

INTEGRATING BLOCKCHAIN AND ARTIFICIAL INTELLIGENCE FOR ENHANCED SUPPLY CHAIN TRANSPARENCY AND EFFICIENCY: A STUDY OF INDIAN MANUFACTURING FIRMS

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Abstract

The integration of digital technologies such as blockchain, artificial intelligence (AI), and the Internet of Things (IoT) is transforming supply chain management (SCM) by enhancing transparency, efficiency, and decision-making. These technologies address traditional challenges like inefficiencies, lack of visibility, and delays, driving the shift toward digital supply chains. However, barriers such as high implementation costs, limited technical expertise, and data security concerns hinder widespread adoption, particularly in sectors reliant on small and medium enterprises (SMEs). This study examines the drivers, challenges, and outcomes of digital technology adoption in the supply chains of Indian manufacturing firms. It highlights the critical role of integration, sector-specific strategies, and organizational readiness in ensuring successful implementation. The findings underscore the transformative potential of these technologies, offering actionable insights for industry stakeholders and policymakers to foster efficiency, resilience, and competitiveness in global markets.

INTRODUCTION

The advancement of digital technologies is reshaping industries in India, including supply chain management (SCM). As a critical component of global trade, supply chains require seamless collaboration among suppliers, manufacturers, distributors, and retailers. However, traditional models often struggle with inefficiencies, lack of transparency, and delays, resulting in higher costs and reduced competitiveness.

Technologies like blockchain, artificial intelligence (AI), and the Internet of Things (IoT) are transforming supply chains by improving transparency, efficiency, and decision-making. Blockchain ensures trust through its secure, transparent ledger, while AI leverages predictive analytics and machine learning to enhance demand forecasting, inventory management, and logistics. These advancements are accelerating the digital transformation of supply chains.

This study explores the factors influencing the adoption of digital technologies in SCM within Indian manufacturing. It provides insights for stakeholders to improve efficiency, enhance competitiveness, and support the transition to digital supply chains.

Sample Size Calculation

The sample size was calculated using the formula:

$$n = N / [1 + N(e)^2]$$

Where:

- n = Sample size
- N = Population size
- e = Acceptable sampling error (5%)

Assuming a population of N = 250,000 firms, the minimum required sample size n was calculated as follows:

$$n = 250,000 / [1 + 250,000(0.05)^2] = 399$$

To account for potential non-responses, the sample size was increased to **450 firms**, ensuring statistical robustness.

RESEARCH DATA ANALYSIS

The purpose of data analysis in this study is to apply suitable statistical tools to examine, transform, and model the collected data. The analysis aims to provide both descriptive and inferential statistical insights, enabling the validation of hypotheses and offering quantifiable, objective, and interpretable results.

Profile of Respondents

The sample includes responses from 430 firms across various sectors within Indian manufacturing. The demographic breakdown of respondents is as follows:

S. No	Parameter	Category	Count	%
1	Firm Size	Small	190	44.2
		Medium	140	32.6
		Large	100	23.2
2	Sector	Automotive	120	27.9
		Consumer Goods	110	25.6

		Pharmaceuticals	100	23.2
		Electronics	100	23.2
3	Geographic Region	Western India	140	32.6
		Southern India	130	30.2
		Northern India	90	20.9
		Eastern India	70	16.3

Descriptive Statistical Analysis

To analyze the central tendency and variability of the data:

1. **Adoption Rates:** On average, 65% of firms have adopted at least one digital technology, with medium-sized firms reporting the highest adoption rate at 73%.
2. **Performance Metrics:** Firms using digital technologies reported a 20% reduction in operational costs and a 30% improvement in delivery times.
3. **Barriers to Adoption:** The most significant barriers included high implementation costs (45%), lack of skilled personnel (30%), and data security concerns (25%).

Inferential Statistical Analysis

1. Exploratory Factor Analysis (EFA): EFA was conducted to identify key factors influencing digital technology adoption. Five components emerged:

1. Organizational Readiness
2. Cost Considerations
3. Technological Benefits
4. Perceived Barriers
5. External Environmental Factors

Factor loadings ranged from 0.72 to 0.89, indicating strong alignment of items within each factor.

2. Regression Analysis: Linear regression was performed to evaluate the impact of organizational, technological, and environmental factors on technology adoption. Results revealed:

Predictor Variable	Beta Coefficient (B)	p-value	Significance
Organizational Readiness	0.412	0.001	Significant
Cost Considerations	-0.290	0.003	Significant
Technological Benefits	0.368	0.000	Significant
Perceived Barriers	-0.220	0.002	Significant
External Environmental Factors	0.175	0.011	Significant

3. Structural Equation Modeling (SEM): SEM was used to test the relationships between adoption factors and supply chain performance metrics. The model demonstrated good fit indices:

- **Chi-square (χ^2):** 8.42, **p-value:** 0.015
- **Root Mean Square Error of Approximation (RMSEA):** 0.04
- **Comparative Fit Index (CFI):** 0.96

Key relationships identified:

- Digital technology adoption positively impacts supply chain transparency ($\beta = 0.47$, $p < 0.001$).
- Integration of blockchain and AI significantly reduces operational inefficiencies ($\beta = 0.39$, $p < 0.01$).

4. Hypothesis Testing:

Hypothesis	Result
Organizational, technological, and environmental factors influence adoption.	Supported
Blockchain enhances supply chain transparency and accountability.	Supported
AI improves operational efficiency and decision-making.	Supported
Integration of blockchain and AI impacts performance metrics.	Supported
Barriers significantly hinder adoption rates.	Supported

The data analysis confirms that digital technologies significantly enhance supply chain performance. The study highlights critical drivers and barriers influencing adoption, providing empirical evidence to support actionable recommendations for Indian manufacturing firms. Additional insights from SEM indicate that strategic integration of blockchain and AI yields substantial efficiency gains and competitive advantages.

Conclusions:

The research highlights the transformative potential of blockchain and AI technologies in revolutionizing supply chain management. These innovations significantly improve transparency, efficiency, and risk management, while their integration addresses inefficiencies and strengthens supply chain resilience. However, challenges such as high implementation costs, skill gaps, and data security concerns necessitate proactive measures, including government support, workforce training, and collaborative partnerships. To maximize their impact, adoption strategies must be tailored to address sector-specific needs and opportunities. Moreover, key factors such as organizational readiness, strong leadership, and supportive regulatory frameworks play pivotal roles in ensuring successful implementation. Looking ahead, digital transformation driven by these technologies is essential for maintaining global competitiveness. Further research on scalable and industry-specific frameworks is critical to unlocking their full potential and paving the way for sustainable and resilient supply chains.

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