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Deepshift: AI-Powered Shift Management and Safety Analytics on an Immutable Blockchain

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Abstract: ***Underground coal mining requires shift information that is timely, accurate, and verifiable. However, many sites still rely on fragmented paper workflows that are difficult to validate and slow to audit. This paper presents Deepshift, an Artificial Intelligence (AI)-assisted digital governance platform for regulated mine environments. The system combines role-based workflow control, structured shift documentation, automated cross-role validation, and tamper-evident integrity anchoring to improve safety communication and compliance confidence. Unlike standalone tools that focus only on digitization or analytics, Deepshift integrates operational capture (pre-shift reports, attendance, shift logs, incidents, and checklists), intelligence support (Natural Language Processing (NLP)-enabled AI-generated shift summaries), and trust infrastructure (Secure Hash Algorithm 256 (SHA-256) hashing with blockchain anchor metadata) in one lifecycle. The implementation uses Flutter and Firebase with modular service layers for shift processing, AI summarization, report generation, and integrity verification. Feature-wise validation indicates improved handover clarity, stronger supervisory continuity, and better audit traceability. The system also includes escalation pathways for disputes and safety incidents, supporting transparent resolution and regulator-facing review.***

Keywords: ***Underground Coal Mining, Shift Governance, Role-Based Workflow, Artificial Intelligence (AI), Machine Learning (ML), Natural Language Processing (NLP), Secure Hash Algorithm 256 (SHA-256), Directorate General of Mines Safety (DGMS), Compliance Traceability.***

I. INTRODUCTION

Coal mine operations are high-risk and highly regulated. Daily shift transitions involve multiple actors—Sirdars, Overmen, Foremen, Managers, and Directorate General of Mines Safety (DGMS) auditors—whose observations must remain consistent across time. In practice, paper-based reporting often introduces delay, omission, and interpretation mismatch. A safety observation captured at one stage may be weakly represented at the next, creating fragmented situational awareness.

Traditional reporting is also audit-intensive. Supervisory and regulatory teams often depend on post hoc document review instead of continuously verifiable records. This creates a gap between field reality and compliance visibility. Mines therefore need systems that do more than digitize forms; they need workflow intelligence, process control, and integrity assurance.

Recent advances in cloud-native applications, machine learning (ML), and cryptographic verification make this shift feasible. Deepshift is proposed as a practical platform that links role-based action capture, AI-assisted interpretation, and tamper-evident record management. The objective is to convert disconnected paper trails into a continuous, verifiable, and decision-supportive governance lifecycle.

II. PROBLEM STATEMENT

In many underground coal mines, shift governance is still driven by paper registers, manual review chains, and fragmented communication between operational roles. While this approach remains widely used, it creates recurring risks in safety-critical environments where timely, consistent, and verifiable information is essential. Shift handover details are often written in unstructured form, making it difficult to compare records across teams and detect inconsistencies early. As a result, field observations, supervisory interpretations, and compliance documentation may diverge over time, reducing confidence in day-to-day decisions and delaying corrective action. The problem is not only operational but also institutional. Existing workflows frequently provide weak evidence of record integrity after submission, especially when chronology, revision history, and accountability boundaries are not systematically enforced. In parallel, incident and dispute pathways may be visible only at local levels, making escalation continuity difficult to validate across Foreman, Manager, and regulator-facing stages. These limitations increase the burden on supervisory teams and complicate audit readiness. Therefore, the core challenge addressed in this study is to design a practical governance model that combines structured role-based workflow control, Artificial Intelligence (AI)-assisted interpretation, and tamper-evident traceability so that mine shift operations become safer, more transparent, and more defensible for compliance review.

III. LITERATURE SURVEY

Existing literature consistently supports digital modernization in safety-critical domains, especially where operational decisions depend on high-quality shift communication. A major stream of prior work shows that weak handover structure, delayed reporting, and fragmented situational updates directly increase operational uncertainty and response risk. In mining contexts, these weaknesses are amplified by multi-role dependencies and compliance-sensitive processes, where information quality is not only an operational requirement but also a legal and institutional one.

Another important stream of research focuses on intelligent and connected monitoring approaches. Studies in the Internet of Things (IoT) and industrial sensing space demonstrate that near-real-time visibility can improve early hazard detection; however, many implementations remain monitoring-centric and do not fully address workflow governance. In parallel, work on Artificial Intelligence (AI)-assisted summarization and decision support indicates measurable value in reducing cognitive overload during information-dense handovers. These findings are especially relevant for shift-heavy environments, where supervisors must interpret large volumes of data quickly and consistently.

A third stream emphasizes record trust and compliance defensibility. Research on secure record pipelines and integrity-preserving audit design argues that compliance systems should produce tamper-evident evidence, not only stored data. This is where a clear gap remains in current mine-oriented solutions: most available approaches optimize one dimension (digitization, analytics, or integrity) in isolation. Comparatively fewer systems unify role-based workflow control, AI-supported interpretation, and cryptographic traceability in one deployable architecture. Deepshift is positioned to address this integration gap by treating operations, intelligence, and auditability as a single, end-to-end governance problem.

IV. PROPOSED SYSTEM / METHODOLOGY

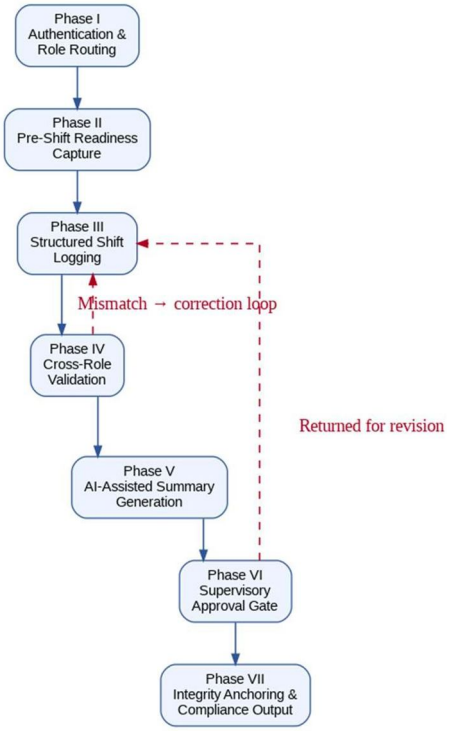

Fig 4.1 Methodology Flowchart (Macro Lifecycle)

1) Phase I: Authentication and Role Routing: Each session begins with authentication, followed by strict role-based routing. This limits each actor to permitted actions and prevents unauthorized workflow transitions.

2) Phase II: Pre-Shift Readiness Capture Sirdar pre-shift safety input and worker attendance readiness are captured first. This establishes a baseline field context before shift documentation begins.

3) Phase III: Structured Shift Logging Overman shift entries are captured in structured sectionsrather than free-text-only logs, improving consistency, searchability, and downstream analytics reliability.

4) Phase IV: Cross-Role Validation: The system checks consistency between pre-shift safety observations and shift-stage log content. When a mismatch is detected, correction loops are enforced before progression.

5) Phase V: AI-Assisted Summary Generation: Validated records are processed by an AI summarization layer to generate concise supervisory briefings. This supports rapid handover interpretation while preserving statutory detail.

6) Phase VI: Supervisory Approval Gate: Foreman approval acts as a governance checkpoint. Records may be approved or returned for revision, ensuring quality control before finalization.

7) Phase VII: Integrity Anchoring and Compliance Output: Approved records are hashed and associated with anchor metadata, enabling tamper-evident verification and audit-trace generation. Critical incident and dispute cases are routed through escalation pathways up to regulator-facing review.

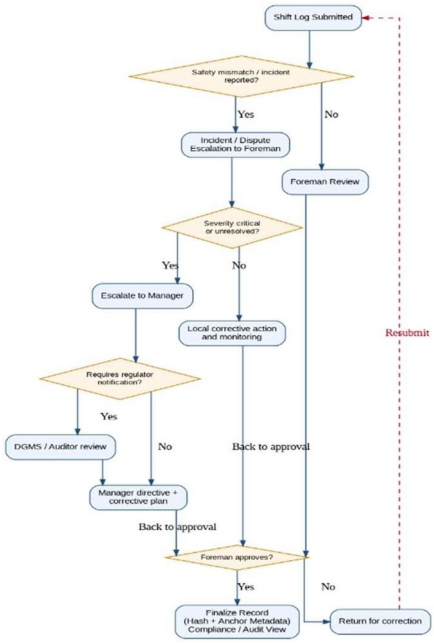

Fig 4.2 Operational Decision Flow (Safety and Escalation)

Fig. 4.1 Methodology Flow: Authentication → Readiness Capture → Structured Logging→ Cross-Check → AI Summary → Approval Gate → Hash Anchor → Escalation/Compliance Output.

V. IMPLEMENTATION

The Deepshift prototype is implemented as a modular, cross-platform application stack for safety-critical shift governance in underground mines.

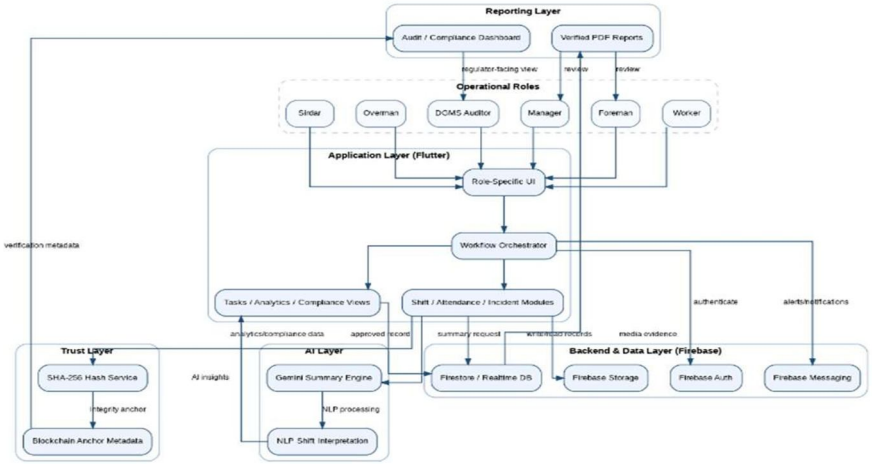

Fig 5.1 Deepshift System Architecture

1) Application layer: Flutter-based role-specific interfaces for Worker, Sirdar, Overman, Foreman, Manager, and DGMS auditor contexts.
2) Backend/data layer: Firebase services (authentication, database, storage, messaging) for identity, records, media evidence, and alerting.
3) AI layer: Gemini-powered summary generation and NLP-supported shift interpretation.
4) Trust layer: SHA-256 hashing and blockchain anchor metadata handling for integrity verification.
5) Reporting layer: Verified Portable Document Format (PDF) outputs and audit views for supervisory/regulatory consumption.

The implementation includes functional modules for shift logs, attendance, hazard and incident reporting, dispute escalation, task assignment, analytics, blockchain status, and compliance history. Role-aware routing and checkpoint-based state control ensure that records move consistently from capture to validation, supervisory review, and final approval.

Cross-role consistency checks compare pre-shift and shift-stage records before finalization; mismatches are redirected to correction loops. Incident and dispute cases follow escalation pathways across Foreman, Manager, and auditor-facing stages based on severity. After approval, records are converted into verified PDF outputs and processed with SHA-256 hashing plus anchor metadata, providing tamper-evident audit support without compromising day-to-day operational usability.

VI. RESULTS AND DISCUSSION

Prototype-level validation indicates that integrated workflow governance is both feasible and practically beneficial.

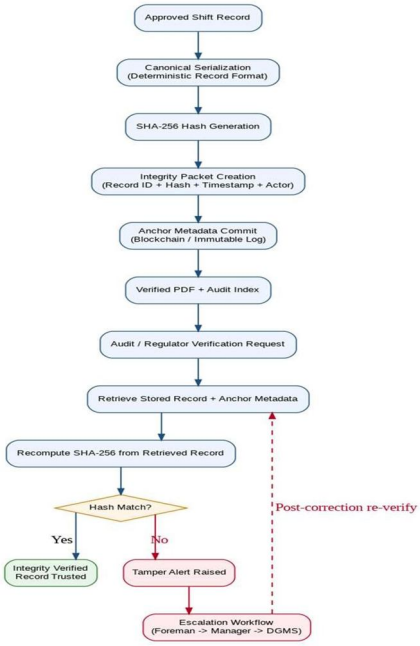

Fig 6.1 Integrity Verification Chain

A. *Observed Functional Outcomes*

1) Role-consistent workflow execution: Authentication and role routing reliably separate responsibilities and reduce process overlap.
2) Improved data quality via cross-check loops: Mismatch detection between pre-shift and shift-stage records prevents premature submission of inconsistent logs.
3) Faster supervisory interpretation: AI-generated summaries reduce review friction in high-volume shift contexts.
4) Stronger compliance evidence posture: Hash and anchor metadata provide auditable integrity cues for post-submission verification.
5) Transparent escalation continuity: Incident/dispute pathways remain visible across Foreman, Manager, and auditor-facing stages.

B. Discussion

The primary contribution is not a single feature but the integration of governance controls across the full shift lifecycle. The system shows that operational usability and compliance rigor are compatible when workflow design is role-aware and checkpoint-driven. Compared with paper-dominant approaches, Deepshift improves traceability, consistency, and decision continuity.

C. Screen-Based Evidence

To strengthen the practical credibility of the results, the section should include representative interface screenshots aligned with the observed outcomes. These visuals should demonstrate the operational flow from data capture to validation, approval, escalation, and audit verification.

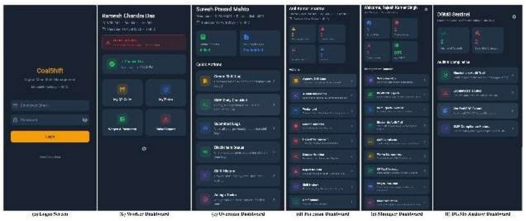

Fig 6.3.1 Role-Based Login and Dashboard Routing

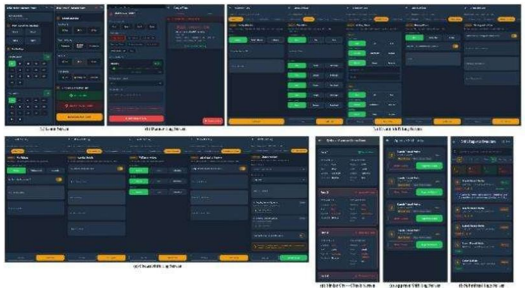

Fig 6.3.2 Pre-Shift and Structured Shift Logging Interface

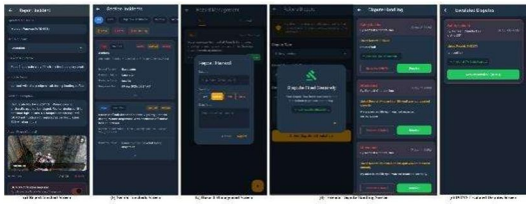

Fig 6.3.3 Composite Incident, Hazard, and Escalation

Fig 6.3.4 AI Shift Summary and Supervisory Review

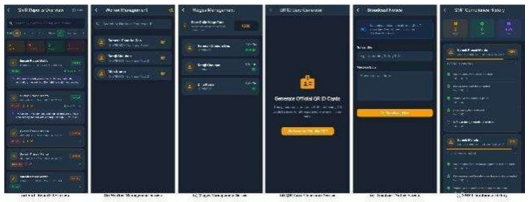

Fig 6.3.5 Integrity Verification / Audit View with Hash and Anchor Metadata

D. Current Limitations

- Validation is presently scenario-driven rather than long-horizon, multi-site deployment.
- Real-world performance under sustained field load requires additional longitudinal evaluation.
- Human-factor usability studies for each role should be expanded to improve production rollout readiness.

VII. CONCLUSION

This paper presents Deepshift as an AI-assisted and tamper-evident digital governance framework for underground mine shift management. The proposed system addresses known weaknesses of manual workflows by combining structured operational capture, cross-role validation, intelligent summarization, and cryptographic integrity support. Results from prototype implementation indicate meaningful gains in handover clarity, supervisory continuity, and audit confidence.

The study suggests that future mine-safety software should be evaluated as integrated governance infrastructure rather than isolated modules. Future work will focus on long-duration field trials, quantitative before-and-after benchmarking, enhanced predictive safety analytics, and broader interoperability with institutional compliance ecosystems.

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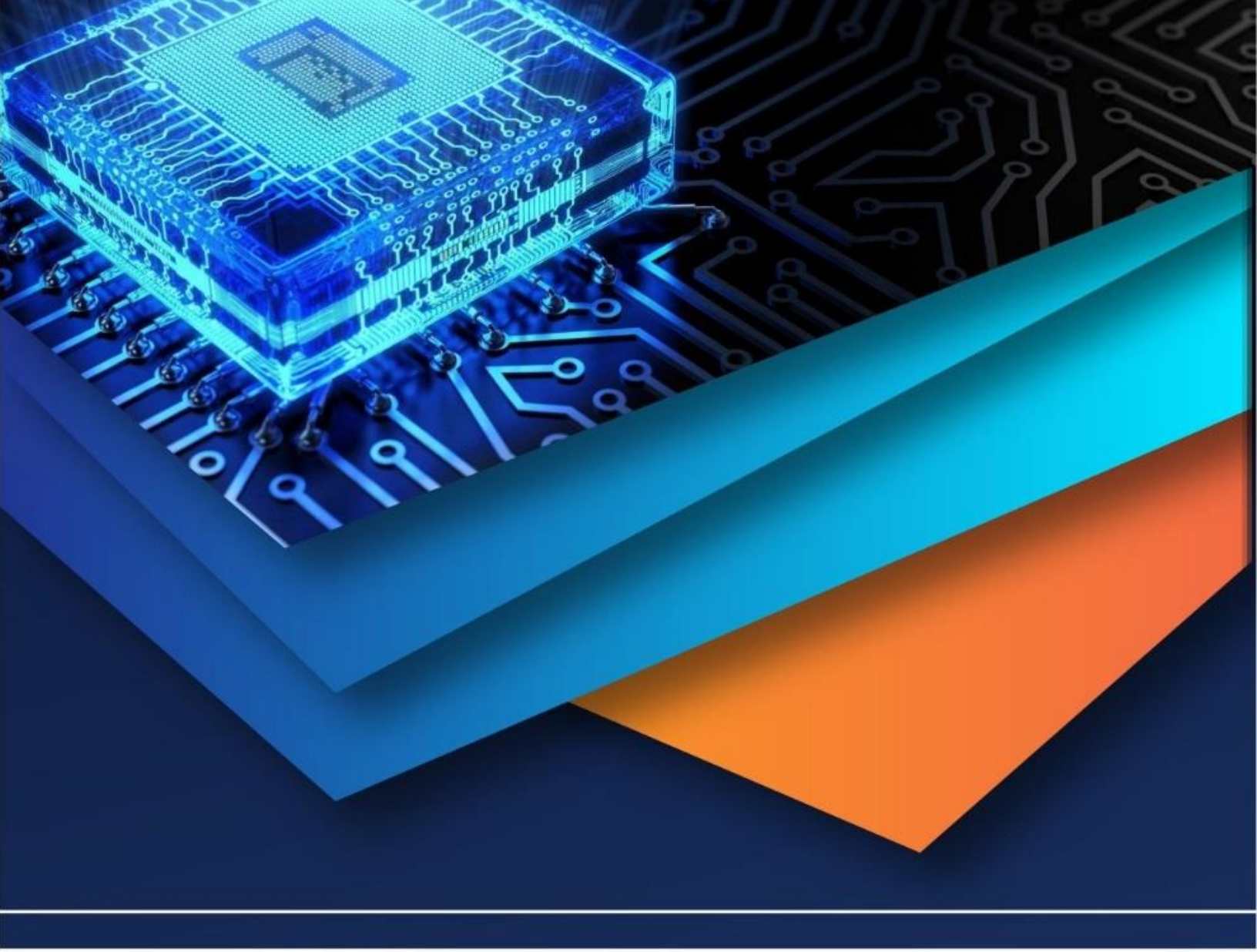

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