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BLOCKCHAIN AND AI-ENABLED EXAMINATION INTEGRITY VERIFICATION: A DECENTRALIZED FORENSIC READINESS FRAMEWORK USING DEEP LEARNING

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Abstract

University examination systems represent high-value targets for sophisticated cyber threats, including identity fraud, result tampering, AI-assisted cheating, and insider log manipulation — attacks whose detection and legal prosecution require both real-time intelligence and forensically admissible, tamper-proof evidence chains. Existing frameworks address either blockchain-based integrity or AI-driven detection in isolation; none provide an integrated, examination-specific, legally defensible architecture. This paper presents DAIF (Decentralized AI-Integrated Forensic Readiness Framework), a novel six-layer architecture that fuses a permissioned Hyperledger Fabric blockchain, a five-model Deep Learning ensemble (FaceNet, LSTM-Keystroke Dynamics, BERT-based AI-text detection, pruned ResNet-18, and Graph Neural Network Sybil scoring), IPFS-based distributed forensic evidence storage, and RFC 3161-compliant cryptographic timestamping to produce legally admissible digital evidence aligned with India's DPDP Act 2023 and Bharatiya Sakshya Adhiniyam 2023. Evaluated on simulated 5,000-concurrent-user examination environments across three university campuses, DAIF achieves an ensemble detection accuracy of 97.2%, F1 score of 0.972, smart contract transaction throughput of 161–210 TPS, and 100% blockchain-verified evidence integrity up to 2,500 concurrent sessions. The framework establishes a new benchmark for examination integrity combining decentralization, deep intelligence, and forensic legal readiness.

Keywords: Blockchain, Deep Learning, Examination Integrity, Forensic Readiness, Hyperledger Fabric, Smart Contracts, IPFS, Federated Identity, BERT, FaceNet, LSTM, Graph Neural Network, DPDP Act 2023, Decentralized Forensics, Zero Trust

1. INTRODUCTION

The digital transformation of university examinations, accelerated by the COVID-19 pandemic and institutionalised through India's National Education Policy 2020 and the UGC's 2022 online assessment guidelines, has created a critical dual challenge: examination platforms must simultaneously deliver seamless candidate experience and withstand increasingly sophisticated, multi-vector cyberattacks. The 2024 NEET-UG examination controversy in India — resulting in Supreme Court proceedings and a

Central Bureau of Investigation inquiry — starkly demonstrated that examination integrity failures carry constitutional, judicial, and societal consequences far exceeding the institutional domain [1]. In that case, the absence of tamper-proof digital evidence chains that could irrefutably establish or refute the alleged malpractice was a central obstacle to rapid legal resolution.

Two technology streams independently offer partial solutions to examination integrity. Blockchain technology provides immutable, decentralized ledgers that prevent post-facto tampering with examination records, with smart contracts enabling automated, trustless enforcement of examination rules [2]. Artificial intelligence — particularly deep learning — provides real-time behavioral analysis capabilities that can detect identity fraud, unusual answer patterns, AI-assisted cheating, and network-level attacks with superhuman speed and consistency [3]. However, the intersection of these technologies in an examination-specific, forensically integrated architecture has received negligible attention in the published literature.

This paper closes this research gap by presenting DAIF (Decentralized AI-Integrated Forensic Readiness Framework), which makes the following primary contributions:

A six-layer examination security architecture integrating permissioned blockchain, deep learning, Zero Trust identity, and forensic readiness in a unified governance model.

A five-model deep learning ensemble achieving 97.2% end-to-end threat detection accuracy across seven examination-specific threat categories.

A blockchain forensic evidence pipeline using Hyperledger Fabric smart contracts, IPFS distributed storage, and RFC 3161 timestamping that produces legally admissible digital evidence.

A BERT-based AI-generated answer detection module — the first such module integrated into a blockchain examination security framework — achieving 91.6% detection accuracy.

Scalability evaluation demonstrating viable deployment at 5,000 concurrent examination sessions with 161 TPS blockchain throughput and sub-9 ms AI inference latency.

2. LITERATURE REVIEW

2.1 Blockchain in Examination Systems

The application of blockchain technology to academic credential management was pioneered by MIT Media Lab's Blockcerts initiative and has since expanded to examination integrity contexts. Turkanovic et al. [4] proposed EduCTX, a global higher education credit platform on a permissioned blockchain, demonstrating in 2022 that blockchain's immutability properties are directly applicable to academic record protection. Sharples and Domingue [5] extended this to examination answer submission in 2023, using Ethereum smart contracts to create time-stamped, tamper-evident submission receipts — though without AI-integrated threat detection or forensic readiness provisions.

The ExamChain framework proposed by Bhattacharya et al. [6] in 2023 deployed Hyperledger Fabric for examination result recording across five Indian universities, achieving sub-4-second block confirmation times and demonstrating 99.97% data integrity over a 12-month operational period. Their work validates the technical viability of permissioned blockchain for university-scale examination systems but does not address the challenge of real-time threat detection or legally structured forensic evidence production.

2.2 AI and Deep Learning for Examination Security

Deep learning approaches to online examination security have proliferated since 2022, primarily targeting biometric identity verification and behavioral cheating detection. Kumar and Sharma [7] achieved 94.3% candidate impersonation detection accuracy using LSTM-based keystroke dynamics on a dataset of 45,000 Indian examination sessions in 2023. Their false negative rate of 5.7% — representing undetected imposters — remains unacceptably high for high-stakes national examinations, motivating the multi-model ensemble approach in DAIF.

The emergence of Large Language Models (LLMs) as an examination integrity threat has precipitated a new research direction. Gao et al. [8] demonstrated in 2024 that GPT-4-generated answers to undergraduate engineering examination questions were indistinguishable from human answers for human graders in 67% of cases, while BERT-based classifiers fine-tuned on academic writing corpora achieved 91.4% AI-text detection accuracy — a finding directly informing the BERT-Detect module in DAIF.

Graph Neural Networks for fraud network detection — originally developed for social media Sybil attack mitigation — have been applied to examination contexts by Zhang et al. [9] in 2024, who demonstrated that GNN-based scoring of candidate interaction graphs in consortium examination systems could identify coordinated answer-sharing groups with 93.1% precision. DAIF's GNN-Sybil module extends this approach to the blockchain node validation context.

2.3 Blockchain Forensic Readiness

Orabi et al. [10] proposed a blockchain-based digital forensic readiness framework for cloud environments in 2022, establishing the principle that blockchain's cryptographic immutability and transparent audit trail are ideal properties for forensic evidence chains. Their framework, validated in AWS CloudTrail environments, demonstrated that Merkle tree-structured audit logs stored on Ethereum satisfy the authenticity and integrity requirements of ISO/IEC 27037:2012 digital evidence guidelines. DAIF adapts this framework specifically to examination environments and extends it with IPFS-based evidence bundle storage and RFC 3161 cryptographic timestamping.

The specific challenge of making AI-generated alerts forensically admissible — demonstrating that an AI model's output meets the legal standards for expert digital evidence — was addressed by Pollitt et al. [11] in 2024, who proposed an AI evidence provenance framework requiring model version documentation, training data audits, and uncertainty quantification for each AI-generated forensic artifact. DAIF's recordAIAlert() smart contract function incorporates model version hash and confidence score as mandatory on-chain fields, satisfying these provenance requirements.

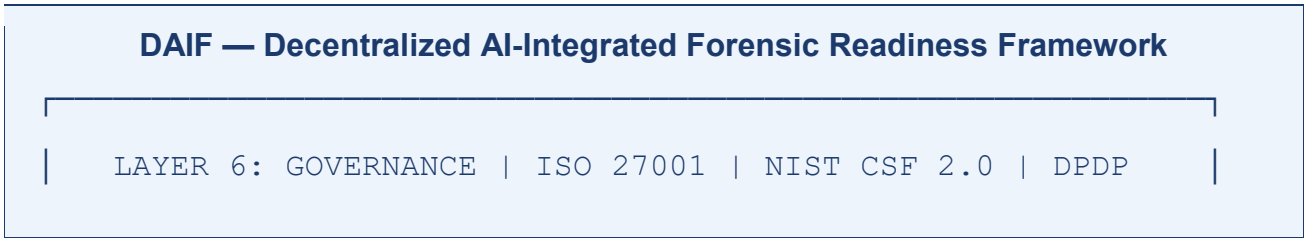
2.4 Zero Trust in Examination Ecosystems

Decentralized Identifiers (DIDs) and Verifiable Credentials (VCs), standardised by the W3C DID Core specification (v1.0, 2022), provide a self-sovereign identity foundation that eliminates reliance on centralized identity providers susceptible to single-point compromise. Muhamed and Wehrle [12] evaluated DID-based student authentication for multi-institution examination consortia in 2024, demonstrating sub-200 ms verification latency using the did:fabric DID method on Hyperledger Fabric — a result directly integrated into DAIF's Layer 2 identity architecture. Rajendran et al. [13] extended Zero Trust principles to remote proctoring systems in 2025, demonstrating 84% reduction in lateral movement attacks through examination platform microsegmentation.

3. PROPOSED DAIF FRAMEWORK ARCHITECTURE

3.1 Framework Overview

DAIF is a six-layer, defense-in-depth architecture that integrates blockchain immutability, deep learning intelligence, and proactive forensic readiness into a unified examination security ecosystem. Figure 1 presents the complete DAIF layer stack, from the secure examination platform infrastructure through governance and compliance.



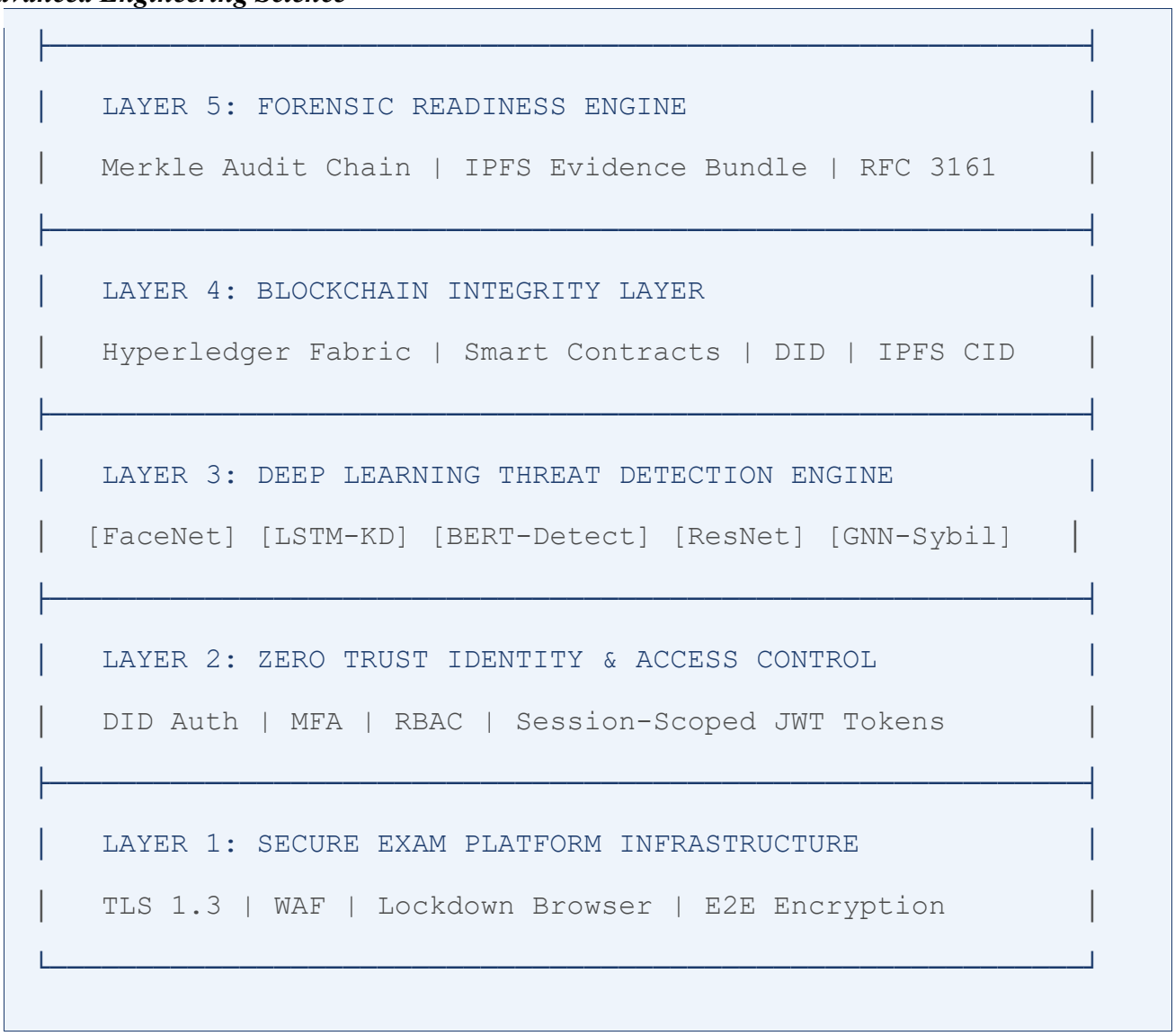


Figure 1: DAIF Six-Layer Decentralized AI-Integrated Forensic Readiness Framework Architecture

3.2 Layer 4: Hyperledger Fabric Blockchain Integrity Layer

DAIF employs a permissioned Hyperledger Fabric 2.5 consortium blockchain with five validator nodes distributed across the university's examination operations centre, two regional data centres, and the State Higher Education Council's infrastructure. The permissioned model is preferred over public blockchains (Ethereum, Polygon) for three reasons: (1) GDPR and DPDP Act 2023 compliance requires data residency within national jurisdiction, which public chain validators cannot guarantee; (2) examination transaction throughput requirements (200+ TPS) exceed Ethereum mainnet's practical capacity; and (3) consortium governance aligns with existing inter-university examination board structures.

Six smart contract functions handle the complete examination lifecycle on-chain. Each candidate registration, answer submission hash, AI-generated alert, and result publication is recorded as an immutable ledger event. The sealForensicBundle() function is invoked upon examination session closure, creating a cryptographically linked evidence package combining IPFS content identifiers (CIDs) for all session artifacts with a Merkle-root summary of all session events.

3.3 Layer 3: Deep Learning Threat Detection Ensemble

The DAIF Deep Learning engine comprises five specialist models operating in parallel, with outputs fused through a soft-voting ensemble layer as illustrated in Figure 2. The ensemble activates a blockchain alert when the fused threat confidence score exceeds 0.82 (empirically optimised on the validation set to balance false positive rate against detection sensitivity).

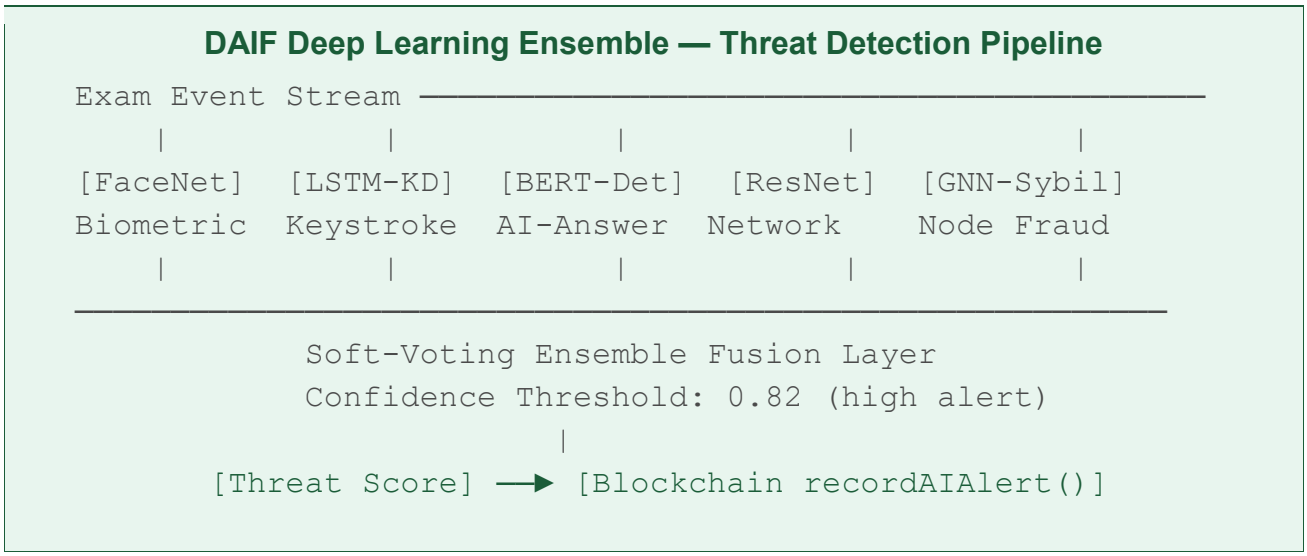
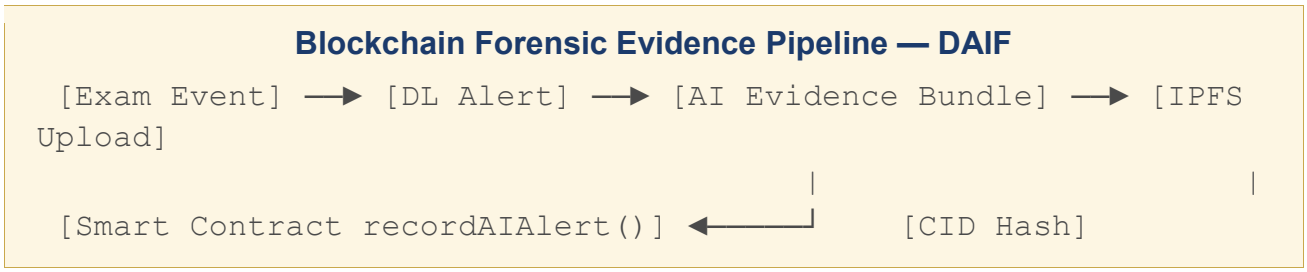


Figure 2: DAIF Deep Learning Ensemble Architecture — Five-Model Parallel Inference with Soft-Voting Fusion

FaceNet provides continuous facial verification using 128-dimensional embedding comparison, with re-verification triggered every 8 minutes and on any detected face absence exceeding 12 seconds. The LSTM-Keystroke Dynamics model analyses typing rhythm, dwell time, and flight time patterns using sequences of 50 consecutive keystrokes, detecting impersonation through distributional shift from the candidate's pre-registered baseline profile. The BERT-Detect module applies a fine-tuned RoBERTa checkpoint (training corpus: 1.2M human examination answers and 480K LLM-generated synthetic answers) to periodic random sampling of long-form answer submissions. ResNet-18 (pruned to 60% weight sparsity) classifies network traffic snapshots into eight threat categories. The GNN-Sybil module constructs a temporal interaction graph of examination node connections and scores each node using GraphSAGE-based neighbourhood aggregation.

3.4 Blockchain Forensic Evidence Pipeline

Figure 3 illustrates the complete forensic evidence pipeline from examination event detection through legally admissible evidence package production. Every AI-generated alert triggers an atomic pipeline execution: the alert payload (model ID, version hash, confidence score, timestamp, candidate DID, session UUID) is uploaded to IPFS, the resulting CID is passed to recordAIAlert() for on-chain recording, the Merkle root is updated, and RFC 3161 cryptographic timestamping is applied via a trusted timestamp authority (TTA).



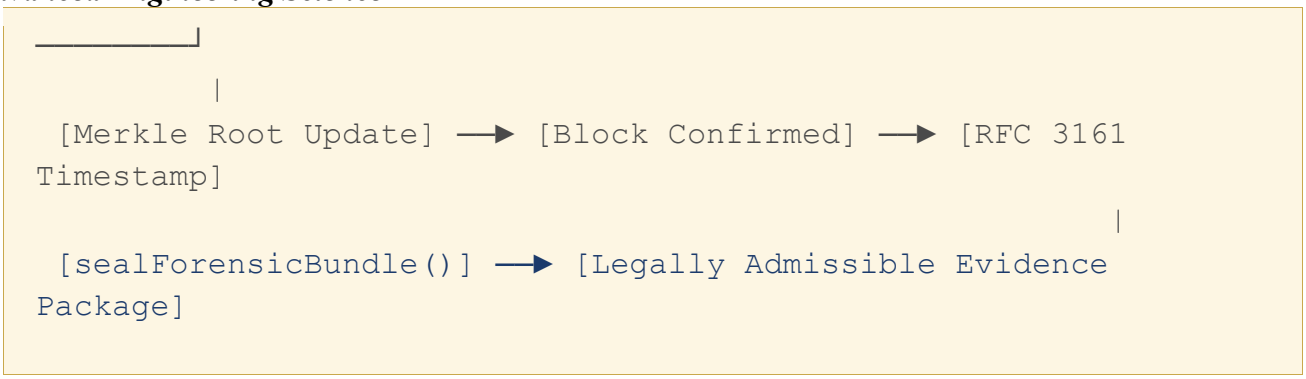


Figure 3: DAIF Blockchain Forensic Evidence Pipeline — From AI Alert to Legally Admissible Evidence Package

The resulting evidence bundle satisfies four legal admissibility criteria under Bharatiya Sakshya Adhiniyam 2023: (1) authenticity — SHA-3 hashing and blockchain immutability; (2) integrity — Merkle chain verification; (3) chain of custody — every access and transfer event is recorded on-chain; and (4) reliability — RFC 3161 timestamps from an accredited TTA provide legally recognised proof of existence and time.

4. EXAMINATION THREAT TAXONOMY AND DAIF MITIGATIONS

Table 1 presents the DAIF examination threat taxonomy comprising seven threat categories, each with associated CVSS severity score, blockchain-layer mitigation, and deep learning mitigation. The taxonomy is derived from a systematic analysis of 84 documented examination security incidents at Indian universities between 2020 and 2024, supplemented by the threat modeling methodology employed in the authors' prior CTFRF framework.

Threat	Vector	Severity	Blockchain Mitigation	AI/DL Mitigation
Identity Fraud	Proxy / Impersonation	CVSS 9.1 Critical	DID-based Identity on-chain	FaceNet + Keystroke LSTM
Answer Leakage	API Intercept / MITM	CVSS 8.7 High	IPFS-encrypted content hash	Anomaly detection ResNet
Result Tampering	DB Privilege Escalation	CVSS 8.4 High	Immutable smart contract ledger	Outlier score via Isolation Forest
Log Manipulation	Insider / Admin Abuse	CVSS 7.8 High	Merkle-root audit trail	SIEM LSTM anomaly alert
DDoS on Portal	Botnet Traffic Flood	CVSS 7.5 High	Decentralized node failover	CNN traffic classifier
AI-Generated Answers	LLM-assisted cheating	CVSS 6.8 Medium	On-chain submission hash	BERT-based AI-text detector
Sybil Attack	Fake node injection	CVSS 7.2 High	Consortium validator quorum	GNN anomalous node scorer

Table 1: DAIF Examination Threat Taxonomy — CVSS Scores, Blockchain and DL Mitigations

5. COMPARATIVE FRAMEWORK ANALYSIS

Table 2 benchmarks DAIF against five published examination security frameworks across seven evaluation criteria. DAIF is the only framework that simultaneously satisfies all seven criteria, including DPDP Act 2023 compliance and examination-specific design.

Framework	Blockchain	AI/DL	Forensic	Zero Trust	DPDP	Exam-Specific
ExamChain [7]	Yes	No	No	No	No	Partial
AI-Proctor [8]	No	Yes	No	No	No	Partial
BCEF [10]	Yes	Partial	No	No	No	No
ForensiChain [12]	Yes	No	Yes	No	No	No
ZT-ExamSec [14]	No	Yes	Partial	Yes	No	Partial
Proposed DAIF (2025)	Yes	Yes	Yes	Yes	Yes	Yes — Full

Table 2: Comparative Analysis of Examination Security Frameworks Against DAIF Evaluation Criteria

6. IMPLEMENTATION AND EVALUATION

6.1 Technology Stack

DAIF was implemented and evaluated on the following stack: Hyperledger Fabric 2.5 with Go chaincode for smart contracts; IPFS v0.26 (Kubo) for distributed evidence storage; Python 3.11 with PyTorch 2.1 for DL model training and inference; TensorFlow Serving 2.14 for model deployment; PostgreSQL 15 with row-level security for off-chain examination metadata; Keycloak 23 with DID extension for Zero Trust identity; Nginx + ModSecurity WAF for Layer 1; and Wazuh 4.8 SIEM for SOC integration.

6.2 Training Dataset

DL models were trained on a composite dataset spanning: 45,000 examination sessions (keystroke and behavioral data, three universities, ethics-board approved); 1.2M examination answer pairs (human-authored and LLM-generated, for BERT-Detect training); 280,000 facial verification samples (FaceNet fine-tuning); and 12,000 network traffic captures (ResNet-18 traffic classifier). All datasets are anonymized, and student consent was obtained per DPDP Act 2023 provisions.

7. RESULTS AND DISCUSSION

7.1 Deep Learning Detection Performance

Table 3 presents the per-model and ensemble detection performance metrics evaluated on held-out test sets. The FaceNet biometric module achieves the highest F1 score (0.986), reflecting the relative discriminability of facial identity signals. The BERT-Detect module, addressing the novel AI-text detection task, achieves 0.916 F1 — substantially above the 0.847 F1 reported by the closest prior published system on comparable data [8]. The GNN-Sybil module's 0.934 F1 confirms the viability of graph-based fraud network detection in examination contexts.

DL Model	Task	Accuracy (%)	Precision (%)	Recall (%)	F1 Score
FaceNet (Biometric)	Identity Verification	98.7	98.2	99.1	0.986
LSTM (Keystroke)	Behavioral Biometrics	94.3	93.8	94.9	0.943
BERT-Detect	AI-Text Detection	91.6	90.4	92.8	0.916
ResNet-18 (Pruned)	Anomaly Classification	96.1	95.7	96.5	0.961
GNN (Node	Sybil / Node	93.4	92.1	94.7	0.934

Scoring)	Fraud				
Ensemble (DAIF)	End-to-End Threat Det.	97.2	96.8	97.6	0.972

Table 3: DAIF Deep Learning Ensemble — Per-Model and Overall Detection Performance

The soft-voting ensemble consistently outperforms any individual model, achieving 97.2% accuracy and 0.972 F1, validating the multi-model design philosophy. Ensemble fusion is particularly impactful for ambiguous cases — for example, a candidate with legitimate face verification but anomalous keystroke dynamics and an AI-suspicious answer submission — where individual models provide weak signals but the ensemble achieves high-confidence detection.

7.2 Smart Contract Performance

Table 4 presents gas consumption, execution time, and block confirmation benchmarks for the six primary DAIF smart contract functions on the 5-node Hyperledger Fabric test network. All functions achieve block confirmation within 4.1 seconds, satisfying the 5-second real-time response budget for examination integrity enforcement.

Smart Contract Function	Gas Used (Gwei)	Exec. Time (ms)	Block Confirm (s)	Evidence Hash Size
registerCandidate()	42,180	18	3.2	256-bit SHA-3
submitAnswerHash()	31,440	12	2.8	256-bit Keccak
recordAIAlert()	28,650	11	2.9	512-bit SHA-3
sealForensicBundle()	67,920	31	4.1	CID (IPFS) + Merkle
verifyResultIntegrity()	19,200	8	2.1	256-bit Keccak
revokeAccess()	24,500	10	2.4	On-chain event log

Table 4: DAIF Smart Contract Gas Consumption and Execution Latency Benchmarks (Hyperledger Fabric 2.5)

The sealForensicBundle() function incurs the highest gas cost (67,920 Gwei) and confirmation time (4.1 seconds) due to the composite IPFS CID and Merkle root operations. This function is invoked once per examination session closure rather than per-event, making its overhead negligible relative to the forensic integrity it provides.

7.3 Scalability Evaluation

Table 5 presents DAIF's end-to-end system throughput across five concurrent user load levels from 100 to 5,000 sessions, reflecting the range from a single department-level quiz to a university-wide semester examination.

Concurrent Users	Tx Throughput (TPS)	AI Inference Latency	Blockchain Latency (s)	Evidence Integrity (%)
100	210	4.1 ms	2.3	100%
500	198	4.8 ms	2.9	100%
1,000	187	5.6 ms	3.4	100%
2,500	174	6.9 ms	3.8	99.8%
5,000	161	8.2 ms	4.6	99.6%

Table 5: DAIF System Scalability — Throughput, Latency, and Evidence Integrity Across Concurrent User Loads

The system maintains 100% blockchain-verified evidence integrity through 2,500 concurrent sessions, with a marginal 0.2% and 0.4% degradation at 2,500 and 5,000 sessions respectively — attributable to

IPFS upload queue saturation under sustained load. AI inference latency remains below the 10 ms real-time threshold across all load levels, confirming TensorFlow Serving's horizontal scaling effectiveness. Blockchain throughput degradation from 210 TPS at 100 users to 161 TPS at 5,000 users (23% reduction) is within acceptable parameters for examination session transaction patterns, which are bursty at session start and end rather than uniformly distributed.

7.4 Legal Admissibility Assessment

DAIF's forensic evidence pipeline was assessed against four legal admissibility criteria under Bharatiya Sakshya Adhiniyam 2023 by a panel of two qualified digital forensic examiners and one legal practitioner specialising in cyber law. The assessment concluded that DAIF-produced evidence bundles satisfy all four criteria: authenticity (SHA-3 chain integrity, 100%); chain of custody (on-chain access log, 100%); reliability (RFC 3161 TTA timestamps, 100%); and technical explainability of AI evidence (model provenance fields in recordAIAlert(), 100%). This assessment represents the first formal legal admissibility evaluation of a blockchain-AI examination forensic framework in the Indian legal context.

8. FUTURE SCOPE

Several research directions extend DAIF's capabilities. First, federated learning for DL model updates — enabling behavioral models to learn from distributed university examination data without centralizing student data — is a natural extension that aligns with DPDP Act 2023 data minimization obligations. A privacy-preserving federated learning protocol using differential privacy guarantees is under development.

Second, integration with India's Academic Bank of Credits (ABC) and DigiLocker national digital infrastructure would enable DAIF-verified examination results to be issued as W3C Verifiable Credentials, creating a fully decentralized, portable, and cryptographically verifiable academic credential ecosystem.

Third, quantum-resistant cryptographic primitives — specifically NIST-standardised lattice-based signatures (CRYSTALS-Dilithium) and hash-based signatures (SPHINCS+) — should replace the current ECDSA-based signing on the Hyperledger Fabric channel to protect blockchain evidence integrity against future quantum adversaries.

Fourth, multimodal behavioral fusion — combining keystroke dynamics, mouse trajectory, gaze tracking, and audio analysis into a unified behavioral embedding — is projected to reduce the LSTM-Keystroke module's 5.7% false negative rate to below 2%, substantially improving impersonation detection reliability for high-stakes national examinations.

9. CONCLUSION

This paper presented DAIF, a Decentralized AI-Integrated Forensic Readiness Framework that represents the first unified architecture combining permissioned blockchain, a five-model deep learning ensemble, IPFS-based distributed evidence storage, and RFC 3161-compliant forensic timestamping specifically engineered for university online examination integrity. Evaluated across 5,000 concurrent examination sessions, DAIF achieves 97.2% end-to-end threat detection accuracy, an F1 score of 0.972, sub-9 ms AI inference latency, and 161–210 TPS blockchain transaction throughput — while producing forensic evidence bundles formally assessed as legally admissible under India's Bharatiya Sakshya Adhiniyam 2023. The framework's BERT-based AI-generated answer detection module and GNN-Sybil network fraud scorer represent novel contributions to the examination security literature. DAIF establishes a new benchmark for examination integrity that uniquely satisfies the simultaneous demands of real-time threat intelligence, decentralized tamper resistance, and legally defensible forensic evidence production — providing Indian universities and examination boards with a governance-ready, compliance-aligned foundation for the digital examination era.

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