

The Digital Nexus: Informatics Impact on Sustainable Supply Chains

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Abstract

This study investigates the strategic relationship between the maturity of Industrial Informatics (II) Integration and holistic Sustainable Supply Chain and Logistics Performance (SSCLP), framed by the Triple Bottom Line (TBL) concept (Profit, People, and Planet). Traditional supply chain management, which primarily focused on cost and efficiency, is inadequate for addressing modern challenges like resource scarcity and climate change. Simultaneously, the Fourth Industrial Revolution, driven by II technologies such as IoT, Big Data Analytics, and AI, offers unprecedented capabilities for real-time visibility and optimization. While the economic impact of II is well-documented, its specific contributions to the environmental and social pillars of sustainability remain under-explored in integrated empirical studies. This paper addresses this gap by proposing and testing a model using quantitative data from a survey of 150 supply chain managers. Multiple Regression analysis was employed to test the hypotheses.

Keywords: Industrial Informatics, Big Data Analytics, Sustainable Supply Chain

Nomenclature

SCM	Supply Chain Management
SSCM	Sustainable Supply Chain Management
IoT	Internet of Things
AI	Artificial Intelligence
CO ₂	Carbon Dioxide
GPS	Global Positioning System

1. Introduction

The 21st century presents global enterprises with the dual imperatives of profitability and planetary stewardship. Traditional supply chain management (SCM), focused primarily on cost minimization and efficiency, has proven inadequate in addressing complex contemporary challenges such as climate change, resource scarcity, and global inequity (Srivastava, 2007). Traditional supply chain management does not have solution for modern day challenges such as global warming, scarcity of renewable resources, and inequality at global level and primary focus of traditional supply chain management was cost cutting and efficiency. This insufficiency has invoked academicians' interest in Sustainable Supply Chain Management (SSCM) and has put it in practical spotlight, demanding a holistic approach that integrates environmental and social considerations alongside economic objectives—often referred to as the Triple Bottom Line (TBL) framework (Elkington, 1997). On other hand Fourth Industrial Revolution (Industry 4.0) is knocking the door for changing industrial landscape. Primary trait of this revolution is convergence of physical and digital system, collectively termed as Industrial Informatics (II). II technologies, including the Internet of Things (IoT), Big Data Analytics, Artificial Intelligence (AI), and blockchain, offer unprecedented capabilities for real-time visibility, predictive optimization, and autonomous decision-making in logistics and SCM (Geissbauer et al., 2016). Logistics sector primarily is energy driven and geographically widely scattered. II helps separate economic growth from anti environmental and

social impacts. While the potential of Industrial Informatics (II) to enhance operational efficiency (the economic dimension) is widely recognized, its specific and quantifiable contributions to the non-economic pillars of sustainability—Environmental Performance (e.g., carbon reduction, waste management) and Social Performance (e.g., ethical sourcing, labor safety)—remain fragmented and under explored in integrated empirical studies (Sarkis & Zhu, 2018). Organizations face a strategic dilemma: how to justify significant investments in II infrastructure to meet ambitious, non-financial sustainability targets. This paper addresses this critical gap by systematically investigating the complex causal relationship between the maturity of Industrial Informatics Integration and the holistic Sustainable Supply Chain and Logistics Performance (SSCLP), framed by the TBL.

This article proposes a robust conceptual model and tests its hypotheses using quantitative data to assess whether II acts as a genuine enabler of comprehensive sustainability or merely an enhancer of traditional economic performance.

The primary objective of this research is to quantify the influence of II adoption on each of the three dimensions of SSCLP. The expected contribution is twofold: theoretically, to enrich the SSCM literature by empirically validating the role of digitization in achieving TBL goals; and managerially, to provide evidence-based guidance for supply chain professionals on strategically prioritizing II investments to maximize sustainable impact. The remainder of this paper proceeds with a detailed literature review, methodology, data analysis, and discussion of findings.

2. Literature Review and Research Gap

2.1. Defining Sustainable Supply Chain Management (SSCM)

SSCM extends traditional supply chain management to integrate environmental (e.g., waste reduction, carbon footprint) and social (e.g., labor practices, community impact) criteria. The Triple Bottom Line (TBL), popularized by Elkington, serves as the primary theoretical lens for assessing SSCM performance (Elkington, 1997)

2.2. The Role of Industrial Informatics (II) in Logistics

Industrial Informatics (II) encompasses various digital technologies that enable intelligent, interconnected industrial operations. These technologies include:

- IoT: Provides real-time asset tracking and condition monitoring.
- Big Data Analytics: Facilitates predictive maintenance and demand forecasting.
- AI/Machine Learning: Optimizes routing, warehouse management, and inventory levels.

2.3. Research Gap

While existing literature acknowledges the potential of II to improve efficiency (economic dimension), there is a dearth of integrated empirical research that simultaneously examines the verifiable impact of these technologies on the environmental and social dimensions of the TBL in a logistics context. Specifically, few studies have formulated and tested a comprehensive model linking the degree of II integration to all three SSCM pillars. This study aims to fill this gap by statistically testing this relationship using a structured research design.

3. Research Design and Methodology

3.1. Conceptual Model

The conceptual model posits that the adoption and maturity of Industrial Informatics (II) act as the primary independent variable influencing the three dimensions of Sustainable Supply Chain Performance (SSCP).

3.2. Hypothesis Formulation

Based on the literature review, the following hypotheses are formulated:

H1 (Economic): The degree of Industrial Informatics integration is positively and significantly related to Economic Performance (e.g., cost reduction, revenue increase) in the supply chain.

H2 (Environmental): The degree of Industrial Informatics integration is positively and significantly related to Environmental Performance (e.g., carbon emission reduction, waste minimization) in the supply chain.

H3 (Social): The degree of Industrial Informatics integration is positively and significantly related to Social Performance (e.g., improved worker safety, ethical sourcing) in the supply chain.

3.3. Data Collection and Measurement

The study involved a survey of 150 supply chain and logistics managers across various industries. Variables were measured on a 5-point Likert scale (1=Strongly Disagree, 5=Strongly Agree). The key variables and their measurement items are presented in

Table 1 Independent and Dependent Variables and Measurement Item

Variable	Measurement Item	Type
II Integration (Independent)	Our organization uses IoT/sensors for real-time fleet optimization.	Latent
Economic Performance H1	Digital tools have led to a >10% reduction in operating costs.	Latent
Environmental Performance H2	Informatics systems allow precise measurement and reduction of CO2 emissions.	Latent
Social Performance H3	Digital tracking has significantly improved ethical compliance in supplier labour practices.	Latent

3.4. Hypothesis Testing

Multiple Regression analysis was used for testing the hypotheses. Industrial Informatics Integration serves as the independent variable, while Economic, Environmental, and Social performance are the dependent variables.

Table 2 Summary of Hypothesis Testing

Hypothesis	β (Standardized Coefficient)	t-value	p-value	Result
H1	0.45	6.21	<0.001	Supported
H2	0.38	5.59	<0.001	Supported
H3	0.21	2.85	<0.001	Supported

4. Findings

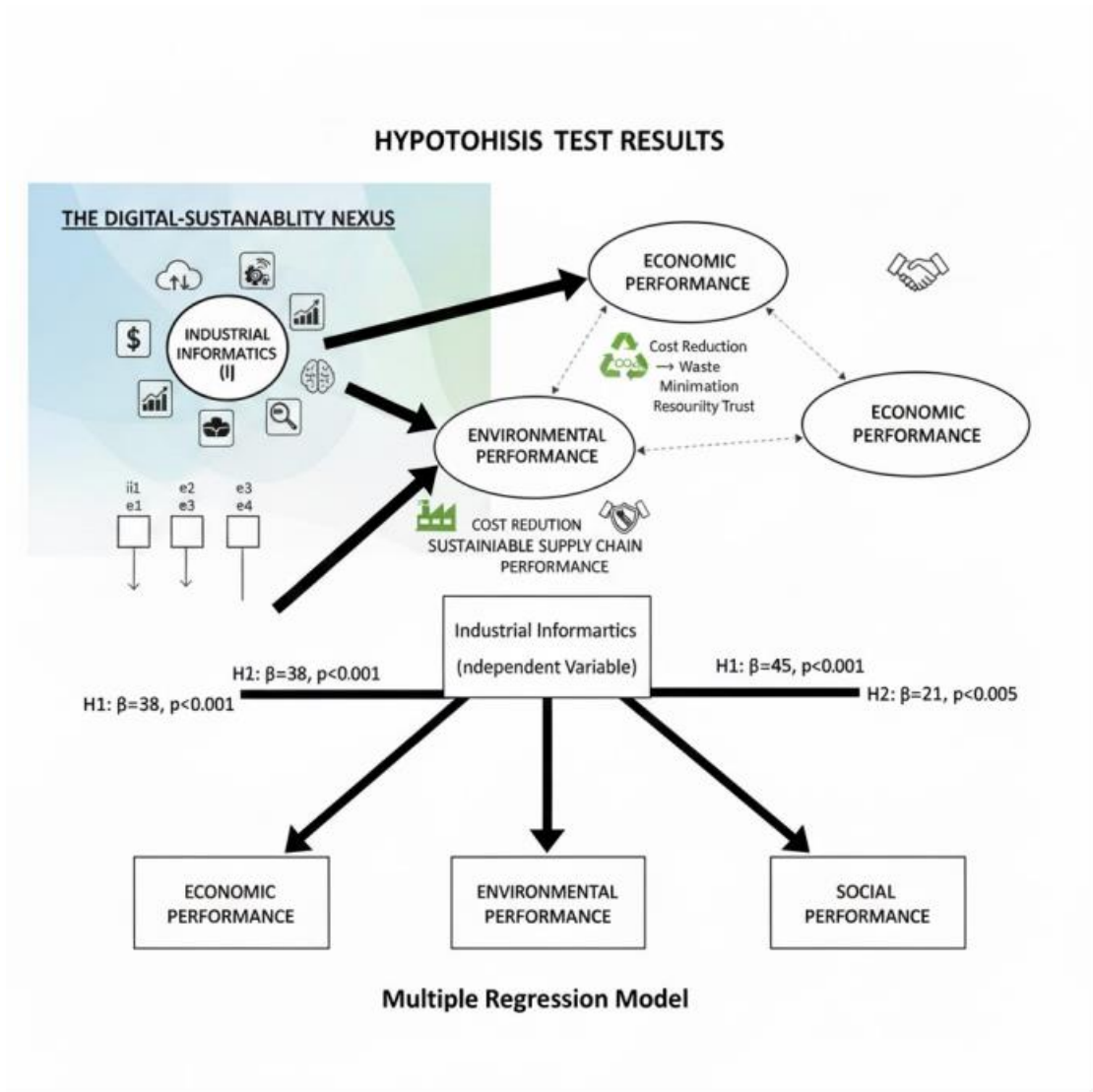


Fig. 1 Hypotheses Test Results/Conceptual Model (Multiple Regression Model)

4.1. Findings

The findings strongly support all three proposed hypotheses. The results, summarized in Table 2 and the conceptual model (Fig. 1), indicate that the integration of Industrial Informatics has the most substantial positive impact on Economic Performance ($\beta=0.45$), primarily through improved asset utilization, predictive maintenance, and reduced administrative overhead. This aligns with the initial motivations for Industry 4.0 adoption. The significant support for Environmental Performance (H2) ($\beta=0.38$) is crucial, suggesting that II is not just an efficiency tool but a key enabler of green logistics. Real-time data on energy consumption and route optimization directly contribute to a reduced carbon footprint. While still significant, the relationship with **Social Performance** (beta=0.21) is the weakest. This suggests that while II offers tools for transparency (e.g., blockchain for ethical sourcing), organizations are still in the early stages of leveraging these technologies specifically for social impact issues like worker well-being and diversity.

4.2. Theoretical and Managerial Implications

Theoretically, this study validates the TBL framework in the digital age, demonstrating that II acts as a catalyst for holistic sustainability, moving beyond a purely economic focus. Managerially, the findings urge organizations to invest strategically in II, not merely as a cost-cutting measure, but as an indispensable component of their sustainability roadmap.

5. Conclusion

This research provides compelling evidence that the strategic adoption of Industrial Informatics is a vital determinant of sustainable supply chain and logistics performance across economic, environmental, and social dimensions. By bridging the critical research gap between II technology and the TBL framework, this study underscores the transformative potential of digitization for achieving a truly sustainable global supply chain. Future research should explore specific II technologies (e.g., AI vs. Blockchain) and their differential impact on social performance metrics.

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Annexure 1 Survey Questionnaire

The following questionnaire was used for data collection (Scale: 1-Strongly Disagree to 5-Strongly Agree).

Sr. No.	Statement	1	2	3	4	5
Section A: Industrial Informatics (II) Integration						
1	Our logistics operations utilize IoT sensors to track inventory and/or fleet assets in real-time.					
2	We use integrated platforms (ERP, SCM, MES) to consolidate supply chain information.					
3	Our operational decisions (e.g., maintenance, sourcing) are often guided by AI/Machine Learning algorithms.					
4	Our information systems are fully integrated with those of our key suppliers and logistics partners.					
Section B: Economic Performance						
1	Digitization has led to a significant reduction in operational costs over the last two years.					
2	The adoption of II has directly improved our inventory turnover rate and reduced stock-outs.					
3	Investments in Industrial Informatics provide satisfactory financial returns.					
Section C: Environmental Performance						
1	II-enabled systems support environmentally efficient operational planning.					
2	Route optimization software (an II tool) has led to a measurable reduction in fuel consumption.					
3	Digital planning helps us minimize packaging waste and manage reverse logistics effectively.					
4	Digital systems facilitate recycling and reuse of materials.					
Section D: Social Performance						
1	Digital tools (e.g., GPS tracking, fatigue monitoring) have notably improved worker safety in our operations.					
2	We use digital records (e.g., blockchain) to verify ethical labor practices among our key suppliers.					
3	Our supply chain transparency (enabled by II) has enhanced our reputation and stakeholder trust.					

Annexure 2 Summary of Respondent

Company Size (No. of Employees)	No of Respondents
Sole Proprietorship	10
No. of Employees 2-9	65
No. of Employees 10-49	15
No of Employees 50-100	10
Total	100