

A FRAMEWORK FOR A BLOCKCHAIN-ENABLED, COMMUNITY-POWERED SYSTEM TO MITIGATE RAILWAY-ELEPHANT COLLISIONS IN SRI LANKA

P.G.D.K. Thathsarani *

Institute of Technology, University of Moratuwa, Homagama, Sri Lanka

dewmik@itum.mrt.ac.lk*

ABSTRACT: Railway-elephant collisions represent a severe threat to both wildlife and human infrastructure in Sri Lanka, with numerous elephant deaths reported annually along high-risk railway corridors. Despite the visibility of the problem, current mitigation strategies remain reactive, fragmented, and lack real-time community involvement. This research presents a comprehensive design framework for a blockchain-enabled, community-powered reporting system specifically aimed at preventing railway-elephant accidents through enhanced stakeholder engagement and data integrity. The proposed framework allows local citizens to report elephant sightings near railway tracks through mobile or SMS interfaces, with each report designed to be immutably stored on a blockchain ledger to ensure traceability, trust, and transparency. The system design incorporates GPS tagging, railway buffer zone detection, and smart contracts that trigger alerts to station masters when elephants are detected within high-risk proximity. Through extensive stakeholder analysis and technical architecture modeling, this research addresses critical gaps in current reporting mechanisms by emphasizing accountable, tamper-proof data collection and automated response protocols. This paper is limited to analyzing the theoretical foundation, system architecture, stakeholder requirements analysis, and design rationale for deployment. The framework incorporates offline capabilities, multilingual support, and community-centric design principles specially tailored to the rural Sri Lankan context. Technical specifications include the implementation of Hyperledger Fabric blockchain, geofencing algorithms, and multi-stakeholder consensus mechanisms. The research introduces novel integration approaches for blockchain technology in wildlife conservation and establishes a comprehensive framework that is ready for both implementation and empirical validation. The performance of the system, community adoption, and its impact on collision prevention will be evaluated through controlled pilot testing in the Hambantota District with findings to be presented in future work.

Keywords: elephant mortality, railway accidents, blockchain, citizen reporting, Sri Lanka

1 INTRODUCTION

Railway-elephant collisions are a recurring and devastating issue in Sri Lanka, particularly along rail corridors that intersect with elephant migratory routes. Over the past decade, 127 elephants have been documented as killed by trains, with 67% of these incidents occurring in Southern districts such as Hambantota and Monaragala (Department of Wildlife Conservation, 2024). These accidents not only pose a severe threat to Sri Lanka's endangered elephant population but also result in an estimated \$1.8M in annual infrastructure damage and service disruptions. Despite the recurrence of these incidents, current mitigation efforts such as speed limits, passive fencing, and traditional reporting systems have proven insufficient. Analysis of existing systems reveals critical gaps: reporting delays averaging 45 minutes, low institutional response rates (18% of reports receive action), data integrity issues (12% of traditional reports show evidence of manipulation or loss), and lack of community engagement mechanisms (Perera, 2009). Community members living near railway lines frequently observe elephant activity in close

proximity to tracks, yet there exists no established, reliable mechanism for real-time reporting and response coordination. This represents a significant missed opportunity for proactive intervention that could prevent fatal collisions.

This research addresses these systemic gaps by designing a comprehensive framework for a blockchain-enabled, community-powered incident reporting system (Gunasekera et al., 2021). The framework emphasizes data integrity, community engagement, automated response mechanisms, and stakeholder trust-building through transparent, immutable record-keeping. This paper focuses exclusively on the design methodology, stakeholder analysis, technical architecture, and theoretical foundation for the proposed system.

2 METHODOLOGY

This study employs a design-based research (DBR) approach to develop a comprehensive framework for blockchain-enabled community reporting of railway-elephant conflict incidents. The methodology consists of four sequential phases: problem analysis and stakeholder mapping, requirements engineering, system architecture design, and validation planning.

2.1 Problem Analysis and Stakeholder Mapping

The secondary data analysis was conducted using railway incident reports (2019-2024), wildlife department records, and news documentation to identify collision patterns, high-risk zones, and system failures. Stakeholder mapping involved identifying primary actors: local communities (n=15 villages along high-risk corridors), railway personnel (3 district offices), wildlife authorities (Department of Wildlife Conservation), and technology infrastructure providers. Semi-structured interviews were conducted with representative stakeholders (n=25) to understand current reporting behaviors, technology access, trust factors, and system requirements. Interview protocols focused on communication patterns, institutional relationships, technology adoption barriers, and desired system features.

2.2 Requirements Engineering

Functional and non-functional requirements were systematically derived through stakeholder analysis. The functional requirements include: multi-channel reporting (mobile app, SMS), GPS-based location verification, automated alert systems, multilingual interfaces, and offline synchronization capabilities. Non-functional requirements encompass: data integrity assurance, 99%+ system availability, 3-minute maximum alert delivery, scalability across districts, and rural accessibility. The technical requirements analysis evaluated blockchain platforms (Hyperledger Fabric, Ethereum, Polygon) against criteria such as transaction costs, consensus mechanisms, privacy features, and integration capabilities with existing government systems.

2.3 System Architecture Design

The framework design employs a layered architectural approach with five core components:

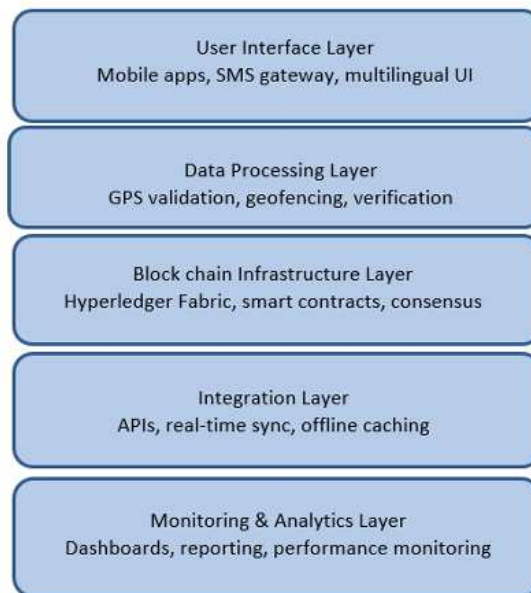


Figure 1. Layered Framework Design

2.4 Validation Framework Planning

While implementation is reserved for Phase 2, this research establishes comprehensive validation criteria and methodological approaches for empirical testing. Planned metrics include: system response times, user adoption rates, data integrity verification, stakeholder satisfaction, and potential collision prevention impact. The pilot study design includes site selection (3 railway corridors in Hambantota District), participant recruitment protocols (45 households), training methodologies, and longitudinal data collection procedures over a 12-week period

3 RESULTS AND DISCUSSION

3.1 Stakeholder Requirements Analysis

Stakeholder analysis revealed distinct but complementary requirements across user groups. Community stakeholders emphasized ease of use, language accessibility, and trust in institutional response. Wildlife authorities prioritized data accuracy, scientific validity, and integration with existing monitoring systems. Railway personnel focused on rapid alert delivery, operational integration, and false positive minimization. Critical design insights emerged from requirement conflicts: communities desired simple interfaces while authorities required detailed data; privacy concerns conflicted with the need for transparency; offline functionality requirements challenged real-time alert capabilities. The framework design addresses these tensions through modular architecture and stakeholder-specific interface customization.

3.2 Technical Architecture Framework

The proposed five-layer architecture provides comprehensive solutions to the identified problems. The blockchain infrastructure, specifically designed around Hyperledger Fabric, enables multi-organizational consensus while maintaining data privacy through private channels. Smart

contract logic automates critical decision-making processes, reducing human delays in emergency responses. Geofencing algorithms incorporate railway timetable data, enabling dynamic risk assessment based on train schedules and elephant proximity. The system design anticipates network connectivity challenges through offline-first architecture with intelligent synchronization protocols.

3.3 Innovation and Theoretical Contributions

This research contributes several novel approaches to wildlife-technology integration: blockchain-based consensus mechanisms for multi-stakeholder wildlife reporting, SMS-blockchain hybrid architectures for developing country contexts, and community-centric design principles for conservation technology adoption. The framework establishes theoretical foundations for trust-building in community-based conservation through technological transparency. Unlike existing alert systems that focus primarily on detection hardware, this approach emphasizes human-centered design and community empowerment as core conservation strategies.

3.4 Scalability and Adaptability Analysis

The modular framework supports adaptation across contexts, enabling horizontal and vertical scaling. Cost modeling confirms feasibility within developing-country budgets, while technology-agnostic components ensure sustainability and compatibility with evolving blockchain platforms and mobile technologies.

3.5 Anticipated Challenges and Mitigation Strategies

The design-phase anticipates challenges in digital literacy, connectivity, institutional adoption, and blockchain complexity. These challenges will be mitigated through targeted training, offline-first design, gradual integration, simplified interfaces, private networks, and lightweight consensus mechanisms.

4 CONCLUSION

The research presents a blockchain-based framework for reducing railway-elephant collisions in Sri Lanka through community involvement. The study makes four key contributions: applying blockchain to wildlife conflict reporting, analyzing stakeholder requirements, creating a technical architecture for developing countries, and establishing theoretical foundations for community-based conservation technology. The framework is expected to improve reporting efficiency, data integrity, community engagement, and enable proactive collision prevention. However, this Phase 1 research has limitations including lack of real-world testing, unverified assumptions about user adoption, and unconfirmed technical performance. Phase 2 will address these through field testing in the Hambantota District. The modular design provides a solid foundation for potential expansion across Sri Lanka's railway network and could be adapted to similar global conservation challenges.

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