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Impact of Blockchain Technology on Supply Chain Traceability and Performance in Indian Automotive Manufacturing Sector

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Abstract— **The automotive manufacturing business in India is faced with an increasing concern of transparency, traceability and effectiveness in the supply chain. Due to the existence of counterfeit parts, multi-level suppliers and other issues in supply chain, the traditional methods are not sufficient. Blockchain technology has the potential to be used as an alternative due to its capability to ensure secure and unchangeable records in the supply chain. This research explores how blockchain technology impacts supply chain traceability and supply chain performance in the Indian automotive manufacturing sector, examining the level of uptake of blockchain technology, the drivers and barriers of adoption, and the impact of blockchain-based traceability on supply chain effectiveness. The literature shows that blockchain enhances supply chain resilience, efficiency and integration, but digital maturity — a crucial element in the automotive sector — has rarely been considered alongside adoption in earlier studies. Trust, organizational preparedness and regulatory forces have been identified as influential in the adoption process, yet literature specific to blockchain adoption in the Indian automotive industry remains scant. A quantitative cross-sectional research design was adopted, with data collected from 202 respondents working in supply chain management, logistics, procurement and operations through a 31-item, five-point Likert-scale questionnaire. Data were analysed using Partial Least Squares Structural Equation Modeling (PLS-SEM); reliability and validity were evaluated using Cronbach's alpha, composite reliability and Average Variance Extracted (AVE); and path coefficients, T-values, P-values and R-square were used to analyse the structural model. Findings indicate that environmental drivers and barriers have high significance in influencing blockchain adoption, whereas technological and organizational drivers have no significant effect. Blockchain adoption significantly influences blockchain-based traceability, confirming its role in enhancing supply chain transparency. Digital maturity has a strong direct influence on supply chain performance and significantly moderates the impact of blockchain adoption on performance.**

Keywords— **Automotive manufacturing, Blockchain, Blockchain adoption, Digital maturity, Supply chain traceability**

I. INTRODUCTION

The automotive manufacturing sector in India boasts one of the highest automobile market turnovers in the worldwide automobile industry, contributing an approximate 7.1 percent of the total gross domestic product of India and providing direct and indirect employment to over 37 million people (SIAM, 2024). Due to the changing nature of global supply chains in an interconnected business environment, companies in the automotive industry are increasingly pressured to assure product authenticity, traceability, regulatory compliance and operational visibility. Centralised supply chain management systems, mainly based on ERP platforms, have been linked with low traceability as data is not interconnected and remains susceptible to manipulation.

This has made the use of blockchain technology as a disruptive innovation for achieving traceability and transparency across supply chains a reality. The fundamental aspects of blockchain — decentralisation, immutability, cryptography and distributed consensus — enable blockchain-based systems to provide immutable, time-stamped transaction records stored in a distributed ledger. Such systems can be especially useful in automotive supply chains to guarantee the traceability of parts, eliminate counterfeiting and enable effective management of product recalls (Al-Swidi et al., 2024).

Despite the enormous potential and success of blockchain in fields such as food, medicine and finance, its application in the Indian manufacturing supply chain setting remains at an initial stage. Owing to the multi-tier ecosystem of Tier I, II and III suppliers in the automotive industry, numerous problems are associated with blockchain adoption, including high implementation costs, integration with legacy systems, low digitalisation among smaller companies, and lack of standardisation (Singh et al., 2023).

This paper squarely addresses that challenge. The research has three objectives: first, to quantify the extent of blockchain technology use among automotive OEMs and suppliers; second, to identify the factors that drive and inhibit adoption; and third, to empirically determine whether and how blockchain-enabled traceability leads to better supply chain performance through the mediating effect of traceability and the conditioning effect of organizational digital maturity. The findings will be useful to both scholarly research and practitioners engaged in blockchain integration within the manufacturing sector of a developing economy.

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II. Literature Review

Bhardwaj et al. (2021) explore the variables that drive blockchain adoption among small and medium enterprises, concluding that the technology enhances transparency, data security and trust in supply chain management, while high implementation costs, lack of awareness and lack of skills remain severe barriers to adoption.

Khanfar et al. (2021) present a systematic review of blockchain applications in sustainable manufacturing supply chains, finding that blockchain enhances traceability and data accountability through immutable transaction records, though most existing studies remain theoretical rather than empirical.

Raja Santhi and Muthuswamy (2022) discuss how blockchain increases transparency, security and traceability of supply chain information by enabling trusted information sharing, in a study that is largely theoretical and highlights the need for empirical research.

Hader et al. (2022) propose integrating blockchain and big data to enhance traceability and visibility in textile manufacturing supply chains, showing that blockchain assists efficient tracking of information and material flow, though the study is confined to a single industry.

Singh et al. (2023) reveal, in a Delphi-based study of the construction supply chain, that blockchain contributes to greater contract transparency, traceability and stakeholder coordination, although adoption remains difficult due to regulatory and technical challenges.

Al-Swidi et al. (2024) study the relationship between blockchain adoption and supply chain performance in the automotive sector, finding that blockchain implementation improves traceability, information exchange and operational effectiveness, with organizational readiness and technical capability as key success factors.

Vu et al. (2025) use a simulation-based approach to show that blockchain enhances tracing accuracy, reduces delays and improves transparency in the food industry, while emphasising the need for empirical research in real-world settings.

III. Research Gap

The literature review reveals the following gaps:

- The unavailability of India-specific studies on the extent of blockchain adoption and its effect on supply chain traceability.
- The lack of quantitative research establishing the correlation between the degree of blockchain implementation and traceability performance measures.
- The lack of focus on sectoral diversity in India, i.e. small and medium enterprises (MSMEs) as opposed to large companies.
- The lack of examination of organizational readiness and implementation barriers that affect blockchain effectiveness.

IV. Objectives

- To ascertain the level of use of blockchain technology in the Indian automotive manufacturing supply chain.
- To determine the major drivers of and obstacles to blockchain adoption.
- To measure the relationship between blockchain-based traceability and supply chain performance.

V. Hypotheses

H01: Technological drivers have no significant influence on blockchain adoption. H1: Technological drivers have a significant positive influence on blockchain adoption.

H02: Organizational drivers have no significant influence on blockchain adoption. H2: Organizational drivers have a significant positive influence on blockchain adoption.

H03: Environmental drivers have no significant influence on blockchain adoption. H3: Environmental drivers play a significant positive role in blockchain adoption.

H04: Barriers do not play a significant role in blockchain adoption. H4: Barriers have a significant influence on blockchain adoption.

H05: Blockchain adoption has no significant impact on blockchain-based traceability. H5: Blockchain adoption exerts a substantial positive effect on blockchain-based traceability.

H06: Blockchain-based traceability does not significantly affect supply chain performance. H6: Blockchain-based traceability significantly and positively influences supply chain performance.

H07: Blockchain-based traceability does not mediate the relationship between blockchain adoption and supply chain performance. H7: Blockchain-based traceability significantly mediates the relationship between blockchain adoption and supply chain performance.

H08: Digital maturity does not moderate the relationship between blockchain adoption and supply chain performance. H8: Digital maturity significantly moderates the relationship between blockchain adoption and supply chain performance.

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VI. Conceptual Framework

This study employs the Technology-Organization-Environment (TOE) theory, the Resource-Based View (RBV), and the Dynamic Capabilities Theory (DCT) to understand the effects of blockchain adoption on supply chain performance. The TOE theory explains how technological, organizational and environmental factors, together with perceived barriers, influence the degree of blockchain adoption.

RBV theory supports the notion that blockchain adoption and traceability act as strategic capabilities for transparency, efficiency and trust, thereby enhancing supply chain performance.

The Dynamic Capabilities Theory emphasises the importance of digital maturity for the successful use of blockchain technologies. Digital maturity enhances the effect of blockchain adoption by moderating its influence on supply chain performance. PLS-SEM was used for analysis owing to its suitability for handling complex, prediction-oriented models.

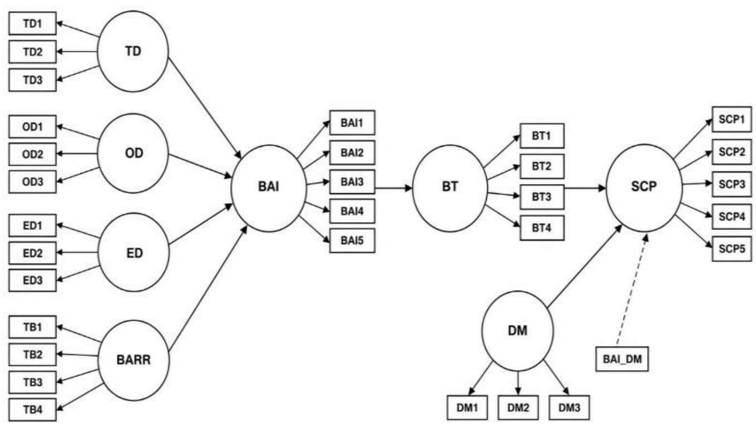

Fig. 1. SEM Model

VII. RESEARCH METHODOLOGY

A. Research Design

This study adopted a quantitative cross-sectional design, implying a single point of data collection through a structured questionnaire. The purpose was to comprehend the current level of blockchain adoption and to test the relationships between the study variables.

B. Population and Sampling

The population comprised professionals in the Indian automotive manufacturing industry dealing with supply chain and operations, including supply chain managers, logistics managers, procurement heads and operations executives. A non-probability convenience sampling method was employed owing to time constraints and the absence of a detailed sampling frame; the questionnaire was administered through online platforms such as LinkedIn, professional groups and personal networks. Purposive sampling further ensured that participants possessed relevant knowledge and experience of supply chain activities.

C. Data Collection

Data were collected between February and April 2026 through an online survey distributed via LinkedIn, professional groups and email. Two hundred and two valid responses were obtained, an adequate sample size for the intended analysis.

D. Measurement Instrument

The questionnaire consisted of 31 items measured on a five-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree), covering the constructs of Technological Drivers (TD), Organizational Drivers (OD), Environmental Drivers (ED), Barriers, Blockchain Adoption (BAI), Blockchain Traceability (BT), Supply Chain Performance (SCP) and Digital Maturity (DM).

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E. Data Analysis

Data analysis proceeded in three steps. Step 1 assessed reliability and internal consistency using Cronbach's alpha. Step 2 examined relationships between variables using Pearson correlation. Step 3 tested the hypotheses using regression analysis (to assess the influence of drivers and barriers on blockchain adoption), a digital-maturity moderation test, and Structural Equation Modeling (SEM). PLS-SEM was selected for its suitability for complex, prediction-oriented models and relatively small sample sizes.

VIII. Descriptive Statistics

Table I presents the mean scores of each construct, averaged across the items constituting each composite. Technological Drivers recorded the highest mean (TD: M = 3.911), indicating strong agreement that blockchain offers significant technological value to supply chain management. Blockchain Traceability (BT: M = 3.835) and Supply Chain Performance (SCP: M = 3.850) were also rated moderately to highly. Blockchain Adoption Intensity (BAI: M = 3.46, SD = 1.376) fell mid-scale, consistent with an industry actively moving from pilots toward implementation. Standard deviations were comparatively high for BAI and Barriers (SD = 1.346), indicating considerable variation in perceptions across respondents.

TABLE I.
DESCRIPTIVE STATISTICS

Construct	Code	Mean	SD	Interpretation
Blockchain Adoption Intensity	BAI	3.46	1.376	Early mainstream
Technological Drivers	TD	3.911	1.131	High perceived tech benefit
Organisational Drivers	OD	3.69	1.224	Moderate–high org. readiness
Environmental Drivers	ED	3.69	1.262	Moderate–high external pressure
Barriers	BARR	3.572	1.346	Moderate–high barrier perception
Blockchain-Based Traceability	BT	3.835	1.231	High traceability capability
Supply Chain Performance	SCP	3.85	1.208	High performance perception
Digital Maturity	DM	3.71	1.275	Moderate–high digital readiness

IX. Reliability And Validity

The measurement model was assessed for reliability and validity prior to estimating the structural model path estimates. Results are shown in Table II. Cronbach's alpha exceeded the minimum acceptable level of 0.70 for all constructs; six constructs exceeded the 'Good' threshold (0.80), and two (BAI and SCP, at 0.925 and 0.919 respectively) approached the 'Excellent' threshold ($\alpha > 0.90$). Composite Reliability (CR) ranged from 0.810 to 0.942, exceeding the minimum acceptable level of 0.70. Average Variance Extracted (AVE) ranged from 0.636 to 0.786, all above the required 0.50 threshold, signifying good convergent validity.

TABLE II. RELIABILITY AND VALIDITY

Construct	Cronbach's α	CR	AVE
BAI	0.925	0.942	0.771
SCP	0.919	0.931	0.755
Barriers	0.910	0.916	0.786
OD	0.826	0.864	0.738
TD	0.811	0.862	0.636
ED	0.832	0.840	0.748
BT	0.828	0.836	0.659
DM	0.808	0.810	0.723

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X. Correlation Analysis

Table III presents the correlations between all variables. Diagonal values represent the square root of AVE; since all diagonal values exceed the corresponding row and column values, discriminant validity is established. Blockchain Adoption Intensity (BAI) is highly correlated with Barriers (r = 0.841), suggesting organizations implementing blockchain also become acquainted with its barriers. BAI also shows a very strong relationship with the Interaction term (r = 0.952), reflecting their direct construction from related items. Environmental Drivers are positively correlated with Organizational Drivers (r = 0.734).

TABLE III. CORRELATION MATRIX

	BAI	BT	BARR	DM	ED	Inter.	OD	SCP	TD
BAI	1	0.644	0.841	0.707	0.753	0.952	0.722	0.758	0.547
BT	0.644	1	0.547	0.686	0.636	0.729	0.738	0.46	0.575
BARR	0.841	0.547	1	0.657	0.655	0.849	0.684	0.73	0.609
DM	0.707	0.686	0.657	1	0.623	0.868	0.603	0.47	0.52
ED	0.753	0.636	0.655	0.623	1	0.779	0.734	0.667	0.602
Interaction	0.952	0.729	0.849	0.868	0.779	1	0.765	0.727	0.627
OD	0.722	0.738	0.684	0.603	0.734	0.765	1	0.681	0.727
SCP	0.758	0.46	0.73	0.47	0.667	0.727	0.681	1	0.612
TD	0.547	0.575	0.609	0.52	0.602	0.627	0.727	0.612	1

XI. SEM Analysis

Path coefficients of the structural model were tested statistically to examine the hypotheses. T-values above 1.96 and P-values below 0.05 were regarded as significant, and beta (β) values indicate the strength and direction of each relationship. Results show that technological and organizational drivers do not significantly influence blockchain adoption ($P > 0.05$), whereas environmental drivers and barriers significantly and positively influence adoption.

Blockchain adoption positively and significantly influences blockchain traceability, indicating that deeper blockchain implementation improves supply chain traceability. However, blockchain traceability does not directly and significantly affect supply chain performance, given the relatively weak correlation between BT and SCP. Digital maturity significantly affects supply chain performance, and the interaction effect between blockchain adoption and digital maturity is also significant, indicating that digitally mature organizations derive greater performance benefits from blockchain adoption. Although the direct effect of traceability on performance is non-significant, the indirect effect was found to be significant, indicating indirect-only mediation.

TABLE IV. HYPOTHESIS TESTING

Hyp.	Relationship	β	T-value	P-value
H1	TD → BAI	-0.126	1.547	0.122
H2	OD → BAI	0.200	1.512	0.131
H3	ED → BAI	0.294	2.653	0.008
H4	Barriers → BAI	0.591	5.122	0.000
H5	BAI → BT	0.650	10.689	0.000
H6	BT → SCP	-0.080	0.494	0.621
H7	DM → SCP	-0.612	2.911	0.004
H8	Interaction → SCP	1.325	7.016	0.000

XII. R-Square Interpretation

The R^2 for Blockchain Adoption (BAI) is 0.793, indicating that technological, organizational, environmental and barrier factors explain 79.3% of the variance in blockchain adoption.

The R^2 for Blockchain Traceability (BT) is 0.415, indicating that 41.5% of the variance in traceability is explained by blockchain adoption. The R^2 for Supply Chain Performance (SCP) is 0.636, indicating that 63.6% of the variance in supply chain performance is explained by traceability, digital maturity and their interaction effect.

TABLE V. REGRESSION (R^2) VALUES

Construct	R^2	Interpretation
BAI	0.793	Strong
BT	0.415	Moderate
SCP	0.636	Strong

XIII. Findings

Environmental drivers and barriers have a major impact on firms' blockchain adoption decisions. Competition, regulations and industry trends are key drivers of adoption behaviour, while the significance of barriers evidences those organizations' awareness of implementation issues and their consideration in decision-making.

Technological and organizational drivers show no significant influence on adoption decisions, suggesting that organizational preparedness and management willingness are not currently the most critical factors.

Blockchain adoption has a strong positive impact on blockchain-based traceability, confirming that adoption results in better supply chain visibility. However, no significant relationship was found between blockchain traceability and supply chain performance directly.

Digital maturity significantly influences supply chain performance, with highly digitally ready organizations performing more effectively. The interaction between digital maturity and blockchain adoption is significant, indicating that digital maturity is a prerequisite for organizations to fully benefit from blockchain technology.

XIV. Conclusion

The study reveals that blockchain technology implementation enhances supply chain traceability in the Indian automotive manufacturing sector, while its impact on supply chain performance is moderate. Adoption of blockchain is primarily influenced by environmental drivers and barriers. Digital maturity emerges as a major factor in enhancing performance, indicating that blockchain adoption is likely to translate into improved supply chain performance only when organizations are digitally ready.

Organizations should focus on developing digital maturity through advanced digital technologies such as IoT, cloud computing and big data analytics to maximise the benefits of blockchain adoption. Given the identified barriers, companies should develop strategies to counter high implementation costs, the lack of technical expertise and implementation challenges. Firms in the automotive industry must also account for external factors that significantly contribute to technology adoption, rather than relying on blockchain alone to improve performance.

XV. Limitations

The study has certain limitations. First, a convenience sample was used, which may affect the external validity of the findings. Second, the research was cross-sectional; hence, the data reflect trends only during the study period and may not represent change over time.

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