logistics Management on achieving Carbon Footprint Reduction for sustainability.
3. To analyze the direct impact of Green Logistics Management on enhancing Digital Operational Efficiency.
4. To evaluate the mediating role of Digital Operational Efficiency in the relationship between Green Logistics Management and Carbon Footprint Reduction.

3. Literature Review and Hypothesis Development

This study integrates **Resource-Based View (RBV)** and Stakeholder Theory. We argue that the bundling of green practices with digital efficiency creates a "Dynamic Capability" that is difficult for competitors to replicate. Previous studies highlight that digital transformation—defined here as **Digital Operational Efficiency** enables enterprises to monitor energy consumption and waste

in real-time. This study extends this by positioning "Digital" as the bridge that connects logistics practices to verifiable carbon reduction. Based on this framework, four hypotheses are established:

3.1 Green Logistics Management (Independent Variable)

Green Logistics Management (GL) has emerged as a strategic imperative for organizations aiming to minimize their environmental impact while maintaining operational efficiency. According to the Office of National Economic and Social Development Council (2021), the logistics sector in Thailand is undergoing a transition toward a more sustainable framework to align with global standards. GL encompasses various practices, including route optimization, energy-efficient warehousing, and eco-friendly packaging.

Empirical evidence from Agyabeng-Mensah and Tang (2021) suggests that the adoption of green logistics practices directly enhances green competitiveness and social performance, which are vital for manufacturing organizations. Furthermore, Inthasang and Wirojtitayawong (2024) highlight that green supply chain management acts as a precursor to sustainable development, particularly within Thailand's automotive parts industry. These practices collectively ensure that logistics activities do not only focus on cost reduction but also on the long-term preservation of ecological resources.

3.2 Digital Operational Efficiency (Mediating Variable)

In the contemporary business landscape, the integration of digital technology is no longer optional. Digital Operational Efficiency (DE) refers to an organization's capability to leverage technologies such as Enterprise Resource Planning (ERP), Cloud Computing, and the Internet of Things (IoT) to streamline operations. Jarusen (2021) emphasizes that digital competency is a significant factor affecting the performance and resilience of SMEs, especially in the context of financial and operational transactions.

The role of DE as a mediator is supported by Zhong et al. (2023), who argue that "Resource Bundling" through digital transformation significantly accelerates the achievement of Environmental, Social, and Governance (ESG) goals. Digital tools provide the "visibility" and "accuracy" required for sustainability reporting. Similarly, Yuan (2023) demonstrates that corporate digital transformation is a key driver for enhancing ESG performance among listed companies. For SMEs, DE serves as the "bridge" that converts strategic green intent into verifiable environmental data, thereby facilitating more effective decision-making processes.

3.3 Carbon Footprint Reduction for Sustainability (Dependent Variable)

The ultimate objective of integrating green practices and digital efficiency is the reduction of the corporate carbon footprint. The Department of Industrial Promotion (2021) and Phumphruek et al. (2022) underscore that sustainability in the industrial sector is heavily dependent on the effective management of greenhouse gas emissions and adherence to international sustainability standards.

Reducing the carbon footprint is critical for SME survival in the global supply chain, particularly under mandates such as CBAM. Pan and Feng (2023) point out that building ESG capabilities within small and medium logistics companies is essential for bridging the "sustainability gap" and gaining a competitive advantage. Furthermore, Zhong (2023) argues that

high-quality development in private enterprises is directly influenced by their ESG performance. Consequently, Carbon Footprint Reduction is not merely an environmental metric but a core component of "High-Quality Development" and long-term organizational viability.

3.4 Hypothesis Development

Based on the synthesized literature, the research model proposes that:

H1: Green Logistics Management directly influences Carbon Footprint Reduction.

H2: Green Logistics Management drives the enhancement of Digital Operational Efficiency.

H3: Digital Operational Efficiency significantly contributes to Carbon Footprint Reduction.

H4: Digital Operational Efficiency (Mediator) significantly mediates the relationship between Green Logistics and Carbon Footprint Reduction.

4. Research Methodology

A cross-sectional quantitative design was adopted. The sample consists of 500 SMEs, primarily from the manufacturing sector (63.4%), where logistics impact is most significant. Beyond descriptive statistics, Structural Equation Modeling (SEM) was used to handle the latent variables and test the mediation effects of Digital Efficiency. The model underwent rigorous testing for Convergent and Discriminant Validity to ensure the robustness of the findings.

5. Conceptual Framework and Model

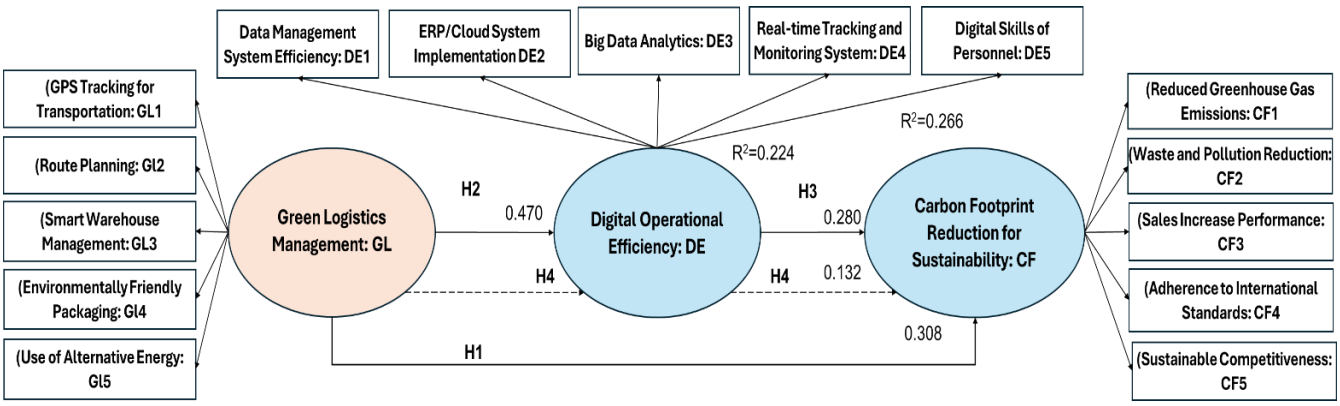
The framework explores the "Digital-Green Synergy":

- Green Logistics (IV): Focused on input optimization (e.g., eco-packaging, fuel efficiency).
- Digital Operational Efficiency (Mediator): Focused on process optimization (e.g., ERP integration, AI route planning).
- Carbon Footprint Reduction (DV): Focused on sustainable output (e.g., measurable reduction in CO_2 emissions). The model posits that digital efficiency is the "Amplifier" that makes green logistics more effective.

6. Results and Statistical Analysis

The analysis of 500 data sets reveals:

- Path GL → DE ($\beta = 0.470$): SMEs that prioritize green strategies are significantly more likely to adopt advanced digital tools.
- Path DE → CF ($\beta = 0.280$): Digital efficiency directly lowers carbon footprints through precision management.
- Mediation Effect: The indirect effect (0.132) is significant, confirming that a "Digital-First" approach to green logistics yields superior environmental results.
- Model Performance: The model explains 26.6% of the variance in sustainability outcomes, indicating a strong fit for SME contexts.



7. Discussion

The findings confirm that digital efficiency helps SMEs overcome the "Greenwashing" risk. Expert interviews emphasize that "Digital is the bridge between intent and reality." For instance, using IoT and Big Data for route planning doesn't just reduce fuel costs; it provides the traceable data that global buyers demand. This shifts the perception of ESG from a "cost center" to a "competitive advantage."

8. Conclusion and Recommendations

- Managerial Implications: Managers must move from "Analog Green" to "Digital Green." Investing in digital infrastructure (Cloud/AI) is essential for future-proofing logistics.
- Policy Recommendations: Governments should provide tax incentives and digital training (Upskilling) for SMEs to foster an integrated D-ESG ecosystem.
- Future Research: Future studies should investigate the role of "Green Organizational Culture" in further driving digital-environmental integration.

References.

Agyabeng-Mensah, Y., & Tang, L. (2021). The relationship among green human capital, green logistics practices, green competitiveness, social performance and financial performance. Journal of Manufacturing Technology Management, 32(7), 1377-1398.

Department of Industrial Promotion. (2021). Annual Report 2021: Department of Industrial Promotion. Ministry of Industry.

Inthasang, C., & Wirojtitayawong, N. (2024). The Influence of Green Product Innovation and Green Supply Chain Management on Sustainable Development of Thailand’s Auto Parts Industry. Journal of Accounting and Management, Mahasarakham University.

Jarusen, J. (2021). The Influence of Fintech Technology on SME Entrepreneurs' Performance. Dusit Thani College Journal.

Logistics System Development Strategy Division. (2021). Thailand Logistics Report 2021. NESDB.

Office of the National Economic and Social Development Council. (2021). Thailand Logistics Report 2021.

Pan, Z. H., & Feng, Z. P. (2023). Bridging the gap: Building environmental, social and governance capabilities in small and medium logistics companies. Journal of Environmental Management, 338, 117758.

Phumphruek, C., et al. (2022). Industrial Sustainability Development.

Yuan, Y. (2023). Corporate Digital Transformation and ESG Performance-Evidence from Chinese-Listed Companies. BCP Business & Management.

Zhong, Y. (2023). The Impact of ESG Performance on the High Quality Development of Private Enterprises. International Journal of Economics, Commerce and Management.

Zhong, Y., Zhao, H., & Yin, T. (2023). Resource Bundling: How Does Enterprise Digital Transformation Affect Enterprise ESG Development? Sustainability, 15(1319), 1-18.