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RESEARCH ARTICLE

Blockchain-Based Supply Chain Traceability and Its Influence on Stakeholder Trust

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Abstract

Supply chains depend on evidence about origin, custody, handling conditions and compliance, yet conventional records are fragmented across organizational boundaries. This paper develops a permissioned blockchain traceability framework and examines how verifiable provenance, event completeness, information accessibility and governance may influence stakeholder trust. A structured methodology combines an event-level data architecture, a smart-contract validation process, a stakeholder trust measurement model and a transparent scenario-based simulation. The proposed framework distinguishes the technical integrity of a ledger from the truthfulness of information entered into it. Illustrative results, generated for methodological demonstration rather than collected from firms or consumers, show how improved traceability can correspond to stronger modeled trust and faster recall identification while exposing tradeoffs in validation latency, privacy and governance. The analysis identifies interoperability, independent verification, selective disclosure and dispute resolution as essential conditions for credible adoption. The paper contributes an auditable analytical framework and testable hypotheses for future empirical studies, without claiming that simulated estimates establish causal effects in operating supply chains.

Keywords: *blockchain; supply chain traceability; stakeholder trust; provenance; smart contracts; transparency; permissioned ledger; governance*

1. Introduction

Supply chains are networks of producers, processors, logistics providers, distributors, retailers, regulators and customers. Each participant creates records that can affect product safety, sustainability claims, authenticity and operational continuity. However, the records are commonly stored in separate enterprise systems, communicated through inconsistent formats and shared only when a problem occurs. The resulting information asymmetry makes it difficult for stakeholders to determine whether a claim about a product is supported by a complete, timely and independently verifiable chain of evidence.

Traceability describes the capacity to reconstruct the history, application or location of an item through recorded identifiers and events. It may support targeted recalls, quality assurance, counterfeiting detection and compliance reporting. Traditional traceability systems can be effective inside a single organization, but coordination becomes more difficult when several firms must reconcile versions of events. A shared ledger can reduce disputes over what was recorded and when, although it cannot automatically verify the physical truth of the recorded observation.

Blockchain introduces an append-oriented sequence of cryptographically linked records governed by agreed rules. In permissioned deployments, known organizations can validate transactions under a consortium

policy. Smart contracts can enforce required fields, authorized roles, custody-transfer conditions and exception handling. These capabilities create a technical basis for a shared audit trail, but the value of the trail depends on sensor quality, data-entry controls, identity management and institutional accountability.

Trust is multidimensional. A buyer may trust the authenticity of provenance evidence but still doubt the competence of a supplier. A regulator may value auditability while requiring confidential access to commercially sensitive details. A consumer may appreciate a simple origin claim without understanding ledger consensus. Accordingly, stakeholder trust should not be equated with a transaction count or the presence of a QR code. It must be measured through transparent constructs such as perceived integrity, competence, benevolence, accountability and willingness to rely on the information.

The present study asks how blockchain-enabled traceability can influence trust through observable information characteristics rather than through technology labels alone. Its first objective is to define a deployable traceability architecture connecting physical events to digital evidence. Its second is to specify measurable variables and a structural model linking provenance quality to trust. Its third is to compare operational scenarios using a reproducible, explicitly synthetic dataset. Its fourth is to identify governance mechanisms that constrain or enable the relationship.

The proposed contribution is a distinction between traceability coverage, verifiability and trust. Coverage concerns the proportion of expected events captured. Verifiability concerns whether recorded events have authenticated issuers and valid evidence. Trust concerns the stakeholder judgment that evidence is reliable enough to inform decisions. These dimensions can move differently: recording more events does not necessarily increase confidence if those events originate from weak or compromised sources.

A permissioned consortium is examined because many commercial supply chains require selective disclosure and predictable governance. Yet permissioning introduces its own tensions: dominant firms may control membership, smaller suppliers may face onboarding costs and validators may share incentives that limit independence. A well-designed system therefore requires audit rights, documented rule changes, data minimization, accessible appeal processes and a route for correcting inaccurate records without silently deleting their history.

The analysis adopts a design-science orientation supported by a transparent simulation, not a claim of completed field experimentation. All numerical results below are illustrative and are presented to show how the model could be evaluated when real data become available. A field study would require ethics review where applicable, validated questionnaires, real transaction logs, sampling documentation and statistical uncertainty estimates.

For managers, the key decision is not simply whether to adopt blockchain, but which traceability problem requires a shared, tamper-evident record, what evidence can be trusted at the point of capture and which stakeholders need access to which facts. For researchers, the challenge is to isolate the effects of provenance visibility from brand reputation, prior relationships, certification and other determinants of trust.

The remainder of the paper reviews theoretical and technical foundations, presents the architecture and mathematical specification, explains the simulated scenarios, interprets the results and concludes with implementation and research implications.

2. Literature Review

2.1 Traceability and information asymmetry

Supply chain traceability has traditionally relied on product identifiers, batch records and exchanges among enterprise systems. Visibility can reduce search costs during a recall, but fragmentation creates reconciliation delays and inconsistent claims. Traceability should be distinguished from transparency: an organization may internally trace a product while disclosing little to external stakeholders. Similarly, a transparent interface may display claims that are not independently verifiable.

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2.2 Blockchain as shared evidence infrastructure

Nakamoto (2008) introduced a peer-to-peer timestamped ledger design, while enterprise applications adapt distributed-ledger concepts to identified participants and different consensus arrangements. Kshetri (2018) discusses blockchain-related opportunities in supply chain objectives; Saberi et al. (2019) connect blockchain adoption to sustainable supply chain management. Their arguments motivate, but do not independently prove, trust improvements across all contexts.

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2.3 Provenance, authenticity and physical-digital linkage

A blockchain can preserve the integrity of a submitted digital record while remaining vulnerable to incorrect input. This is frequently described as an oracle problem: the ledger cannot directly know whether a temperature sensor was calibrated, a certificate was genuine or a custody handoff occurred as reported. Tamper-evident packaging, independent inspections, signed sensor messages and sampling audits are complementary controls. Without them, immutable misinformation can circulate more efficiently.

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2.4 Trust theory and stakeholder differences

Mayer, Davis and Schoorman (1995) conceptualize organizational trustworthiness in terms of ability, benevolence and integrity. McKnight, Choudhury and Kacmar (2002) develop measures relevant to trust in electronic contexts. In a supply chain, buyers may emphasize delivery reliability and dispute resolution, consumers may emphasize authenticity and safety, and regulators may emphasize completeness and accountable access. Therefore, trust measurement should be stakeholder-specific and should not assume that a single scale captures every relationship.

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2.5 Governance and adoption constraints

Distributed records require institutional agreements on validator membership, permissions, legal responsibilities, standards and changes to smart contracts. Adoption also entails integration costs, data confidentiality risks, cybersecurity exposure and uneven digital maturity. Wüst and Gervais (2018) provide criteria for deciding whether a blockchain is appropriate; their decision-oriented perspective cautions against replacing a trusted central database when decentralization offers little additional value.

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2.6 Empirical evidence and research gap

Published case studies and conceptual papers describe improvements in provenance and coordination, but results vary by industry, implementation maturity and measurement design. Trust is sometimes inferred from transparency features rather than directly measured. This creates a gap for studies that separately measure

traceability completeness, independent verification, perceived evidence quality and behavioral reliance. A further gap concerns whether privacy-preserving disclosure can maintain confidence without revealing sensitive supplier relationships.

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3. Research Methodology

This section specifies a proposed design-science and quantitative evaluation protocol. The simulation is a methodological illustration; no primary survey, industrial pilot or real-world performance trial is claimed.

3.1 Research design and hypotheses

The design contains five linked stages: map stakeholder requirements; define a standardized event schema; validate and commit events; calculate traceability and governance indicators; and evaluate stakeholder trust and operational outcomes. Unit of analysis for operational records is a product batch event, while unit of analysis for perceived trust is a stakeholder respondent.

H1 proposes that greater verified event coverage is positively associated with perceived evidence integrity. H2 proposes that evidence integrity positively predicts stakeholder trust after controlling for prior relationship quality. H3 proposes that independent verification strengthens the association between traceability visibility and trust. H4 proposes that excessive disclosure of sensitive information can weaken adoption even when technical traceability improves.

3.2 System architecture and event capture

Each product lot receives a persistent identifier linked to a standard event structure: event identifier, lot identifier, actor identifier, event type, event time, location, evidence hash, signature, visibility class and previous custody reference. Raw documents and high-volume sensor data remain in access-controlled off-chain storage, while their hashes and verification metadata are committed to the ledger.

Actors sign events using managed organizational credentials. A gateway validates identity and required fields before smart-contract execution. Consensus nodes operated by independent consortium members finalize approved transactions. An application layer exposes role-specific views for suppliers, logistics firms, buyers, auditors and consumers. Physical-digital binding requires periodic independent checks, not merely QR-code issuance.

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Figure 1. Proposed validation and trust-evaluation workflow

Stage	Control / output
Physical product event	Lot scan, sensor record, custody evidence
Identity and data validation	Verify signer, schema, timestamps and supporting evidence
Smart contract and consensus	Check transfer rule, commit event hash, record exception
Traceability analytics	Compute completeness, verification and retrieval time
Stakeholder evaluation	Measure perceived integrity, trust and willingness to rely
Governance feedback	Audit exceptions, remediate errors and update access rules

3.3 Data collection and sampling protocol

A future empirical study should recruit multiple supply chain organizations across at least three tiers, collect time-stamped event logs and administer separate surveys to purchasing managers, quality officers, auditors and consumers. Stratified sampling by role and firm size can reduce overrepresentation of large organizations. Sample size should be justified by power analysis based on the number of predictors and expected effect sizes.

The event dataset should contain expected and observed events, invalid signatures, independent verification flags, recall search times and exception closure dates. Survey items should use a consistent five- or seven-point Likert scale, randomized where appropriate, with validated measures adapted carefully to the supply chain setting. Respondents must be informed of data use and consent requirements.

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3.4 Mathematical indicators and measurement

Let E represent the number of expected traceability events and V the number of valid captured events. Traceability coverage is the proportion of valid events among expected events. Let A denote independently authenticated events and V denote valid captured events. Verification ratio represents the share of recorded events with independent support.

$$C = V / E$$

Where C is coverage, V is valid captured events, and E is expected events; E must be greater than zero.

$$Q = A / V$$

Where Q is verification ratio, A is independently authenticated events, and V is valid captured events.

$$T = w_1 I + w_2 K + w_3 G + w_4 R$$

Where T is composite trust; I is perceived integrity, K is competence, G is accountability, R is willingness to rely, and weights w_1 through w_4 sum to one.

$$T = \beta_0 + \beta_1 C + \beta_2 Q + \beta_3 G + \beta_4 P + \varepsilon$$

Where β terms are regression coefficients; P represents prior relationship quality; ε is the unexplained error. Coefficients require real observations for estimation.

$$L = t_2 - t_1$$

Where L is event finalization latency, t_1 is submission time and t_2 is final confirmation time.

$$S = (B - N) / B \times 100$$

Where S is percentage recall-search time reduction; B is baseline minutes and N is minutes under the new scenario.

3.5 Smart contract rules and exception management

A custody transfer is accepted only when the initiating organization is authorized, the receiving organization is recognized, the lot exists, the previous custodian matches the ledger state and the evidence passes required validation. A failed rule produces an auditable exception instead of an accepted transfer. An authorized correction references the original event and appends a reason and countersignature.

The contract should version its rules, log governance approvals and avoid placing confidential personal or commercial information directly on an immutable ledger. Encryption, access policies, key rotation and retention schedules remain necessary. A consortium governance board should review disputes and assess validator concentration and conflicts of interest.

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3.6 Simulation setup and reproducibility

For demonstration, four hypothetical scenarios are constructed: conventional fragmented records, basic blockchain logging, blockchain with independent evidence verification, and blockchain with verification plus governed selective disclosure. The scenarios use predetermined values chosen to illustrate model sensitivity. They are not estimated from an observed distribution and must not be described as experimental findings.

The trust index uses a zero-to-100 scale for interpretability. Event coverage and independent verification are percentages, and recall identification is minutes. Results should be recalculated with real event logs and stakeholder survey responses before making claims of statistically significant change. Sensitivity checks should vary event error rates, validator availability and survey weights.

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3.7 Validity, ethics and statistical evaluation plan

Construct validity requires checking internal consistency, convergent validity and discriminant validity of trust items. Operational metrics should be independently audited. Regression assumptions, multicollinearity, confidence intervals and potential clustering within firms should be examined. A longitudinal or staggered rollout would be stronger than a cross-sectional comparison for causal inference.

Privacy safeguards include minimizing personally identifying records, obtaining lawful processing grounds and using selective disclosure. Firms should retain a documented process for revoking credentials, resolving false provenance claims and responding to security incidents. Pre-registration and publication of de-identified codebooks would improve reproducibility.

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4. Illustrative Results and Discussion

IMPORTANT: The following numerical values are synthetic scenario assumptions used only to demonstrate evaluation and chart presentation. They are not field measurements, survey responses or empirically estimated effects.

Scenario	Coverage %	Verified %	Trust index /100	Recall min	Latency s
Fragmented baseline	68	24	58	180	1.0
Basic shared ledger	86	52	67	110	2.4
Verified ledger	94	82	79	62	3.1
Verified and governed	96	90	85	45	3.4

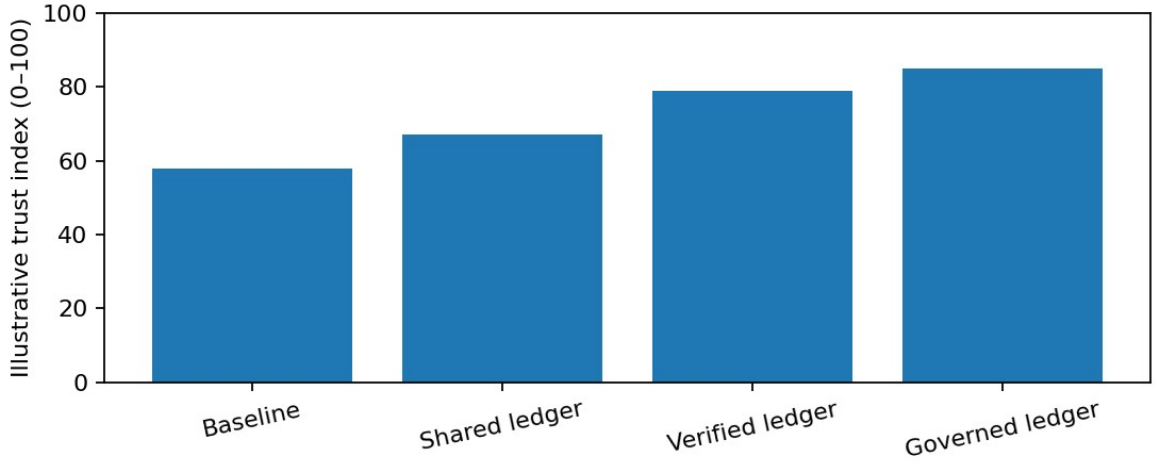


Figure 2. Synthetic stakeholder trust scores by hypothetical traceability configuration.

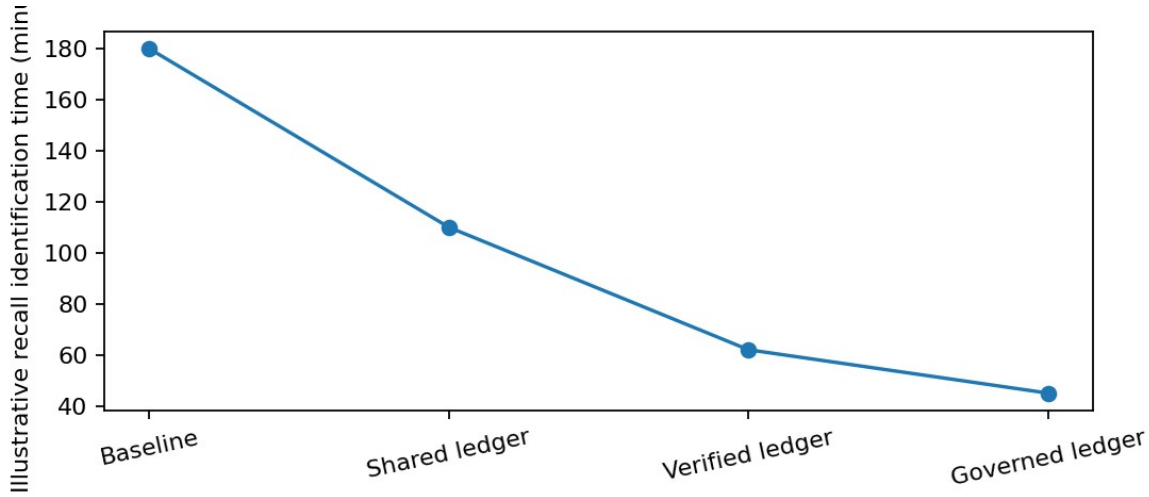


Figure 3. Synthetic recall identification time across configurations.

The illustrative trust index rises from 58 in the baseline to 85 in the governed verification scenario, a difference of 27 index points. This is an assumed comparison, not an estimated effect. The largest conceptual contribution of the verified scenarios is stronger evidence quality rather than ledger deployment alone. A shared ledger that accepts unverified records may improve audit availability without resolving the underlying truthfulness problem.

The illustrative recall identification time falls from 180 to 45 minutes, corresponding to a 75% scenario reduction. Faster retrieval is plausible when standardized events and shared identifiers replace manual reconciliation, but actual improvement will depend on product complexity, completeness, system uptime and cross-enterprise integration. Event finalization latency rises from 1.0 to 3.4 seconds in the assumed scenarios, demonstrating that stronger controls can impose processing overhead.

4.1 Scenario sensitivity

Condition	Assumed trust index	Interpretation
Governed ledger, reference	85	High verification and controlled disclosure
Governed ledger, weak sensor assurance	73	Ledger cannot correct false physical inputs
Governed ledger, poor dispute resolution	70	Accountability weakness undermines confidence
Governed ledger, restricted stakeholder access	76	Insufficient transparency limits perceived usefulness

Sensitivity values are also illustrative. They show why the conceptual model must account for verification quality, dispute resolution and access rights rather than treating adoption as a binary variable. A field evaluation should compare these mechanisms with validated survey scales and appropriate uncertainty intervals.

5. Managerial Implications

Implementation should begin with a high-value use case such as regulated provenance, counterfeit exposure or slow recall reconciliation. Managers should specify which events are mandatory, who is accountable for recording them, and which external checks make the evidence credible. The governance charter should establish independent validator representation, change control, dispute resolution, correction procedures and fair supplier onboarding. Success should be measured through event completeness, verified evidence, exception closure time, recall performance, stakeholder trust and total operating cost. Adoption should proceed only when the incremental value of shared governance exceeds integration and compliance costs.

6. Limitations and Future Research

The numerical analysis is illustrative and does not establish causation, external validity or statistical significance. The trust index is not derived from a validated survey in this manuscript. Future studies should compare matched supply chains, collect repeated measurements before and after implementation, estimate measurement reliability, test moderating effects of governance and examine whether results differ across food, pharmaceuticals, textiles and electronics. Comparative cost analysis against well-governed centralized databases is also necessary.

7. Conclusion

Blockchain-based traceability can provide a shared, tamper-evident record of supply chain events, but trust is not produced by immutability alone. Credible provenance depends on authenticated event capture, independent physical verification, usable disclosure and accountable consortium governance. The proposed architecture and mathematical indicators clarify how traceability coverage, evidence verification, operational responsiveness and stakeholder trust may be evaluated together. Illustrative scenarios suggest testable directions for improvement while highlighting latency, privacy and governance tradeoffs. The principal conclusion is conditional: blockchain may support stakeholder trust when trustworthy evidence and institutional safeguards accompany the technology. Rigorous field studies are required to determine the magnitude and durability of any real-world effect.

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