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# MATHEMATICAL AND COMPUTER MODELING

DOI: 10.20998/2079-0023.2026.01.04
UDC 519.2

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## TRUSTED RFID EVENT MODELING FOR AUDIT, SECURITY, AND PROVENANCE IN PATIENT APPOINTMENT WORKFLOWS

This paper is devoted to the development and investigation of an approach to auditing, security, and provenance of RFID-based patient interactions within appointment-centered workflows in medical information systems. The paper analyzes the limitations of traditional RFID implementations in healthcare, which are typically focused on simple identifier retrieval and do not ensure contextual integrity, traceability, or verifiability of clinical actions, leading to risks related to inconsistent medical records and reduced reliability of appointment outcomes. The proposed solution treats RFID readings as trusted context-aware events embedded into the lifecycle of a patient appointment and forming a verifiable chain of clinical interactions. A formal model of a trusted RFID event is introduced, incorporating actor, temporal, spatial, and clinical context parameters, enabling its use as an atomic unit of audit and provenance. The approach establishes a relationship between RFID event chains and appointment results, where the outcome of a patient visit is derived from a sequence of validated and contextually consistent events rather than solely from declarative records. To ensure interoperability and standardized audit mechanisms, the proposed model is aligned with HL7 FHIR resources, including AuditEvent and Provenance, enabling representation of both event-level actions and their origins within a unified framework. A risk-based approach to RFID infrastructure security is incorporated, allowing differentiation of protection mechanisms depending on the criticality of clinical interactions. The client–server architecture of the medical information system is extended with event-driven server-side processing of RFID interactions, ensuring validation, authorization, and consistency of clinical workflows. The results demonstrate that the proposed approach improves auditability, traceability, and reliability of RFID-based patient appointment management compared to traditional identification-centric solutions, making it suitable for deployment in real healthcare environments requiring high levels of trust and accountability.

**Keywords:** RFID, patient identification, trusted events, audit, provenance, appointment workflows, healthcare information systems

**Introduction.** The ongoing digital transformation of healthcare systems has significantly increased the volume of medical data and the complexity of clinical workflows. Modern medical information systems are required not only to store and manage electronic health records but also to ensure the integrity, traceability, and accountability of clinical actions. Patient appointments represent a central organizational unit in such systems, structuring interactions between patients, healthcare professionals, and clinical processes. However, in many cases, the results of patient visits are still primarily based on declarative records entered by medical personnel, which may lack sufficient evidence of actual clinical actions and introduce risks related to human error, data inconsistency, and limited auditability [1, 2].

Radio Frequency Identification (RFID) technology has been widely adopted in healthcare as a solution for automated patient identification, asset tracking, and medication management. Compared to traditional barcode-based systems, RFID enables contactless identification, supports real-time data acquisition, and improves operational efficiency in dynamic clinical environments [3–5]. Recent studies show that RFID-based systems can reduce medication errors, improve patient safety, and enhance workflow efficiency, particularly in high-load hospital settings [6, 7].

Despite these advantages, most existing RFID implementations in medical information systems are limited to simple identifier retrieval and access control. RFID tags are typically treated as static identifiers that provide access to patient data, while the interactions themselves are not interpreted as clinically meaningful events. As a result, RFID-based actions are rarely integrated into the logical structure of patient appointments and do not provide sufficient support for audit, provenance, or verification of clinical outcomes [8, 9].

At the same time, modern healthcare systems increasingly require mechanisms that ensure traceability, data provenance, and accountability of clinical processes, especially in the context of patient safety and regulatory compliance. Standards such as HL7 FHIR introduce structured representations for audit trails and provenance, including resources such as AuditEvent and Provenance, which enable tracking of actions and their origins within healthcare systems [10, 11]. However, the integration of real-time identification technologies such as RFID with these standardized models remains insufficiently explored, particularly in the context of appointment-centered workflows and verification of clinical outcomes [12, 13].

This paper addresses the identified gap by proposing an approach in which RFID interactions are treated as trusted, context-aware events embedded within the lifecycle of patient appointments. In the proposed model, each RFID interaction contributes to a verifiable chain of events that supports audit, provenance, and validation of appointment outcomes. This enables a transition from declarative recording of clinical results to their evidence-based verification, improving the reliability, traceability, and accountability of medical information systems in real healthcare environments.

**Related works and problem statement.** Reliable patient identification is a fundamental requirement for ensuring safety and quality in healthcare delivery. In modern clinical environments, identification processes are tightly integrated with various stages of patient care, including admission, diagnosis, treatment, and follow-up. Failures in identification can lead to serious consequences such as incorrect medication administration, duplication of medical records, delays in treatment, and clinical decision errors. As healthcare systems become increasingly digital and interconnected, the need for robust and scalable identification mechanisms continues to grow, especially in high-load environments where multiple interactions occur simultaneously [14, 15].

Traditional identification methods, including manual verification and barcode-based systems, have contributed to improving standardization and reducing certain types of human error. However, these approaches remain dependent on direct interaction, line-of-sight scanning, and correct user behavior, which limits their effectiveness in dynamic and time-critical clinical workflows. In addition, barcode systems are susceptible to physical damage and often require repeated scanning, which may introduce delays and reduce usability in practice [16, 17].

Radio Frequency Identification (RFID) technology has emerged as a promising alternative, enabling contactless identification and real-time data acquisition in healthcare environments. RFID systems allow automatic detection of tags without the need for direct line-of-sight and support simultaneous identification of multiple entities, including patients, medical staff, equipment, and medications. These capabilities contribute to improved workflow efficiency, reduced manual workload, and enhanced situational awareness within clinical settings [18, 19].

Recent studies highlight the growing adoption of RFID in various healthcare applications, including patient tracking, medication administration, and asset management. In particular, RFID-based systems have been shown to reduce identification-related errors, improve compliance with clinical procedures, and support automation of routine tasks. Furthermore, integration of RFID with mobile devices and hospital information systems enables seamless access to patient data and facilitates real-time decision-making by healthcare professionals [20, 21].

At the same time, the effectiveness of RFID systems depends on multiple technical and organizational factors, including tag placement, environmental conditions, reader configuration, and system integration. Challenges such as signal interference, reading accuracy, and infrastructure costs may affect system performance and limit large-scale deployment in certain healthcare settings. Nevertheless, ongoing advancements in RFID technology and its integration with digital health infrastructures continue to expand its potential as a key component of modern medical information systems [22, 23].

Despite widespread RFID use in healthcare, most systems remain limited in scope and integration. Tags are typically used as static identifiers for record access or simple actions, reducing interactions to basic lookups without clinical context. As a result, RFID events are treated as isolated technical operations rather than meaningful clinical events, limiting their role in validation, reasoning, and higher-level decision-making [24, 25].

This issue is critical in appointment-centered workflows, where identification is part of a sequence of clinical steps. The same RFID action is used for admission, examination, medication, or discharge, each requiring different rules and context. Yet many systems process them uniformly, ignoring context. This loses semantic meaning, weakens workflow control, and increases the risk of errors or Another critical issue is the lack of contextual awareness in RFID data processing. Reliable interpretation requires factors like actor identity and role, location, appointment state, and intended action. However, most systems ignore this context, relying only on identifier matching, which limits validation and increases the risk of inappropriate or unauthorized operations in complex clinical environments [26].

From an architectural perspective, traditional RFID systems rely on synchronous request–response models, where each identification triggers an immediate server call. While simple, this limits scalability and flexibility. In high-load environments like hospitals, it can cause bottlenecks, higher latency, and reduced responsiveness. It also complicates multi-stage workflows requiring asynchronous processing, event correlation, and coordination across distributed components [27].

Beyond scalability issues, synchronous models create tightly coupled architectures where identification logic, business rules, and UI are interdependent. This reduces maintainability and makes it hard to adapt to new workflows, integrations, or regulations. As healthcare systems become more distributed and interoperable, these limitations grow increasingly problematic [24].

Another limitation is weak support for auditability and traceability. RFID interactions are often treated as transient and not stored in a structured, context-rich form. Even when logged, they lack detail to reconstruct who did what, under which conditions, and in what clinical context. This complicates incident analysis, compliance verification, and quality assurance processes [28].

Moreover, the lack of explicit links between identification events and higher-level clinical constructs, such as appointments or treatment episodes, further limits traceability. Without this linkage, it is hard to verify whether recorded outcomes match the actual sequence of actions. This gap between data and verifiable evidence is a critical weakness of many medical systems and undermines trust in digital health records [28].

Current RFID systems offer limited support for data provenance, as they rarely capture the full chain of actions leading to a clinical outcome. This makes it hard to assess data reliability, detect inconsistencies, or trace errors. The issue is especially critical in complex, multi-actor, distributed workflows, where tracing data to its origin is key for accountability and trust [25].

The limitations of existing RFID systems highlight the need for a different model that goes beyond simple identifier-based access and includes contextual, verifiable, and traceable representations of clinical interactions. Identification should be treated not as an isolated operation but as part of clinical workflows, linked to appointments and outcomes. This requires viewing RFID interactions as structured, context-aware events that reflect real actions and support reliable audit and verification.

In this approach, each RFID interaction is a trusted, context-rich event (actor, location, time, clinical stage), forming an atomic unit in a verifiable chain of actions within an appointment. Identification becomes evidence of interaction rather than just access.

Linking events to appointments provides context, enabling scenario differentiation and context-specific rules like role-based access, location constraints, and workflow conditions, improving safety and correctness [29].

Trusted events enable building verifiable chains of clinical interactions, where each action links to previous ones within an appointment. Outcomes are derived not as declarations but from validated event sequences, making them evidence-based. This increases reliability of medical records and supports accountability, especially in critical scenarios like medication administration or invasive procedures [30].

To ensure interoperability and standardization, the model aligns with HL7 FHIR. RFID trusted events map to resources like AuditEvent (actions) and Provenance (data origin and history), enabling consistent representation of event chains and their links to clinical entities such as appointments and encounters. This supports both internal processing and compliant data exchange within a unified framework [31].

Another key aspect is a risk-based approach to RFID processing. Clinical actions differ in criticality, so they require different validation levels. For example, check-in may need minimal checks, while medication or treatment actions require stricter controls like multi-factor verification and enhanced auditing. Embedding risk awareness allows the system to adapt its behavior, ensuring appropriate security and reliability [32].

Event-based RFID representation improves auditability, traceability, and analysis. Each interaction is a structured, context-rich event, enabling reconstruction of the full action sequence within an appointment. This supports incident investigation, quality assurance, and compliance by revealing workflow deviations and root causes. Unlike traditional logs, it provides a coherent, semantically meaningful view of clinical processes [30].

Overall, a trusted event-based RFID model enables more reliable, transparent, and accountable healthcare systems. Linking identification events to appointment workflows and deriving outcomes from validated event chains addresses key limitations and supports next-generation systems focused on safety, traceability, and trust.

**Trusted RFID event model for appointment-centered clinical traceability.** The limitations of RFID identification in healthcare call for a shift from viewing interactions as isolated technical operations to modeling them as part of clinical workflows. Traditional systems treat RFID as a means to retrieve identifiers and grant access, ignoring its role within broader care processes.

In practice, identification occurs within structured workflows, especially patient appointments, where each interaction (admission, examination, medication, discharge) is context-dependent and contributes to outcomes. Yet most systems fail to link identification events to this context, creating a gap between recorded data and actual clinical practice.

This gap affects the reliability of appointment outcomes, which are often recorded as assumed actions rather than verifiable ones. Without links to traceable events, it is hard to assess data integrity, audit processes, or investigate incidents.

To address this, a trusted event-based RFID model is proposed, centered on patient appointments as the core context. Each interaction is treated as a structured, context-aware event representing a clinical action, enriched with attributes like actor, location, time, and purpose for proper interpretation within an appointment.

A core principle is that trust in clinical data must be established, not assumed. RFID interactions become trusted events only after validation of integrity, context, and rule compliance, turning them into reliable evidence rather than transient signals.

Patient appointments act as containers that organize events into coherent workflows. Events within an appointment form a sequence reflecting the visit's progression, providing a basis for deriving outcomes from verifiable evidence rather than assumptions.

The approach shifts from identifier-centric, access-based models to an evidence-based view of clinical interactions, where RFID events ensure traceability, accountability, and data reliability. By formalizing context-aware identification events, it enables integration of RFID into healthcare systems while supporting efficiency and clinical trust.

To achieve consistent and verifiable interpretation, the model defines a trusted event as a structured entity combining identification data with clinical context. This allows RFID interactions to act as atomic units of clinical activity, forming the basis for audit, traceability, and outcome validation.

A trusted RFID event is defined as a tuple:

$$E = \{uid, t, actor, role, loc, ctx, appointment\_id\}, \quad (1)$$

where $uid$ represents the unique identifier associated with the patient's RFID tag; $t$ denotes the timestamp of the interaction; $actor$ identifies the entity (e.g., healthcare professional or device) initiating the event; $role$ specifies the clinical role of the actor, such as physician, nurse, or technician; $loc$ (location) describes the spatial context in which the interaction occurs; $ctx$ (context) represents the clinical intent of the action (e.g., appointment confirmation, examination, medication administration); and $appointment\_id$ links the event to a specific patient appointment, providing the primary contextual framework for its interpretation.

Contextual parameters distinguish this model from identifier-centric ones, enabling a semantically rich view of interactions. The appointment_id is key, linking each event to a specific visit, allowing identical RFID actions to be interpreted differently depending on context and supporting context-aware validation.

An RFID event is not inherently trustworthy; trust is derived from completeness, consistency, and alignment with clinical context. It becomes trusted only if it answers core accountability questions (who, patient, where, when, process), shifting RFID from passive identification to evidence generation.

The model also supports composability: trusted events form ordered sequences reflecting appointment progression. These preserve temporal and contextual links, enabling workflow reconstruction and analysis, and serving as a basis for event chains and appointment outcomes.

Formalizing RFID interactions as trusted events supports integration with interoperability standards and audit frameworks. Structured events with defined attributes align with audit logging and provenance tracking, enabling consistent mapping to standardized clinical actions and ensuring compatibility and extensibility within healthcare ecosystems.

Overall, the model provides a formal foundation for interpreting identification as verifiable clinical actions. By enriching events with context and linking them to appointments, it shifts from identifier-based access to evidence-based processing, supporting traceability, accountability, and reliability in modern healthcare systems.

In this model, an RFID interaction is not immediately trusted; trust is derived through validation and contextualization. Raw identification alone is insufficient, so each interaction passes through stages that establish its validity and clinical meaning.

The first stage is structural validation, which checks completeness and consistency of essential attributes (identifier, timestamp, actor). It ensures the event meets format requirements but does not interpret its meaning

Next is contextual validation, where the system evaluates the event against clinical context (actor role, location, appointment state). This distinguishes identical actions under different conditions and ensures only contextually valid events proceed.

The next stage is constraint and policy validation, where domain rules and organizational policies (role-based, temporal, workflow-specific) determine if the action is allowed. Separating this from contextual validation keeps the model flexible and extensible.

After passing validation, the event becomes eligible for clinical interpretation and is mapped to a specific action within the appointment workflow. It is no longer a technical signal but a representation of a real clinical interaction, enabling alignment with actual clinical practices.

The final stage is persistence and traceability, where the event and its validation outcome are stored in a structured log. This preserves each interaction as evidence for audit, workflow reconstruction, and incident analysis, unlike traditional transient identification actions.

Thus, transforming an RFID interaction into a trusted clinical event is a multi-stage process ensuring technical correctness and clinical validity. Explicitly modeling these stages provides a clear, reproducible mechanism for trust formation across clinical scenarios.

The overall validation and trust formation process is shown in Fig. 1.

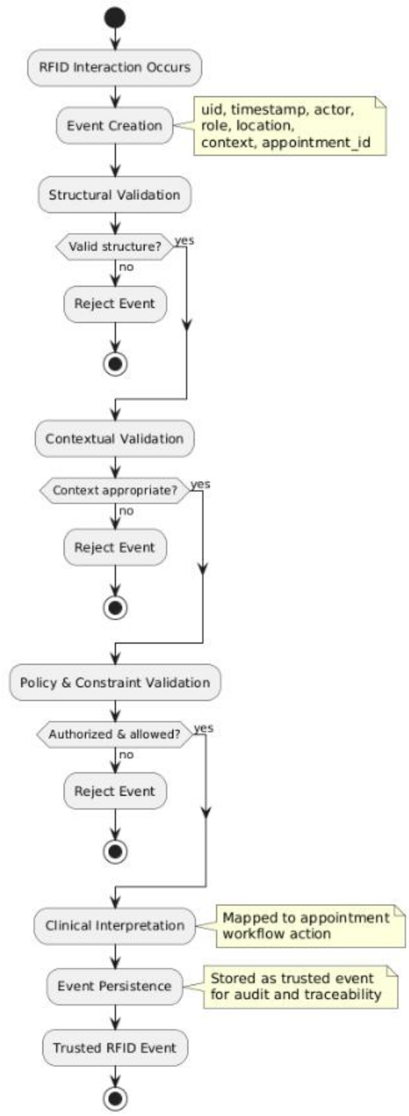


Fig. 1. Stages of validation and trust formation for RFID-based clinical events within appointment-centered workflows

While the formalization of RFID interactions as trusted events provides a foundation for representing clinical actions, the full semantic value of these events emerges only when they are interpreted within a structured clinical context. In the proposed approach, such a context is defined by the patient appointment, which serves as the primary organizational unit for grouping, interpreting, and validating events. This appointment-centered perspective enables the transformation of isolated interactions into coherent representations of clinical workflows.

A patient appointment is a bounded episode of care involving interactions such as identification, examination, diagnostics, treatment, and follow-up. Linking each RFID event to a specific appointment provides context, allowing events to be interpreted both individually and in relation to others within the same process.

The integration of trusted RFID events into appointment-centered workflows is shown in Fig. 2.

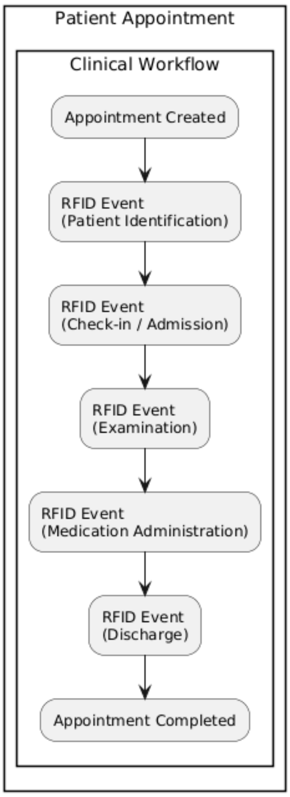


Fig. 2. Integration of trusted RFID events into appointment-centered clinical workflows

The appointment_id attribute is key, linking each event to a specific visit and enabling contextual interpretation. This ensures identical RFID actions can have different meanings depending on the appointment. For example, a scan during admission differs clinically from one during medication, despite using the same mechanism.

Within the appointment-centered model, events are not processed in isolation but are interpreted as components of a broader workflow. The appointment acts as a container that organizes events into a structured sequence, reflecting the actual progression of the clinical process. This structure allows the system to enforce workflow-specific constraints, such as permissible transitions between stages of care, required actions, and dependencies between events. As a result, the system can detect inconsistencies, prevent invalid operations, and ensure that clinical processes follow defined rules.

Another important aspect of this integration is the ability to correlate events across multiple actors and locations within the same appointment. In real healthcare scenarios, a single patient visit may involve several healthcare professionals and multiple departments. By associating all relevant events with a shared appointment context, the system enables a unified view of the clinical process, facilitating coordination, communication, and comprehensive analysis of performed actions.

The appointment-centered model also provides a basis for linking RFID events with higher-level clinical entities and outcomes. Since each event is contextualized within a specific visit, it becomes possible to evaluate not only individual actions but also their collective contribution to the overall result of the appointment. This establishes a direct connection between low-level identification interactions and high-level clinical semantics, bridging the gap between technical data acquisition and meaningful clinical interpretation.

While individual trusted RFID events provide a reliable representation of atomic clinical actions, their full value is realized when they are considered as part of a structured sequence within a patient appointment. In the proposed model, events associated with a specific appointment are organized into event chains, which reflect the temporal and logical progression of clinical interactions. These chains serve as a bridge between low-level identification events and high-level clinical outcomes, enabling a consistent and verifiable interpretation of patient visits.

An event chain represents an ordered sequence of trusted RFID events linked by a common appointment context. Each event in the chain corresponds to a specific action performed during the visit and is enriched with contextual attributes that allow it to be interpreted within the workflow. The ordering of events is primarily determined by temporal relationships, but it is also influenced by clinical logic, such as dependencies between actions and permissible transitions within the workflow.

The concept of event chains enables the system to move beyond isolated event processing toward a holistic representation of clinical processes. Instead of evaluating individual interactions independently, the system can analyze the entire sequence of actions associated with an appointment. This makes it possible to assess whether the performed actions are consistent, complete, and aligned with expected clinical procedures.

The relationship between RFID event chains and appointment outcomes is illustrated in Fig. 3.

Within this framework, the outcome of a patient appointment is no longer treated as a purely declarative record but as a result derived from a sequence of validated events. Each outcome is supported by an underlying chain of actions that can be reconstructed, verified, and analyzed. This establishes a direct link between recorded clinical data and the actual interactions that occurred during the visit, significantly improving the reliability and credibility of medical records.

The use of event chains also enables the detection of inconsistencies and anomalies in clinical workflows. For example, if a required action is missing from the sequence, or if events occur in an invalid order, the system can identify such deviations and flag them for further review. This capability is particularly important in safety-critical scenarios, where incomplete or incorrect workflows may lead to adverse outcomes.

Another important advantage of this approach is its support for post-event analysis and audit. Since each event in the chain is recorded as a structured and contextualized entity, it becomes possible to reconstruct the entire appointment process with a high degree of detail. This allows healthcare organizations to investigate incidents, verify compliance with clinical protocols, and assess the quality of care provided.

Furthermore, the event chain model provides a foundation for integrating advanced analytical and decision-support mechanisms. By analyzing patterns of events across multiple appointments, the system can identify trends, detect potential risks, and support optimization of clinical workflows. This extends the role of RFID from a passive identification technology to an active component of data-driven healthcare systems.

Overall, the introduction of event chains transforms the interpretation of RFID interactions from isolated technical signals into a coherent and verifiable representation of clinical processes. By linking appointment outcomes to sequences of trusted events, the proposed model establishes a foundation for evidence-based clinical data, enhancing traceability, accountability, and trust in healthcare information systems.

While the proposed trusted event-based model provides a conceptual and formal framework for interpreting RFID interactions within appointment-centered workflows, its practical value depends on the ability of a system to support and reflect this model in real-world operation. In this context, the implementation of a medical information system serves not as the primary contribution, but as a validation that the proposed approach can be effectively realized and integrated into everyday clinical processes.

In the developed system, patient appointments are represented as central entities that organize clinical interactions and serve as containers for trusted RFID events. All interactions involving patient identification are implicitly or explicitly associated with a specific appointment, ensuring that events are never processed in isolation. This design enables consistent contextualization of actions and aligns system behavior with the conceptual model described in previous sections.

The practical representation of the proposed model, including the interaction between appointments, RFID events, and system components, is illustrated in Fig. 4.

Within the system, trusted RFID events are reflected through changes in the state of domain entities, such as patients, appointments, and clinical actions. For example, an identification event associated with a scheduled appointment may trigger a transition from a “planned” to an “active” state, while subsequent events contribute to the progression and eventual completion of the visit. This demonstrates that RFID interactions are not merely recorded but actively influence the lifecycle of clinical processes.

The system interface provides a visual representation of these processes, allowing users to observe and manage appointments, patient data, and associated interactions. However, the interface itself does not define the logic of event processing; instead, it reflects the underlying event-based model. This separation ensures that the interpretation of RFID events remains consistent regardless of the client interface used, supporting heterogeneous environments that include web applications, mobile devices, and RFID-enabled readers.

Another important aspect of the implementation is the persistent storage of events and their outcomes. Each trusted RFID event, along with its contextual attributes and processing result, is recorded as part of a structured data

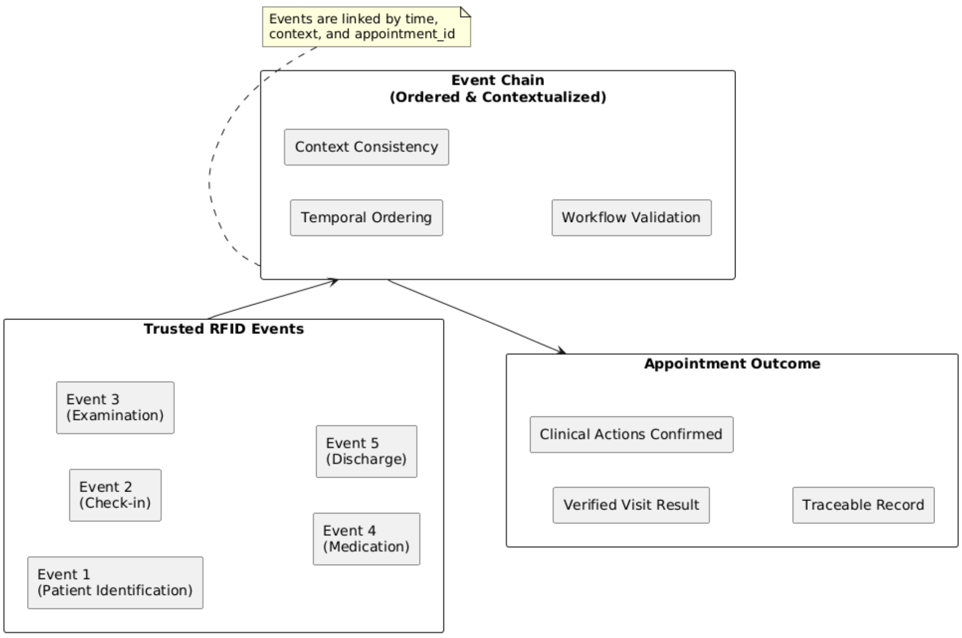


Fig. 3. Formation of appointment outcomes based on chains of trusted RFID events

model. This enables full traceability of clinical interactions and supports audit and analysis of appointment workflows. By maintaining a detailed history of events, the system provides a reliable basis for reconstructing clinical processes and verifying the correctness of recorded outcomes.

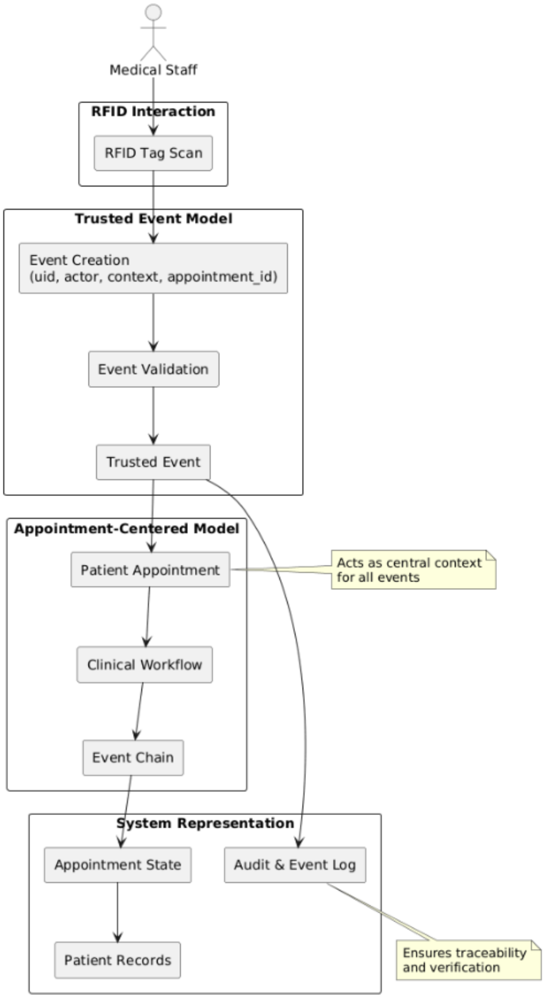


Fig. 4. Practical representation of appointment-centered workflows and trusted RFID event integration in a medical information system

The integration of trusted events into appointment-centered workflows also enables consistent synchronization between different system components. Changes triggered by RFID interactions are propagated across the system, ensuring that all representations of clinical data remain aligned. This is particularly important in distributed environments, where multiple users and systems may interact with the same patient data simultaneously.

Overall, the practical implementation confirms that the proposed trusted event-based model can be effectively applied within a medical information system, providing a coherent link between identification technologies and clinical workflows. By ensuring that RFID interactions are interpreted, validated, and recorded as context-aware events within patient appointments, the system supports traceability, accountability, and evidence-based representation of clinical outcomes.

The proposed trusted event-based model, together with its practical representation, demonstrates a consistent and extensible approach to integrating RFID-based identification into appointment-centered clinical workflows. By redefining RFID interactions as structured, context-aware, and verifiable events, the model overcomes the limitations of traditional identifier-centric approaches and enables a deeper integration of identification processes into the semantic structure of healthcare information systems. This shift allows identification to be interpreted not merely as a technical operation, but as a clinically meaningful action that contributes to the overall outcome of a patient appointment.

A key contribution of the proposed approach lies in the explicit linkage between RFID events and patient appointments, which serve as the primary contextual framework for interpreting clinical interactions. This appointment-centered perspective ensures that events are not processed in isolation but are embedded within coherent workflows that reflect real-world clinical processes. As a result, identical identification actions can be interpreted differently depending on their context, enabling more precise validation, improved safety, and greater alignment with clinical intent.

The introduction of a multi-stage validation process further strengthens the reliability of the model by ensuring that only structurally correct, contextually appropriate, and policy-compliant events are considered trusted. This approach establishes a clear mechanism for trust formation, transforming raw identification data into evidence that can be used for audit, verification, and decision-making. In contrast to conventional systems, where trust is often implicitly assumed, the proposed model provides an explicit and reproducible process for establishing the validity of clinical interactions.

Another important aspect of the model is the concept of event chains, which enables the representation of patient appointments as sequences of interrelated actions. By organizing trusted events into ordered chains, the system can capture the temporal and logical structure of clinical workflows, supporting both real-time validation and retrospective analysis. This allows appointment outcomes to be derived from verifiable evidence rather than declarative assumptions, significantly enhancing the reliability and credibility of medical records.

From a system perspective, the practical implementation confirms that the proposed model can be effectively realized within a medical information system without introducing excessive complexity. The separation between event generation, validation, contextual interpretation, and persistence ensures flexibility and scalability, while the use of appointment-centered modeling provides a consistent structure for integrating diverse clinical interactions. The system interface, in turn, serves as a reflection of the underlying model, demonstrating that the proposed approach can be seamlessly incorporated into real-world workflows and user environments.

Furthermore, the model supports key requirements of modern healthcare systems, including traceability, accountability, and auditability. By representing RFID interactions as persistent and context-rich events, the system enables detailed reconstruction of clinical processes and facilitates post-incident analysis, compliance verification, and quality assessment. This capability is particularly important in safety-critical environments, where the ability to verify performed actions is essential for ensuring patient safety and maintaining trust in digital health systems.

Overall, the presented approach establishes a coherent conceptual and practical framework for transforming RFID-based identification into a foundation for evidence-based clinical data processing. By linking trusted events with appointment-centered workflows and deriving outcomes from structured event chains, the model provides a scalable and reliable solution for integrating identification technologies into modern healthcare information systems.

**Conclusions.** This work addresses reliability, traceability, and verifiability of patient-related interactions, highlighting limitations of conventional RFID systems that treat interactions as simple identifier retrieval without context or links to clinical processes. This reduces data integrity, auditability, and reliable validation of appointment outcomes.

To address this, a trusted event-based RFID model is proposed, centered on patient appointments as the main clinical context. RFID interactions are treated as structured, context-aware events representing atomic clinical actions, enriched with attributes such as actor, role, location, time, and appointment link.

A key contribution is a multi-stage validation process, where events become trusted only after structural, contextual, and policy checks. This provides a reproducible way to transform raw identification into verifiable clinical evidence and supports a shift from access-based to evidence-based data processing.

Another key aspect is integrating trusted RFID events into appointment-centered workflows. Linking each event to a specific appointment provides consistent context, enables differentiation of similar actions under different conditions, and enforces workflow-specific constraints, improving safety and alignment with real clinical practice.

Event chains extend this by representing appointments as sequences of related actions. Outcomes are derived from validated, consistent event chains rather than declarations, linking results to evidence and improving reliability, transparency, and credibility of medical data.

Practical implementation confirms applicability in real systems. Trusted events integrate into appointment management, workflows, and data storage without excessive complexity. Separation of representation, validation, and interpretation ensures flexibility, scalability, and consistency across components.

The results show the approach provides a strong basis for next-generation healthcare systems focused on traceability, accountability, and trust. By redefining RFID identification as a source of verifiable clinical events, it improves patient safety, supports audit and compliance, and enables more reliable digital representations of clinical processes.

Future work may extend the model with advanced event correlation, real-time analytics, and decision-support integration, as well as alignment with standards like HL7 FHIR for audit and provenance. Further research may explore use in distributed, large-scale environments, including mobile platforms and Internet of Medical Things, enhancing robustness and adaptability of appointment-centered, event-driven systems.

**Declaration on the use of generative AI.** During the preparation of this work, the authors used ChatGPT for language editing, text refinement, and assistance in structuring the manuscript, as well as Grammarly for grammar and spell checking. After using these tools, the authors reviewed, edited, and validated all content and take full responsibility for the content of this publication.

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*Received 14.03.2026*
*Accepted 06.04.2026*
*Published 20.05.2026*

УДК 519.2

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## МОДЕЛЮВАННЯ ДОВІРЕНИХ RFID-ПОДІЙ ДЛЯ АУДИТУ, БЕЗПЕКИ ТА ПОХОДЖЕННЯ ДАНИХ У ПРОЦЕСАХ ВІЗИТІВ ПАЦІЄНТІВ

Ця робота присвячена розробці та дослідженню підходу до аудиту, безпеки та відстеження походження даних (provenance) RFID-взаємодій із пацієнтами в рамках процесів, орієнтованих на візити, у медичних інформаційних системах. У статті проаналізовано обмеження традиційних реалізацій RFID у сфері охорони здоров’я, які зазвичай зводяться до простого зчитування ідентифікатора та не забезпечують контекстної цілісності, трасованості та верифікованості клінічних дій, що призводить до ризиків, пов’язаних із неузгодженістю медичних записів і зниженням надійності результатів візитів.Запропоноване рішення розглядає RFID-зчитування як довірені контекстно-орієнтовані події, інтегровані в життєвий цикл візиту пацієнта та такі, що формують верифікований ланцюг клінічних взаємодій. Запроваджено формальну модель довіреної RFID-події, яка включає параметри актора, часу, просторового та клінічного контексту, що дозволяє використовувати її як атомарну одиницю аудиту та відстеження походження даних.У роботі встановлюється зв’язок між ланцюгами RFID-подій та результатами візитів, де підсумок відвідування пацієнта формується на основі послідовності валідуваних і контекстно узгоджених подій, а не виключно на основі декларативних записів. Для забезпечення інтероперабельності та стандартизованих механізмів аудиту запропонована модель узгоджується зі стандартами HL7 FHIR, зокрема ресурсами AuditEvent і Provenance, що дозволяє представляти як окремі дії, так і їх походження в межах єдиної уніфікованої моделі.У підході також реалізовано ризик-орієнтований підхід до забезпечення безпеки RFID-інфраструктури, що дозволяє диференціювати механізми захисту залежно від критичності клінічних взаємодій. Архітектура медичної інформаційної системи розширена за рахунок подієво-орієнтованої серверної обробки RFID-взаємодій, що забезпечує валідацію, авторизацію та узгодженість клінічних процесів.Отримані результати демонструють, що запропонований підхід покращує аудитованість, трасованість і надійність управління візитами пацієнтів на основі RFID порівняно з традиційними рішеннями, орієнтованими лише на ідентифікацію, що робить його придатним для впровадження в реальних медичних інформаційних системах із високими вимогами до довіри та підзвітності.

**Ключові слова:** RFID, ідентифікація пацієнта, довірені події, аудит, відстеження походження даних, процеси візитів пацієнтів, медичні інформаційні системи

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