Blockchain-Enabled Digital Ticketing and Maintenance System for Hospital Fire Safety

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BLOCKCHAIN-ENABLED DIGITAL TICKETING AND MAINTENANCE SYSTEM FOR HOSPITAL FIRE SAFETY

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Fire safety management in hospital buildings is a complex and resource-intensive task due to the presence of vulnerable occupants, continuous operations, and the critical role of fire protection systems. While sensor-based monitoring and scheduled inspections support the identification of technical failures, many deficiencies—such as obstructed escape routes or malfunctioning alarm components—are often detectable only through direct human observation. In large healthcare facilities, reliance solely on dedicated inspection teams can lead to delays in detection and response, increasing potential risks. This paper proposes a digital maintenance reporting and ticketing system tailored to hospital environments, enabling frontline users to report fire safety anomalies within a structured workflow. The system integrates user-generated reporting with centralized task management and traceability mechanisms. By incorporating human factors into maintenance processes, the approach aims to enhance user engagement, improve reporting behavior, and reduce response times. Ultimately, the proposed solution contributes to strengthening fire safety performance and supporting more proactive and efficient risk management in healthcare settings.

Keywords: Management, Operation, Decision Making, Automation.

1 INTRODUCTION

Hospitals are among the most critical building types for fire safety due to their complexity, vulnerable occupants, and continuous operations. Although fires are relatively rare, their consequences are disproportionately severe (US Fire Administration 2021). Effective fire safety requires not only technical systems but also strong organizational and managerial processes (World Health Organization 2020, Roggio et al. 2023). Regulations emphasize systematic management, including maintenance and monitoring (INSiC 2022), aligned with continuous prevention approaches (ISO 2018). However, gaps persist due to aging infrastructure and limited resources (INAIL 2022), with frequent deficiencies in protection systems and evacuation conditions (Roggio et al. 2023).

Advanced systems such as EVAC can improve emergency response if properly maintained (NFPA 2024), though effectiveness depends on reliable processes (INSiC 2022, NFPA 2024). Digital maintenance systems enhance traceability but often suffer from low engagement (World Health Organization 2020). Human factors are crucial, as staff face barriers to reporting (Benn et al. 2009, Roggio et al. 2023), making engagement essential (World Health Organization 2020, Okafor et al. 2022). Gamification may improve participation (Lilis et al. 2017, O'Donnell et al. 2013, Lamri et al. 2022), though risks remain (Hammond and Collins 2023), and evidence in hospital fire safety is still limited (Roggio et al. 2023).

2 STATE OF THE ART

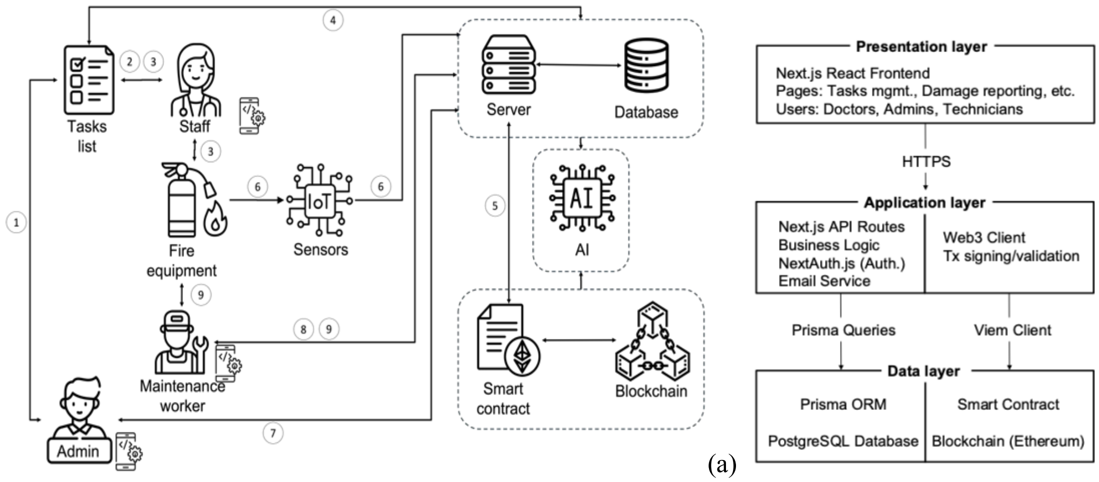
Existing literature shows that hospital infrastructure management is traditionally supported by Computerized Maintenance Management Systems and web-based platforms for scheduling preventive maintenance, managing work orders, and tracking assets (Tiwari et al. 2018). While these tools improve operational organization, limitations remain in terms of real-time visibility, traceability, and adaptability to the complex and regulated hospital environment (Tiwari et al. 2018). Blockchain applications in healthcare have mainly focused on electronic health records, secure data sharing, and access control (Azaria et al. 2016). These studies highlight benefits such as improved data integrity, transparency, and auditability (Azaria et al. 2016, Mettler 2016), but also identify challenges related to scalability, privacy, and system integration (Mettler 2016). Despite its potential, the use of blockchain for hospital infrastructure and maintenance management remains underexplored and rarely combined with maintenance workflows and stakeholder-oriented reporting approaches (Lee and Lee 2018).

Overall, existing research provides fragmented solutions, often addressing ticketing systems, maintenance platforms, or blockchain independently. Significant gaps persist in the digitalization of inspection processes, which are frequently paper-based, and in the integration of maintenance management with secure audit trails and decision-support analytics. These limitations highlight the need for unified systems integrating ticketing, recurring task management, infrastructure modeling, Voice of Customer principles, and blockchain technologies.

3 METHODOLOGY

The functioning and the architecture of the developed system are described in Figure 1. In particular, the proposed system behaves as follows (Figure 1a). (1) the admin populates the list of the tasks that the doctors in charge of inspecting fire equipment have to carry out; (2) the doctor in charge daily checks the list of tasks and performs the verification of fire equipment; (3) the doctor specifies, using the platform, if the equipment is working or needs maintenance; (4) after the check, all the information is sent to the backend, in particular it is stored on a local database, (5) and in parallel information is also stored on a smart contract hosted on the Ethereum blockchain, thus providing a certification and a timestamp. (6) Additionally, the system could also perform automatic checks on equipment, by periodically gathering data from sensors. (7) The administrator can check the status of fire equipment. The system also sends notifications in case an item is broken or needs maintenance. (8) In case some equipment needs maintenance, the administrator can assign a maintenance worker; (9) the maintenance worker could replace/fix the broken equipment and update the information on the system (server and smart contract).

For sake of completion, sensors and AI are also included in Figure 1. The objective was to show to the reader the potentiality of the proposed system, even though those two components have not yet been integrated in our platform. Concerning sensors, as briefly presented above, they are planned to be used to automatically monitor the state of the equipment. Sensors data could be either stored on the local database, or on shared databases such as the InterPlanetary File System (IPFS). For what it regards AI, it is planned to be used to perform predictive maintenance. In fact, AI could be used to process sensors data together with data related to the occupation of premises, previous history of equipment and others, and propose to the administrator a maintenance plan.



(a) (b)

Fig. 1: System Overview (a) and Layered System Architecture (b)

Figure 1b shows the three-layer architecture of the system. In particular, concerning the Presentation layer, the system relies on a Next.js React frontend, which is responsible for user interaction and interface rendering. The frontend provides functionalities such as task management and damage reporting, tailored to different user roles, including doctors, administrators, and technicians. The interactions between the frontend and backend are performed through HTTPS, enabling secure communication.

The Application layer is implemented using Next.js API Routes, which act as a centralized backend and follow a Backend-for-Frontend (BFF) pattern. This layer coordinates the interactions between the presentation layer and the data layer. Authentication and authorization are managed through NextAuth.js. In addition, the application layer integrates an email service to support system notifications (to the administrator and to the maintenance worker). This layer also handles blockchain interactions through a Web3 module (viem). This module is responsible for transaction construction, signing, and validation, and acts as an interface between the application and the blockchain network. By letting the application interact with the blockchain, the system avoids a direct client-side interaction with smart contracts, hiding the complexity to the user, but still maintaining certification advantages provided by the blockchain layer.

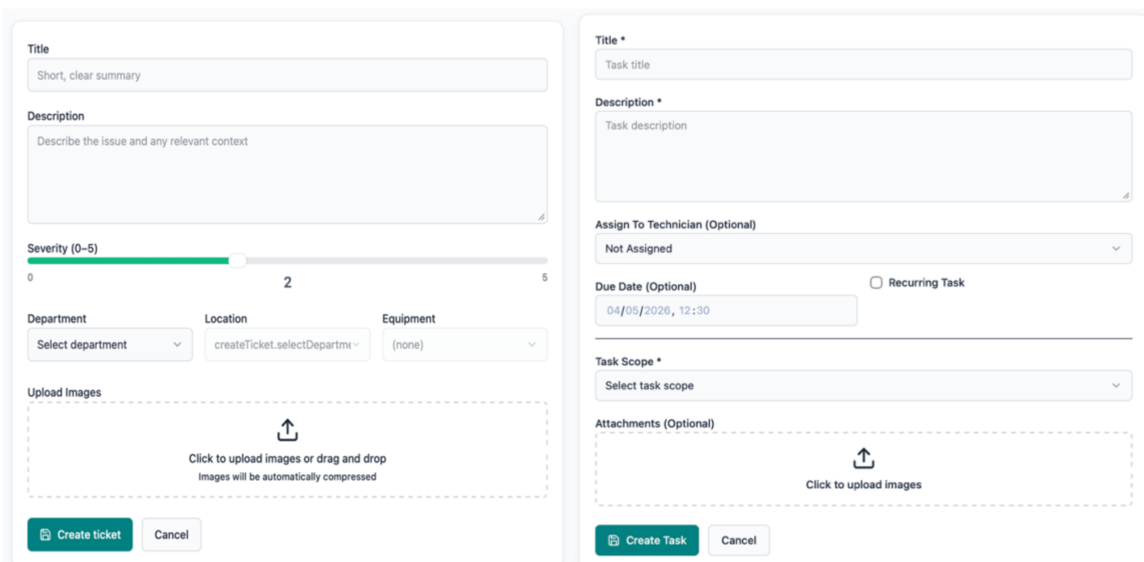
The Data layer includes both off-chain and on-chain components. Off-chain data, including user information, or task metadata, is stored in a PostgreSQL relational database. Data access is mediated by Prisma ORM, a type-safe framework for accessing relational databases through an abstracted data access layer. On-chain data is managed via a smart contract deployed on the Ethereum blockchain. The smart contract is responsible for storing the result of each equipment verification task, thus providing a transparent and tamper-proof record of verification results.

4 CASE STUDY

This section presents a case study illustrating the application of the proposed digital ticketing and maintenance management system to hospital fire safety management. The case study demonstrates how the methodology described in the previous section is operationalized through a web-based platform to support reporting, inspection, corrective maintenance, and performance monitoring of fire protection systems.

Fire safety anomalies may be identified either during scheduled inspections or through direct observation by frontline staff. As shown in Figure 2a, direct observation leads users to create a fire safety ticket directly interacting with the platform through a structured reporting interface,

including a short description of the issue, an assessment of severity, and the association of the report with a specific department, location, and fire safety asset. This structured approach reduces ambiguity in reporting and supports analysis and timely prioritization of fire safety interventions.
Furthermore, the system supports the definition of recurring or scheduled inspection tasks for fire safety equipment. As illustrated in Figure 2b, administrators can create recurring tasks associated with a specific inspection scope, defining periodic controls on individual fire safety items. In the context of this case study, each recurring task corresponds to the daily verification of a specific component of the fire protection system, such as detectors, alarm devices, fire doors, or evacuation elements. This mechanism ensures systematic and continuous monitoring of critical assets, reducing reliance on ad hoc inspections and supporting compliance with fire safety regulations. In case of recurring inspection, the administrator can assign the task to a technician directly when filling the task form. In case of a reported anomaly, once a ticket is generated, it enters a centralized workflow managed by administrative or technical staff. By pressing the green button, maintenance tasks can be assigned to qualified technicians and tracked throughout their lifecycle. Technicians update task status directly through the platform, ensuring traceability of maintenance activities from assignment to completion.
To further strengthen traceability and accountability, the system integrates blockchain-based storage for critical fire safety events. Each fire safety ticket is immutably registered on the blockchain and associated with a unique transaction hash and timestamp. The platform provides an audit and verification view that enables consistency checks between off-chain data and on-chain records through hash matching, ensuring data integrity and supporting regulatory audits without exposing sensitive operational information.
Finally, to support managerial oversight, the platform provides an analytics dashboard (Figure 2b) summarizing key performance indicators (KPIs). These include the total number of fire safety tickets, their distribution by status (open, in progress, completed), reporting trends over time, and average resolution time. The continuous and aggregated visualization of these indicators enables administrators to monitor system performance, identify recurring issues, and prioritize interventions based on objective and up-to-date data rather than periodic or fragmented reports.



(a) (b)

Figure 2: Fire safety ticket creation (a) and Task creation (b).

5 LEGAL ASPECTS

Consistent with the fire safety management logic discussed in the Introduction, where compliance depends on continuous control, documentation, and timely remediation, the proposed digital ticketing system can be read as an organizational-control instrument rather than a mere IT add-on. In many European jurisdictions, adverse events and technical malfunctions may trigger scrutiny, but the attribution of responsibility often turns on whether the operator maintained an adequate system for identifying hazards, escalating them to the competent function, implementing corrective measures, and verifying closure. The workflow described in this paper (contextual asset/room identifiers, QR-triggered ticket creation, time-stamping, role assignment, and closure supported by evidence) directly targets these systemic failure points by rendering the reporting-and-remediation cycle auditable and reviewable over time.

From a liability-risk standpoint, the main contribution is traceability and governance: the platform reduces the likelihood that anomalies remain informal, fragmented across channels, or “known but unmanaged”, and it shortens the interval between detection and intervention. In post-incident settings (e.g., internal investigations, external inspections, claims, or criminal proceedings), contemporaneous records, a transparent escalation logic, and verifiable closure can support the argument that reasonable organizational measures were implemented and effectively maintained, rather than existing only as written procedures. This resonates with healthcare scholarship on systemic negligence, which highlights how institutional accountability may attach to deficiencies in reasonably safe systems of work, including reporting and governance structures (Heywood 2021). Related analyses of organizational criminal liability similarly stress the relevance of management choices and system design in attributing responsibility beyond frontline conduct (Wells 2013).

The approach should be framed as complementary to mandated inspections and professional maintenance: user contributions add an additional detection and verification layer, but do not replace statutory duties. Accordingly, the governance elements embedded in the system are also legally salient: calibrated incentives, validation for high-criticality tickets, and clear role definitions reduce the risk of superficial reporting or strategic behavior. Where reports include personal data (e.g., identities, photos), privacy-by-design controls (data minimization, role-based access, retention limits, security logging) are necessary to avoid creating parallel compliance and evidentiary risks.

6 CONCLUSIONS

This article presents a digital ticketing and maintenance management system designed to support fire safety in hospital environments through structured reporting workflows, and blockchain-based auditability. Addressing limitations of traditional inspection practices, the approach considers both technical and organizational factors that often delay the identification and resolution of fire safety issues.

The system enables frontline staff to contribute to detecting and verifying anomalies, complementing inspections and sensor-based monitoring. Structured reporting, task assignment, and feedback mechanisms enhance accountability and traceability.

Blockchain integration ensures an immutable record of fire safety events, improving transparency, regulatory compliance, and post-incident analysis. The case study demonstrates the feasibility of the approach, combining digital workflows and audit trails within a unified platform. Future work will focus on empirical validation in real hospital settings, assessing user adoption, reporting quality, and overall fire safety performance.

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