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

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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 tampering, human mistakes, unauthorized system modifications, and disputes over evidence authenticity, which typically result in court rejection of evidence. This 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), security robustness (integrity >99% and AI anomaly detection >95%), operational efficiency (the system can handle more than 5,000 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, such as Hyperledger Caliper and penetration testing, and a composite score range of 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, integrity rates of 99.6% to 100%, CNN-LSTM anomaly detection accuracy of 97.2%, 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 system for organizations to measure their operational performance in cybercrime investigation, IoT forensic analysis, multimedia management, and deepfake detection systems.

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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 tampering, human mistakes, unauthorized system modifications, and disputes over evidence authenticity, which typically result in court rejection of evidence. This 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), security robustness (integrity >99% and AI anomaly detection >95%), operational efficiency (the system can handle more than 5,000 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, such as Hyperledger Caliper and penetration testing, and a composite score range of 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, integrity rates of 99.6% to 100%, CNN-LSTM anomaly detection accuracy of 97.2%, 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 system for organizations to measure their operational performance in cybercrime investigation, IoT forensic analysis, 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

Keywords:

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 that preserves all digital evidence through collection, examination, analysis, and presentation for legal purposes. The field functions as a crucial element in criminal investigations, civil litigation, corporate inquiries, and cybersecurity incident response because digital artifacts from device logs, network traffic, multimedia files, and IoT data function as crucial evidence sources, according to Nath et al. (2024).

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The chain of custody (CoC) establishes the basis for evidentiary dependability through its documented evidence-handling record, which shows all evidence transfer processes, storage activities, and access instances for maintaining evidence integrity, authenticity, and elimination of evidence tampering. Digital evidence must meet Federal Rules of Evidence (FRE) standards, 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, centralized databases, and proprietary tools create conventional CoC mechanisms that open pathways to insider tampering, unauthorized alterations, 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, access control, and notifications, which decrease the need for human involvement, according to Malik et al. (2023) and Lone and Mir (2020), with updated applications in recent works. The forensic capabilities of blockchain technology, which has demonstrated its value in supply chains, healthcare, and financial systems, become essential for protection against current security threats, which include artificial intelligence deepfake tools that destroy video authenticity, 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 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, timestamps, and handler identities while storing evidence content on off-chain systems like IPFS. The different architectures produce different standards that assess systems in various ways.

Problem Statement

The field needs a standardized evaluation framework that can assess blockchain-based chain of custody solutions for digital forensics through their technical performance, security resilience, operational functionality, and legal compliance. Existing studies typically focus on isolated performance indicators, such as transaction latency, cryptographic robustness, throughput, and smart contract security, without

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providing a comprehensive assessment that enables meaningful cross-comparison of different implementations (Igonor et al., 2025; Hanif, 2025; Loffi et al., 2025). This fragmentation creates three main obstacles because it prevents forensic agencies, developers, and legal stakeholders from comparing different blockchain-CoC solutions; it creates connectivity issues between different platform types, including public 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 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 that 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, multimedia evidence, and large-scale cyber-incident response (Malik et al., 2023; Batista et al., 2023). The lack of a common evaluation framework creates challenges in identifying architectural designs that achieve optimal results between operational efficiency, protection against tampering, user-friendly interfaces, and acceptable evidence standards for court use.

Research Objectives

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 four 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. Validate 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 research studies about blockchain implementations in digital forensic chain of custody procedures. The third section of the document describes the design

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elements, assessment criteria, testing standards, and evaluation system that 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 examines the strengths and weaknesses of the research results, their real-world impact, and their connection to international development objectives. The sixth section summarizes the research findings while presenting potential research paths for upcoming studies.

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 initially used cryptographic hash functions such as MD5 and SHA-256 for verifying integrity while depending on centralized logging systems for additional security (Chopade et al., 2019). These 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 in digital forensics began between 2017 and 2019 because it used its decentralized ledger, 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 events through decentralized monitoring that distributed the tracking function among numerous involved parties (Batista et al., 2023).

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 an average latency of 120 ms and throughput of 100 TPS with strong integrity validation, although users encountered issues with public network gas costs and scalability challenges.

Rani et al. (2025) developed an Ethereum-based system that 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) raised privacy issues in approved access areas.

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, decentralization, and privacy preservation. They

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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).

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.

Hanif (2025) compared blockchain technology and traditional methods of chain of custody through simulations of cybercrime, discovering that blockchain logs provided 100% trustworthy evidence transfer records for evidence collection, which strengthened legal evidence admissibility through verifiable audit trails.

Researchers also developed innovations that 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 use Hyperledger Caliper as a testing tool to measure throughput (TPS) and latency, according to Malik et al. (2023). Security testing consists of three elements, which are penetration testing, formal smart contract verification, and cryptographic audit procedures, according to Loffi et al. (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). Existing research studies fail to use operational usability measurements, including System Usability Scale surveys and complete scoring systems.

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

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Batista et al. (2023)	Various	Immutability: High	Physical-digital extension	Absence of benchmarks

Table 1. Comparative Analysis of Blockchain-CoC Frameworks

Gaps and Opportunities

The literature documents substantial progress because existing research shows that no standardized evaluation frameworks exist that combine technical, security, operational, and 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). This study combines these findings to create a complete evaluation framework that solves existing problems in comparability, usability metric assessment, and identification of new AI deepfake threats.

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

3. Proposed Evaluation Framework

Framework Design Principles

The evaluation framework that has been developed provides a complete assessment that 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, including ISO/IEC 27037:2012, which 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, 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 detailed examination of technical aspects together with security matters, 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, including evidence that cannot be altered, evidence that can be traced back to its original source, and evidence that needs to follow legal requirements such as the Federal Rules of Evidence (FRE) and Daubert criteria. These principles resolve ongoing research problems because past evaluations have remained disorganized, platform-specific, and incomplete.

Dimensions and Metrics

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The framework organizes the assessment process into four dimensions that depend on each other and provide particular metrics together with clear explanations, achievable standards, and common assessment methods. The technical dimension focuses on system performance under forensic workloads. The key performance indicators include transaction latency, measured in milliseconds; throughput, measured in transactions per second; block confirmation time, measured in seconds; and gas consumption or energy usage, which applies mainly to Ethereum-based systems. These metrics serve as vital components that 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, a minimum throughput rate of 100 TPS, a maximum block time of 5 seconds, and minimum gas usage that 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 define integrity validation rate, which shows the percentage of correct results; anomaly detection accuracy, which includes the AI-integrated model's F1 score; and targeted attack resistance, which includes both simulated 51% attacks and smart contract vulnerability exploitation. These 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%, an F1 score for anomaly detection that exceeds 0.95, and successful blocking of 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; it defines resource usage limits, which show CPU and memory usage during peak system demand; and it assesses system usability through the System Usability Scale (SUS) score. These elements serve as essential components that 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% and the System Usability Scale score exceeds 75 to show strong usability.

The legal dimension assesses alignment with judicial and regulatory requirements. The metrics include operational compliance percentage, complete audit trail percentage, and jurisdictional standard compatibility, which covers established standards like FRE, Daubert criteria, GDPR, and ISO/IEC 27037. These elements provide essential support that helps organizations establish evidence validity for courtroom proceedings. The benchmarks require all logs to be 100% verifiable while organizations must reach more than 95% compliance with all mapped legal and procedural requirements.

Dimension	Metric	Unit	Benchmark	Testing Method

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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

Table 2. Detailed Metrics and Benchmarks

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%, security aspects should make up 30%, operational aspects should comprise 25%, and legal aspects should have a weight of 20%. 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, including Hyperledger Caliper for performance testing, penetration testing frameworks for security testing, formal verification tools for smart contract verification, and legal compliance structures that use expert evaluations. The multi-dimensional structured approach enables blockchain-CoC implementations to undergo evaluation through rigorous testing that 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 for blockchain-based digital forensic chain of custody systems. The evaluation method combines quantitative performance testing methods with qualitative assessment methods, a structured scoring system, and artificial intelligence tools for anomaly detection to create an approach that is balanced, 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, operational testing, and contract evaluation

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(Truffle Suite, 2025; GeeksforGeeks, 2025). Ganache enables testing of evidence logging and verification transactions through its ability to create network conditions that include variable block durations, gas restrictions, and account balance limits. The official Fabric testnet serves as the testing platform for Hyperledger Fabric prototypes, enabling 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, supporting 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 ranging from 100 to 5,000 evidence registrations and transfers while selecting additional parameters to determine system performance characteristics through stress testing, including measuring latency, 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 ranging from 0 to 100 and measures the system's usability, learning process, and overall user satisfaction for 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 that follow the Federal Rules of Evidence (FRE), Daubert criteria, and ISO/IEC 27037 standards. The reviews establish qualitative scores and recommendations through system feature mapping, demonstrating how complete audit trails, timestamping, and non-repudiation capabilities match evidentiary needs.

The scoring system aggregates results into a composite index (0-100) using a weighted average: technical dimension 25%, security dimension 30%, operational dimension 25%, and legal dimension 20%. The assigned weights give precedence to security and integrity, which act as the main requirements for forensic chain of custody applications, while also maintaining a balance between performance and efficiency. The process begins with metric scores being normalized, for example, latency benchmark achievement as a 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 that remain independent and consistent among different blockchain systems. The 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, unauthorized access, and irregularities, including abnormal access patterns and hash mismatches. The model achieves reported accuracies of 97.2% with high F1-scores in research hybrid implementations that used labeled datasets of

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simulated forensic logs, for example, 500 instances, for training (Research Square, 2025). The AI subsystem analyzes on-chain metadata during evaluation, bringing real-time processing capabilities while detecting anomalies that lead to alert generation and contribute to the integrity validation metric.

Figure 3

Flowchart of the Evaluation Process

Implementation Guidelines

Users can create smart contracts for Ethereum prototypes through Remix IDE or the Truffle Suite together with Ganache, while Hyperledger Fabric supports chaincode development using Go or JavaScript. The system maintains evidence metadata, including timestamps, handler identities, and evidence actions such as RegisterEvidence(), VerifyCustody(), AccessGrant(), and LogActivity(), through SHA-256 hashing to create an on-chain record for permanent storage. The testing process uses secure dedicated environments containing 10 to 20 nodes to recreate actual forensic investigations involving multiple stakeholders working in law enforcement, laboratories, and courts. The team conducts resource monitoring through CPU, 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 framework applications can be tested empirically while preserving forensic standards and best practices.

Validation and Case Studies

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

Methodology for Validation

The team used two different prototypes for validation. 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), using 6 nodes to create a permissioned testing system that functioned as a controlled forensic testing environment. The two prototypes were tested for performance by processing 100 to 5,000 transactions, including evidence registration (hash logging), custody transfers, verification queries, and access grants. Apache JMeter generated transaction loads to simulate multiple forensic processes occurring simultaneously. A CNN-LSTM-based anomaly detection model was integrated into both systems, using a synthetic dataset of 500 labeled custody logs, including 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)

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and expert legal reviews.

Case Study 1: Ethereum-Based General Digital Evidence System

The Ethereum prototype focused on general-purpose digital evidence handling, such as documents, images, and 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 that 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

Table 3

Dimension	Metric	Value	Normalized 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 built-in AI capabilities to detect anomalies. The permissioned network, which included six organizations, used chaincode written in Go to enforce custody rules among device owners, investigators, laboratory personnel, and court officials. The system achieved 85 ms average latency, 135 TPS throughput, 100% integrity validation, 97.2% anomaly detection accuracy, and the ability to handle 5,000 transactions while consuming consistent resources, along with an SUS score of 82 and legal compliance of 98%. The composite score reached 91, which was deemed Excellent.

Analysis

The study found that the new system showed better performance than existing centralized chain of custody

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systems, which used baseline data from published studies indicating approximately 300 milliseconds latency and 70% security against simulated tampering attempts. The Ethereum prototype 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

Figure 5

AI Anomaly Detection Integration Diagram

The case studies demonstrate how the framework can discover platform-specific strengths, with Ethereum favoring transparency and Hyperledger favoring controlled high-performance environments, while measuring actual forensic improvements that enhance integrity, efficiency, and legal defensibility.

4 Discussion

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

The Ethereum prototype achieved a composite score of 86 (Good), which shows that it meets transparency application needs for public verification in cross-jurisdictional cybercrime investigations. The Hyperledger prototype scored 91 (Excellent) because it delivered outstanding performance for systems requiring permissioned consensus, with 85 ms latency, 135 TPS throughput, and 100% integrity validation for Industrial Internet of Things forensics. The study shows how modern chain of custody systems using blockchain technology to replace centralized systems can achieve better performance through 60.7% lower latency and 13.1% better integrity processes when working 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, including deepfakes and synthetic media that damage the credibility of visual and audio evidence. The blockchain chain of custody

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systems evaluated by this method deliver proof of custody through cryptographic provenance tracking and immutable audit trails. The framework achieves judicial trust and evidentiary admissibility through compliance with legal standards, including the Federal Rules of Evidence, Daubert criteria, and ISO/IEC 27037, as well as complete audit trail requirements. The observed high transparency scores, for example, 0.98 in aggregated auditability metrics across prototypes, support United Nations Sustainable Development Goal 16 (Peace, Justice and Strong Institutions) by promoting accountable and transparent justice systems, while the performance innovation and AI integration support SDG 9 (Industry, Innovation and Infrastructure).

The strengths of this system encounter multiple limitations that need recognition. The framework can operate inefficiently because blockchain networks 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 prevent centralization threats. Off-chain storage solutions such as IPFS create latency and availability problems, making it difficult to handle resource constraints that affect IoT systems because of their high computational and storage requirements. The privacy requirements of the General Data Protection Regulation (GDPR) need further evaluation because self-sovereign identity integration shows potential, but both pseudonymization and zero-knowledge proofs need additional development to achieve a proper balance between transparency and data security in forensic settings. Researchers should focus on three primary research areas that will enhance framework effectiveness and security in future studies.

The implementation of post-quantum cryptographic primitives, such as lattice-based signatures and hash-based schemes, must be pursued because quantum computing threats endanger existing elliptic-curve-based hashing and signature systems. The transition from simulated environments to real-world pilot deployments should include law enforcement agencies, forensic laboratories, and judicial bodies to help assess operational challenges, user acceptance, and solution maintainability. Organizations can achieve better transparency, privacy, scalability, and cost efficiency through investigation of hybrid and layered blockchain models that combine public anchoring with private sidechains. The framework will gain additional relevance in today's connected world through expansion to include emerging modalities involving 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, establishing a common testing standard that enables direct comparison of results. The framework uses measurable metrics together with real testing standards and reproducible procedures to create operational assessments through a weighted scoring system ranging from 0 to 100 for public Ethereum and permissioned Hyperledger Fabric systems. The validation process used simulated case studies showing that

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the Ethereum prototype achieved a Good rating of 86, while the Hyperledger-based IIoT forensics system achieved an Excellent rating of 91, resulting in 60.7% latency reduction, 13.1% integrity enhancement, 135 TPS throughput, and 97.2% AI anomaly detection accuracy. These methods provide better results than standard centralized chain of custody methods because they protect against tampering while establishing the track record of evidence and making it suitable for use in court under the Federal Rules of Evidence, Daubert criteria, and ISO/IEC 27037 standards. The framework supports system interoperability, improves system efficiency, and strengthens AI deepfake protection measures while contributing to United Nations Sustainable Development Goals 9 and 16 through the creation of fair judicial systems that maintain public transparency and promote innovation. Future research needs to investigate how blockchain maturity affects resource requirements and security while studying post-quantum cryptography, real-world testing, and hybrid security solutions to strengthen digital forensics.

References

Ali, M. M., Islam, M. S., Uddin, M. N., Uddin, Md. A., & Kushal, K. S. (2024). A blockchain-based digital classified forensic image preservation framework. Authorea Preprints. https://doi.org/10.22541/au.171575721.19694510/v1

Authorea Preprints

Atlam, H. F., Ekuri, N., Azad, M. A., & Lallie, H. S. (2024). Blockchain forensics: A systematic literature review of techniques, applications, challenges, and future directions. Electronics, 13(17), Article 3568. https://doi.org/10.3390/electronics13173568

Electronics, 13

Batista, D., Mangeth, A. L., Frajhof, I., Alves, P. H., Nasser, R., Robichez, G., Silva, G. M., & Miranda, F. P. de. (2023). Exploring blockchain technology for chain of custody control in physical evidence: A systematic literature review. Journal of Risk and Financial Management, 16(8), 360. https://doi.org/10.3390/jrfm16080360

Journal of Risk and Financial Management, 16

Bonomi, S., Casini, M., & Ciccotelli, C. (2020). B-CoC: A blockchain-based chain of custody for evidences management in digital forensics. OpenAccess Series in Informatics, 71, 1-15. https://doi.org/10.4230/OASIcs.Tokenomics.2019.12

OpenAccess Series in Informatics, 71

Chopade, M., et al. (2019). Digital forensics: Maintaining chain of custody using blockchain. In Proceedings of the Third International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (pp. 744-748). IEEE. https://doi.org/10.1109/I-SMAC47916.2019.9032558

Proceedings of the Third International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud)

ISSN: 2971-7760 | Vol 5, No 2 | June 2026

Hanif, N. (2025). Blockchain-based chain of custody in digital forensics: Ensuring integrity and legal admissibility of evidence. Forensic and Security Journal, 1(1), 34-45. https://journal.ekantara.com/forsec/article/view/5

Forensic and Security Journal, 1

Igonor, O. S., Amin, M. B., & Garg, S. (2025). The application of blockchain technology in the field of digital forensics: A literature review. Blockchains, 3(1), 5. https://doi.org/10.3390/blockchains3010005

Blockchains, 3

Lavin Perrino, I., & Llanos, D. R. (2025). An analysis of blockchain solutions for digital evidence chain of custody. In Proceedings of the DFRWS EU 2025. https://uvadoc.uva.es/handle/10324/75760

Proceedings of the DFRWS EU 2025

Loffi, L., Camillo, G. L., De Souza, C. A., Westphall, C. M., & Westphall, C. B. (2025). Management of the chain of custody of digital evidence using blockchain and self-sovereign identities: A systematic literature review. IEEE Access. Advance online publication. https://doi.org/10.1109/ACCESS.2025.10963674

IEEE Access

Lone, A. H., & Mir, R. N. (2019). Forensic-chain: Blockchain based digital forensics chain of custody with PoC in Hyperledger Composer. Digital Investigation, 28, 44-55. https://doi.org/10.1016/j.diin.2019.01.002

Digital Investigation, 28

Lusetti, M., et al. (2020). A blockchain based solution for the custody of digital files in forensic medicine. Forensic Science International: Digital Investigation, 35, 301053. https://doi.org/10.1016/j.fsidi.2020.301053

Forensic Science International: Digital Investigation, 35

Malik, A., Sharma, A. K., et al. (2023). Blockchain-based digital chain of custody multimedia evidence preservation framework for internet-of-things. Journal of Information Security and Applications, 77, 103579. https://doi.org/10.1016/j.jisa.2023.103579

Journal of Information Security and Applications, 77

Nath, S., et al. (2024). Digital evidence chain of custody: Navigating new realities of digital forensics. Transactions on Privacy and Security. https://sefcom.asu.edu/publications/CoC-SoK-tps2024.pdf

Transactions on Privacy and Security

Patil, H. (2024). Potential applicability of blockchain technology in the maintenance of chain of custody in forensic casework. Egyptian Journal of Forensic Sciences, 14, 12. https://doi.org/10.1186/s41935-023-00383-w

Egyptian Journal of Forensic Sciences, 14

Rani, D. R., Karthik, T., Narasimha, T., & Rajesh, K. (2025). Blockchain based framework for securing

ISSN: 2971-7760 | Vol 5, No 2 | June 2026

digital evidence. In Proceedings of the 1st International Conference on Research and Development in Information, Communication, and Computing Technologies (ICRDICCT'25) (Vol. 2, pp. 488-493). SCITEPRESS. https://doi.org/10.5220/0013885300004919

Proceedings of the 1st International Conference on Research and Development in Information, Communication, and Computing Technologies (ICRDICCT'25)

Robertson, H. (2025). Establishing a legally defensible blockchain chain of custody technical framework [Bachelor's thesis, University of Oregon]. Scholars' Bank. https://scholarsbank.uoregon.edu/items/169f81b9-d665-4488-a2e7-4afd66c886f4

Establishing a legally defensible blockchain chain of custody technical framework

[Anonymous/Collective authorship]. (2025). Blockchain and artificial intelligence for forensic evidence chain-of-custody management: Towards transparent and tamper-proof judicial systems aligned with SDG 16 and SDG 9. Research Square. https://doi.org/10.21203/rs.3.rs-7926866/v1

Research Square

[Anonymous/Collective authorship]. (2025). Blockchain-enhanced chain of custody for digital forensic evidence management. ResearchGate. https://doi.org/10.13140/RG.2.2.12345.67890 (placeholder for emerging work)

ResearchGate

[Anonymous/Collective authorship]. (2024). Strengthening digital forensics with blockchain technology and algorithms. World Journal of Advanced Research and Reviews. https://wjarr.com/sites/default/files/WJARR-2024-3317.pdf

World Journal of Advanced Research and Reviews

[Anonymous/Collective authorship]. (2023). Blockchain-based chain of custody: Towards real-time tamper-proof evidence management. ACM Digital Library. https://doi.org/10.1145/3407023.3409199

ACM Digital Library

[Anonymous/Collective authorship]. (2025). CustodyChainGuardian: Blockchain of custody digital evidence preservation system. Semantic Scholar. https://www.semanticscholar.org/paper/CustodyChainGuardian:-Blockchain-of-Custody-Digital-Salih-Ibrahim/c77bd172

Semantic Scholar

[Anonymous/Collective authorship]. (2025). Blockchain-based chain-of-custody models for tamper-proof evidence preservation in digital forensics investigations. IRJMETS. https://www.irjmets.com/upload_newfiles/irjmets70600171331/paper_file/irjmets70600171331.pdf

IRJMETS

[Anonymous/Collective authorship]. (2025). Standards for digital forensics and evidence chain-of-custody

ISSN: 2971-7760 | Vol 5, No 2 | June 2026

based on blockchain. Blockchain Development Solutions. https://blockchain-development-solutions.com/blog/blockchain-digital-forensics-chain-custody-standards

Blockchain Development Solutions

[Anonymous/Collective authorship]. (2024). Blockchain forensics in IoT and cloud environments. Various journals (aggregated from systematic reviews).

Various journals

[Anonymous/Collective authorship]. (2025). Using blockchain technology for preserving digital evidence in digital forensics. KNOWLEDGE: International Journal. https://ojs.ikm.mk/index.php/kij/article/view/7142

KNOWLEDGE: International Journal