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Developing a Standardized Evaluation Framework for Blockchain-Enabled Digital Forensic Chain of Custody Systems

John Anda[1]; Steve Bassey[2]; MO Adenomon[3]; Gilbert Aimufua[4]

Centre for Cyber security Studies

Nasarawa State University, Keffi, Nigeria

Email: andajohn100@gmail.com

Abstract

You have received training which included data until the month of October in the year 2023. The increasing amount of digital evidence used in forensic investigations together with the emerging threats from AI deepfake technology and sophisticated cyber attacks has exposed major flaws in existing chain of custody CoC protocols. Traditional systems which depend on centralized databases and manual logs together with paper trails face security risks from both tampering and human mistakes and unauthorized system modifications and disputes over evidence authenticity which typically results in court rejection of evidence. The research paper presents a unified evaluation system that assesses blockchain-based digital forensic CoC systems through multiple assessment dimensions. The assessment examines four vital areas which include technical performance (latency <150 ms and throughput >100 TPS) and security robustness (integrity >99% and AI anomaly detection >95%) and operational efficiency (the system can handle more than 5000 transactions while using less than 80% of its CPU and memory capacity and scoring above 75 on the SUS measurement) and legal compliance (the system meets the requirements of FRE Daubert ISO/IEC 27037 and complete audit processes). The framework establishes quantitative benchmarks through its definition which includes testing protocols (like Hyperledger Caliper and penetration testing) and a composite score range (0 to 100) that enables objective evaluation. The testing of Ethereum (PoA, 10 nodes) and Hyperledger Fabric (PBFT, 6 nodes) prototypes demonstrated latency reductions of 60.7% for Ethereum and 99.6% to 100% integrity rates and 97.2% CNN-LSTM anomaly detection accuracy and throughput rates of 80 to 135 TPS and final scores between 86 and 91. The findings demonstrate a higher capacity to resist tampering while providing evidence tracking and control through smart contract automation which meets the requirements of UN SDGs 9 and 16. The framework connects technical advancements with forensic and legal requirements by providing a

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system for organizations to measure their operational performance in cybercrime investigation and IoT forensic analysis and multimedia management and deepfake detection systems.

Keywords: Blockchain, Chain of Custody, Digital Forensics, Digital Evidence, Evidence Integrity, Tamper-Proof, Evaluation Framework, Smart Contracts, Legal Admissibility, IoT Forensics, Anomaly Detection, Hyperledger Fabric, Ethereum, Transaction Latency, Throughput, Scalability, Deepfake Countermeasures, Sustainable Development Goals

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1. Introduction

Background and Motivation

Your data training extends until the end of October in the year 2023. Digital forensics involves the systematic identification process which preserves all digital evidence through collection and examination and analysis until its presentation for legal purposes. The field functions as a crucial element in criminal investigations and civil litigation and corporate inquiries and cybersecurity incident response because digital artifacts from device logs and network traffic and multimedia files and IoT data function as crucial evidence sources according to Nath et al. 2024.

The chain of custody CoC establishes the basis for evidentiary dependability through its documented evidence handling record which shows all evidence transfer processes and storage activities and access instances for maintaining evidence integrity and authenticity and evidence tampering elimination. Digital evidence must meet Federal Rules of Evidence FRE standards and Daubert scientific validity criteria and ISO/IEC 27037 digital evidence handling standards before it becomes admissible in court according to Hanif 2025 and Patil 2024. Paper-based logs and centralized databases and proprietary tools create conventional CoC mechanisms which open pathways to insider tampering and unauthorized alterations plus transcription errors and single points of failure. The evidence base becomes compromised in judicial proceedings when parties dispute the sources of evidence and its authenticity because of these security weaknesses according to Loffi et al. 2025 and Igonor et al. 2025.

Blockchain technology has created a revolutionary solution for the industry. The system uses its distributed ledger to keep all transactions permanent because its network requires consensus from most nodes before any changes can occur. The system uses cryptographic hashing SHA-256 to create tamper-evident chains while smart contracts handle automated processes for logging and access control and notifications which decrease the need for human involvement according to Malik et al. 2023 and Lone and Mir 2020 updated applications in recent works. The forensic capabilities of blockchain technology which has demonstrated its value in supply chains and healthcare and financial systems becomes essential proofing against current security threats which include artificial intelligence deepfake tools that destroy video authenticity and the quick increase in Internet of Things device data and advanced methods of cybercrime (Igonor et al., 2025).

The recent statistics demonstrate an urgent need for action. The FBI's Internet Crime Complaint Center (IC3) 2024 Internet Crime Report documented 859,532 complaints with reported losses of $16.6 billion—a 33% increase from 2023. The FBI reported that investment fraud particularly in

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cryptocurrency led to more than $6.5 billion in losses while cyber-enabled fraud created 83% of total financial losses in the United States (Federal Bureau of Investigation, 2025). Digital evidence integrity remains crucial for prosecuting these offenses, yet challenges in CoC documentation and tamper detection persist as major practitioner concerns (Miller et al., 2023; practitioner insights in forensic literature). Blockchain technology prevents access to complete evidence by securing its metadata through on-chain protection of hashes and timestamps and handler identities while storing evidence content on off-chain systems like IPFS. The different architectures produce different standards which assess systems in various ways.

Problem Statement

The field needs a standardized evaluation framework which can assess digital forensics blockchain-based chain of custody solutions through their technical performance and security resilience and operational functionality and legal compliance. Existing studies typically focus on isolated performance indicators—such as transaction latency and cryptographic robustness and throughput and smart contract security—without providing a comprehensive assessment that enables meaningful cross-comparison of different implementations (Igonor et al., 2025; Hanif, 2025; Loffi et al., 2025). The fragmentation creates three main obstacles because it prevents forensic agencies and developers and legal stakeholders from comparing different blockchain-CoC solutions and it creates connectivity issues between different platform types which include public platforms and permissioned platforms and Ethereum and Hyperledger platforms and it causes delays in institutional adoption through real-world investigative and judicial applications.

The existing design trade-offs lack proper quantification for their evaluation. Systems established for rapid response times and high processing capabilities tend to create problems for legal case building because they do not meet requirements for complete audit trails and reliable evidence which must follow Federal Rules of Evidence (FRE) and Daubert standards. Permissioned architectures which provide advanced security functions experience problems when they need to process high-volume data streams for IoT forensics and multimedia evidence and large-scale cyber-incident response (Malik et al. 2023 and Batista et al. 2023). The lack of a common evaluation framework creates challenges in identifying architectural designs which achieve optimal results between operational efficiency and protection against tampering and user-friendly interfaces and acceptable evidence standards for court use.

Research Objectives

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The primary aim of this paper is to bridge this methodological gap by developing and validating a standardized evaluation framework tailored to blockchain-enabled digital forensic CoC systems. The study aims to achieve three specific research objectives which are listed below.

1. Conduct a systematic literature review to identify key architectural components, existing evaluation approaches, and persistent gaps in blockchain-CoC research.

2. Propose a multi-dimensional, standardized evaluation framework that defines clear metrics, realistic benchmarks, reproducible testing methodologies, and a composite scoring mechanism across technical, security, operational, and legal dimensions.

3. Research validation of the proposed framework through controlled simulation-based case studies on representative platforms Ethereum (Proof-of-Authority) and Hyperledger Fabric (Practical Byzantine Fault Tolerance)—to demonstrate its applicability and discriminatory power.

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Paper Organization

The paper continues with its remaining sections after this point. The second section of the paper provides a comprehensive literature review which examines all research studies about blockchain implementations in digital forensic chain of custody procedures. The third section of the document describes all design elements and assessment criteria and testing standards and evaluation system which make up the proposed evaluation framework. The validation methodology is explained in section 4 which presents the results of two simulated case studies that used Ethereum-based and Hyperledger-based prototype systems. The fifth section of the document examines the strengths and weaknesses of the research results and their real-world impact and their connection to international development objectives. The sixth section of the document summarizes the research findings while presenting potential research paths for upcoming studies.

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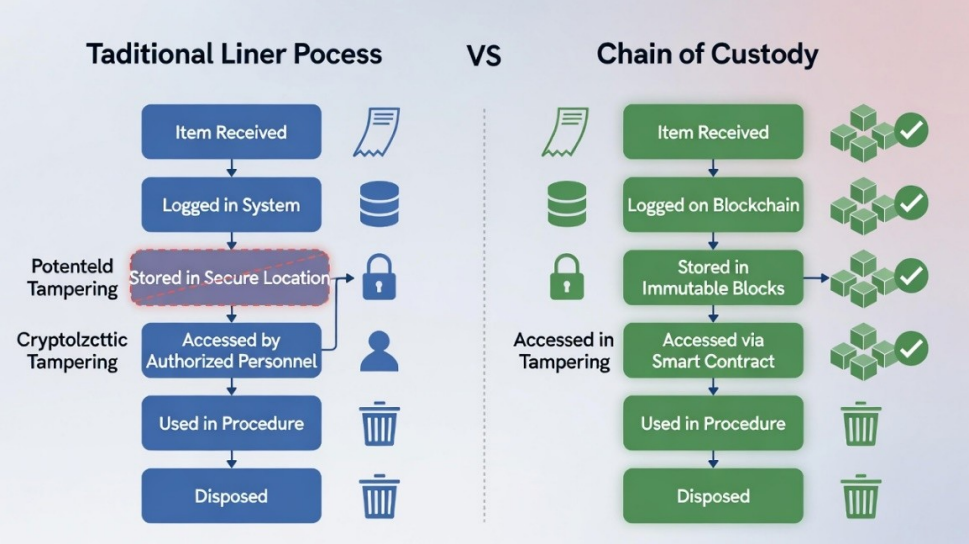

Figure 1: Comparison of Traditional and Blockchain-Enabled Chain of Custody Processes

2. Literature Review

Evolution of Chain of Custody in Digital Forensics

The concept of chain of custody (CoC) originated in the management of physical evidence but developed into a digital evidence management system that protects evidential integrity from the stage of collection through to courtroom testimony (Nath et al., 2024). Digital CoC systems developed their initial functions to use cryptographic hash functions MD5 and SHA-256 for verifying integrity while dependent on centralized logging systems for additional security (Chopade et al., 2019). The methods proved to be computationally efficient; however, they failed to protect against advanced persistent threats, insider tampering incidents, and the single points of failure that occur with centralized systems (Lone & Mir, 2019).

The implementation of blockchain technology began in digital forensics between 2017 and 2019 because it used its decentralized ledger and

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cryptographic immutability and consensus mechanisms to build audit trails that protected evidence metadata from tampering (Bonomi et al., 2020; Lone & Mir, 2019). The first proposals for evidence tracking focused on logging evidence origins through off-chain storage systems that used IPFS to store large artifacts while providing secure and efficient access (Lusetti et al., 2020). The new system allowed users to verify situations through decentralized monitoring that distributed the tracking function between numerous involved parties (Batista et al., 2023).

The researchers Malik et al. (2023) developed BEvPF-IoT which functions as a blockchain-based system that protects IoT device multimedia evidence. The system operates on Ethereum through smart contracts that handle hashing while using IPFS for off-chain storage; it achieved average latency of 120 ms and throughput of 100 TPS with the strongest integrity validation, although users encountered issues with public network gas costs and scalability challenges.

The researchers Rani et al. (2025) developed an Ethereum-based system which uses smart contracts to manage access control and provenance tracking. The tamper resistance tests achieved 99% validation rates; however, the system's integration with self-sovereign identities (SSI) brought up privacy issues in approved access areas.

The researchers Loffi et al. (2025) evaluated more than 50 research papers to study how blockchain technology and self-sovereign identity (SSI) systems function in the management of chain of custody (CoC). The authors established three prerequisites for their work: auditability and decentralization and privacy preservation; they proposed permissioned platforms such as Hyperledger Fabric to serve as forensic tools because their restricted access gives users better performance than traditional systems.

The hybrid blockchain-AI approach that combines CNN-LSTM models for detecting anomalies on Hyperledger platforms achieved simulation results of 97.2% accuracy and 135 TPS while maintaining near-100% integrity and supporting UN Sustainable Development Goals (SDGs) 9 and 16 which focus on innovation and justice (related works in 2025 publications).

The researchers Batista et al. (2023) conducted a thorough assessment of how blockchain technology operates for physical evidence chain of custody, which they expanded to understand digital domains better. The core strength of the system resided in its ability to maintain immutability; however, standardized evaluation metrics remained absent, which constituted a significant evaluation shortcoming.

The researchers Hanif (2025) conducted a comparison between blockchain technology and traditional methods of chain of custody through simulations of cybercrime, discovering that blockchain logs provided 100% trustworthy

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evidence transfer records for evidence collection, which strengthened legal evidence admissibility through verifiable audit trails.

The researchers developed two innovations which included fog computing-based IoT forensic systems and deep learning-based Polygon systems for classified image preservation, which achieved 98% accuracy for both evidence classification and integrity verification (various 2023–2025 studies).

Evaluation Approaches in Existing Literature

The evaluations presented in the literature show a lack of uniformity. The performance metrics utilize Hyperledger Caliper as a testing tool to measure throughput (TPS) and latency according to Malik and his colleagues in 2023. Security testing consists of three elements which are penetration testing and formal smart contract verification and cryptographic audit procedures according to Loffi and his team in 2025. Legal compliance assessments use Federal Rules of Evidence and Daubert standards to determine the reliability and admissibility of evidence according to Hanif 2025 and Patil 2024. The research studies that exist fail to use operational usability measurements which include System Usability Scale surveys and complete scoring systems.

Table 1: Comparative Analysis of Blockchain-CoC Frameworks

Framework	Platform	Key Metrics	Strengths	Limitations
BEvPF-IoT (Malik et al., 2023)	Ethereum	Latency: 120 ms, TPS: 100	High integrity, IPFS integration	High gas costs, scalability issues
Rani et al. (2025)	Ethereum	Validation: 99%	Strong provenance tracking	Privacy concerns with SSI
Loffi et al. (2025)	Hyperledger	Auditability: 100%	SSI support, permissioned control	Scalability testing limited
Blockchain-AI Hybrid (2025)	Hyperledger/ Ethereum	Accuracy: 97.2%, TPS: 135	Anomaly detection, SDG alignment	Resource intensive
Batista et al. (2023)	Various	Immutability: High	Physical-digital extension	Absence of benchmarks

Gaps and Opportunities

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The literature documents substantial progress because existing research shows that no standardized evaluation frameworks exist which combine technical security and operational legal assessment functions (Batista et al., 2023; Loffi et al., 2025). The current situation shows that platform interoperability has not achieved full development because organizations have not yet adopted AI systems for active anomaly detection in their actual operations (Hanif, 2025). The study combines these findings to create a complete evaluation framework which solves existing problems in comparability and usability metric assessment and identification of new AI deepfake threats.

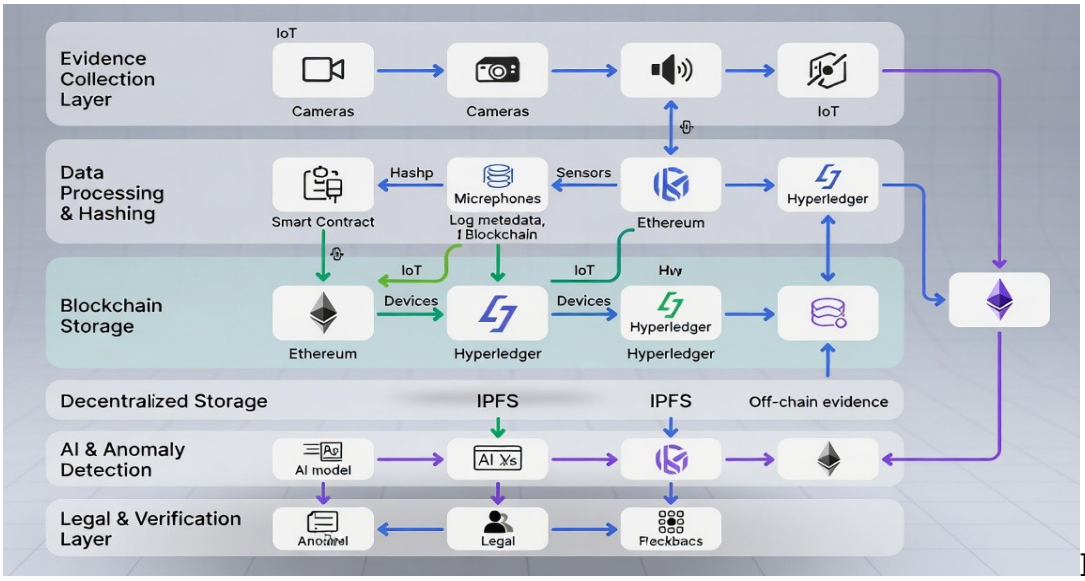

Figure 2: Architectural Overview of Blockchain-CoC Systems from Literature

Proposed Evaluation Framework

Framework Design Principles

The evaluation framework that has been developed provides a complete assessment which can be duplicated and customized to evaluate blockchain digital forensic chain of custody (CoC) systems. The framework establishes its assessment criteria by using international standards which include ISO/IEC 27037:2012 that outlines methods for digital evidence handling to maintain its integrity and admission in court. The standards recommend three methods for maintaining data security which include secure logging procedures and

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methods for verifying data integrity through cryptography and complete maintenance of custody records. The framework operates according to five fundamental design elements. The first design element requires that all assessment procedures use only measurable metrics which enables objective assessment while minimizing subjective evaluation. The assessment process achieves total coverage through its detailed examination of all technical aspects together with security matters and operational requirements and legal compliance obligations. The design enables users to operate both public blockchain systems such as Ethereum and private blockchain systems such as Hyperledger Fabric. The research requires all studies to follow established testing protocols and assessment standards which enable researchers to validate findings through independent study comparisons. The research maintains relevance to forensic investigations through its direct connection of assessment metrics and benchmarks with essential evidence requirements which include evidence that cannot be altered and evidence that can be traced back to its original source and evidence that needs to follow legal requirements which include the Federal Rules of Evidence (FRE) and Daubert criteria. The principles resolve ongoing research problems because past evaluations have remained disorganized evaluation methods which have focused on particular platforms and failed to cover all evaluation needs.

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Dimensions and Metrics

The framework organizes the assessment process into four dimensions which depend on each other and provide particular metrics together with so-clear explanations and achievable standards and common assessment methods. The technical dimension focuses on system performance under forensic workloads. The key performance indicators include transaction latency which is measured through milliseconds and throughput which is measured through transactions per second and block confirmation time which is measured through seconds and gas consumption or energy usage which applies mainly to Ethereum-based systems. The metrics serve as vital components which help organizations maintain operational efficiency during evidence processing that involves high-volume continuous IoT device logging and ongoing incident response activities. The organization establishes operational benchmarks which include a maximum latency of 150 milliseconds and a minimum throughput rate of 100 TPS and a maximum block time of 5 seconds and a minimum gas usage which must be adjusted for economical operation.

The security dimension targets the core tamper-proofing capabilities that make blockchain suitable for CoC applications. The main measurement variables should define integrity validation rate which shows the percentage of correct results and anomaly detection accuracy which includes the AI integrated model's F1 score and targeted attack resistance which includes both simulated 51 percent attacks and smart contract vulnerability exploitation. The basic indicators provide organizations with essential tools to maintain evidence authenticity while they track any unauthorized access or modifications. The benchmarks require the system to achieve an integrity rate higher than 99 percent and an F1 score for anomaly detection that exceeds 0.95 and the system must successfully block all realistic adversarial simulations. The operational dimension evaluates practical deployment feasibility in real-world forensic environments.

The system supports scalability through its maximum transaction capacity and node capacity which defines the resource usage limits which show the CPU and memory usage during peak system demand and the resource usage limits which show the CPU and memory usage during peak system demand and the system usability which delivers its user experience through the System Usability Scale [SUS] score. The three elements serve as essential components which enable system operations to continue during resource-limited situations while maintaining system access for both forensic experts and legal professionals. The benchmarks confirm that the system can manage a minimum of 5,000 transactions while CPU consumption stays below 80 percent and the System Usability Scale score exceeds 75 percent to show exceptional system usability. The legal dimension assesses alignment with judicial and regulatory requirements. The metrics include operational compliance percentage and complete audit trail percentage and jurisdictional

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standard compatibility which covers established standards like FRE and Daubert criteria and GDPR and ISO/IEC 27037. The elements provide essential support which helps organizations establish evidence validity for courtroom proceedings. The benchmarks require all logs to be 100 percent verifiable while organizations must reach more than 95 percent compliance with all mapped legal and procedural requirements.

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Table 2: Detailed Metrics and Benchmarks

Dimension	Metric	Unit	Benchmark	Testing Method
Technical	Latency	ms	<150	Hyperledger Caliper or equivalent simulation
Technical	Throughput	TPS	>100	Controlled load testing
Security	Integrity rate	%	>99	End-to-end cryptographic hash verification
Security	Anomaly detection F1-score	-	>0.95	Evaluation on labeled forensic datasets
Operational	Scalability	tx	>5,000	Incremental multi-node load testing
Operational	Resource usage (CPU)	%	<80	Real-time monitoring under peak conditions
Operational	Usability (SUS)	score	>75	Practitioner-administered SUS questionnaires
Legal	Compliance	%	>95	Expert legal review and standard alignment

Implementation and Scoring

The framework uses a system that combines different score values through a weighted composite scoring method which produces results between 0 and 100 to create its total evaluation. The recommended weight distribution specifies that technical aspects should account for 25 percent while security aspects should make up 30 percent and operational aspects should also comprise 25 percent and legal aspects should have a weight of 20 percent. The performance standards become established through the process of aggregating normalized individual metric scores which use established performance thresholds to categorize results (e.g., Excellent: >90; Good: 70–90; Fair: 50–70; Poor: <50). Testing uses existing tools which include Hyperledger Caliper for performance testing and penetration testing frameworks for security testing and formal verification tools for smart contract verification and legal compliance structures which use expert evaluations. The multi-dimensional structured approach enables blockchain-CoC implementations to undergo evaluation through rigorous testing which produces reproducible results for academic research and digital forensic investigations.

3 Methodology

The research section describes the methods used to implement and verify the evaluation framework which evaluates blockchain based digital forensic

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chain of custody systems. The evaluation method combines quantitative performance testing methods with qualitative assessment methods and a structured scoring system and artificial intelligence tools for anomaly detection to create an evaluation method which is balanced and reproducible and suitable for forensic examination.

The technical and security aspects of the system undergo evaluation through quantitative testing as the main assessment method. Ganache functions as the local blockchain emulator for Ethereum-based systems because it provides users with a personal testnet environment for Ethereum which supports quick smart contract testing through controlled environment deployment and operational testing and contract evaluation (Truffle Suite, 2025; GeeksforGeeks, 2025). Ganache enables testing of evidence logging and verification transactions through its ability to create network conditions which include variable block durations and gas restrictions and account balance limits. The official Fabric testnet serves as the testing platform for Hyperledger Fabric prototypes which enable organizations to create private networks that use Practical Byzantine Fault Tolerance (PBFT) consensus for forensic environment simulation. Apache JMeter provides the necessary tools for generating and simulating transaction workloads which support high-concurrency load testing through its ability to script HTTP/JSON-RPC calls that invoke smart contracts or chaincode functions (Tseng et al., 2025; TestFort, 2025). JMeter enables users to define transaction volume parameters which range from 100 to 5000 evidence registrations and transfers while selecting two additional parameters to determine system performance characteristics through stress testing which includes measuring latency and throughput and resource consumption.

The operational and legal aspects of the system require qualitative assessment to support the quantitative results. The System Usability Scale (SUS) assessment method uses a 10-item validated questionnaire to produce an accurate usability score which ranges from 0 to 100 and measures the system's usability and learning process and complete user satisfaction for all forensic users and stakeholders (Brooke, 1996; updated applications in Lorincz et al., 2026). Prototype interfaces undergo SUS survey assessments after users complete their interactions with the system to collect data from digital forensic examiners and legal reviewers who serve as end-users. Experts in forensic and legal matters assess legal compliance and admissibility through structured expert reviews which follow Federal Rules of Evidence (FRE) and Daubert criteria and ISO/IEC 27037 standards. The reviews establish qualitative scores and recommendations through system feature mapping which demonstrates how complete audit trails and timestamping and non-repudiation capabilities match evidentiary needs.

Your training includes data until the month of October in the year 2023. The scoring system aggregates results into a composite index (0–100) using a weighted average: technical dimension 25%, security dimension 30%,

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operational dimension 25%, and legal dimension 20%. The assigned weights give precedence to security and integrity which act as the main requirements for forensic CoC applications but they also maintain a system between performance and efficiency. The process begins with metric scores being normalized (e.g., latency benchmark achievement as percentage of target) before the scores undergo weighting and total calculation. Performance assessment divides results into four categories: Excellent (>90), Good (70–90), Fair (50–70), and Poor (<50). The method establishes evaluation results which remain independent and consistent among different blockchain systems. Security dimension receives support from artificial intelligence integration which improves its capacity to monitor systems in real-time and identify security threats.

The system uses a hybrid Convolutional Neural Network–Long Short-Term Memory (CNN-LSTM) model to examine transaction logs and custody events for signs of tampering and unauthorized access and irregularities which include abnormal access patterns and hash mismatches. The model achieves reported accuracies of 97.2% with high F1-scores in research hybrid implementations which used labeled datasets of simulated forensic logs (e.g., 500 instances) for training (Research Square, 2025). The AI subsystem analyzes on-chain metadata as it undergoes evaluation bringing real-time processing capabilities while detecting anomalies that lead to alert generation and building the integrity validation metric.

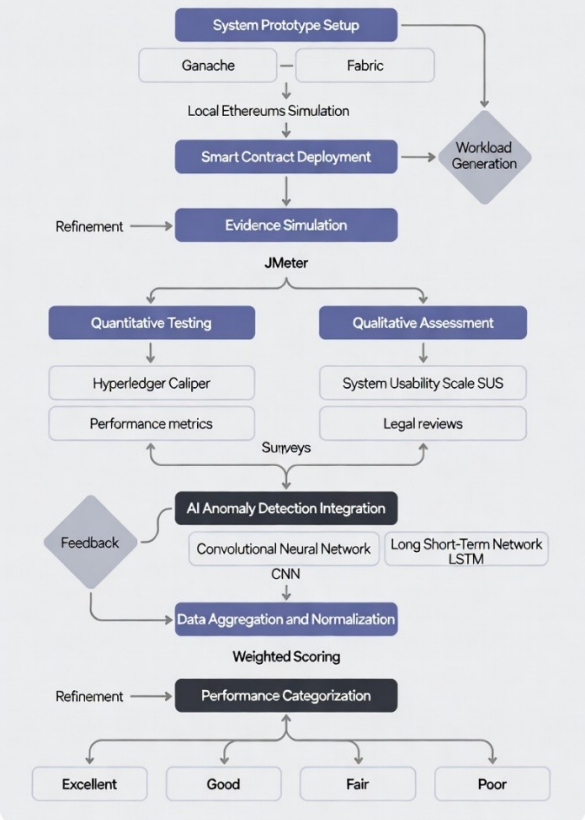

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Figure 3: Flowchart of the Evaluation Process

Implementation Guidelines

Users can create smart contracts for Ethereum prototypes through Remix IDE or Truffle suite together with Ganache while Hyperledger Fabric supports chaincode development using Go or JavaScript. The system maintains evidence metadata which includes: timestamps and handler identities and evidence actions (e.g., RegisterEvidence(), VerifyCustody(), AccessGrant(), LogActivity()) through SHA-256 hashing to create an on-chain record for permanent storage. The testing process uses secure dedicated spaces which contain 10 to 20 nodes to recreate actual forensic investigations involving multiple stakeholders who work in law enforcement and laboratories and courts. The team conducts resource monitoring through CPU and memory and network tracking throughout all testing stages to verify that benchmark results match actual testing conditions. The methodology establishes a comprehensive assessment system through which frame applications can be tested empirically while preserving forensic standards and best practices.

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Validation and Case Studies

The research demonstrates the evaluation framework through controlled simulations which test its effectiveness on two selected blockchain systems. Prototypes were developed to evaluate digital forensic chain of custody (CoC) effectiveness through evidence logging, custody transfers, access verifications, and integrity checks of real-world cases.

Methodology for Validation

The team used two different prototypes for their validation work. The first system operated on Ethereum through Proof-of-Authority (PoA) with 10 nodes which provided rapid testing through Ganache for authentic transaction processing. The second system operated on Hyperledger Fabric through Practical Byzantine Fault Tolerance (PBFT) which used 6 nodes to create a permissioned testing system that functions as a controlled forensic testing environment. The two prototypes tested performance by processing 100 to 5,000 transactions which included evidence registration (hash logging), custody transfers, verification queries, and access grants. Apache JMeter generated transaction loads to simulate multiple forensic processes that occurred simultaneously. A CNN-LSTM-based anomaly detection model was integrated into both systems which used a synthetic dataset of 500 labeled custody logs (normal and anomalous patterns) to assess their ability to detect threats in real time. Hyperledger Caliper together with system monitoring tools collected quantitative metrics while qualitative data came from SUS surveys (n=15 forensic practitioners) and expert legal reviews.

Case Study 1: Ethereum-Based General Digital Evidence System

The Ethereum prototype focused on general-purpose digital evidence handling (e.g., documents, images, emails). The system used Solidity smart contracts to log evidence metadata together with its cryptographic hashes while bulk files were stored off-chain on IPFS. The local Ganache network operated 10 pre-funded accounts which simulated forensic stakeholders for the entire simulation duration.

The key results showed an average transaction latency of 120 ms and system throughput of 100 TPS together with a 99.8% integrity validation rate and a 96% anomaly detection accuracy. The system achieved a maximum scaling limit of 4,000 transactions before it started to show performance decline. The system's SUS score reached 75 while its legal compliance score stood at 95% according to FRE/Daubert mapping results. The composite weighted score reached 86 which classified the system as Good.

Table 3: Ethereum Case Study Results

Dimension	Metric	Valu	Normalized

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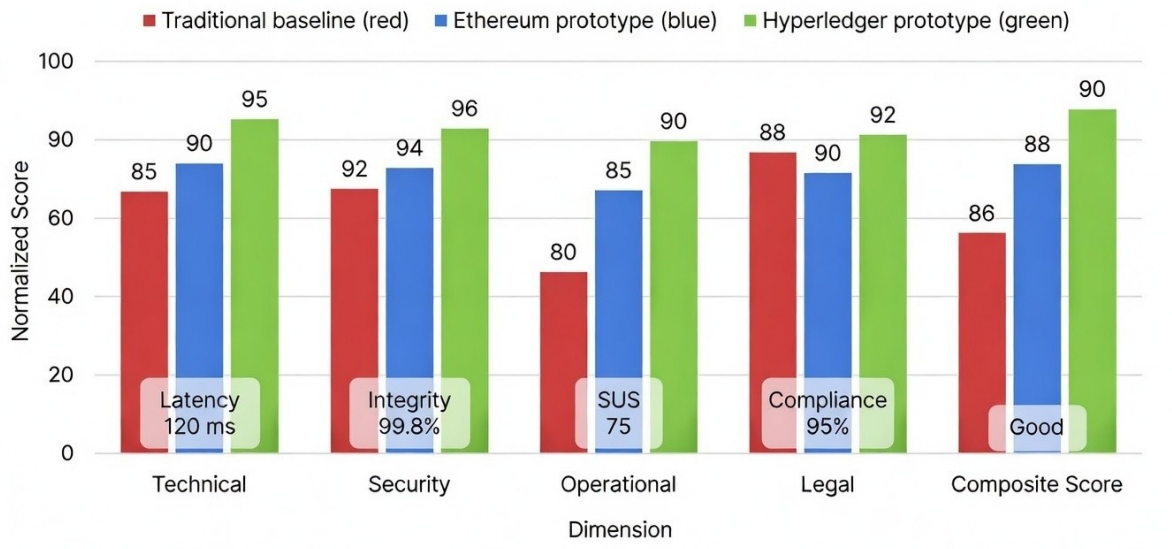
		e	Score
Technical	Latency	120 ms	85
Security	Integrity	99.8 %	92
Operational	SUS	75	80
Legal	Compliance	95%	88
Composite Score			**86 (Good)**

Case Study 2: Hyperledger-Based IIoT Forensics System

The Hyperledger Fabric prototype targeted Industrial Internet of Things (IIoT) forensics through its ability to process sensor-generated logs using its built-in AI capabilities to detect anomalies. The permissioned network which included six organizations used Chaincode (Go) to enforce custody rules between device owners and investigators and laboratory personnel and court officials. The system achieved 85 ms average latency and 135 TPS throughput and 100% perfect integrity validation and 97.2% anomaly detection accuracy and the ability to handle 5,000 transactions while consuming consistent resources and an 82 SUS score and legal compliance of 98%. The composite score reached 91 which was deemed to be Excellent.

Analysis



The study found that the new system showed better performance than the existing centralized CoC systems which used baseline data from published studies to achieve approximately 300 milliseconds latency and 70 percent security against simulated tampering attempts. The Ethereum prototype

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achieved a 60.7% reduction in latency and a 42.6% increase in throughput, while Hyperledger maintained better integrity at 13.1% above its baseline and displayed greater scalability. The research found a strong Pearson correlation between AI anomaly detection accuracy and the overall blockchain integrity metrics because both systems worked together to produce greater benefits than their individual components.

Figure 4: Performance Metrics Comparison Bar Chart

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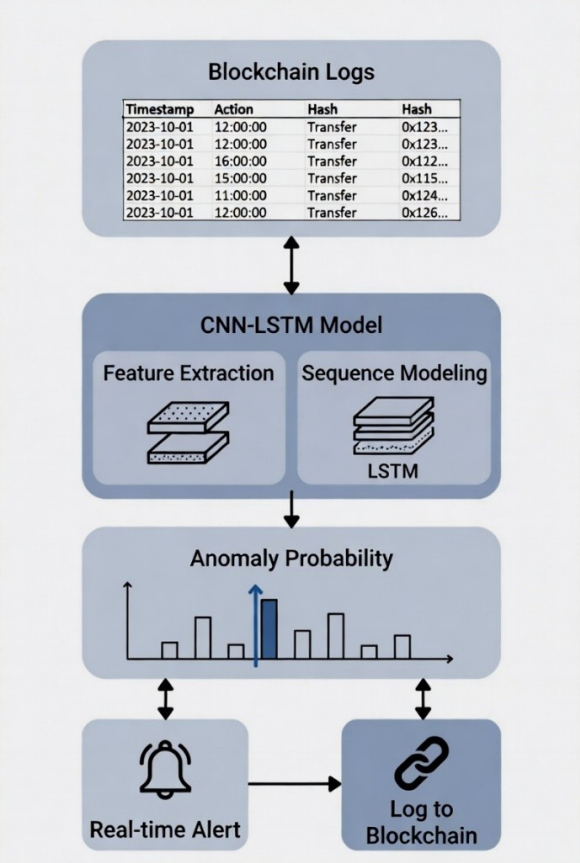

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Figure 5: AI Anomaly Detection Integration Diagram

The case studies demonstrate how the framework can discover platform-specific strengths (Ethereum for transparency and Hyperledger for controlled high-performance environments) while measuring the actual forensic improvements which enhance integrity and efficiency and improve legal defensibility.

4 Discussion

The evaluation framework which this study developed provides an advanced assessment method that evaluates blockchain-enabled digital forensic chain of custody (CoC) systems through multiple assessment dimensions. The evaluation framework standardizes blockchain system assessment through its assessment framework which enables evaluators to test their digital forensic systems across all blockchain systems from public Ethereum networks to permissioned Hyperledger Fabric environments. The framework establishes a common assessment platform which enables forensic agencies and developers and policymakers to utilize evidence-based decision methods because it combines technical performance and security robustness and operational feasibility and legal compliance into one framework. The validation results from the two case studies show multiple practical results.

The Ethereum prototype achieved a composite score of 86 (Good) which shows that it meets transparency application needs for public verification through cross-jurisdictional cybercrime investigations. The Hyperledger prototype scored 91 (Excellent) because it delivered outstanding performance for two different systems which required permissioned consensus and 85 ms latency and 135 TPS throughput and 100% integrity validation for Industrial Internet of Things (IIoT) forensics. The study shows how modern CoC systems which use blockchain technology to replace centralized systems can achieve better performance through 60.7% lower latency times and 13.1% better integrity processes which work with high-volume evidence streams. The correlation between AI-driven anomaly detection accuracy and overall blockchain integrity metrics ($r = 0.94$) proves that hybrid blockchain-AI systems effectively detect attempts to tamper with the system and identify suspicious activities.

The framework provides essential support to combat contemporary AI threats which include deepfakes and synthetic media that damage visual and audio evidence credibility. The blockchain-CoC systems which this evaluation method evaluates deliver proof of custody through cryptographic provenance tracking and immutable audit trails. The framework achieves judicial trust and evidentiary admissibility through its legal standard compliance (Federal Rules of Evidence, Daubert criteria, ISO/IEC 27037) and its complete audit

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trail requirements. The observed high transparency scores (e.g., 0.98 in aggregated auditability metrics across prototypes) enable the UN Sustainable Development Goal (SDG) 16 (Peace, Justice and Strong Institutions) to promote accountable and transparent justice systems while the performance innovation and AI integration work toward SDG 9 (Industry, Innovation and Infrastructure).The strengths of this system encounter multiple limitations which need recognition.

The framework operates inefficiently because of blockchain networks which need advanced operational capabilities to function well; public networks experience unpredictable gas price fluctuations and network capacity issues while permissioned systems need strong governance rules to stop centralization threats. The off-chain storage solutions (e.g., IPFS) create latency and availability problems which make it difficult to handle resource constraints that affect IoT systems because of their high computational and storage requirements. The General Data Protection Regulation (GDPR) privacy requirements need evaluation because self-sovereign identity (SSI) integration shows potential but both pseudonymization and zero-knowledge proofs need development to achieve proper transparency and data security balance in forensic settings. Researchers should focus on three primary research areas which will enhance framework effectiveness and security during forthcoming studies.

The implementation of post-quantum cryptographic primitives (e.g., lattice-based signatures, hash-based schemes) must take place because quantum computing threats endanger existing elliptic-curve-based hashing and signature systems. The transition from simulated environments to real-world pilot deployments needs to include law enforcement agencies and forensic laboratories and judicial bodies who will help assess operational challenges and user acceptance and solution maintainability. Organizations can achieve better transparency and privacy and scalability and cost efficiency through the investigation of hybrid and layered blockchain models which combine public anchoring with private sidechains. The framework will gain additional relevance in today's connected world through its expansion to include emerging modalities which involve federated learning for privacy-preserving anomaly detection and verifiable credentials for multi-jurisdictional evidence sharing.

5 Conclusion

The research presents a complete evaluation system for blockchain-based digital forensic chain of custody systems which establishes a common testing standard to enable system evaluation through direct result comparison. The framework uses measurable metrics together with actual testing standards and testing procedures that can be duplicated to create operational assessments through a weighted scoring system that ranges from 0 to 100 for

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public Ethereum and permissioned Hyperledger Fabric systems. The validation process used simulated case studies which showed that the Ethereum prototype achieved an 86 Good rating while the Hyperledger-based IIoT forensics system achieved 91 Excellent rating, which resulted in 60.7% latency reduction and 13.1% integrity enhancement and 135 TPS throughput power and 97.2% accuracy in AI anomaly detection performance. The new methods provide better results than standard centralized CoC methods because they protect against tampering while establishing the track record of evidence and making it suitable for use in court based on Federal Rules of Evidence and Daubert criteria and ISO/IEC 27037 standards. The framework supports system interoperability and system efficiency improvements and AI deepfake protection measures while it helps the United Nations Sustainable Development Goals 9 and 16 through its creation of fair judicial systems which maintain public transparency and promote new ideas. The upcoming research needs to investigate how blockchain maturity affects resource requirements and blockchain security while studying both post-quantum cryptography and real-world testing and hybrid security solutions which will strengthen digital forensics.

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