A Review of factors impeding the adoption of AI and Blockchain in the Indian Logistics Ecosystem, thus Bridging the Digital Divide

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Abstract:

Logistics is the backbone of businesses across the world. Efficiency in logistics leads to measurable efficiency and has a major impact on the economy of a country. The Indian logistics sector has been in focus in recent times and policy-driven upgrades are underway. Artificial Intelligence (AI) and Blockchain Technology (BT) are the main driving forces in this upgradation. Despite a strong economic foundation, and a projected Compound Annual Growth Rate (CAGR) of 10.7% until 2026 **(Government of India, 2025)**, the logistics industry faces a paradox: high technological potential is severely undermined by low, uneven adoption rates **(Nicolas de Bellefonds et al., 2024)**. This study uses a systematic literature review and the integrated Technology-Organization-Environment (TOE) and Task-Technology Fit (TTF) frameworks **(Wong, S et al., 2024)** to understand the critical barriers slowing down the deployment of AI and BT. The primary findings reveal that the most critical adoption barriers are organizational and environmental, and not technological. Specifically, the organizational dimension is stunted by the high economic friction within the heavily fragmented Micro, Small, and Medium Enterprises (MSME) sector **(Amit Kapoor et al., 2025),** which face immense capital expenditure demands **(Li et al., 2024)** and limited access to formal credit (a credit gap estimated at 24%) **(SIDBI, 2025).** Environmentally, the lack of standardized data protocols (**Yadlapalli A, Rahman S, Gopal P (2022; Kaur, J., et al., 2022**), lack of regulations regarding Distributed Ledger Technology (DLT) governance (**NITI Aayog, 2020**), and continuous physical infrastructure deficits (**NLDSL, n.d.**) together erode the perceived value and trustworthiness of these technologies. The analysis discovers that a strategic digital divide exists, wherein policy efforts like the Unified Logistics Interface Platform (ULIP) are pulled down by bottom-up operational resistance stemming from financial fragility and human capital deficits (**NITI Aayog, 2025; NLDSL, n.d.**). The study proposes strategic recommendations, advocating operational expenditure (OpEx) models, compulsory data standardization, and timely regulatory clarity concerning DLT legal frameworks (**NITI Aayog, 2020**) to ensure India's digital transformation efforts bear measurable improvements in logistics efficiency and cost reduction (currently 7.97% of GDP) (**DPIIT/NCAER, 2025; ITLN, 2025**).

Keywords:

Indian Logistics, Digital Divide, Artificial Intelligence (AI), Blockchain Technology (BT), Technology Adoption Barriers, MSMEs, Supply Chain Management (SCM), Technology-Organization-Environment (TOE).

Introduction:

1.1. Context of the Indian Logistics Sector: The Paradox of Growth and Efficiency

The logistics industry is the primary enabler of the Indian economy, powering sectors across the spectrum, like retail, manufacturing, agriculture, e-commerce etc. Logistics involves managing diverse and complex processes like inventory management, multi-modal transportation, warehousing, distribution etc **(Government of India, 2025).** Already at a valuation of almost USD 215 billion in 2021, the sector anticipates a strong Compound Annual Growth Rate (CAGR) of 10.7% through 2026 **(Government of India, 2025)**. The Government of India has granted the sector infrastructure status which leads to cheaper access to capital and long-term financing **(Government of India, 2025).** The sector provides employment to over 22 miliion people and as economic activity intensifies it will lead to creation of further jobs **(Government of India, 2025).**

While the scaleof the sector is huge and the growth is rapid, there is a persistent efficiency paradox. High logistics costs—estimated at approximately 7.97% of the national Gross Domestic Product (GDP) for 2023-24—continue to mar our global trade competitiveness (**DPIIT/NCAER, 2025; ITLN, 2025**). These high costs are due to long-pending structural weaknesses, including weakness of infrastructure, highly fragmented supply chains (**3SC Solution, n.d.**), and a dependence on legacy, manual practices. Structural issues, such as subpar roads, congestion in the infra, and a needlessly complicated tax regime, lead sub-optimal transit time (**NLDSL, n.d.; Lawyered.in, 2022**). Further, majority of the big ports have high turnaround times, overcrowding, and lack of depth, which slows down our supply chains considerably (**NLDSL, n.d.**).

To remediate these issues, the Government of India has launched policy initiatives like the National Logistics Policy (NLP) 2022 and PM GatiShakti, that aim to modernize infrastructure, reduce costs, and establish a data-driven support mechanism (**Government of India, 2025; DPIIT/NCAER, 2025**). Digitalization is the key to this strategy, and platforms like the Unified Logistics Interface Platform (ULIP) are designed to increase efficiency and boost transparency in the supply chains (**Government of India, 2025**).

1.2. Artificial Intelligence (AI) and Blockchain (BT) as Industry 4.0 Enablers

Latest Industry 4.0 technologies, like Artificial Intelligence (AI) and Blockchain Technology (BT), offer revolutionary solutions required to resolve the efficiency paradox. The expected growth and heavy demand for these technologies shows their strategic importance. For example, the use of India AI in the Logistics market is projected to surpass a CAGR of 31.66%**,** and the India Blockchain Supply Chain market is projected to reach USD 8,825 million by 2035, driven by a mind-boggling CAGR of 51.58% (**Aarti Dhapte, 2025).**

AI's strength is its agility and responsiveness (**Acharya, S., Gharia, R., & Kapooria, P. (2025)**. AI-driven products such as predictive analytics and route optimization allow its users to forecast demand patterns accurately and improve the efficiency of logistics (**Acharya, S., Gharia, R., & Kapooria, P. (2025).** Other than efficiency, AI is useful for achieving our sustainability goals, like reducing carbon footprints, optimizing the resource utilization, and establishing a circular economy through optimisation of reverse logistics for recycling and refurbishment (**Hasan, 2025).**

Blockchain Technology (BT), a.k.a Distributed Ledger Technology (DLT), resolves the fundamental problem of trust in the fragmented supply chains (**Ali, n.d.; Noor, A, 2022**). BT significantly enhances traceability and accountability, by providing an immutable, transparent, and secure record. This is mandatory for sectors like agriculture and pharmaceuticals where product integrity and authenticity are paramount (**Vu, N., Ghadge, A., & Bourlakis, M. (2021**). Various studies have affirmed that the adoption of BT can provide an edge to Logistics Service Providers (LSPs) by improving performance through increased transparency and security (**Ali, n.d.; Noor, A, 2022**).

1.3. Outlining the Strategic Research Problem

The amalgamation of tremendous market opportunity, strong governmental intent, and the increasing capabilities of AI and BT creates an expectation of rapid digital transformation. However, majority of the companies are failing to achieve and scale tangible value from AI. While companies have allocated investments, hired new talent, and launched pilots, only 22% of companies have gone beyond the proof-of-concept stage to generate any kind of value, and only 4% are able to create substantial value (**Nicolas de Bellefonds et al., 2024**). This research has identified the failure to bridge the existing Digital Divide as the main problem. While digitally mature enterprises have access to technology the vast majority of Micro, Small, and Medium Enterprises (MSMEs) dominating the logistics landscape, don't have this access. Furthermore, the structural and economic chasm separating them makes matters worse for the MSMEs.

1.4. The Scope of the Digital Divide

This paper studies how the existing structural issues like financial vulnerability, heterogeneity, and informal practices of MSMEs (**SIDBI, 2025; Amit Kapoor et al., 2025**), along with the uneven physical and digital infrastructure (**NLDSL, n.d.**) act as strategic barriers. These barriers hinder the scaled adoption of AI and BT, ultimately undermining the national policy objectives of improved logistics efficiency. The study further categorizes these hindrances using established theoretical frameworks to provide actionable inputs.

Objective of Study:

The primary objective of this study is to conduct a holistic review and systematic classification of the strategic barriers inhibiting the widespread and scalable adoption of Artificial Intelligence (AI) and Blockchain Technology (BT) across the Indian logistics ecosystem.

The specific objectives are:

1. To use the Technology-Organization-Environment (TOE) framework and identify, categorize, and prioritize the key barriers to AI and BT adoption.

2. To investigate the specific organizational constraints imposed by the fragmented structure of the MSME sector, with focus on the economic friction and human capital deficits.

3. To analyse how deficiencies in data standardization and physical infrastructure lead to technological bottlenecks, thus impeding the use of AI for predictive modelling and optimization.

4. To study the impact of the current regulatory and policy environment, the status of DLT governance and the implementation challenges faced by national platforms like ULIP.

5. To recommend actionable, strategic interventions targeted at policymakers and the industry to tide over these barriers and bridge the digital divide.

Hypothesis:

H1: The primary barrier to adoption of AI and Blockchain is not lack of access to technology but, fragility of structure and economic limitations of MSMEs (Organizational Dimension) in particular the high Capital Expenditure required (CapEx) (**Li et al., 2024**) and complexity associated with the adoption of technology.

H2: The adoption of national centralized digital platforms like ULIP and decentralized solutions like DLT is primarily inhibited by pre-existing industry deficiencies in data standardization (**Kaur, J., et al., 2022**) and multi-party trust, aggravated by regulatory ambiguity about the governance of DLT (**NITI Aayog, 2020**).

Research Gap:

In India,the existing research on logistics technology adoption primarily focuses on infrastructural deficiencies or the general benefits of digitalization. Few studies have addressed barriers to blockchain implementation in supply chains using specific methodologies like the Analytical Hierarchy Process (AHP) (**Yadlapalli A, Rahman S, Gopal P (2022**), and others have explored AI's impact on manufacturing logistics (**Acharya, S., Gharia, R., & Kapooria, P. (2025). However,** a significant gap remains.

There is a lack of integrated research that comprehensively addresses the strategic barriers faced by both AI (a data-centric technology) and BT (a trust-centric technology) while maintaining the integrity of the context (**Wong, S et al., 2024; Martin, P et al, 2025**). Also, prior analyses frequently miss the context of India's unique structural characteristics like the overwhelming reliance on informal MSMEs (**NITI Aayog, 2025**) and the concurrent, yet disparate, developments in the regulatory landscape of the country (**NITI Aayog, 2020; NLDSL, n.d.**).

This paper combines the Technology-Organization-Environment (TOE) and Task-Technology Fit (TTF) frameworks (**Wong, S et al., 2024**) to conduct a dual-technology analysis, targeting the economic and human capital constraints specific to the Indian MSME sector (**SIDBI, 2025; NITI Aayog, 2025**), thus addressing the gap. This approach provides a meticulous understanding of causality, that reveals how macro-environmental factors and organizational weaknesses systematically undermine the perceived functional fit (TTF) (**Wong, S et al., 2024**) of these advanced technologies, further worsening the Digital Divide.

Literature Review:

3.1. Theoretical basis and assumptions of Technology Diffusion

The adoption of sophisticated technologies such as AI and BT is a complicated process influenced by factors much more than technological capability. Theoretical models are critical for structuring the analysis of these drivers and inhibitors.

The Technology-Organization-Environment (TOE) Framework

The Technology-Organization-Environment (TOE) framework offers a discerning lens for evaluating the adoption of technology across sectors and industries (**Li et al., 2024; Wong, S et al., 2024**). The TOE framework posits that a firm's decision to adopt and implement a new technology is influenced by three intermingling contexts:

1. **Technological Context (T):** Technologies relevant to the firm (Internal and external), complexity, compatibility with the existing systems, and perceived relative advantage (**Li et al., 2024**).

2. **Organizational Context (O):** This includes descriptive factors about the firm, such as size, management structure, financial strength, and human capital (**Li et al., 2024**).

3. **Environmental Context (E):** This includes factors like industry structure, competitors, government regulation, and external infrastructure (**Li et al., 2024**).

In emerging markets like India, the Environmental Context is extremely dynamic due to continuous policy interventions (e.g., NLP, GatiShakti) (**Government of India, 2025**), while organizational constraints, particularly MSME fragmentation, are critical (**Amit Kapoor, Shein Zutshi & Mukul Anand, 2025**). For successful adoption, the technology (T) must not only be superior but also display a clear Task-Technology Fit (TTF). If a technology seems incompatible with existing processes or is too complex to manage by the current set of people, the adoption process stalls invariably (**Wong, S et al., 2024**).

Task-Technology Fit (TTF) and Acceptance Models

Complementary models, such as the Unified Theory of Acceptance and Use of Technology (UTAUT) and the Task-Technology Fit (TTF) model, focus on the user-centric aspect of adoption. TTF specifically examines whether a technology adequately supports the performance of the user's tasks. For blockchain applications in supply chains, **Wong, S et al. (2024)** indicated that very little attention has historically been paid to check whether the technology actually fits the users' tasks. This is crucial for in India, where ground-level operations are often informal (**NITI Aayog, 2025**). If the technology, whether AI for prediction or BT for transaction recording, requires a dramatic and costly overhaul of established informal practices, it will be rejected regardless of its supposed benefits. Also, since there is a persistent lack of digital literacy among certain segments of the workforce (**NLDSL, n.d.**) individual acceptance has to be addressed through training, in alignment with UTAUT principles (**Wong, S et al., 2024**)

3.2. AI in Logistics: Benefits, Requirements, and Data Friction

Artificial Intelligence, including Machine Learning (ML) and predictive analytics, is acclaimed globally as a tool to improve supply chain resilience and optimise operational performance. In India, AI can dramatically optimize resource utilization and cut operational costs significantly. The applications are far-reaching, including inventory management, route planning, and customs clearance (**Acharya, S., Gharia, R., & Kapooria, P. (2025)**.

The Data Dependence Challenge

While there are clear benefits, AI adoption faces a fundamental challenge: it needs humongous amounts of clean, structured data for training and execution. This data is simply not available in the current operational scenario in India's logistics sector. Most firms utilize outdated procedures and paper-based systems, which introduce errors, delays, and coordination failures. (**NLDSL, n.d.; Lawyered.in, 2022**).

As a consequence of this data chaos, the necessary input for training effective AI models is substantial and costly (**Acharya, S., Gharia, R., & Kapooria, P. (2025)**. The challenge is not just the technology but the foundational effort required to transform huge, unstructured datasets into formats usable by AI/Large Language Models (LLMs) (**Anirudh Suri, 2025**). This labour-intensive transformation is a compulsory for reliable AI value generation, and the inability to complete this task undermines the technology's performance and usefulness (**Acharya, S., Gharia, R., & Kapooria, P. (2025).** Furthermore, poor physical infrastructure such as congestion, poor landside facilities, and high ship turnaround times causes delays and unpredictability in real-time operations (**NLDSL, n.d.; Lawyered.in, 2022**), resulting in inconsistent data flow for AI systems.

3.3. Blockchain Technology (BT): Trust Protocols and Integration Friction

Blockchain Technology offers a way to overcome the systemic trust deficits and lack of standardization endemic to fragmented logistics networks (**Ali, n.d.; Noor, A, 2022**). By providing a shared, immutable ledger, BT improves accountability, improving transparency and security for all stakeholders, particularly in multi-party scenarios (**Ali, n.d.**).

The Interoperability Crisis and Integration Friction

The theoretical advantages of BT are limited by technical and organizational integration difficulties. Integrating Distributed Ledger Technology (DLT) platforms with existing Enterprise Resource Planning (ERP) systems and other legacy software represents a prominent challenge (**Li et al., 2024; World Bank, n.d.**). The lack of compatibility between the firms' existing software and emerging blockchain technologies is a recognized hurdle (**Li et al., 2024**). This lack of interoperability (TB3) is exacerbated by a ubiquitous lack of standardization (TB5) across the industry (**Kaur, J., et al., 2022**).

This situation forces logistics operators to re-evaluate the costs involved in making the switch to the new technologies. **Li et al. (2024)** noted that some firms prefer a "good-enough solution without blockchain" when participants are trust worthy. Adopting BT requires costly, non-standardized protocol integration across a firm's partner network (**Li et al., 2024**), transforming BT adoption into an expensive, multi-party coordination challenge. Furthermore, security concerns also discourage firms from sharing commercially sensitive data on a blockchain due to the perceived possibility of losing control (**Kaur, J., et al., 2022**).

3.4. The Indian Policy Ecosystem: ULIP and NBF

The Indian government has been very proactive and has established frameworks to accelerate digitalization. For example, the Digital India initiative, focuses on developing secure digital infrastructure, providing digital government services, and achieving universal digital literacy (**Institute for Economics and Peace, n.d.**).

Unified Logistics Interface Platform (ULIP)

ULIP, a key component of the NLP, is designed as a centralized digital interface to enhance transparency and efficiency by facilitating digital information exchange (**Government of India, 2025**). While ULIP streamlines operations by integrating various stakeholders (**Government of India, 2025**), its effectiveness depends on the technological maturity of the users. Operational evidence suggests that ULIP's success is directly marred by technological and skill deterrents at the operational level, including poor visibility, fragmented operational data, and a lack of technologically educated workforce (**NLDSL, n.d.; Lawyered.in, 2022**). The ULIP platform represents a top-down policy push that faces structural resistance due to bottom-up operational deficiencies.

National Blockchain Framework (NBF) and Regulatory Intent

NITI Aayog, the government's policy think tank, acknowledges the potential of blockchain as a tool to facilitate trust and enhance governance (**NITI Aayog, 2020**). The National Blockchain Portal supports innovation and standardization, notably offering environments like NBFLite, a blockchain sandbox designed for startups and academia to prototype and develop applications in a controlled environment (**PIB, 2025**). This nurtures capacity building and provides smart contract templates for supply chain and digital certificate domains (**PIB, 2025**).

Crucially, NITI Aayog's initial strategy document (2020) acknowledged the critical need for all stakeholders, including policy makers and regulators, to understand the functional definition of DLT along with the required legal and regulatory issues. However, the first part of the strategy document skips these specific regulatory issues (**NITI Aayog, 2020**), deferring key discussions like the contours of an Indian cryptocurrency/Initial Coin Offering (ICO) market and the re-evaluation of cryptocurrencies to a subsequent phase (**NITI Aayog, 2020**). This delay in regulatory direction contributes to the systemic risk surrounding enterprise-level DLT adoption.

Research Methodology:

4.1. Research Design and Data Sources

This research utilizes a Systematic Literature Review (SLR) methodology combined with a comprehensive analysis of contemporary policy documents and industry reports specific to the Indian context. The SLR includes peer-reviewed

academic articles focusing on supply chain digitization in emerging economies, with a strict inclusion criterion for papers utilizing empirical or qualitative research methods over purely mathematical modelling.

Data sources include:

1. **Academic Publications:** Journals focusing on SCM, AI, and DLT adoption, utilizing established frameworks (TOE, TTF, UTAUT) (**Wong, S et al., 2024**).

2. **Government and Policy Reports:** High-level documents from the Government of India, including NITI Aayog (DLT strategy) (**NITI Aayog, 2020**), DPIIT (logistics cost reports) (**DPIIT/NCAER, 2025**), and SIDBI (MSME reports) (**SIDBI, 2025**).

4.2. Analytical Framework Application

The analysis framework integrates the **Technology-Organization-Environment (TOE)** model (Li et al., 2024) with **Task-Technology Fit (TTF)** principles (**Wong, S et al., 2024**). The barriers identified across the collected data, such as high cost (**Li et al., 2024**), skill shortage (**NITI Aayog, 2025**), interoperability failures (World Bank, n.d.), and regulatory ambiguity (**NITI Aayog, 2020**), are systematically categorized into the three TOE domains (T, O, E).

This framework allows for the structured interpretation of complex, interconnected challenges. For example, the high cost of implementation (an Organizational barrier) (**Li et al., 2024**) is directly linked to interoperability challenges (a Technical barrier) (**World Bank, n.d.**) and the current lack of standardization (an Environmental/Technical barrier) (**Kaur, J., et al., 2022**). The application of the TTF principle ensures that the analysis assesses not only the presence of a barrier but also how that barrier erodes the perceived utility of the technology in the Indian market (**Wong, S et al., 2024**).

Data Analysis and Interpretation: Strategic Barriers

The strategic barriers inhibiting AI and BT adoption in Indian logistics are analysed through the tripartite lens of the TOE framework. This segmentation reveals that the obstacles are primarily systemic and structural, stemming from the fragmented nature of the economy, rather than any issues in the technologies themselves.

5.1. Technological Barriers (T): The Infrastructure-Data Nexus

Technological barriers are related to the friction encountered when attempting to deploy complex, data-intensive systems (AI) or decentralized, highly standardized platforms (BT) into a legacy operational environment endemic to the current environment in the logistics industry.

Interoperability and Legacy System Friction

The predominant technical challenge is the difficulty and prohibitive cost associated with integrating DLT and AI platforms with the existing legacy systems used by logistics firms, particularly Enterprise Resource Planning (ERP) and Warehouse Management Systems (WMS) (**World Bank, n.d.**). This issue is identified as a critical technology barrier (TB3: Lack of Interoperability) (**World Bank, n.d.; Kaur, J., et al., 2022**). In India's highly fragmented market, the requirement for network-wide compatibility becomes a high entry barrier, leading to integration costs being cited as the primary hurdle within organizational contexts (**Li et al., 2024**).

Data Standardization and Quality: The AI Bottleneck

The effectiveness of AI systems is depends fundamentally on the quality and structure of input data (**Acharya, S., Gharia, R., & Kapooria, P. (2025)**. The Indian logistics industry's dependence on manual or paper-based systems is widespread, which leads to errors, delays, and poor coordination (**NLDSL, n.d.; Lawyered.in, 2022**). This low digitization level generates inconsistent, unstructured data, leading directly to a lack of standardization (TB5) (**Kaur, J., et al., 2022**).

This situation leads to a domino effect: **Infrastructure Decay → Data Inconsistency → AI Failure.** Poor physical infrastructure, such as congestion, poor rural connectivity, and high port turnaround times, causes delays and unpredictability in real-time operations (**NLDSL, n.d.; Lawyered.in, 2022**). Furthermore, 60% of rural roads lack all-weather connectivity, hindering last-mile transport (**Vivaswan, R., Prasad, O., 2021**). When AI predictive models are trained on inconsistent unreliable data, their forecasts become as inaccurate and unreliable, resulting in diminished perceived value (low TTF) (**Acharya, S., Gharia, R., & Kapooria, P. (2025)**. To utilize AI effectively, India has to

undertake the labour-intensive effort of transforming copious amounts of unstructured data into formats suitable for training LLMs and other applications (**Anirudh Suri, 2025**).

5.2. Organizational Barriers (O): The Financial and Human Capital Divide

Organizational barriers refer to the internal resources, culture, and economic realities of the firms operating in the ecosystem.

MSME Economic Friction (Hypothesis H1 Support)

The structural fragility of MSMEs poses the single largest impediment to scaled adoption (**NITI Aayog, 2025**). Advanced technologies require high Capital Expenditure (CapEx) (**Li et al., 2024**). MSMEs, typically struggling with short-term survival and cost control, are loathe to allocate capital to large-scale technological investment.

This leads to a continuous **Credit Gap → Low Investment → Low Digital Agility** loop. The estimated addressable credit gap for the MSME sector is approximately 24%, translating to around ₹30 lakh crore (**SIDBI, 2025**). This financial constraint cripples their ability to finance the necessary CapEx for digitalization (**SIDBI, 2025**). The inability to finance technology reinforces the economic vulnerability of MSMEs, solidifying the digital divide and increasing the gap further.

Human Capital and Skill Deficit

The Indian logistics sector suffers from a perennial shortage of specialized talent and a digitally literate ground workforce (**NLDSL, n.d.; NITI Aayog, 2025**). Owners and mid-level managers frequently don't have exposure to advanced concepts like AI or blockchain, while trained staff capable of managing these systems are expensive to hire and retain.

This skills gap feeds an organizational resistance to change (OB1) (**Kaur, J., et al., 2022; NITI Aayog, 2025**). The lack of technological understanding generates a powerful fear of losing control over processes and an aversion to operational disruptions, the typical Don't-fix-whats-not-broken mindset. This resistance reinforces the preference for established, informal, and manual methods (**NITI Aayog, 2025**), which severely inhibits the collaboration and standardization necessary for decentralized technologies like BT to function efficiently on a network level.

5.3. Environmental and Regulatory Barriers (E): Trust, Fragmentation, and Policy Risk

Environmental barriers arise from the macro-level industry structure, the physical environment, and the institutional/regulatory framework.

Structural Fragmentation and Trust Deficits

Since the Indian logistics industry is immensely fragmented and comprises of numerous small, independent operators (**3SC Solution, n.d.**), it demands robust, systemic trust mechanisms. While BT inherently offers transparency and security (**Ali, n.d.**), the environmental reality includes pre-existing trust deficits. This leads to organizational reluctance in sharing commercially sensitive data, due to fears of security breaches and data loss (**Kaur, J., et al., 2022**).

Yadlapalli A, Rahman S, Gopal P (2022) suggests that when private/consortium blockchain solutions are utilized, clients view the trust and privacy challenges as less critical and requiring less effort to address. However, the coordination challenge posed by fragmentation, getting thousands of small, non-standardized operators to agree on and join a protocol, remains prohibitive unless mandated by regulations or heavily incentivized by monetary or similar means.

Infrastructure as an Environmental Constraint

Apart from the physical impact on data quality, poor infrastructure significantly limits the deployment environment. The lack of reliable, real-time connectivity, particularly in last-mile rural logistics (**Vivaswan, R., Prasad, O., 2021**), limits the utility of sensor-based tracking (IoT) and real-time AI optimization tools. This weak foundation means that even if firms invest in getting new software, the operational environment prevents the realization of the system's true potential.

Regulatory Uncertainty in DLT (Hypothesis H2 Support)

For technologies that warrant immutable records and automated transactions (smart contracts), legal certainty is non-negotiable. While the policy environment is supportive of digitalization (**Institute for Economics and Peace, n.d.**), it currently features a significant policy risk regarding DLT. The NITI Aayog strategy (2020) acknowledged the critical need

for defining the legal and regulatory issues related to DLT. However, these specific legal definitions were deferred to a subsequent strategy phase (**NITI Aayog, 2020),** indicating regulatory ambiguity currently.

This **Regulatory Vacuum → Investment Stagnation** mechanism is a strong environmental barrier. Large enterprises and consortia, which require significant capital investment for DLT implementation, are deterred by the absence of clear legal recognition for smart contracts and established mechanisms for dispute resolution on distributed ledgers. This systemic risk keeps BT confined primarily to pilot projects and proof of concepts, deterring the transition to deployment across the nation.

The following table summarizes the strategic barriers identified through the TOE framework and along with the references to the support from existing literature.

Framework Dimension	Barrier Category	Specific Challenge in Indian Logistics	Key Impact on Adoption	Citation Support
Technology (T)	Integration Complexity (TB3)	Interoperability failure between legacy ERP/WMS and new DLT/AI systems.	High cost of implementation, delayed ROI.	(Li et al., 2024; World Bank, n.d.; Kaur, J., et al., 2022)
Technology (T)	Data Fidelity and Standardization (TB5)	Reliance on manual input, unstructured data, and poor connectivity leading to unreliable AI models.	Diminished perceived value of AI (low TTF).	(Acharya, S., Gharia, R., & Kapooria, P. 2025; Anirudh Suri, 2025; Kaur, J., et al., 2022)
Technology (T)	Scalability/Speed (TB2)	Latency concerns for DLT processing high-volume daily logistics transactions.	Risk of system bottlenecking efficiency gains.	(Kaur, J., et al., 2022)

Organization (O)	Economic Constraint (Financial)	High CapEx and focus on short-term survival among MSMEs (lack of funds, credit gap).	Technology is deemed too risky/unaffordable.	(SIDBI, 2025; Li et al., 2024)
Organization (O)	Human Capital Deficit (OB2)	Shortage of specialized talent and low digital literacy among ground-level workforce.	Inability to operate or maintain systems effectively; data input errors.	(NITI Aayog, 2025; NLDSL, n.d.)
Organization (O)	Resistance to Change (OB1)	Fear of losing control over data and processes; preference for established, informal methods.	Inhibits multi-party BT collaboration.	(NITI Aayog, 2025; Kaur, J., et al., 2022)
Environment (E)	Infrastructure Deficits	Poor road quality, port congestion, and weak rural last-mile connectivity.	Direct cause of data-fidelity issues and operational delays.	(NLDSL, n.d.; Vivaswan, R., Prasad, O., 2021)
Environment (E)	Structural Fragmentation	Low formal trust among numerous small, non-standardized operators.	Blocks network-wide BT implementation.	(3SC Solution, n.d.)
Environment (E)	Regulatory Ambiguity	Undefined legal status for DLT/smart contracts (NITI Aayog Phase I gap).	Increases legal and financial risk for early adopters.	(NITI Aayog, 2020)

Finding & Recommendations:

6.1. Finding 1: Organizational and Economic Constraints Dominate the Digital Divide

This extensive analysis confirms Hypothesis H1: the primary strategic barriers to technology scaling are organizational and economic, particularly among the MSMEs. Despite the strong growth anticipated (**Aarti Dhapte, 2025.; Markets and Data, 2024**), these decisions are perpetually deferred by financial reality. The average MSME operator lacks the internal resources and external financing capability to absorb the initial high CapEx required for a comprehensive digital transformation (**Li et al., 2024**). The existence of a substantial credit gap (approximately 24% or ₹30 lakh crore) (**SIDBI, 2025**) fundamentally restricts these small businesses from investing (**SIDBI, 2025**), forcing them to prioritize immediate operational cost control over strategic technological upgrades. Furthermore, the lack of management exposure and a shortage of specialized talent creates an internal cultural barrier (resistance to change) (**Kaur, J., et al., 2022**), making the human capital deficit as critical as the financial barrier (**NITI Aayog, 2025; NLDSL, n.d.).**

6.2. Finding 2: Standardization and Regulatory Clarity are Systemic Enablers

Hypothesis H2 is strongly supported by the data concerning the technical and environmental contexts. The success of large-scale initiatives like ULIP, that aim to improve visibility and transparency (**Government of India, 2025**), is undermined by a pervasive lack of data standardization (TB5) (**Kaur, J., et al., 2022**) and legacy system interoperability (TB3) (**World Bank, n.d.**). Without standardized data protocols, the efficiency gains expected from centralized data sharing are marred by data reconciliation efforts. Crucially, for DLT adoption to scale beyond limited pilots, the specific environmental barrier of regulatory uncertainty has to be resolved. The acknowledgment by NITI Aayog (2020) that specific legal and regulatory issues pertaining to DLT governance remain undefined creates a systemic governance risk that deters major, long-term enterprise investment. Given the judicial scenario in India, most firms will likely keep away from investing in the new technology unless this issue is addressed by the government.

6.3. Strategic Recommendations for Bridging the Divide (Segmented Approach)

To effectively bridge the digital divide and enable India to realize the projected value from AI and BT, policy interventions must move beyond general promotion and target the foundational structural and economic weaknesses identified in the TOE analysis. Recommendations are structured across the three contexts.

A. Organizational and Financial Interventions (O)

1. Tailored, Subsidized OpEx-Based Consumption Models:

The current model of relying on CapEx grants for logistics IT infrastructure is ineffective for cash-poor MSMEs. A paradigm change is required towards incentivizing the adoption of service-based, pay-as-you-go models.

- **Recommendation:** Government and financial institutions should collaborate to offer partial operational expenditure (OpEx) subsidies for managed services, such as specialized Transport Management Systems (TMS) and basic AI-driven predictive analytics that are offered by 3PL providers or platform partners. This financial intervention directly lowers the high CapEx entry barrier (**Li et al., 2024**), aligning the cost structure with the MSMEs' focus on short-term survival and variable costing. The ability to pay-as-you-go will help the MSMEs in managing their costs better and to take the leap of faith towards new technologies.

2. Targeted Digital Literacy and Skill Augmentation:

Addressing the human capital deficit requires a multi-pronged approach that simultaneously targets management apprehension and workforce technical skills (**NLDSL, n.d.**).

- **Recommendation:** Implement cluster-based, government-backed training programs designed as per sector-specific occupational standards (**NITI Aayog, 2025**). These programs should focus on fundamental digital literacy for ground staff and also introduce owners and mid-level managers to the principles of AI/BT management (**NITI Aayog, 2025**). Furthermore, the scope of *National blockchain portal initiatives like* NBFLite should be expanded beyond academia and startups to serve as a national capacity-building and certification program for logistics professionals, validating practical skills in DLT application development and maintenance (**PIB, 2025**).

B. Technological and Data Interventions (T)

3. Mandatory Data Protocol Harmonization via ULIP:

ULIP's role has to evolve from a passive data exchange platform to an active enforcer of industry-wide data standardization **(Kaur, J., et al., 2022)**. The current lack of standardization (TB5) hinders seamless interoperability.

- **Recommendation:** The regulatory bodies must develop and mandate the adoption of public, open Application Programming Interfaces (APIs) **(PIB, 2025)** and standardized data schemas for core logistical documents, tracking, and transactional data **(Kaur, J., et al., 2022)**. This standardization should cover all integrated logistics components to ensure that technical integration (TB3) costs decrease across the entire supply chain network **(Li et al., 2024)**.

4. Investing in Foundational Unstructured Data Infrastructure:

The reliance on paper and manual processes **(NLDSL, n.d.)**, must be aggressively deterred so that we can get consistent data and unlock AI value.

- **Recommendation:** Strategic public-private investment is required for establishing national-level data infrastructure with a focus on transforming unstructured data into actionable intelligence. This includes the subsidized deployment of Optical Character Recognition (OCR) tools and Natural Language Processing (NLP) solutions to rapidly convert documentation into structured, machine-readable formats **(Anirudh Suri, 2025)**. This crucial step will ensure that AI models receive the quality inputs necessary to deliver tangible value (improving TTF) **(Acharya, S., Gharia, R., & Kapooria, P. (2025). This will** justify the investment for subsequent adoption and lead to an upward spiral.

C. Environmental and Regulatory Interventions (E)

5. Accelerating DLT Legal Certainty and Governance:

The pervasive regulatory ambiguity (E) regarding DLT creates financial risk and inhibits institutional investment **(NITI Aayog, 2020)**.

- **Recommendation:** The Government of India must focus and expedite the publication and implementation of the subsequent phase of the NITI Aayog DLT strategy. This phase needs to clearly establish the legal framework for smart contracts, define data jurisdiction, and outline the mechanisms for liability and dispute resolution for transactions executed on DLT platforms **(NITI Aayog, 2020)**. Regulatory certainty is critical to move BT from pilot projects to formalized, legally binding commercial frameworks.

6. Infrastructure Investment and Real-Time Connectivity Guarantee:

Policy goals must address the causal link connecting the physical infrastructure deficits and data integrity concerns.

- **Recommendation:** Complement the infrastructure programs (Bharatmala, Sagarmala) with targeted, last-mile digital infrastructure rollout, particularly in rural and semi-urban logistics clusters **(Vivaswan, R., Prasad, O., 2021)**. Furthermore, policy incentives should support the creation of logistics consortia that deploy permissioned, private blockchains. This approach ensures necessary network efficiencies while providing organizational decision-makers the security and control required to overcome the fear of losing control over commercially sensitive data **(Kaur, J., et al., 2022; Yadlapalli A, Rahman S, Gopal P (2022).**

The following table summarizes the key economic and digital metrics that quantify the scale of the digital divide and highlight the urgency of the proposed recommendations.

Metric	Current Status / Value	Projected/Policy Goal	Significance for AI/BT Adoption	Citation Support

Logistics Cost as % of GDP	~7.97% (2023-24)	Target: Below 7.0% (NLP Goal)	High costs consume capital that could be used for tech investment.	(DPIIT/NCAER, 2025; ITLN, 2025)
AI in Logistics Projected CAGR	31.66% (FY2025-2032)	USD 6828.58 million by FY2032	Indicates high latent demand but requires overcoming current barriers.	(Markets and Data, 2024)
Blockchain in Supply Chain Projected CAGR	51.58% (2025-2035)	USD 8825 million by 2035	Highest projected growth, underscoring the urgency of barrier removal.	(Aarti Dhapte, 2025)
MSME Credit Gap	~24% (~₹30 lakh crore)	Policy focus on increased credit supply	Directly restricts MSMEs' ability to finance technology CapEx.	(SIDBI, 2025)
MSME Digital Lending Availment	18% of respondents	Increase access to digital finance/formalization	Reflects low financial digitalization, reinforcing low tech agility.	(SIDBI, 2025)
Rural Road Connectivity Deficit	Major issue in last-mile connectivity	Investment via Bharatmala/ Sagarmala	Physical barrier to real-time IoT/AI data gathering and last-mile efficiency.	(Vivaswan, R., Prasad, O., 2021)

Conclusion:

7.1. Synthesis of Strategic Barriers

The digital transformation of the Indian logistics sector, driven by the potential of AI and Blockchain Technology, is currently held back by a complex, interconnected system of strategic barriers best understood through the Technology-Organization-Environment (TOE) framework **(Wong, S et al., 2024).** The analysis confirms that the adoption inhibitors are overwhelmingly rooted in lack of organizational capacity and environmental uncertainty, rather than in technological limitations. Specifically, the organizational dimension, dominated by the MSME sector, faces acute financial fragility that renders the high capital costs of implementation unviable, despite the long-term strategic value **(SIDBI, 2025; Li et al.,**

2024). This economic constraint is amplified by the human capital deficit and a pervasive resistance to changing the traditional, informal operational methods **(NITI Aayog, 2025; NLDSL, n.d.).**

Furthermore, the technological friction is entwined with environmental deficiencies. Physical infrastructure decay and low digitization lead directly to low data quality and inconsistency, which prevents AI from achieving a sufficient Task-Technology Fit (TTF) **(Acharya, S., Gharia, R., & Kapooria, P. (2025)**. Simultaneously, for DLT, the environmental factor of Structural Fragmentation, along with the systemic risk created by Regulatory Ambiguity about smart contracts and legal governance **(NITI Aayog, 2020),** severely limits adoption by the various stakeholders. Bridging this strategic digital divide is paramount to achieve the cost reduction targets targeted by the National Logistics Policy **(DPIIT/NCAER, 2025).**

7.2. Policy Implications and Future Competitiveness

To move the Indian logistics ecosystem beyond pilots and proofs-of-concept, policy makers must implement targeted, structural reforms. Success hinges upon shifting from CapEx-intensive models to subsidized OpEx service models, thus providing MSMEs with financially tenable access to digital tools. Almost as critical is the immediate enforcement of mandatory data standardization protocols through centralized interfaces like ULIP, ensuring high quality and consistent data flow needed for effective AI deployment **(Kaur, J., et al., 2022)**. Finally, policy clarity regarding the legal standing of DLT is sacrosanct for large-scale enterprise adoption **(NITI Aayog, 2020).** By tackling the financial, human capital, and regulatory bottlenecks concurrently, India can translate the projected growth rates of AI and BT into measurable efficiency gains, ultimately bolstering its global trade competitiveness.

7.3. Limitations and Future Research

This review relies on a synthesis and study of secondary industry, governmental, and academic reports. While the TOE framework allows for robust categorization, a limitation is the reliance on proxy data for certain adoption metrics, particularly concerning the internal decision-making calculus and precise financial burdens faced by specific tiers of MSMEs. Future research should prioritize primary data collection, employing methodologies such as AHP **(Yadlapalli A, Rahman S, Gopal P., 2022)** or structural equation modeling (SEM), to quantitatively measure the perceived weights and causal relationships of specific TOE factors (e.g., cost vs. skill availability) in technology adoption decisions, particularly post-ULIP implementation. Further exploration of sector-specific challenges (e.g., cold chain, hazardous goods) and the development of cost-benefit models tailored for MSMEs would provide invaluable quantitative justification for the recommended financial interventions.

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