International Journal of Computer Applications Technology and Research
Volume 15–Issue 11, 51 – 59, 2026, ISSN: -2319–8656
DOI:10.7753/IJCATR1511.1005

From Fragmented Systems to Integrated Care: An Enterprise Architecture Approach to Healthcare Interoperability

Anuoluwapo Odusami
Independent Researcher
Colorado, USA

Abstract: Healthcare providers continue to grapple with fragmented information technology (IT) systems that create data silos, inhibit unified access to patient records, and undermine care delivery, patient safety, and operational efficiency. This paper applies Enterprise Architecture (EA) principles and the Architecture Design Cycle to analyze the "as-is" state of healthcare IT infrastructure and to design a "to-be" solution built on FHIR-native microservices, an AI-powered Clinical Decision Support System (CDSS), and a hybrid cloud, hybrid database architecture. The proposed three-tier platform separates the presentation, application-logic, and data layers, and incorporates a defense-in-depth security architecture that reconciles interoperability with HIPAA compliance. Literature evidence indicates that microservices adoption can increase deployment frequency by up to 78% and reduce critical outages by up to 76%, while FHIR-native approaches can achieve interoperability success rates as high as 97%. Validated against real-world implementations such as Epic's MyChart, Kaiser Permanente's mobile application, and Cerner's HL7-compliant integration suite, this paper demonstrates that EA-driven, FHIR-native microservices integrated with AI-powered CDSS offer a feasible pathway to overcoming healthcare IT fragmentation, enhancing patient safety, and reducing administrative costs.
Keywords: Enterprise Architecture; FHIR Microservices; Clinical Decision Support Systems (CDSS); Healthcare Interoperability; Hybrid Cloud; Information Security

1. INTRODUCTION

In recent times, the healthcare industry has been increasingly exploring digital technologies such as AI, big data analytics, and interoperable systems in a way that will improve workflow and support healthcare business model transformation [1]. This trend is a result of the benefits of digital transformation projects driving the value-based healthcare shifts focused on improving care delivery and patient outcomes. These shifts are primarily driven by the need to meet increasing patient expectations, unified access to patients' medical records, and reducing operational costs [2].

1.1 Background and Problem Statement

"Healthcare providers still face a major challenge with fragmented IT systems caused by a lack of seamless interoperability between disparate IT systems, resulting in data silos inhibiting unified access to patient medical records [3]. This hinders overall effective care delivery, resulting in increased operational costs, poor patient outcomes, and administrative inefficiency". KLAS Research reveals that despite the significant adoption of IT systems like Electronic Medical Records (EMR), only 44% of healthcare providers' EMR systems are interoperable with other systems [4].

A Statista survey further reveals that 56% of healthcare providers' interoperability goals in the United States are driven by patient outcomes, while 54% are driven by clinical workflow optimization needs. Thus, underscoring the increasing need to address the inherent challenges of data fragmentation and clinical operations workflows. Furthermore, over 3 million deaths occur globally linked to patient safety incidents. Most of these incidents have been attributed to a lack of effective communication between practitioners and patients due to fragmented data.

This accounts for 60% of all caregivers' adverse incidents. Consequently, these incidents account for 15% of healthcare providers' OPEX [5]. Additionally, administrative inefficiencies also account for an estimated cost of 21% - 31% of the US total healthcare expenditure, further straining the available resources for patient care [5]. This further stresses the need for this transformation as the global healthcare IT market continues to experience exponential growth. The healthcare IT market rose to $420.2 billion in 2024 and is projected to continue to grow at 14.7% annually, reflecting the urgency and scale of the ongoing digital transformation efforts within the healthcare industry to improve overall care delivery.

1.2 Research Aim and Proposed Approach

"By applying Enterprise Architecture principles and the Architecture Design Cycle to analyze and transform "as-is" healthcare business architecture, healthcare providers can overcome IT systems silos that resulted in data fragmentation through the adoption of interoperability standards such as Fast Healthcare Interoperability Resources (FHIR) and incorporating AI-based Clinical Decision Support Systems (CDSS), enabling seamless real-time sharing of data, enhancing patient safety, and improving administrative work processes".

2. LITERATURE REVIEW AND RELATED WORK

2.1 Physical Infrastructure and Enterprise Architecture

The healthcare industry continues to innovate and undergo digital transformation. The strategic business rationale for this is to improve or enhance patient outcomes and care delivery through advanced technologies and interoperable systems [2]. According to Lal [3], despite the widespread adoption of Electronic Medical Records (EMR), issues with fragmented IT physical infrastructure persist and continue to pose a great barrier to seamless data exchange and operational efficiency. Many healthcare providers still rely on obsolete and disconnected infrastructure/technologies, and this legacy infrastructure, along with existing fragmented/siloed data, poses one of the biggest hindrances to interoperability.

This section examines the IT components of physical infrastructure, such as IT networks, data centers, and mobile technology, and their roles within healthcare IT architecture, focusing on interoperability and clinical operations workflows.

Enterprise architecture (EA) frameworks serve as a fundamental aspect of healthcare IT architecture by ensuring alignment of critical IT components that make up the physical infrastructure with the healthcare provider's business processes [6]. Eithar Mohamed and Nur Azaliah [7] argue that EA provides a blueprint to ensure enterprise information systems deliver their intended business benefits, focusing on the business layer, application layer, data layer, and ultimately the IT infrastructure layer.

Physical IT infrastructure components, including legacy IT systems like servers, isolated networks, and heterogeneous devices, create fragmented infrastructures that result in siloed data that inhibits effective care delivery and increases operational cost. Fragmented infrastructures are widely seen as responsible for clinical inefficiencies and poor patient care.

2.2 Healthcare Networks, Data Centers, and Mobile Technologies

Building on this overview of enterprise architecture's role in physical infrastructure, the following subsections examine each of the core physical infrastructure components in turn, beginning with IT networks. IT networks ensure data exchange between healthcare IT systems and devices, and scalable and robust IT networks support real-time integrated care enabled by real-time interoperability. However, some IT networks are still fragmented due to legacy or outdated network devices, such as switches and routers, lacking support for modern security and communication protocols, coupled with the non-adoption of interoperability standards such as Fast Healthcare Interoperability Resources (FHIR) [8]. Furthermore, healthcare providers face challenges implementing new technologies due to the existing legacy network devices with speed performance constraints.

Data centers are responsible for hosting medical applications such as EMR and their databases. However, a data center's departmentally focused architecture results in its siloed nature, further resulting in data storage that is fragmented and difficult to access due to a lack of efficient data management. However, Hybrid cloud infrastructure presents scalable options that allow the incorporation of AI-enabled clinical decision support systems, but this also presents new challenges in integrating with on-premises and cloud data, which may result in new silos.

Mobile technologies enable improved access to data at the point of care. Manhattan Research revealed that 63% of healthcare practitioners use tablets, while 56% use their smartphones to access healthcare IT systems, thereby enhancing workflows and responsiveness for healthcare practitioners. However, these mobile devices' capabilities and security policies can also contribute to increasing data fragmentation and vulnerabilities.

2.3 Cloud Computing in Healthcare

Beyond on-premises physical infrastructure, cloud computing has emerged as a central strategy for addressing many of these same fragmentation challenges. Cloud computing plays a key role in today's IT architecture, providing healthcare providers with scalable, flexible, and resilient IT resources to meet the increasing business needs of the modern healthcare industry. It enables integration of virtualized infrastructure, software, and data management systems to provide on-demand cloud services, serving as a complementary infrastructure or a complete alternative to the traditional on-prem infrastructure. Some 70% to 80% of healthcare providers have adopted cloud computing to improve clinical operations, leveraging the flexibility and scalability it provides in comparison to on-prem infrastructure, and further stresses that though cloud computing offers tangible benefits, healthcare providers must be strategic about its adoption.

Cloud computing enables the transformation of healthcare IT infrastructure by improving interoperability, centralizing data management, and supporting advanced technologies such as AI. The adoption of cloud computing allows healthcare providers to balance scalability with compliance regarding hosting and managing electronic medical records (EMR), AI-enabled clinical decision support systems (CDSS), telemedicine, and big data clinical applications. Furthermore, cloud architecture provides support for unified patient data access, thereby preventing data fragmentation by leveraging HL7 interoperability standards such as FHIR.

Major cloud service providers (CSPs) have already connected over 300 million patient records across thousands of healthcare providers globally using interoperability tools such as FHIR-compliant APIs. Despite this advancement, the healthcare industry still faces interoperability challenges, inhibiting seamless data exchange between disparate IT infrastructures/systems and healthcare providers, which has been attributed to a lack of adoption of standards like FHIR [8].

Similarly, cloud computing platforms can power AI-driven CDSS to enhance patient outcomes and also support scalability for telemedicine and mobile technologies, thereby expanding healthcare access to a wider pool of patients while reducing operational expenditure (OPEX) and improving clinical operational resilience/workflows, also serving as a cost-effective alternative to traditional on-prem data centers. In response to the increasing clinical operational and patient outcomes enhancement needs of the healthcare industry, CSPs like Amazon Web Services (AWS) now offer cloud solutions specifically tailored to address those needs, focusing on interoperability, security, and regulatory compliance [9].

Although cloud computing may reduce reliance on on-premises data centers, physical IT infrastructures are still required to establish network connectivity, local edge processing, and integration with clinical devices. The hybrid cloud model architecture enables seamless interoperability between the on-premises data center and the cloud environments [10]. In adopting cloud computing for healthcare, it is important to understand how to integrate cloud services with existing on-premises IT infrastructure/systems, cloud-enabled AI applications, and mobile health technologies to deliver improved patient care.

This means developing cloud strategies that will effectively address IT fragmentation, enhance interoperability, enable scalable clinical workflows, and foster patient-centric health tech innovation.

2.4 Database Design, Integration, and Master Data Management

Underlying both on-premises and cloud deployments is the database layer, where design and administration practices play an equally critical role in determining whether healthcare data remains fragmented or becomes interoperable. Database design and administration are key to addressing the challenges of data fragmentation and interoperability confronting the healthcare industry. Today's healthcare IT systems, like Electronic Medical Records (EMR), utilize hybrid database models, a combination of relational database systems (RDBMS) and NoSQL database systems, due to the heterogeneous nature of medical data [11]. RDBMS is the common database in healthcare and is used to manage structured data, such as patient information, medical records, and billing history, and

overall tracking of patient care and outcomes, while a NoSQL database is used to store unstructured data, such as medical images and notes [12].

Effective schema designs for databases based on entity-relationship modelling and principles of normalization result in the reduction of redundancy while maintaining referential integrity. This enables complex clinical workflows across multiple healthcare providers' disparate data sources. Moreover, clinical data warehouses are representations of transformation and evolution in today's healthcare database design because they transform disparate data stores into data-driven analytical platforms [13].

They also support clinical research and population health management, and improvement in quality initiatives, provided they comply with interoperability and normalization standards that support the evolving data requirements of the healthcare industry. Studies reveal that data warehouse architectures using federated models support secure querying across heterogeneous sources without compromising data sovereignty or privacy control. Nevertheless, database administration practices still contribute to data fragmentation despite these advancements, given that a study carried out on care fragmentation highlights that patients with complex, multimorbid conditions experienced an increase in healthcare providers' transitions and hospital encounters, correlating with database complexity and siloed data environments.

At the same time, legacy database governance inconsistency, lack of normalization, and lack of standardized patient identifiers contribute to the duplication of records that inhibit accuracy in matching patients' medical records across systems [14]. Adding to this concern, fragmented databases have been linked to an increase in the rate of inappropriate medication use and adverse patient outcomes, stressing the urgent need for integrated database management systems in healthcare. In healthcare database integration, semantic interoperability standards such as FHIR ensure best practices for database integration.

FHIR-based architecture improves real-time data exchange and clinical data reuse, thereby enhancing care coordination and clinical decision support. Relatedly, Master Data Management (MDM) frameworks also allow synchronization of core data entities like patients, healthcare providers, and locations that are across disparate healthcare IT systems, reducing duplication and enhancing data integrity [15]. API-first approach using FHIR allows for incremental integration without complete database migration, enabling legacy systems to be interoperable with modern clinical apps such as EMRs with minimal or no disruption.

Notably, healthcare providers that have implemented database integration comprehensively have witnessed measurable gains, including lower operational costs, improved care coordination, and better patient outcomes, leveraging unified data access and evidence-based clinical decision-making [13].

2.5 Monolithic and Microservices-Based Software Architectures

Beyond how data is stored, the architecture of the software applications built on top of these databases further shapes the extent of interoperability across the healthcare ecosystem. Today's healthcare industry's "as-is" software mostly consists of legacy systems, vendor-specific EMRs, and other disparate clinical applications that evolved in isolation, resulting in fragmented healthcare software ecosystem challenges currently facing the industry. Healthcare providers are confronted with numerous software and development challenges that directly contribute to IT fragmentation issues, mostly of which can be attributed to legacy systems, vendor-specific Electronic Medical Records (EMR), and monolithic architectures, all of which collectively inhibit unified data access and clinical workflow efficiency [16].

According to Tummers et al. [17], health information software like EMR still lacks interoperability across providers, resulting in ineffective communication challenges being faced by healthcare practitioners due to siloed data across disparate healthcare systems/software. This argument was further stressed by Arjan et al. [18], who stated that fragmented healthcare software poses a major barrier to the successful and effective integration of digital healthcare innovations. Nonetheless, healthcare software/systems are developed with a layered architecture, which consists extensively of a data layer, business layer, service layer, business process layer, and presentation layer.

However, most healthcare software architectures are mainly comprised of monolithic systems with the following components: user interface/presentation layer, business logic/application layer, and database/data layer. These layers are tightly integrated into single units that can be deployed [19]. This software architecture guides the design and maintenance and provides system architectural analysis for the development of healthcare software [17]. Studies have revealed that ineffective software development has resulted in EMR usability challenges, such as interoperability failures and workflow mismatches, which directly contribute to errors in patients' medical records, wrong diagnoses, and compromised patient safety.

For example, a study conducted on twelve healthcare providers reveals that monolithic EMR requires 67% more time to implement new features and faces 3.4 times more integration challenges compared to modular designs. What is more, monolithic systems can take up to 14.3 months to fulfill regulatory compliance updates, in contrast with modular designs, which ensure this in just 7.8 months. Modular architecture using microservices has proven to provide improved flexibility and scalability compared to monolithic software, with 78% of organizations that transitioned from monolithic to microservices witnessing improvements in deployments and a reduction in outages [20].

Healthcare providers rely on layered architectures incorporated with service-oriented architecture (SOA) with SOAP and REST/JSON interfaces for modern software development. That said, integration with legacy systems remains challenging due to the associated complexities with interoperability because of the non-implementation of standards like FHIR [20]. Healthcare software maintenance requires continuous integration (CI) and continuous development (CD) to meet increasing clinical needs and to address the challenges of effectively managing the software lifecycle, as such necessitating the adoption of DevOps practices for modern monolithic and microservice-based software development and deployment [21].

Nevertheless, healthcare software architecture continues to contribute to the fragmentation issues facing the healthcare industry due to monolithic software, a lack of adoption of interoperability standards, complex deployment processes, coupled with maintenance bottlenecks. These factors collectively continue to inhibit unified patient data access and effective clinical workflows [20], [16].

2.6 Full-Stack Healthcare Platforms and Existing Implementations

Given these architectural challenges, it is useful to examine how comprehensive full-stack development approaches have been applied in practice to address IT fragmentation. The data fragmentation and interoperability challenges facing the healthcare industry continue to hinder unified patient data access and overall effective healthcare delivery [18]. Based on these identified issues, exploring comprehensive full-stack web development approaches could offer solutions to address these lingering issues through the application of enterprise architecture principles to designing healthcare applications. Healthcare applications are often divided into a three-tier architecture, which includes the presentation layer/frontend, logic layer/middleware, and data layer/backend, thereby enabling the separation of concerns and support for scalability and flexibility to meet increasing clinical needs [19]

To illustrate this, Epic Systems Corporation's EMR architecture demonstrates a comprehensive implementation, given that a three-tier architecture was adopted for its development, with the data tier using the InterSystems Caché database, the application tier using Caché ObjectScript to execute business logic, and the presentation tier having two user interfaces: Hyperspace for healthcare practitioners and MyChart for patients [22]. In a similar vein, studies have also shown that a three-tier architecture for clinical information systems enables each tier to scale independently, thereby allowing for individual tier updates without disruption to other tiers [23].

Another study examined inpatient portal usability, and the findings suggest that errors encountered by portal users are attributable to issues with system design, assumptions about functionalities, and insufficient user knowledge [24]. This exemplifies the potential challenges of ineffective designs for the front-end/presentation and business logic layers of a full-stack clinical application. Epic's MyChart is considered the healthcare industry standard or benchmark for patient portal architecture, and it is integrated into Epic's EMR to centralize real-time medical information that's accessible to both patients and health practitioners.

MyChart's development is focused on user-centric design, which prioritizes user interface (UI) and user experience (UX), and ensures the implementation of customized usability that presents the most relevant information based on individual user needs [22]. Likewise, MyChart enables patients to access complete medical histories, records, and active prescriptions in real time, and equally supports data entry from patients through mobile medical devices used in monitoring blood glucose or pressure levels.

Healthcare Mobile EMR applications like Kaiser Permanente's app witnessed over one million downloads, and it demonstrates full-stack implementation in healthcare with its broad functionalities and features such as secure email communication with providers, appointment scheduling and management, prescription refills and medication tracking, medical history viewing, etc. [25]. On top of this, Cerner's integration solution enables healthcare providers to connect their existing IT systems and medical devices seamlessly via Cerner's EMR, leveraging its integrated modular architecture and its HL7-compliant APIs [26].

MERN stack implementation provides a comprehensive framework for developing full-stack healthcare applications and optimizing clinical workflow. Healthcare MEAN-based applications incorporate NoSQL databases like MongoDB for flexible FHIR-compliant storage for the backend, Express.js RESTful API serving as middleware, React.js creating reusable components for the user interfaces along with virtual DOM optimization, and Node.js enabling event-driven, non-blocking I/O for real-time healthcare platforms [27]. Nevertheless, React.js implementation in healthcare application development allows component-based architecture, which enables modular, reusable UI components for patient portals and EMR interfaces (frontends), with virtual DOM.

Thereby improving performance and users' experience for real-time healthcare systems [28].

2.7 Artificial Intelligence and Clinical Decision Support Systems

While these full-stack platforms address structural fragmentation, artificial intelligence and algorithmic approaches offer a complementary path to resolving the semantic and analytical dimensions of interoperability. Given that the healthcare industry is confronted by IT fragmentation and interoperability challenges, advanced technologies such as AI and algorithms could provide the needed solutions, leveraging technologies or solutions like Machine Learning (ML) algorithms, AI-driven Clinical Decision Support Systems (CDSS), and natural language processing (NLP), thereby enabling seamless data sharing, enhancing patient safety, and improving clinical workflows [29]. A study examined how AI is transforming CDSS along with ML, NLP, and deep learning. The findings suggest that CDSS integrated with AI could revolutionize healthcare delivery by enhancing healthcare practitioners' decision-making and patient outcomes, arguing that healthcare providers could benefit from AI-powered CDSS applications. These technologies enable real-time patient diagnosis, personalized treatment recommendations, clinical documentation, early disease detection, etc. [29]. However, another study stressed that AI-powered CDSS successful adoption is dependent on a user-centered design that addresses usability, clinical workflow integration, ethical considerations, and trust while equally preventing algorithmic bias and ensuring interpretability [30].

Along similar lines, research analyzed semantic interoperability using FHIR, and the results were promising for the use of ML and NLP for processing unstructured data. As part of that same review, 70 other studies were examined, and they provided classifications of solutions addressing semantic interoperability at different levels: collecting, extracting, and annotating data, modeling EMR data from legacy systems, and applying transformation and mapping to FHIR models and terminologies. It also established that NLP techniques extracted and mapped unstructured clinical notes and other medical reports to appropriate concept codes for FHIR terminology, thus accelerating the adoption of interoperability.

A study asserts that to successfully apply ML methods for integrating data across disparate medical information databases, ML classifiers must achieve good F1 scores for intra-database mapping and correctly classify 90-96% of healthcare variables across multiple databases. Another study focused on the integration of multimodal data suggests that AI consistently integrates complementary biological and clinical data such as genomics, medical imaging, electronic medical records, and wearable device data, providing comprehensive insights into patient conditions, thus ensuring correct diagnoses, personalized treatments, and enhanced patient outcomes [31].

International Journal of Computer Applications Technology and Research
Volume 15–Issue 11, 51 – 59, 2026, ISSN: -2319–8656
DOI:10.7753/IJCATR1511.1005

Medical data interoperability gaps could be bridged by AI through the standardization and processing of data from disparate sources with varying formats, such as HL7, FHIR, CDA, and proprietary structures. AI algorithms can also map variables between different EMRs automatically, address semantic inconsistencies, and enable real-time data exchange at the point of care [1]. Likewise, AI in healthcare transformation cuts across applications ranging from connected care through virtual assistants, diagnostics, to automated clinical administrative tasks using NLP technology in the documentation of patient visits in EMRs, thereby streamlining clinical workflow.

Nevertheless, advanced technologies like AI, NLP, ML, and AI-powered CDSS provide evidence-based solutions that will address the IT fragmentation challenges facing the healthcare industry by leveraging data integration automation, semantic interoperability, and clinical decision support based on intelligence, thereby ensuring seamless data sharing and enhancing patient safety [1].

2.8 Information Security, Privacy, and Regulatory Compliance

Yet, the same data sharing that AI and interoperability technologies enable also introduces new information security challenges that must be addressed. The healthcare industry continues to face information security (IS) challenges that directly contribute to the existing fragmentation and interoperability issues, further exacerbating them. As healthcare providers continue to seek ways to achieve data sharing that's seamless, along with unified patient access, factors such as information security vulnerabilities, regulatory compliance challenges, and IS risks emanating from fragmented IT systems continue to prevent interoperability through the additional barriers these factors create [32].

Gates [33] argues that as long as EMRs remain interoperable, they are prone to cyber-attacks, and interoperability also presents a danger to patients' access to medical records and personal information. Healthcare providers or organizations are faced with a myriad of regulatory compliance requirements that they will have to navigate while equally addressing issues posed by fragmented IT infrastructures. A study has shown that data privacy challenges include inconsistent data definitions, inadequate standardized protocols, and insufficient IT infrastructure across jurisdictions.

It also uncovered that fragmented IT systems contribute to the increase in data breach likelihood as a result of incomplete or inaccessible patient records existing across disparate databases. Healthcare practitioners in the public health industry are confronted by significant bottlenecks when implementing privacy and security controls to address IS risks, necessitating a policymaker shift in focus toward training and enforcement of IS.

According to Atkins [32], IT systems fragmentation impacts compliance directly through incomplete or inaccessible patient records and, as such, increases the likelihood of a data breach. Relatedly, a study analyzed compliance risks and revealed that disconnected systems generate inconsistent documentation trails, triggering red flags during audits and Office of Civil Rights (OCR) investigations. That same study also examined information blocking under the ONC Cures Act Final Rule and attributed the delays or restrictions in information exchange between healthcare providers to IS risk concerns and the associated substantial regulatory penalties [34].

Interconnected IT systems, EMRs, and medical devices, including IoTs, make it increasingly challenging to protect patient data and healthcare processes effectively. This was underscored by the WannaCry incident, which highlights the real-world consequences of vulnerabilities for healthcare providers and patients' well-being [35]. At the same time, fast technology integrations such as FHIR integrations improve clinical operational efficiency but could also introduce new IS risks that could impact patient safety and confidentiality [34], [35].

The review of EMR interoperability and security through distributed ledger technologies reveals that blockchain is promising in enhancing data security; however, it also presents implementation challenges, such as integration with existing healthcare IT systems. Beyond this, addressing healthcare data privacy challenges requires harmonized worldwide regulations and collaboration. Nevertheless, as information security challenges continue to impact healthcare interoperability, initiatives such as the CMS Interoperability Framework present a balanced approach for information sharing between healthcare providers and patients while ensuring medical data protection and privacy [36].

In this regard, Health-ISAC guidelines stressed the key importance of digital identity to new interoperability architectures, as it ensures that only authorized users have access to sensitive data while also enabling FHIR patient access APIs that allow third-party app integrations [34].

3. METHODOLOGY: ENTERPRISE ARCHITECTURE DESIGN APPROACH

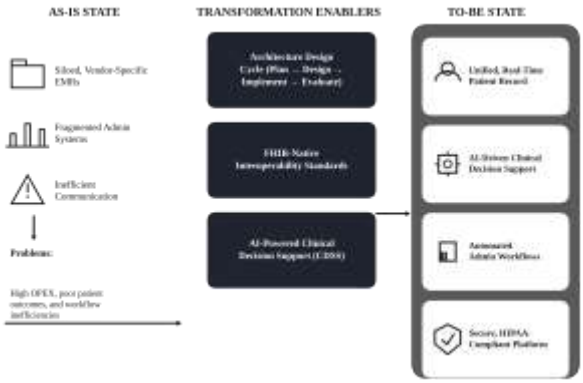


Figure 1: Conceptual Business Architecture

Enterprise Architecture (EA), a management tool, provides a structured framework to address issues created by data fragmentation by ensuring alignment of healthcare providers' business information systems needs/business strategies with their information needs. In other words, it enables the analysis and documentation of a healthcare provider's IT capabilities in its present and future states through an integrated business and technology approach [6]. The rationale for EA's framework adoption is based on its support for the robust assessment of the existing "as-is" business architecture.

It also enables effective mapping of existing processes, system landscapes, and IT capabilities [7]. The baseline findings reveal bottlenecks with the existing architecture, which hinder seamless data exchange among care providers. Healthcare providers can transform from the "as-is" state to a desired "to-be" architecture by using the architecture design cycle, which ensures a structured approach for iterative planning, design, implementation, and evaluation phases. This approach ensures

International Journal of Computer Applications Technology and Research
Volume 15–Issue 11, 51 – 59, 2026, ISSN: -2319–8656
DOI:10.7753/IJCATR1511.1005

alignment of IT solutions with changes in operational and regulatory needs of healthcare providers while also addressing risks associated with technical debts and resource constraints.

4. PROPOSED SYSTEM ARCHITECTURE

4.1 Architectural Components and Implementation Design

The proposed solution suggests building upon the business architecture depicted in Figure 1, leveraging the implementation of systems architecture that addresses healthcare IT Fragmentation using a multi-layered approach that is aligned with the principle of Enterprise Architecture (EA) [6]. The solution is developed using a three-tier architecture design, which separates the presentation layer from the application/logic layer and the data layer to enable independent scalability and modular updates without disrupting the entire system [23]. Figure 2 summarizes the proposed architecture and its cross-cutting security controls.

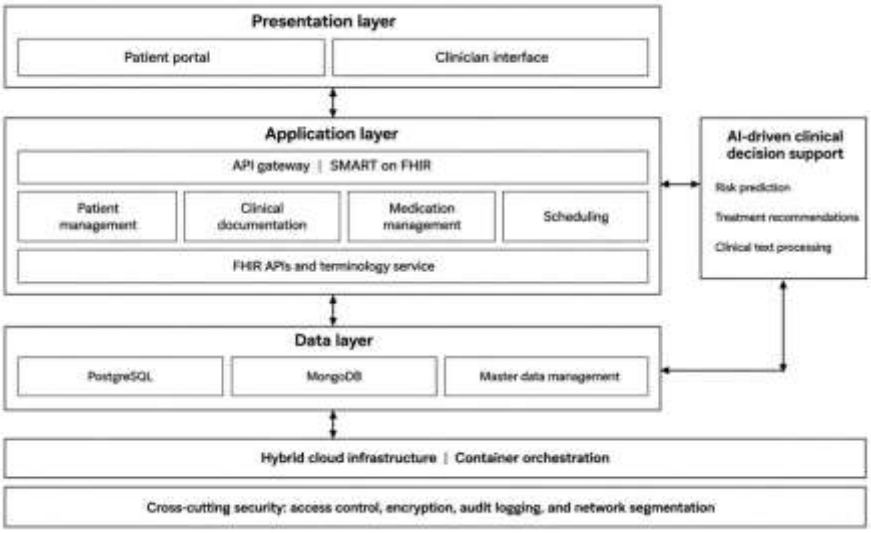


Figure 2. Proposed healthcare interoperability architecture showing the presentation, application, and data layers, AI-driven clinical decision support, and cross-cutting security controls.

The presentation layer provides customized interfaces for patient portals (Epic's MyChart equivalent) and health practitioners' workstations (Hyperspace-equivalent), which implement React.js component-based architecture to create responsive user-centric interfaces [22], [28]. The application logic layer hosts the FHIR- compliant microservices that execute discrete business logic for patient enrollment, scheduling of appointments, clinical documentation, and medication and billing management using Node.js with Express.js to support real-time healthcare workflows [27].

The solution relies on an FHIR-native microservices architecture, which functions as the core of the innovation, replacing the existing monolithic legacy systems. FHIR REST APIs are used for standardized communication between microservices that run separate healthcare domain logic functions, thereby ensuring semantic interoperability. The architecture consists of four main microservices: The Patient management service handles the management of patient demographic information, medical records and consent through FHIR Patient and Person and RelatedPerson resources.

Clinical documentation service handles the management of encounter notes and observations, and diagnostic reports through FHIR Composition and Observation, and DiagnosticReport resources. Medication management service handles prescription management and medication administration, and reconciliation through FHIR MedicationRequest and MedicationAdministration and MedicationStatement resources. Scheduling service manages appointment scheduling and resource allocation through FHIR Appointment, Schedule, and Slot resources. Terminology service ensures vocabulary management to ensure semantic consistency throughout the platform.

The data layer implementation comprises a hybrid database architecture combining PostgreSQL to handle Atomicity, Consistency, Isolation, and Durability (ACID) transactional workloads for structured data such as patient information, medical histories, billing records, etc., while storing FHIR-compliant unstructured data such as clinician notes, medical diagnostic images, and dynamically changing data schemas using MongoDB [11], [12]. Master Data Management (MDM) ensures the synchronization of patient, provider, and location entities is consistent across disparate systems and, as such, prevents duplication and enhances data integrity [15].

A hybrid cloud architecture is implemented to balance both regulatory compliance and scalability [10]. Therefore, the infrastructure consists of the following core components: Kubernetes technology supports automated deployment and management of containerized microservices while also enabling scalability and ensuring high availability, leveraging its faulty/failed components automatic detection and replacement capabilities to ensure system availability 24/7 to support continuous patient care. A unified API gateway is responsible for ensuring scalable and secure communication by managing all traffic between patient applications, internal services, and backend services, including implementing OAuth 2.0 authentication, rate limiting, and monitoring.

Service Mesh enables secure communication between services, traffic management, and monitoring microservices, thereby supporting complex healthcare workflows. Complementing this, cloud services integration utilizing AWS, Azure, or Google Cloud solutions that are tailored toward health care, such as compliance with the Health Insurance Portability and Accountability Act, cloud monitoring, and multi-tenancy architectures [9]. The solution utilizes AI-powered Clinical

Decision Support Systems (CDSS) to address the thesis statement's key objective of enhancing patient care and administrative workflows.

The Extract, Transform, and Load (ETL) pipelines in a real-time environment extract patient data from FHIR repositories, transforming it and loading it for machine learning in AI-ready formats. Trained models are used to make predictions on risks, early interventions, personalized treatment options, and diagnostic support utilizing neural networks, decision trees, and ensemble approaches [29]. In parallel, an NLP Module extracts and maps unstructured texts such as clinical notes, radiology results, and discharge summaries to FHIR terminology codes to accelerate semantics´ interoperability implementation.

Exposed Representational State Transfer Application Programming Interface (RESTful API) endpoints enable AI predictions to be integrated into medical workflows through EMR interfaces, while minimizing disruption and maximizing medical utility, along with the implementation of interpretable AI techniques to instill trust among healthcare practitioners via transparent decision-making processes and elimination of algorithm biases [30]. To address the security (IS) challenges that were identified, the proposed solution is the implementation of a defense-in-depth security architecture [34].

These entail the implementation of OAUTH2.0 SMART on FHIR, Role-based access control, least privilege principle, Role-based access control, end-to-end encryption of the data during transit (using TLS 1.3) and at rest using AES-256, comprehensive auditing capabilities that facilitate HIPAA compliance and compromise identification/detection, Zero Trust Network Architecture with Micro-segmentation, isolating critical medical/clinical applications, and Continuous security scanning that's integrated into CI/ CD pipelines so that patches are applied quickly.

The proposed solution adopts Development and Operations (DevOps) practices, which involve the use of the CI/CD pipeline, thereby supporting the accelerated delivery of software that meets the requirements of the system. Compliance of the system with the FHIR standard through functional and security requirements of the system is validated by automated testing frameworks before the software is deployed in production. Infrastructure-as-code (IaC) ensures the provisioning environment remains consistent across the key stages from development to production [21].

5. DISCUSSION AND LITERATURE-BASED EVALUATION

This proposed solution addresses the inherent issues of fragmentation of IT in healthcare through evidence-based architectural approaches. New feature implementation in monolithic EMRs requires up to 67% more time, and they are also prone to 3.4 times more integration challenges in comparison to modular designs, given that it takes an average of 14.3 months for monolithic designs as opposed to an average duration of 7.8 months for modular designs to implement updates required for regulatory compliance. FHIR-based microservice architecture enables up to 78% improvement in deployment frequency and up to 76% in the reduction of critical outages, thereby supporting the scalability of independent services and enabling faster regulatory compliance [20].

Since only 44% of EMR systems are currently interoperable according to Sergey [4], the proposed solution's FHIR-native approach has an unparalleled 97% interoperability success rate, with a 93% semantics mapping accuracy, as well as a latency of only 220 milliseconds when exchanging data in real time. The AI-powered CDSS focuses on addressing the deaths of 3 million patients annually globally due to communication failures induced by fragmented data, as highlighted by Jeremy et al. [5], through real-time diagnostics, recommendations for personalized treatments, and integration of multimodal data, thus improving patient outcomes [29], [31].

The proposed solution is targeted to address the waste in expenditure of 21%-31% on administrative inefficiencies by optimizing the workflow through automation and utilizing the patient portals with an average System Usability Scale score of 74.3 [5], [24], [22]. The hybrid database architecture based on the MDM ensures the reduction of issues of duplication of records and the discrepancies associated with patient identification of patients as such reducing operational cost and improving care coordination [14], [13].

The defense in depth security architecture reconciles the requirements of information sharing with HIPAA compliance as well as addressing information security vulnerabilities [33], [34], [36]. The feasibility of the implementation should be validated against the functionalities of Epic's MyChart system and the Kaiser Permanente mobile app, as well as by Cerner's HL7-compliant products [22], [25], [26]. The proposed solution presents an advanced perspective beyond current practice through the incorporation of FHIR native microservices and AI/CDSS integration, capitalizing on the increasing annual growth of the healthcare IT market, growing at 14.7% per annum.

6. CONCLUSION AND FUTURE DIRECTIONS

As healthcare providers/organizations continue to grapple with fragmented IT systems issues that also continue to create data silos, inhibiting unified patient record access, resulting in increased operational costs, poor patient outcomes, and clinical administrative inefficiencies [3], [4]. This paper demonstrates that EA principles provide a structured approach to addressing the challenges through FHIR-native microservices architecture integrated with AI-driven CDSS, deployed on a hybrid cloud infrastructure adopting comprehensive IS frameworks.

The solution highlights challenges using evidence-based patterns, for instance, 78% deployment improvements and 76% outage reductions from microservices adoption [20], 97% interoperability success rate using FHIR standards, while addressing 3 million deaths from fragmented data-induced communication failures using AI-CDSS [5] and eliminating 21%-31% administrative waste using automated workflows [5]. Beyond this, the database hybrid model eliminates duplication of records [14], [15], along with the defense-in-depth security architecture that reconciles HIPAA compliance with interoperability mandates [34], [36].

Real-world examples of practical implementations offered by Epic, Kaiser Permanente, and Cerner validate the feasibility of the technology [22], [25], [26], while also considering the growing valuation of the healthcare IT market, which stands at USD 420.2 billion with an unprecedented growth rate of 14.7% annually. This establishes the market demand and availability of investment capital. Healthcare providers/organizations that implement an integrated platform that offers interoperability will experience real-time data sharing that's seamless, enhanced patient care safety, improved healthcare administrative efficiency, including paving the way for future innovations that are value-driven.

7. REFERENCES

[1] Maleki, Varnosfaderani S., and Mohamad Forouzanfar. 2024. The Role of AI in Hospitals and Clinics: Transforming Healthcare in the 21st Century. Bioengineering (Basel) (MDPI) 1. doi:10.3390/bioengineering11040337.

[2] Angelos I., Stoumpos, Kitsios Fotis, and Talias d Michael A. 2023. Digital Transformation in Healthcare: Technology Acceptance. International Journal of Environmental Research and Public Health (MDPI) 20 (3407): 1-2. doi:10.3390/ijerph20043407.

[3] Lal, Rohinee. 2024. Top Five IT Challenges Facing Healthcare Technology Leaders. Signify Research. September 19. https://www.signifyresearch.net/insights/top-five-it-challenges-facing-healthcare-technology-leaders/.

[4] Sergey, Ivanov. 2025. EHR interoperability: an end-to-end guide & best practices. Itransition. April 17. https://www.itransition.com/healthcare/ehr/interoperability.

[5] Jeremy, Howick, Bennett-Weston Amber, Solomon Josie, Nockels Keith, Bostock Jennifer, and Keshtkar Leila. 2024. How does communication affect patient safety? Protocol for a systematic review and logic model. BMJ Open 1-2. doi:10.1136/bmjopen-2024-085312.

[6] Arjen, Maris, Hoppenbrouwers Stijn, Ravesteijn Pascal, and Hillegersberg Jos van. 2021. Enterprise Architecture in Healthcare Networks: A Systematic Literature Review. Communications of the IIMA. International Information Management Association (IIMA). 74-75. https://scholarworks.lib.csusb.edu/cgi/viewcontent.cgi?article=1446&context=ciima.

[7] Eithar Mohamed, Mahmoud Nasef, and Abu Bakar Nur Azaliah. 2020. Enterprise Architecture "As-Is" Analysis for Competitive Advantage. International Journal of Advanced Computer Science and Applications 11: 102-103. http://eprints.utm.my/93840/1/NurAzaliah2020_EnterpriseArchitectureAsIsAnalysisforCompetitiveAdvantage.pdf.

[8] Adetunji, Ademola, George Carlisle, and Mapp Glenford. 2024. Addressing the Interoperability of Electronic Health Records: The Technical and Semantic Interoperability, Preserving Privacy and Security Framework. Edited by Douligeris Christos. Applied System Innovation (MDPI) 2. doi:10.3390/asi7060116.

[9] Accenture. 2020. Cloud Marketplaces Accelerate Digital Transformation in Healthcare. White Paper, Accenture | AWS. https://pages.awscloud.com/rs/112-TZM-766/images/ACN_AWS_Healthcare%20POV_FINAL.pdf.

[10] Abughazalah, Mona, Alsaggaf Wafaa, Saifuddin Shireen, and Sarhan Shahenda. 2024. Centralized vs. Decentralized Cloud Computing in Healthcare. Applied Sciences (MDPI) 14: 1-27. doi:10.3390/app14177765.

[11] Palojoki, Sari, Lasse Lehtonen, and Riikka Vuokko. 2024. Semantic Interoperability of Electronic Health Records: Systematic Review of Alternative Approaches for Enhancing Patient Information Availability. JMIR Medical Informatics 12. doi:10.2196/53535.

[12] Campbell, Robert J. 2004. Database Design: What HIM Professionals Need to Know. Perspectives in Health Information Management (PubMed Central). https://pmc.ncbi.nlm.nih.gov/articles/PMC2047327/pdf/phim0001-0006.pdf.

[13] Nwosu, Nelly Tochi. 2024. Reducing operational costs in healthcare through advanced BI tools and data integration. World Journal of Advanced Research and Reviews 1144-1156. doi:10.30574/wjarr.2024.22.3.1774.

[14] Hashimoto, RE, ED Brodt, AC Skelly, and JR Dettori. 2014. Administrative Database Studies: Goldmine or Goose Chase?. Science in Spine (Spectrum Research Inc.) 5: 74-76. doi:10.1055/s-0034-1390027.

[15] Loshin, David. 2011. Master Data Management and Data Quality. In Master Data Management, 327-350. doi:10.1016/B978-0-12-373717-5.00019-1.

[16] Bathelt, F., Lorenz, S., Weidner, J. et al. 2024. Application of Modular Architectures in the Medical Domain - a Scoping Review. Journal of Medical Systems (Springer) 49 (27). doi:10.1007/s10916-025-02158-3.

[17] Tummers, J., H. Tobi, C. Catal, and B. Tekinerdogan. 2021. Designing a reference architecture for health information systems. BMC Medical Informatics and Decision Making 21: 2-14. doi:10.1186/s12911-021-01570-2.

[18] Arjan, H.J. Huizing, Iris, Eekhout, Buuren Stef van, Blanson Olivier, and Henkemans. 2025. Data-Driven Healthcare Innovations in a Fragmented Healthcare System: A Modular Approach. Intelligent Health Systems – From Technology to Data and Knowledge 328-332. doi:10.3233/SHTI250338.

[19] Plaza, Andrea M., Díaz, Jessica, and Jennifer Pérez. 2018. Software architectures for health care cyber-physical systems: A systematic literature review. Journal of Software Evolution and Process 30 (7). doi:10.1002/smr.1930.

[20] Katkuri, Rameshreddy. 2025. Revolutionizing healthcare with secure and scalable microservices. World Journal of Advanced Research and Reviews 26 (01): 1731-1739. doi:10.30574/wjarr.2025.26.1.1235.

[21] Miloš, Milić, and Dragana Makajić-Nikolić. 2022. Development of a Quality-Based Model for Software Architecture Optimization: A Case Study of Monolith and Microservice Architectures. Symmetry (MDPI) 14 (9): 1824. doi:10.3390/sym14091824.

[22] Chishtie, J., N. Sapiro, N. Wiebe, L. Rabatach, D. Lorenzetti, AA. Leung, D. Rabi, H Quan, and CA. Eastwood. 2023. Use of Epic Electronic Health Record System for Health Care Research: Scoping Review. Journal of Medical Internet Research 25. doi:10.2196/51003.

[23] Chu, Stephen, and Branko Cesnik. 2000. A three-tier clinical information systems design model. International Journal of Medical Informatics (ScienceDirect) 91-107. doi:10.1016/S1386-5056(00)00057-5.

[24] AHRQ. 2017. Portals in inpatient care (PIC): Evaluating the usability, use and patient experience. Agency for Healthcare Research and Quality (AHRQ). https://digital.ahrq.gov/sites/default/files/docs/citation/r21hs024349-mcalearney-final-report-2017.pdf.

[25] Chen, Catherine, Garrido Terhilda, Chock Don, Okawa Grant, and Liang Louise. 2009. The Kaiser Permanente Electronic Health Record: Transforming And Streamlining Modalities Of Care. Health Affairs 28 (2). doi:10.1377/hlthaff.28.2.323.

[26] Rybakov, Andrii. 2025. Mastering Cerner Integration: How to Connect Healthcare Systems & Enhance Patient Care. Spsoft. June 10. https://spsoft.com/tech-insights/guide-to-mastering-cerner-integration/.

[27] Padam, Sinha, Chaubey Shipra, Pratap Singh Varenya, Maurya Sonal, Chaurasia Priyanshu, and Verma Kapil. 2024. Revolutionizing Healthcare: A MERN Stack Approach to Comprehensive Web Application Development. International Journal of Intelligent Communication and Computer Science 1 (2): 69-80. https://ijiccs.in/p5v2.pdf.

[28] Farrel, Farhan, Cahyo Wibowo Nur, and Hadiwiyanti Rizka. 2025. Information System Development for Dental Clinic Using ReactJS and Prisma ORM. Binary Digital Technology 8 (1). doi:10.32877/bt.v8i1.2616.

[29] Mohammed, A. S., A. R., Neravetla, V. K. Nomula, Gupta K., and Dhanasekaran S. 2024. Understanding the Impact of AI-driven Clinical Decision Support Systems. 15th International Conference on Computing Communication and Networking Technologies (ICCCNT). Kamand, India: IEEE. 1-6. doi:10.1109/ICCCNT61001.2024.10726136.

[30] Giebel, G.D., P. Raszke, H. Nowak, L. Palmowski, M. Adamzik, P. Heinz, M. Tokic, et al. 2025. JMIR Medical Informatics 13. doi:10.2196/69688.

[31] Hao, Y., C. Cheng, J. Li, H. Li, X. Di, X. Zeng, S. Jin, et al. 2025. Multimodal Integration in Health Care: Development With Applications in Disease Management. Journal of Internet Research 27 (e76557). doi:10.2196/76557.

[32] Atkins, Stacey. 2025. Part 2: Interoperability and System Fragmentation in Healthcare. American Institute of Healthcare Compliance. Oct 28. https://aihc-assn.org/part-2-interoperability-and-system-fragmentation-in-healthcare/.

[33] Gates, Lancer. 2024. Cyber Attacks on Interoperable Electronic Health Records: A Clear and Present Danger. Missouri Medicine 121 (1): 6-9. https://pmc.ncbi.nlm.nih.gov/articles/PMC10887471/pdf/ms121_p0006.pdf.

[34] H-ISAC. 2021. Identity, Interoperability, Patient Access, and the 21st Century CURES act: A Health-ISAC Guide for CISOs. White Paper, Health-ISAC. https://health-isac.org/wp-content/uploads/H-ISAC_CuresAct-Interoperability-White-Paper.pdf.

[35] Aldosari, Bakheet. 2025. Cybersecurity in Healthcare: New Threat to Patient Safety. Cureus 17 (5). doi:10.7759/cureus.83614.

[36] CMS.gov. 2025. White House, Tech Leaders Commit to Create Patient-Centric Healthcare Ecosystem. Centers for Medicare & Medicaid Services. Jul 30. https://www.cms.gov/newsroom/press-releases/white-house-tech-leaders-commit-create-patient-centric-healthcare-ecosystem.