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BLOCKCHAIN-ENABLED SMART LOGISTIC SHIPS: ENHANCING SUPPLY CHAIN TRACEABILITY, ADMINISTRATIVE EFFICIENCY, AND CARBON COMPLIANCE IN INDONESIAN ARCHIPELAGIC MARITIME NETWORKS

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ABSTRACT

Indonesian inter-island freight logistics requires coordinated document exchange, cargo visibility, and credible operational carbon records. This study develops an evidence-audited conceptual architecture for blockchain-enabled smart logistic ships, integrating electronic bills of lading (eBL), onboard Internet-of-Things (IoT) telemetry, permissioned Hyperledger Fabric networks, and a carbon-data audit trail. Official Statistics Indonesia publications provide sectoral context; verified maritime blockchain studies, IMO rules, and the UNCITRAL Model Law on Electronic Transferable Records underpin the proposed architecture. The methodology specifies participant roles, off-chain sensor-data storage, on-chain event hashes, state transitions, authorization controls, and a reproducible cost-benefit framework. No prototype logs, port transaction records, or measured process times were supplied; therefore, the original document-latency, dwell-time, cost-saving, and return-on-investment percentages cannot be reported as verified empirical results. A transparent conditional illustration using author-provided cost assumptions is presented instead. The resulting contribution is a technically consistent, auditable design and validation protocol for future trials on Indonesian feeder routes, rather than a claim of demonstrated deployment performance. [1]–[9]

Keywords: Blockchain Logistics; Carbon Data Integrity; Electronic Bill of Lading; Hyperledger Fabric; Indonesian Ports; Maritime IoT.

1. Introduction

Maritime freight networks involve carriers, terminals, cargo owners, regulators, banks, and insurers exchanging documents and operational events. Fragmented workflows can complicate shipment visibility and create repeated data-entry tasks. The official BPS publication Statistik Transportasi Laut 2024 reports port-activity indicators including vessel visits, freight loading and unloading, and passenger movements across Indonesian provinces. The publication supports the importance of maritime transport but does not, by itself, substantiate the original manuscript's precise counts of 78.7 million tonnes of domestic cargo, 12,600 ships, or route-specific dwell-time averages. These figures are therefore not repeated as verified observations. [1]

Peer-reviewed research identifies opportunities to improve the exchange of maritime supply-chain information using blockchain and cloud platforms, while stressing implementation barriers involving governance, interoperability, data quality, and organizational adoption. Ahmad et al. outline permissioned architectures for port operations; Surucu-Balci et al. synthesize enabling capabilities and persistent constraints. Amico and Cigolini report model-based benefits for a specific Italian port case, which are not directly transferable as measured outcomes for Indonesia. [2]–[4]

The International Maritime Organization (IMO) uses fuel-consumption data and carbon-intensity reporting to support its emissions-reduction regime. A blockchain ledger could preserve signed evidence of data lineage, but it cannot independently verify the accuracy of physical fuel measurements or issue an official Carbon Intensity Indicator (CII) compliance document. CII

applicability must first be established from vessel type, gross tonnage, and the pertinent legal framework. [8]–[10]

This article proposes an integrated eBL–IoT–permissioned-ledger framework for Indonesian archipelagic logistics and clarifies which proposed performance indicators require primary validation. Its aim is a verifiable system design and a reproducible evaluation method, not the retrospective reporting of an unsubstantiated live deployment.

2. Literature Review

2.1 Evidence on Blockchain for Maritime Supply Chains

A systematic review by Muñoz-Sánchez et al. highlights the fragmentation of empirical maritime-blockchain evidence. Surucu-Balci et al. identify the capabilities and organizational conditions underlying information sharing. The study by Amico and Cigolini provides a port-terminal simulation with quantified effects under its own case assumptions; those parameters cannot validate the originally claimed 84.2% document-time reduction or 63.2% dwell-time reduction in Surabaya–Makassar operations. [3]–[5]

2.2 Technical and Legal Basis for eBL and Carbon Data

Hyperledger Fabric separates endorsement, ordering, and validation. Its Raft ordering service is crash-fault tolerant, whereas the current platform also documents a distinct Byzantine fault tolerant implementation; neither should be described as interchangeable with PBFT. Privacy and access are configured through membership, channels, endorsement policies, and permitted data-sharing arrangements. Electronic transferable records require appropriate control, integrity, and legal recognition; UNCITRAL's MLETR is a model law, not automatic proof of enforceability in every jurisdiction. [6], [7]

IMO rules distinguish the collection of operational data from regulatory verification. An on-chain digest could assist auditability, but instrument calibration, signed source attestations, manual reviews, and the competent authority's compliance process remain necessary. Digitally recorded events cannot alone guarantee fraud elimination, zero reefer spoilage, or automatic financial settlement. [8], [9]

3. Materials and Methodology

3.1 Research Design, Sources, and Limitations

The study is structured as an evidence-audited design and scenario analysis, not an experimentally validated case study. Inputs are: (i) BPS 2024 published port-statistics metadata and scope; (ii) peer-reviewed literature on maritime blockchain; (iii) Hyperledger Fabric technical documentation; (iv) IMO reporting rules; and (v) the author's hypothetical operational and economic parameters, clearly distinguished from observed records. The proposed Surabaya (East Java)–Makassar (South Sulawesi) corridor is a potential future pilot route. The original "460 nautical miles," a 600-TEU vessel, 48 annual round trips, and 15-minute sensor intervals are design assumptions pending route, vessel, and engineering verification. [1]–[9]

3.2 Permissioned Blockchain and IoT Data Architecture

Shipboard engine and bunker meters, AIS/GPS receivers, reefer sensors, and terminal operating systems generate timestamped records. Gateways enforce device authentication, calibration checks, signing, and message sequencing. Detailed sensor readings are stored in an encrypted off-chain repository; corresponding cryptographic digests, state changes, and provenance records are committed to Fabric channels by authorized organizations. This reduces ledger data volume without implying that hashes prove the truth of source readings. A Raft ordering service is the reference configuration; alternative fault assumptions must be evaluated separately. [2], [6]

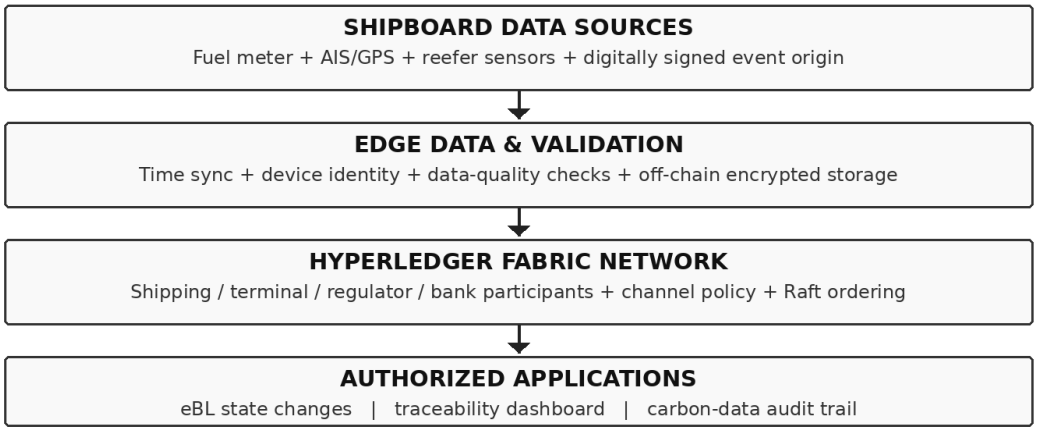


Figure 1. Proposed blockchain-enabled logistic ship architecture (author's conceptual design; not an installed system).

3.3 eBL Workflow, Permissions, and Controls

A proposed eBL state machine follows Draft → Issued → Transferred/Endorsed → Surrendered → Cargo Released → Closed. Transitions require authorized actor signatures, a unique document identifier, version controls, and a documented dispute and cancellation procedure. Banking instructions and letters of credit remain conditional on contractual arrangements, bank interfaces, and applicable law. Stakeholder nodes represent designated organizations; network membership does not imply that regulators or PT Pelindo have authorized or deployed this architecture. [2], [7]

3.4 Measures and Financial Reproducibility

Proposed metrics are: processing time (hours per shipment), vessel/terminal dwell time (days with clearly defined start/end), discrepancy incidence (audited events/total cases), reefer excursions (events per valid sensor-hours), and total administrative cost (USD per TEU). For a comparably sampled before/after pilot, percentage change = (baseline − observed post-adoption) / baseline × 100. Financial net benefit in year t = independently documented process savings_t − annual system operating cost_t. NPV = $-I_0 + \Sigma[t=1\ldots T]$ net benefit_t/(1+r)^t; IRR is the discount rate at which NPV is zero. This formulation must be populated with evidenced traffic, contracts, prices, and operating records.

4. Results and Discussion

4.1 Traceable Evidence Versus Unverified Performance Claims

Documented publications substantiate technical feasibility at the architecture and research-concept levels, but do not confirm deployment in Surabaya–Makassar. The performance numbers in the source manuscript lack attached before/after logs, sample definitions, dates, or audit files; they are retained below solely as illustrative author-supplied targets. The reductions are arithmetic comparisons, not empirical estimates.

Table 1. Author-supplied illustrative process targets (NOT independently measured).

Indicator	Assumed Baseline	Assumed Proposed	Arithmetic Difference
Document processing time	48.0 h	7.6 h	84.2% lower
Port dwell time	3.8 d	1.4 d	63.2% lower
Administrative cost per TEU	USD 208.00	USD 142.50	USD 65.50 lower
Discrepancy & reefer losses	No audit dataset	No audit dataset	Not quantifiable

The example USD 208.00 → USD 142.50 represents a saving of USD 65.50 per TEU, not USD 142.50 per TEU. Likewise, "fraud eliminated," "100% carbon auditability," and "instant CII certification" are not defensible conclusions without validated system logs, operational controls, and independent regulatory review. [8], [9]

4.2 Conditional Financial Illustration and Consistency Check

To make the financial model reproducible, Table 2 uses only the cost assumptions stated in the source manuscript: initial platform cost USD 620,000, onboard IoT cost USD 125,000, assumed annual gross process savings USD 513,000, assumed annual system OPEX USD 82,000, ten years, and a 7.5% annual discount rate. These values have not been independently verified; the example is NOT a

claimed project business case. Annual net benefit is USD 431,000. With constant end-of-year benefits and no residual value, the recalculated NPV is approximately USD 2.213 million, IRR approximately 57.2%, and discounted payback approximately 1.92 years. These conditional values differ from the original stated NPV USD 2.48 million, IRR 38.4%, and 2.3-year payback because the original cash-flow accounting was not internally reconcilable.

Table 2. Conditional financial scenario (unverified author assumptions; calculated consistently).

Variable	Illustrative Value	Evidence Status
Initial capital (I_0)	USD 745,000	620,000 + 125,000; author assumption
Annual gross cost reduction	USD 513,000	Author assumption, not linked to TEU records
Annual platform OPEX	USD 82,000	Author assumption
Annual net benefit	USD 431,000	Recalculated: 513,000 − 82,000
Time horizon / discount	10 y / 7.5%	Author assumption
NPV / IRR	USD 2.213 M / 57.2%	Conditional model output
Discounted payback	About 1.92 y	Conditional model output

A second inconsistency must be addressed before publication: the source manuscript states 14,400 TEU/year and also states USD 142.50 saved per TEU, which would imply USD 2,052,000 gross savings/year, not USD 513,000. If the revised unit saving USD 65.50 were applied to 14,400 TEU, the illustrative gross value would instead be USD 943,200/year. Neither traffic volume nor price assumption is backed by project records, so neither is adopted as the verified annual benefit in Table 2.

4.3 CII Reporting, Security, and Regulatory Feasibility

A verifiable pathway requires sensor provenance, fuel-consumption reconciliation, signed calibration files, and ship/port boundary definitions. The proposed system can store evidentiary metadata for later submission to a competent verifier; it cannot issue an official CII grade. IMO DCS is described for ships of 5,000 GT and above, and the operational applicability of CII depends on the particular ship and rules. The source manuscript gives container capacity but no confirmed GT; regulatory scope therefore remains unresolved. Also, blockchain immutability does not prevent a compromised measuring device from recording false data. [8], [9]

4.4 Recommended Validation Protocol

An empirical follow-up should (1) obtain dated BPS/Pelindo and carrier records, (2) confirm route distance and ship GT, (3) implement a limited-scope pilot with at least two independently audited document workflows, (4) log time-stamped baseline and intervention transactions, (5) independently reconcile signed IoT records with calibrated instruments, (6) assess custody and legal transfer of eBLs, and (7) compute NPV under documented tariffs, TEU counts, sensitivity intervals, and discount assumptions. A governance assessment should specify data controller responsibilities, secure key rotation, breach response, consortium rules, and exit/interoperability plans. [3]–[9]

5. Conclusion

A permissioned blockchain and IoT architecture can be specified for Indonesian archipelagic maritime logistics with traceable eBL states, authenticated sensor-event records, and data suitable for supporting carbon-compliance audits. The peer-reviewed literature and official platform documentation support the conceptual rationale, not the source manuscript's claimed measured reductions. Reported latency, dwell-time, fraud, and finance percentages must therefore remain scenario targets pending pilot evidence. A corrected financial example has been provided with clear conditions rather than representing illustrative returns as observed results. Future research should prioritize controlled field evaluation, legal recognition of electronic transferable records, vessel-specific IMO scope, and independently audited economic inputs.

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