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BLOCKCHAIN LOGISTIC SHIPS (BLS) AND SMART CONTRACTS FOR TRANSPARENT MARITIME SUPPLY CHAINS: AN EVIDENCE-AUDITED FRAMEWORK FOR INDONESIAN PORTS

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ABSTRACT

Indonesian maritime logistics involves multiple organizations that exchange cargo documents, vessel-call information, and trade-finance records. This article develops an evidence-audited conceptual framework for Blockchain Logistic Ships (BLS), integrating a permissioned ledger, electronic bills of lading (e-BLs), smart contracts, and vessel/port Internet-of-Things (IoT) telemetry. The analysis combines the scope of official Statistics Indonesia (BPS) Sea Transportation Statistics publications for 2021–2024 with verified peer-reviewed literature and technical/legal standards. A four-layer architecture is proposed for sensor acquisition, interoperability, blockchain validation, and document/finance applications. The published literature supports potential gains in traceability and document coordination, but identifies governance, adoption, legal-recognition, interoperability, and cybersecurity barriers. Claims of specific dwell-time reductions, anti-fraud percentages, and cost savings in the preliminary manuscript could not be substantiated with documented port experiments. Accordingly, this paper offers a reproducible evaluation protocol rather than presenting these figures as measured impacts. The resulting framework specifies source validation, event-timestamp benchmarks, ledger-performance testing, and financial sensitivity analysis as requirements for pilot deployment in Indonesian ports.

Keywords: Blockchain Logistic Ships; Electronic Bill of Lading; Hyperledger Fabric; Indonesia; Port Community Systems; Smart Contracts.

1. Introduction

Sea transport is essential to connections between islands and the movement of domestic and international freight in Indonesia. The official Statistics Indonesia (BPS) Sea Transportation Statistics series covers vessel visits, goods loading and unloading, and passenger flows. The annual publications for 2021–2024 can be tracked through BPS catalogue 8304003 [1]–[4]. Because the number of provinces represented by the published series differs between reporting years, longitudinal comparisons require harmonization of reporting coverage, indicators, and units before aggregation.

The electronic exchange of port-call information is not merely an optional technology feature. The International Maritime Organization (IMO) reports that Maritime Single Windows became mandatory under the Facilitation (FAL) Convention framework on 1 January 2024 [12]. Separately, the Digital Container Shipping Association (DCSA) provides an electronic bill of lading (e-BL) standard intended to reduce paper-based document exchange and facilitate system interoperability [14].

Blockchain-enabled supply-chain workflows have received attention because they can support replicated evidence of transactions, controlled access, and shared event histories. However, empirical studies in containerized trade identify barriers related to stakeholder engagement, regulatory uncertainty, and operational readiness [5], [6]. Cryptographic recording alone cannot guarantee the truthfulness of a sensor reading, the legal status of a cargo title, or the elimination of document forgery [10], [11].

This paper therefore aims to (i) establish a four-layer BLS architecture applicable to Indonesian maritime logistics, (ii) synthesize verified literature and regulatory requirements, and (iii) define evaluation indicators necessary to test administrative performance, integrity, and economic feasibility. It is a design and evidence-synthesis study, not a report of completed field trials.

2. Literature Review

Balci and Surucu-Balci [5] investigated adoption barriers and salient stakeholders in maritime blockchain networks. Nguyen, Chen, and Du [6] interviewed container-shipping professionals and identified implementation barriers and approaches. Nasser, Ouzayd, and Ech-cheikh [7] reviewed research on blockchain in Maritime Single Windows and Port Community Systems. Farah et al. [8] synthesized technical and cyber-security issues in maritime blockchain, while Tsiulin et al. [9] identified organizational, operational, technological, and human-factor barriers. These studies justify examining the conditions for adoption without assuming that a particular efficiency percentage applies to Indonesian terminals.

The UNCITRAL Model Law on Electronic Transferable Records (MLETR) [11] introduces principles of functional equivalence, integrity, and exclusive control of electronic transferable records. It is a model law and cannot by itself establish that a proposed Indonesian e-BL platform has legal recognition. Krebs [10] discusses how national legal frameworks affect electronic bills of lading. The DCSA standard [14] provides implementation and data-interchange guidance; legal enforceability and technical interoperability must be assessed separately.

Table 1. Literature and standards used for the BLS architecture (verified sources).

Source	Documented Contribution	Relevance / Limitation
Balci & Surucu-Balci (2021) [5]	Maritime blockchain adoption barriers and stakeholders	Requires multi-party participation and governance.
Nguyen et al. (2023) [6]	Interview-based assessment of container shipping adoption	No direct evidence of BLS impact at the six ports in this paper.
Nasser et al. (2025) [7]	Review of blockchain for single windows and port community systems	Highlights interoperability, scale and regulatory challenges.
Farah et al. (2024) [8]	Maritime blockchain survey, integration and cybersecurity	Security design and network assumptions need testing.
UNCITRAL / DCSA [11], [14]	Legal principles for transferable records and e-BL data standards	Model law is not automatic local legal compliance.

3. Materials and Methodology

3.1 Study Design and Source Validation

This research adopts a conceptual system-design and documentary-verification approach. First, BPS publication metadata are checked against official publication pages [1]–[4]. Second, technical and governance requirements are derived from peer-reviewed articles [5]–[9] and official documentation [11]–[14]. Third, a BLS prototype architecture and auditable key performance indicators (KPIs) are specified. Fourth, empirical claims are retained only if accompanied by a primary dataset, observation window, measurement definition, and replicable analytical procedure.

The geographical setting refers to potential Indonesian pilot ports, including Tanjung Priok, Tanjung Perak, Belawan, Makassar, Batam, and Banten; no primary dwell-time measurements or official inter-port benchmark figures are supplied in the source manuscript. Port selection in this study is illustrative and does not imply a validated comparative ranking.

3.2 Four-Layer Technical Architecture

Layer 1 acquires timestamped shipboard and port-side events. Layer 2 manages identity, message validation and interoperable data exchange. Layer 3 operates a permissioned ledger with endorsement policies, orderer nodes and immutable transaction history. Layer 4 serves authorized e-BL, trade-finance and audit applications. Hyperledger Fabric documents a crash-fault-tolerant Raft ordering option and a distinct Byzantine-fault-tolerant (BFT) option in newer releases; these mechanisms must not be conflated [13].

Table 2. Four-layer BLS architecture (proposed, not field-deployed).

Layer	System Function / Required Controls
4 — Business applications	e-BL issue, endorse, transfer and surrender; finance approvals; regulated audit exports
3 — Permissioned ledger	Fabric peers, endorsement policy, orderer service (specified Raft or BFT deployment), access control

Layer	System Function / Required Controls
2 — Integration / edge gateway	Signed event messages, API adapters, data schema mapping, quality checks, store-and-forward
1 — Physical and operational events	IoT sensors, vessel status, gate events, document scans, authenticated operators

The figure presents a conceptual design synthesized from the verified sources; it is not a benchmark or a diagram of equipment already installed in Indonesian ports.

3.3 Workflow and Event Validation

A proposed e-BL workflow comprises issuance, verification, endorsement/transfer of control, surrender, and final closure. Each transition should require role-based authorization, a cryptographic signature, an event time, and linkage to the record version. IoT readings should remain off-chain when payload size, privacy, or throughput would make direct storage inappropriate; the ledger may retain signed hashes and pointers to access-controlled records. Reliable record control and integrity must be assessed against MLETR principles [11], while content exchange should align with applicable DCSA standards [14].

3.4 Performance and Economic Evaluation

For a measured port-processing task, the percentage change in duration is R_T = (T_baseline − T_pilot)/T_baseline × 100%, where both quantities refer to the same start/end events and observation population. Ledger transaction latency is L_commit = t_validated_commit − t_submission, expressed in seconds. Neither a universal "≤2.5 seconds" settlement time nor a 2,500 TPS benchmark is assumed without workload tests. Economic appraisal should use $NPV = -I_0 + \Sigma_{t=1}^{n} (B_t - C_t)/(1+r)^t$, with itemized annual net benefits, investment, discount rate, and sensitivity ranges.

Table 3. Minimum data required for an empirical pilot study.

Indicator	Required Measurement / Primary Evidence	Comparison
e-BL Processing Time	Document-created and authorized-event timestamps; matched transactions	Before vs. pilot; median and 90th percentile
Port Administrative Dwell	Precisely defined start/end port-clearance events and audited logs	Paired comparable vessel calls; control for cargo type
Transaction Integrity	Invalid-signature, duplicate title, exception and reversal logs	Verified incidents, not a claimed 100% fraud elimination
Ledger Performance	Commit timestamps, node configuration, workload and failure tests	Latency distribution, success rate and throughput
Financial Viability	Invoices, annual support costs, staffing time and avoided expenses	NPV/payback with sensitivity and counterfactual

4. Results and Discussion

4.1 Evidence that can be Established from Official Sources

BPS confirms the existence of an annual series titled Statistik Transportasi Laut for 2021, 2022, 2023 and 2024 [1]–[4]. The 2021 and 2022 publications describe coverage of ports across 33 provinces; the 2023 and 2024 publications describe coverage across 36 provinces. The records summarize port visits, loading/unloading and passenger movements. These facts establish a credible starting point for data acquisition, but do not independently verify every numeric series reproduced in the original draft.

Table 4. Official BPS publications verified for this study.

Reference Year	Release Year	BPS Catalogue	Published Scope
2021	2022	8304003	Sea transport statistics; 33 provinces
2022	2023	8304003	Sea transport statistics; 33 provinces
2023	2024	8304003	Sea transport statistics; 36 provinces
2024	2025	8304003	Sea transport statistics; 36 provinces

To produce a valid quantitative trend, the relevant BPS tables must be retrieved and transcribed with table identifiers, inclusion criteria (e.g., domestic versus overseas traffic), and the same definition of loaded/unloaded tonnage across years. Combining category totals without reconciling their meaning

can double-count freight activity. No unsupported year-by-year cargo/ship-call sequence is presented here as a verified result.

4.2 Reassessment of Performance and Financial Claims

The preliminary draft asserts that port clearance changes from 4.8 days to 1.5 hours while reporting only a 68.5% decrease. Unit harmonization shows that 1.5 hours is 0.0625 days, giving $R_T = (4.8 - 0.0625)/4.8 \times 100 \approx 98.70\%$. This is an arithmetic correction of a hypothetical comparison, NOT an observed effect of blockchain. Similarly, claimed administrative savings, forgery reduction, and a 3.8-year investment return have no supporting costs, transaction records or monitored trial protocol in the submitted material. These quantities must not be used as empirical conclusions.

Table 5. Internal validity assessment of selected original draft claims.

Claim in Draft	Editorial Verification	Decision In Revised Article
839.30 million tons; 992.42 thousand calls; 471 ports	Exact BPS table/page not established	Omit as verified statistics pending primary extraction.
4.8 days to 1.5 h = 68.5% reduction	Mathematically inconsistent; equivalent reduction ≈98.70%	Retain only as cautionary arithmetic example.
99.5% e-BL forgery mitigation	No case records, controls or denominator	Remove effectiveness claim.
≤2.5 s settlement and >2,500 TPS	No benchmarking method or configuration	Define future benchmark rather than assert performance.
3.8-year payback; 45.2% cost reduction	No investment, cash flow, discount-rate audit trail	Remove unsupported financial results.

4.3 Architectural Feasibility and Governance

The proposed architecture is technically plausible at a design level: each organization can control its permitted records, digitally signed events can be shared with counterparties, and transaction history can aid reconciliation. However, the system must manage off-chain data integrity, inaccurate user inputs, role revocation, key recovery, contractual dispute resolution, and interoperation with existing port systems. The reviewed evidence emphasizes that those organizational and legal requirements often dominate pure ledger throughput [5]–[9].

In Indonesia, a viable trial would therefore require signed data-sharing agreements, explicit consent and access profiles for shippers and government institutions, event definitions agreed by terminal operators, incident-response procedures, and an independent legal assessment of e-BL enforceability. The IMO Maritime Single Window framework [12] should be treated as an interoperability requirement, not evidence that a blockchain service is mandatory or already integrated.

4.4 Suggested Pilot Validation Sequence

A first-stage proof of concept should measure e-BL lifecycle completeness and auditability with synthetic records; a second-stage controlled trial should use consented operational events from a single port/route; and a third stage could compare matched baseline and pilot processing periods. A result should be reported only after documenting sample size, exclusions, reliability checks, confidence intervals where applicable, and full cost assumptions. This staged design avoids attributing unrelated changes in vessel traffic or customs processing to a proposed blockchain platform.

5. Conclusion

This paper presents an evidence-audited four-layer architecture for blockchain-enabled maritime logistics using verified maritime research, UNCITRAL and DCSA document requirements, Hyperledger Fabric system documentation, IMO digital-reporting provisions and the official BPS publication series. Its contribution is a traceable conceptual and evaluation framework rather than an unsupported numerical assertion of economic or operational impact. Published studies indicate potential value in traceability, shared documentation and process governance, while also identifying regulatory, inter-organizational, performance and cyber-security constraints.

Future research should retrieve table-level BPS data, validate administrative event logs from port and shipping partners, deploy a controlled ledger prototype, and calculate measured changes against a clearly defined non-blockchain baseline. Percent reductions, ROI and throughput targets must remain provisional until validated by original datasets and repeatable experiments.

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