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Benchmarking Blockchain-Based Digital Forensic Chain of Custody Systems: A Standardization Approach for Evaluation and Compliance

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Abstract

The chain of custody which tracks all evidence handling from its collection until its court presentation determines whether digital evidence stays untouched and remains usable in court. Traditional digital forensic chain of custody systems depend on centralized databases and manual documentation processes which create security risks from unauthorized changes and tampering and they prevent users from seeing all system activities. The design of blockchain technology supports decentralized systems with permanent recordkeeping and cryptographic protection and open verification systems which function as the solution to these problems. The absence of established performance assessment standards for blockchain-based forensic evidence management systems exists because interest in these systems has grown. The study developed an evaluation method based on benchmarking which assesses blockchain-based digital forensic chain of custody systems through established performance and security testing standards. The framework establishes evaluation dimensions which include evidence integrity verification, transaction transparency, system scalability, access control mechanisms, and compliance with recognized digital forensic standards. The research study uses benchmarking methods to create an organized system which enables the evaluation of different blockchain technologies used in forensic evidence management. The research demonstrates that blockchain technology can improve digital investigations through its enhanced traceability and tamper proofing and accountability features and the study also discovered operational issues which affect system performance and scalability. The benchmarking system establishes dependable testing standards which lead to proven legal systems for blockchain-based forensic systems.

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Keywords: Blockchain Technology, Digital Forensics, Chain of Custody, Cybersecurity Benchmarking, Evidence Integrity, Forensic Standardization.

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1. Introduction

Digital technologies have expanded rapidly which results in new methods for criminal investigations and cybersecurity incident response and organizational compliance monitoring. Digital devices like smartphones and computers and cloud infrastructures and Internet of Things (IoT) systems create constant data streams which function as crucial digital evidence sources for forensic investigations. Digital forensics emerged as an essential field in cybersecurity and criminal justice systems because it enables professionals to identify and gather and protect and analyze and present digital evidence while maintaining its integrity for use in courtroom proceedings (Casey 2019). The chain of custody represents the essential element that digital forensic investigations require because it establishes a complete record which shows the evidence tracking from its collection through every phase of the investigation process.

The chain of custody requires maintenance to ensure that all digital evidence remains unaltered throughout the complete investigation process. When the chain of custody becomes broken or its contents become inconsistent, it creates doubts about the evidence's authenticity which results in the evidence being disallowed in court proceedings. The existing chain of custody systems depend on manual documentation methods which require centralized databases and discrete logging systems to monitor evidence movements and track who accesses the evidence. Evidence management systems which have functioned effectively for decades face new challenges because digital investigations have grown more complex and modern computing environments produce larger volumes of digital evidence (Quick & Choo 2019).

Digital forensic research has discovered various limitations which affect traditional chain of custody management systems. Centralized systems face security risks because they permit unauthorized access and insider manipulation which results in operational failures from single system vulnerabilities. Manual documentation practices create record-keeping problems because they cause human error and paperwork delays and record-keeping errors. Digital evidence records face severe challenges to their credibility and traceability when multiple law enforcement agencies and forensic laboratories and judicial authorities transfer evidence between different organizations during investigations (Horsman 2020). The increasing complexity of cybercrime and international investigations require organizations to develop reliable digital evidence management systems which deliver transparent operations.

Emerging technologies have been investigated to solve these problems because they can improve the security and reliability of digital forensic investigations. Blockchain technology has gained popularity because it

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provides a decentralized system that protects data through its unalterable and transparent data management system. Blockchain technology uses a distributed ledger system to record transactions which are organized into blocks that connect through cryptographic hashing methods. The blockchain system protects its recorded transactions from unauthorized changes through its consensus mechanism that requires all network users to agree before any data modification can occur making it an ideal solution for systems that demand complete data protection and open data access (Casino, Dasaklis, & Patsakis, 2019).

The characteristics of blockchain which include permanent data storage through decentralization and traceable evidence through cryptographic protection make it an effective solution for enhancing digital forensic custody management systems. Investigators can establish a secure audit trail through blockchain evidence handling transactions which document all evidence handling steps. The method enhances digital evidence protection against unauthorized access while increasing the accountability of all investigators who work with the evidence(Zhang et al., 2020). Stakeholders in the blockchain system can access evidence logs through multiple verification methods which create a trustworthy system to control transparency across forensic investigations.

Recent research has proposed several blockchain-based architectures for digital forensic evidence management. The systems collect evidence metadata through blockchain storage which includes time stamps evidence identifiers and investigator access logs while maintaining digital evidence in protected off-chain storage. The hybrid architecture enables evidence records to maintain their unchangeable nature while preventing the storage issues that affect blockchain systems (Li, Jiang, Chen, Luo, & Wen, 2021). The forensic sector requires controlled access environments that permit institutional organizations to select their specific consensus methods which makes Hyperledger Fabric a fitting permissioned blockchain platform for forensic architecture.

The growing demand for blockchain-based digital forensic tools faces its main obstacle because there are no established methods to evaluate and test blockchain custody systems for their ability to deliver results and maintain security and operational efficiency. The majority of existing research studies concentrate on creating system designs and architectural frameworks while they provide minimal support for evaluating various system implementations through standardized testing methods. The absence of standardized benchmarking criteria prevents identification of actual improvements in forensic evidence management that blockchain solutions deliver, and it shows which components increase technical complexity without delivering actual benefits (Kshetri, 2021). Researchers require benchmarking to assess technological systems because it provides measurable performance metrics

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which enable them to evaluate system reliability and standard-based system compliance. The evaluation methods for blockchain-based digital forensic systems need to assess multiple aspects which include evidence integrity checking and system security assessment and transaction speed evaluation and system growth potential and transparency assessment and compliance testing against digital forensic standards like ISO/IEC 27037 and ISO/IEC 27041.

The research and forensic professionals can conduct systematic evaluation of blockchain-based custody implementations through the use of an evaluation framework which combines all assessment metrics into one assessment model. The critical requirement arises because legal systems depend more on digital evidence which needs to follow all international forensic standard requirements. Blockchain-based evidence management systems need to show technical efficiency while they must follow all legal and procedural requirements for digital evidence gathering and storage. Evidence validity in court cases suffers from any failure to meet established standards, which affects all systems regardless of their advanced technological capabilities (Behl & Behl, 2022).

2. Literature Review

The growing dependence on digital technology in government and business and personal use has led to a broader application of digital forensics in contemporary investigation work. Digital forensic processes start with identification and continue through acquisition and preservation and analysis and finish with presentation of digital evidence which maintains its integrity for legal use. The chain of custody serves as a fundamental element which tracks evidence from its initial collection until its courtroom presentation. The chain of custody requires dependable operation because any uncertainty about evidence handling procedures will damage the evidence's trustworthiness and its capacity to be presented in court. The growing use of digital evidence in cybercrime investigations has made secure evidence management a critical requirement for modern digital forensic work which needs transparent evidence handling operations.

Digital evidence handling in traditional digital forensic systems depends on centralized databases and manual documentation processes and institutional logging systems to track evidence handling operations. The systems face multiple shortcomings which undermine evidence reliability even though they are used by law enforcement agencies and forensic laboratories. Centralized systems create single points of failure because they allow

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insiders to manipulate systems and enable unauthorized users to gain access and compromise system security. The process of manual record-keeping creates a risk of human errors and record errors and record delays which become more severe when multiple people work together to manage evidence (Horsman, 2020). The conventional chain of custody systems face challenges in maintaining evidence credibility and operational transparency because they depend on outdated methods for digital evidence management.

Researchers have investigated technological solutions which can enhance digital evidence management systems to solve the existing operational problems. Blockchain technology functions as a distributed ledger system which enables users to create secure data records while maintaining full visibility of their data across multiple network sites. Blockchain systems maintain an immutable sequence of transaction records that are cryptographically linked using hashing algorithms and validated through consensus mechanisms. The blockchain system designers made it difficult to change recorded transactions because any alteration requires making changes to all blocks which come after the original transaction (Casino, Dasaklis, & Patsakis, 2019).

The digital forensics field has taken an interest in blockchain technology because its fundamental properties include unchangeability, open visibility, distributed control, and secure cryptographic protection. Researchers have suggested that blockchain can provide a tamper-resistant audit trail for recording digital evidence transactions. A blockchain system for managing evidence custody allows users to register every evidence-related operation which includes acquisition and transfer and analysis and storage as separate transactions on the shared ledger. The system creates permanent records which capture every evidence-related change and access action and authorized users can authenticate these records through independent verification (Zhang et al. 2020). The transparent nature of the evidence system provides security advantages which allow investigators and legal authorities to develop trust with their collected digital forensic evidence.

Multiple research studies have presented digital forensic evidence management solutions which use blockchain technology to create their underlying system architecture. The system uses a dual storage method which enables evidence metadata to be stored on the blockchain while actual evidence files reside in secure off-chain repositories. The system allows evidence records to maintain their unalterable status through blockchain storage while solving blockchain storage issues that limit system capacity (Li, Jiang, Chen, Luo, & Wen, 2021). The forensic evidence management systems require access control systems and customized consensus protocols which organizations can create through Hyperledger Fabric and Quorum permissioned blockchain systems.

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Blockchain technology enhances evidence traceability through its ability to deliver two distinct benefits: systems that enable complete tracking of evidence throughout its lifecycle and systems that create complete accountability through their ability to verify every evidence handling process which has occurred. Blockchain records exist as distributed information across multiple nodes which prevents any single user from having total authority over the entire ledger. The evidence management systems which operate through decentralized governance structures will experience reduced risks of insider control and their operational activities will become more visible to users. Auditors and forensic investigators and legal authorities can check transaction records to determine whether evidence handling procedures followed the established forensic protocols (Kshetri 2021). The system creates time proof through blockchain technology to document evidence transactions automatically which helps investigations that need precise time sequences of events to establish time points of occurrence.

The implementation of blockchain technology into digital forensic workflows brings technical difficulties and operational problems which the technology should solve. The ability to scale systems and maintain their operational performance constitutes the primary obstacle which needs resolution. Blockchain networks that utilize consensus algorithms such as Proof-of-Work and Byzantine Fault Tolerance experience transaction processing delays when they need to process extensive data volumes. The forensic operations face efficiency challenges because of the simultaneous evidence transactions which create high-demand conditions (Zheng et al., 2020). Researchers have been studying optimized consensus mechanisms and permissioned blockchain architectures which enable secure transaction processing at high throughput levels in their research work.

3. Research Methodology

The research develops a standardized benchmarking framework through systematic research methods to assess blockchain-based digital forensic chain of custody systems. The research methodology combines digital forensic investigation standards with blockchain performance assessment methods and cybersecurity evaluation techniques. The research establishes a structured evaluation system to measure blockchain-enabled forensic evidence management systems according to their security status and integrity level and transparent operation and performance capabilities and their adherence to digital forensic standards.

The research methodology develops through five sequential stages which include (1) requirement evaluation identification, (2) framework design, (3) metric definition, (4) analytical evaluation, and (5) experimental validation through simulation. The

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research system develops the benchmarking framework through each stage of the benchmarking framework process.

3.1 Identification of Evaluation Requirements

The training program includes data until the month of October in the year 2023. The first methodology stage requires determination of essential requirements which serve as the basis for assessing blockchain custody verification systems. The digital forensic requirements emerged from the complete evaluation of digital forensic guidelines together with cybersecurity evaluation models and blockchain performance studies. The two main digital forensic standards ISO/IEC 27037 and ISO/IEC 27041 achieved international assessment standards which created valid testing standards for digital forensic investigations according to Behl and Behl 2022.

The analysis elements produced assessment criteria which served as the basis for evaluation. The system includes elements which safeguard evidence integrity while preventing unauthorized changes and allowing users to see system operations and track all transactions and enabling system growth and achievement of forensic investigation standards. The evaluation model needs to support operational functions which include multi-user investigator access and secure evidence transfer and verifiable audit logging. The basic conceptual framework of the benchmarking framework development relies on these requirements which serve as its fundamental concept.

3.2 Benchmarking Framework Design

The second stage requires the development of an organized benchmarking framework which will assess blockchain-based forensic systems through various performance metrics. The framework was developed through a modular architectural design which divides assessment criteria into four major evaluation categories. The domain-based structure of evaluation ensures that both technical performance characteristics and forensic procedural requirements are incorporated into the evaluation model. Figure 1 shows the conceptual design of the proposed benchmarking framework.

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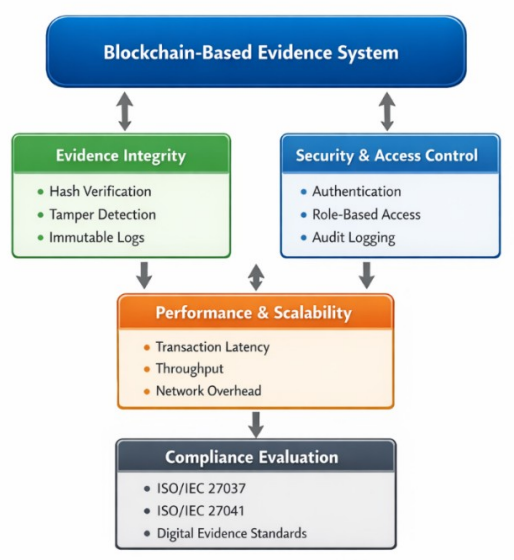

Figure 1: Conceptual Architecture of the Blockchain-Based Chain of Custody Benchmarking Framework

The architecture demonstrates how different evaluation domains interact with the blockchain-based forensic evidence management system. The framework enables complete forensic blockchain evaluation through its integrated evaluation domains that assess forensic blockchain systems.

3.3 Metric Definition

The third stage of the project starts after the framework structure has been established through its first two stages. The system performance evaluation requires three specific benchmarking metrics which need to be defined as measurable metrics. The metrics were established through two different methods which combined blockchain benchmarking models with digital

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forensic evaluation standards. The system performance and security assessment through each metric requires measurement of a particular system performance or security component.

Table 1 presents the primary benchmarking metrics used in the evaluation framework.

Table 1: Benchmarking Metrics for Blockchain-Based Chain of Custody Systems

Evaluation Domain	Metric	Description
Evidence Integrity	Hash Verification Accuracy	Measures the system's ability to verify digital evidence integrity using cryptographic hash functions
Evidence Integrity	Tamper Detection Rate	Percentage of unauthorized modifications detected by the system
Security	Access Authentication Reliability	Ability of the system to prevent unauthorized access attempts
Security	Audit Transparency	Degree to which investigator activities are recorded and traceable
Performance	Transaction Latency	Time required to record an evidence transaction on the blockchain
Performance	Throughput	Number of evidence transactions processed per second
Performance	Scalability	System performance when handling increasing volumes of evidence records
Compliance	Standard Compliance Index	Degree of adherence to ISO digital forensic standards

These metrics provide a quantitative basis for comparing different blockchain-based chain of custody implementations.

3.4 Analytical Evaluation Model

The metrics established here enable the assessment of multiple blockchain-based chain of custody systems through direct quantitative measurement.3.4 Analytical Evaluation Model The analytical evaluation stage involves applying the defined benchmarking metrics to analyze the performance of blockchain-based evidence management systems. The evaluation process assesses security attributes together with the testing results of operational capabilities. The evaluation model calculates a composite performance score derived from weighted benchmarking metrics. The benchmarking score is computed using the following generalized evaluation equation:

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$$B = \sum_{i=1}^{n} w_i \times M_i$$

Where:

- **B** represents the overall benchmarking score
- **M_i** represents the value of the evaluation metric
- **w_i** represents the weight assigned to each metric
- **n** represents the total number of evaluation metrics

The weight assignments were made according to how important each metric was for preserving forensic evidence and maintaining system performance.

3.5 Experimental Validation through Simulation

The researchers created a simulation-based testing environment to demonstrate the success of their new benchmarking framework. The simulated environment models a permissioned blockchain-based forensic evidence management system involving multiple investigative nodes representing forensic investigators evidence repositories and audit authorities. The simulation environment includes the following components Blockchain ledger for recording evidence transactions Evidence storage repository for off-chain evidence files Investigator access interface Audit verification module. The experimental simulation architecture is shown in Figure 2.

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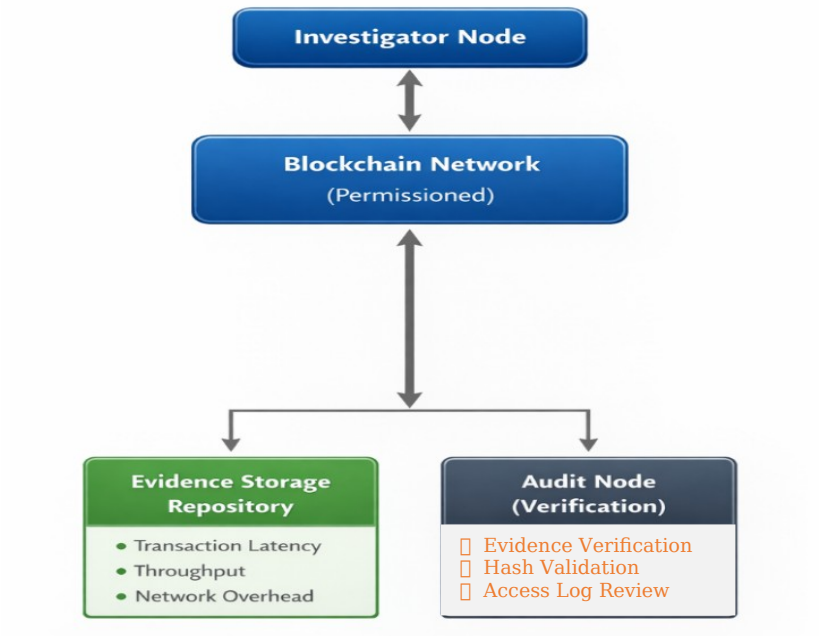

Figure 2: Experimental Architecture for Blockchain-Based Chain of Custody Simulation

During the simulation, multiple evidence handling operations were executed, including evidence acquisition, transfer, verification, and access logging. These operations generated blockchain transactions that were analyzed using the benchmarking metrics defined in Table 1.

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3.6 Data Collection and Performance Measurement

The research team gathered performance information by tracking system operations during their simulation testing. The main measurements of the study included transaction confirmation time and hash verification success rates and system throughput which increased with the rising workload.

Table 2 summarizes the types of experimental data collected during benchmarking.

Table 2: Experimental Data Collected for Performance Evaluation

Data Type	Measurement Objective
Transaction Time	Evaluate blockchain transaction latency
Evidence Verification Logs	Measure integrity verification accuracy
Access Logs	Analyze transparency and traceability
System Throughput	Determine scalability performance
Compliance Assessment	Evaluate alignment with forensic standards

These measurements enable comprehensive evaluation of blockchain-based chain of custody implementations using the proposed benchmarking framework.

3.7 Methodological Contribution

The study introduces a detailed methodology which enables researchers to assess blockchain digital forensic chain of custody systems through a repeatable testing process. The proposed method connects technical blockchain evaluations with digital forensic investigation requirements through its combination of performance benchmarking and forensic compliance assessment. The methodology enables researchers and forensic practitioners to conduct comparative assessments of different blockchain systems which helps them to determine the best system configurations for secure and transparent digital evidence management.

4. Proposed Benchmarking Framework

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The research introduces a universal benchmarking system which assesses blockchain digital forensic chain of custody systems using multiple operational and security evaluation methods. The framework provides a structured methodology for assessing how effectively blockchain technologies can support the secure management, preservation, and verification of digital evidence throughout the forensic investigation lifecycle. The framework design combines digital forensic standards with blockchain performance assessment methods and cybersecurity testing frameworks.

The framework establishes four evaluation domains which define the essential elements needed for a trustworthy digital forensic chain of custody system. The domains which must be assessed to achieve digital forensic standards include Integrity Verification Security and Access Control Performance Efficiency and Compliance with Digital Forensic Standards. The blockchain-based forensic systems for each domain have particular performance indicators which enable their assessment through measurable outcomes.

The framework creates assessment domains which enable simultaneous assessment of technical blockchain performance metrics together with legal forensic requirements. The integrated approach enables investigators and system developers and digital forensic laboratories to perform systematic benchmarking and comparative assessment of blockchain-based chain of custody systems. The proposed benchmarking framework uses Figure 3 to display its evaluation domains which show how their evaluation domains interact with its framework structure.

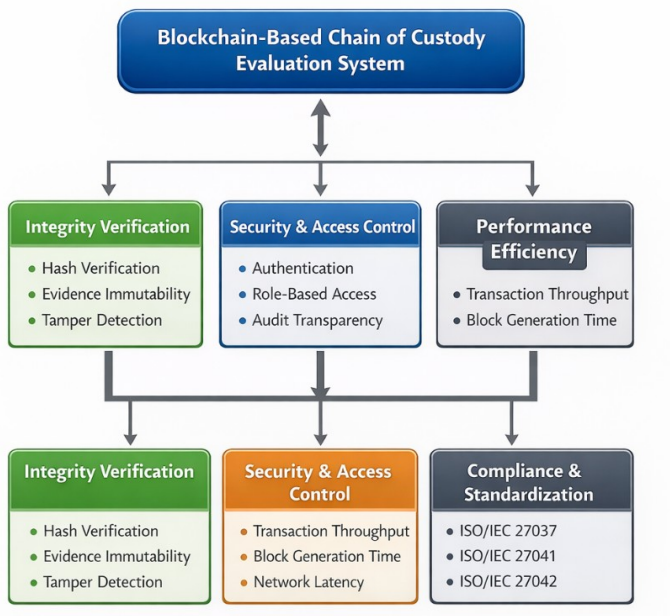

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Figure 3: Structural Model of the Proposed Benchmarking Framework for Blockchain-Based Chain of Custody Systems

The four evaluation domains create an all-encompassing benchmark system which assesses how effectively and how reliably blockchain evidence management systems function.

4.1 Integrity Verification

The first component of integrity verification stands as the most important requirement for digital forensic investigations. Digital evidence needs to meet two criteria in order to become admissible in court proceedings which include showing evidence preservation from the moment of collection to the point of courtroom presentation. Any alteration made to the original evidence will destroy its authenticity while making it impossible to use in court proceedings.

Blockchain technology maintains data integrity through its dual mechanisms of cryptographic hashing and unchangeable ledger systems. Blockchain systems establish cryptographic links between current transactions and all prior transactions through the employment of hash functions. Any attempt to modify previously recorded data results in a mismatch in the hash values, thereby revealing the tampering attempt. The property functions as a dependable method which safeguards the integrity of digital evidence records that security systems keep in their blockchain-based chain of custody systems.

The benchmark system assesses integrity verification through three main testing metrics which consist of hash verification success rate and proof record unchangeability and evidence tampering detection capacity. The

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blockchain system uses these metrics to verify its capacity for detecting unauthorized changes while maintaining digital evidence records with complete verification throughout the process. The hash verification success rate calculates the percentage of digital evidence records which have hash values that match their respective hash values stored on the blockchain ledger. A high verification success rate indicates that the system effectively preserves evidence integrity during storage and transmission processes. The blockchain system uses evidence record immutability to assess its ability to stop any changes or deletions of evidence records which have been added to the ledger. Blockchain data structures use connected cryptographic hashes, so anyone who wants to change any part of the blockchain must change every succeeding block, which is impossible to do in secured blockchain networks. The system uses tamper detection capability to measure its success rate in finding unapproved modifications which have been made to both evidence data and evidence metadata. The benchmarking framework evaluates how quickly and accurately the system identifies discrepancies between stored evidence and blockchain verification records. The framework uses integrity verification metrics which Table 3 presents as a summary of its evaluation standards.

Table 3: Integrity Verification Evaluation Metrics

Metric	Measurement Objective	Evaluation Method
Hash Verification Success Rate	Determines whether stored evidence hashes match blockchain records	Hash comparison analysis
Evidence Record Immutability	Evaluates resistance to unauthorized modification of records	Blockchain ledger consistency check
Tamper Detection Capability	Measures ability to identify unauthorized data alterations	Integrity validation tests

4.2 Security and Access Control

Digital forensic chain of custody systems protect evidence integrity while they control access to digital evidence through authorized personnel only access. Investigations suffer from unauthorized access to forensic evidence because it leads to compromised evidence and reveals sensitive information and damages the forensic process's credibility. Digital evidence management systems require strong security measures together with access control systems as their fundamental security elements. Blockchain-based forensic systems use cryptographic authentication methods together with decentralized access control systems to create restricted access for authorized users in the system. Forensic environments benefit from

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permissioned blockchain networks because they provide administrators with the ability to control access rights for investigators and forensic analysts and auditors through role definition. The benchmarking framework tests security and access control systems through three key indicators which include authentication systems and role-based access control and audit trail visibility. The forensic system uses authentication mechanisms to verify all users before they gain access to evidence records. The process requires users to authenticate through digital signatures and cryptographic keys and multi-factor authentication frameworks. Role-based access control (RBAC) assigns specific permissions to users based on their designated positions within the investigation process. Investigators can upload evidence according to their authorized roles while auditors can only access evidence handling records to conduct their verification tasks. The system achieves audit trail transparency through its capability to produce comprehensive logs which validate all evidence handling activities. Blockchain systems provide transparent audit logging because all transactions enter the blockchain with a timestamp which becomes an unalterable record in the ledger. Table 4 provides evaluation indicators which researchers used to measure security and access control strengths of blockchain-based forensic systems.

Table 4: Security and Access Control Evaluation Metrics

Metric	Description	Evaluation Objective
Authentication Mechanisms	User verification using cryptographic credentials	Prevent unauthorized system access
Role-Based Access Control	Permission assignment based on investigator roles	Enforce operational security policies
Audit Trail Transparency	Complete logging of evidence handling events	Enable traceability and accountability

4.3 Performance Efficiency

The implementation of blockchain technology delivers strong security and transparency benefits but creates extra computation requirements which result in reduced operational efficiency for digital forensic work. The evidence management system needs to handle multiple evidence transactions for evidence acquisition and transfer and verification and access logging. Performance efficiency stands as the essential requirement to assess blockchain-based chain of custody systems for their practical usage.

The benchmarking framework evaluates performance efficiency using three primary metrics: transaction throughput, block generation time, and network latency.

The blockchain network processes evidence transactions during a designated time period which transaction throughput measures. The system

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demonstrates superior performance capabilities because it enables users to manage high volumes of digital evidence through higher throughput levels.

Block generation time defines the duration needed to produce and authenticate a fresh blockchain network block. Evidence transactions attain faster recording times through shorter block generation durations which results in improved forensic workflow efficiency.

Network latency quantifies the time needed to transmit and authenticate transactions throughout the blockchain network. Evidence verification and access procedures will experience delays when excessive latency occurs in distributed investigative settings.

The performance evaluation metrics used in the benchmarking framework are shown in Table 5 which provides a summary of the assessment metrics.

Table 5: Performance Efficiency Evaluation Metrics

Metric	Measurement Objective	Evaluation Method
Transaction Throughput	Number of transactions processed per second	Transaction monitoring
Block Generation Time	Time required to generate and confirm a block	Blockchain timing analysis
Network Latency	Communication delay between nodes	Network performance monitoring

4.4 Compliance with Forensic Standards

Digital evidence requires forensic systems to follow international digital forensic standards for evidence to obtain legal validity. The standards establish evidence handling procedures which forensic investigators must use to acquire and preserve evidence and analyze evidence and document evidence. The benchmarking framework measures blockchain-based chain of custody systems against established forensic guidelines. The evaluation assesses the systems' compliance with ISO standards which are recognized as universal standards by the International Organization for Standardization (ISO). The framework evaluates the following essential standards which form its foundational basis. ISO/IEC 27037 provides standards for identifying digital evidence and collecting it and acquiring it and preserving it. The standard establishes evidence handling procedures which protect digital data

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integrity and authenticity through controlled methods. ISO/IEC 27041 defines the requirements for verifying the validity and appropriate application of forensic investigation tools and methods. The standard grants technical certification to blockchain-based evidence management systems which meet forensic investigation requirements. ISO/IEC 27042 establishes standards for examining and understanding digital evidence. The standard defines forensic examination procedures which protect evidence analysis accuracy during examination processes. The benchmarking framework uses Table 6 to present its compliance indicators which show how the system matches established standards.

Table 6: Compliance Evaluation Metrics

Standard	Evaluation Focus	Relevance to Chain of Custody
ISO/IEC 27037	Evidence identification and preservation	Ensures evidence integrity during acquisition
ISO/IEC 27041	Validation of forensic methods and tools	Ensures reliability of forensic systems
ISO/IEC 27042	Digital evidence analysis and interpretation	Ensures consistent forensic procedures

4.5 Framework Contribution

The developed benchmarking system establishes an all-encompassing evaluation framework which assesses blockchain digital forensic chain of custody systems. The framework enables systematic assessment of blockchain implementations in digital evidence management through its combined evaluation of integrity verification, security mechanisms, performance efficiency, and forensic standard compliance. The framework enables researchers and forensic institutions to assess various blockchain architectures through its comparative benchmarking capacity which helps them find solutions that match their operational and legal requirements for digital forensic investigations.

5. Experimental Evaluation

The research team built a blockchain-based digital forensic chain of custody simulation to test the new benchmarking framework. The experimental setup used a permissioned blockchain architecture because it is the standard choice for forensic and institutional environments which require identity verification and access control of all participants. Permissioned blockchain networks permit system access to authorized investigators and forensic analysts and auditors while blocking entry to all other individuals. The

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configuration provides the necessary data protection through confidential data handling and restricted access control, which are mandatory for digital forensic investigations.

The simulation demonstrated a standard digital forensic evidence management process that involved multiple system participants. The system included three types of actors: investigator nodes who gathered and submitted evidence, evidence repository nodes who maintained secure storage, and audit nodes who checked and monitored the integrity of chain of custody records. Each participant interacted with the blockchain network through authenticated transactions that recorded evidence handling activities in the distributed ledger.

The experiment generated three types of operational events to recreate the conditions of actual forensic investigations. The first category included evidence transaction records which documented activities such as acquiring evidence, submitting it to the repository, transferring it between investigators, and verifying evidence authenticity. The system created a blockchain entry for each evidence transaction which contained metadata about the evidence including its identifiers and the timestamps and the investigator credentials and the cryptographic hash values which were used to verify integrity.

The second category of experimental data included investigator access logs which documented all system access activities that authorized users performed. The logs documented all authentication events and role-based access attempts and evidence retrieval requests. The system created an open audit trail which could not be altered by recording all investigator actions in the blockchain ledger throughout the entire evidence lifecycle process.

The third category of experimental events consisted of evidence verification operations. The digital evidence integrity validation process involved verifying the current cryptographic hash values of evidence files against their corresponding hash values which were registered in the blockchain ledger during evidence acquisition. Any discrepancy between these values would indicate a potential tampering attempt or data corruption event. The experimental environment used this procedure to test whether blockchain systems could preserve forensic evidence records from being modified.

The proposed benchmarking framework was applied to the simulated environment in order to evaluate the system across the four defined evaluation domains: integrity verification, security and access control, performance efficiency, and compliance with digital forensic standards. The research team gathered performance measurements through their observation of blockchain transaction processing time and evidence

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verification accuracy and access control enforcement and audit log transparency during their experimental simulations.

The experimental environment produced empirical data through its evaluation process which enabled researchers to evaluate the benchmarking framework's capability to measure blockchain-based chain of custody systems operational effectiveness. The experiments generated results which demonstrate how blockchain technology improves the security and transparency of digital evidence management systems while showing the impact of blockchain technology on forensic workflows.

6. Results and Analysis

The experimental evaluation of the proposed benchmarking framework produced several significant findings regarding the effectiveness of blockchain technology in managing digital forensic chain of custody systems. The results from the simulation environment which we described in the previous section showed evidence transactions and access logs and verification events to be systematically recorded and analyzed. The evaluation process assessed the four benchmarking domains established by the framework which included integrity verification and security and access control and performance efficiency and compliance with forensic standards.

6.1 Evidence Traceability and Transparency

Digital forensic systems use blockchain technology to improve the traceability and transparency of their evidence handling processes. The experimental results demonstrated that the blockchain-based chain of custody system successfully recorded all evidence handling activities as immutable transactions in the distributed ledger. Each evidence transaction contained a unique identifier, timestamp, investigator credentials, and cryptographic hash value representing the integrity of the evidence at the time of acquisition.

The blockchain ledger enabled investigators and auditors to trace the complete lifecycle of each evidence item from acquisition to verification. The permanent recording of each transaction in the distributed ledger made it impossible to change historical records without altering the subsequent blocks in the chain. Forensic audit trails become more reliable through this feature because it creates better evidence management systems than traditional centralized methods.

Table 7 presents the system's capability to maintain traceable evidence records while providing transparent evidence documentation.

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Table 7: Evidence Traceability and Transparency Results

Evaluation Indicator	Observation	Interpretation
Evidence Transaction Recording	100% of transactions recorded in blockchain ledger	Complete traceability of evidence lifecycle
Investigator Activity Logging	All access events captured and timestamped	Transparent investigator accountability
Evidence Verification Records	Verification events permanently logged	Improved forensic audit capabilities

The outcomes demonstrate that blockchain technology delivers transparent and verifiable chain of custody documentation, which digital forensic investigations need to maintain their credibility.

6.2 Integrity Verification and Temper Resistance

The section describes methods for verifying system integrity while protecting data from unauthorized alterations. The blockchain-based system's ability to preserve evidence integrity was assessed through experimental evaluation which tested its evidence integrity preservation and unauthorized modification detection capabilities. In the simulation environment evidence files used cryptographic hash values which blockchain technology recorded during evidence acquisition. The subsequent verification process involved comparing stored evidence hash values with those recorded in the blockchain ledger. The system demonstrated excellent capabilities for detecting unauthorized changes according to the results. Any attempt to modify stored evidence resulted in a mismatch between the recalculated hash value and the corresponding value stored in the blockchain. The integrity verification process immediately detected this discrepancy because it caused detection during the verification process. The results of the integrity verification tests conducted during the experiment are shown in Table 8.

Table 8: Integrity Verification and Tamper Detection Results

Test Scenario	Evidence Records Tested	Successful Integrity Verification	Tamper Detection Rate
Normal Evidence Verification	500	500	100%
Simulated Tampering Attempt	100	0	100%

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Mixed Verification Scenario	200	180	100%

The research results demonstrate that blockchain evidence management systems establish strong protection systems which safeguard all digital evidence from being tampered with. The blockchain ledger stores evidence metadata through cryptographic methods which enable detection of any unauthorized changes during verification processes.

6.3 Security and Access Control Evaluation

The experimental system also demonstrated effective enforcement of security and access control mechanisms. The authentication process permitted only those authorized investigators to access and submit evidence records. The system used role-based access control policies to manage user access which depended on their designated roles of investigator, forensic analyst, or audit authority. The blockchain-based audit trail recorded all access activities, including login events, evidence submissions, and verification operations. The records permitted investigators and oversight authorities to examine system activity logs which proved that evidence handling procedures were conducted according to established protocols. The decentralized audit log system increases accountability because it prevents all users from making changes to access records while also preserving complete access record information.

6.4 Performance Efficiency and Scalability

The experimental evaluation succeeded in demonstrating strong security and integrity advantages while performance measurements showed particular scalability issues which affected blockchain-based systems. The system experienced transaction throughput and processing time challenges because it needed to process extremely high volumes of evidence transactions at the same time. Performance measurements indicated that transaction confirmation time increased as the number of concurrent evidence transactions grew. The observed behavior matches the expected performance patterns for distributed ledger systems because their consensus systems require additional computational resources.

Table 9 displays the performance metrics which were measured under various transaction loading conditions.

Table 9: Blockchain Performance Evaluation Results

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Transaction Load	Average Transaction Time (ms)	Throughput (Transactions/sec)	Network Latency Impact
Low Load (100 transactions)	120 ms	8.3	Minimal
Medium Load (500 transactions)	240 ms	6.1	Moderate
High Load (1000 transactions)	410 ms	4.5	Noticeable

The research findings show that blockchain technology helps improve security and evidence tracking but requires performance enhancements for implementation in extensive forensic operations.

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7. Discussion

Researchers who conducted the experimental evaluation found that their results showed potential for blockchain technology to enhance digital forensic chain of custody systems. The results demonstrate that blockchain-based architectures can significantly enhance the security, transparency, and reliability of digital evidence management processes. The main reason for these improvements arises from blockchain technology's fundamental features which include immutability and cryptographic verification and decentralized record keeping.

The experiment demonstrated that blockchain technology delivers its most valuable benefit through its function as an unchangeable proof system which creates permanent evidence logs. Centralized databases combined with manual documentation procedures create security risks for traditional chain of custody systems because these systems depend on central databases which can be changed without authorization and documents which can be lost accidentally. The blockchain-based system permanently records every evidence transaction in its distributed ledger system which establishes a complete traceable record of all evidence handling activities. This capability enhances the legitimacy of forensic investigations while it enhances the evidentiary value of digital records which courts use during legal proceedings.

The experimental evaluation revealed an important finding about the system which can identify evidence tampering through its use of cryptographic hash verification mechanisms. Blockchain records create hash representations of evidence files which means any attempt to change the original evidence will create a different hash value during verification. Investigators use this property to quickly detect attempts to manipulate evidence while they maintain the integrity of forensic investigations.

The evaluation showed that transparent audit trails function as essential tools for maintaining accountability in forensic evidence management systems. The blockchain ledger recorded every investigator action which involved submitting evidence and verifying it and accessing it. Auditors and oversight authorities can use this transparency to track forensic processes while they check whether evidence handling practices are being followed according to established guidelines.

The experimental results demonstrate benefits but also show the difficulties which arise from using blockchain technology in digital forensic environments. The performance analysis showed that evidence transaction processing time increases with the rise of evidence transaction volume. The problem occurs because blockchain networks depend on their consensus mechanisms which need multiple nodes to work together for transaction

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authentication. The system performance issues will impact efficiency because high-volume investigative settings generate numerous evidence transactions every day.

Research should focus on creating optimized blockchain systems which will serve forensic applications as their future solution to current challenges. Lightweight consensus algorithms and side-chain architectures together with hybrid storage models which keep major evidence files off-chain while their verification metadata remains in the blockchain ledger indicate three potential solutions. The system can achieve higher scalability through these methods which retain blockchain technology's security and transparency advantages.

8. Conclusion

The digital forensic investigations require dependable methods which enable the preservation of digital evidence custody records. The research introduced a standardized framework which enables organizations to assess their capabilities in managing digital evidence through blockchain-based digital forensic systems. The evaluation framework consisted of four main assessment categories which included integrity verification, security and access control, performance efficiency, and digital forensic standard compliance. The framework combines measurable evaluation metrics with its four assessment domains to enable organizations to evaluate blockchain-based forensic evidence management system performance assessment. The experimental assessment proved that blockchain technology enhances evidence tracking capabilities while increasing system transparency and protecting against unauthorized access. The evidence transactions become permanently documented through the immutable ledger system which enables verification of all evidence transactions thereby enhancing forensic accountability. The cryptographic hashing mechanisms enable detection of unauthorized changes which occur to stored evidence records. The assessment found system performance and scalability constraints which became evident when the system handled numerous evidence transactions.

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