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Research Article

Enhancing Health Information systems Integration and Interoperability through Smart Healthcare Data Hubs

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ABSTRACT

When there is a scenario in which an organization operation is interacting with different cloud providers for organizational needs, it must have to address challenges like interoperability issues, and lack of resilience. The proposed architecture design for ensuring interoperability at Smart Healthcare Data Hubs (SHDH) addresses critical challenges such as integrating diverse data sources, maintaining data quality, and ensuring system resilience. By adopting a service-oriented architecture (SOA) approach, the design utilizes industry-standard protocols and data formats to facilitate seamless communication and data exchange among various healthcare systems. To further enhance interoperability, the architecture incorporates a semantic layer based on ontologies and controlled vocabularies, enabling effective integration of data from systems that utilize different data models. This system is a reliable and interoperable platform that will empower healthcare organizations to share data efficiently, ultimately improving patient outcomes and enhancing healthcare delivery. The evaluation denotes the architecture's effectiveness including accuracy and performance, which will be compared against existing approaches in the aspect of interoperability.

Keywords: Interoperability, Communication, Health Data Exchange, Data Formats, Service Oriented Architecture, and Accuracy.

INTRODUCTION

There are number of challenges to be faced when sharing of health data over different vendors platform. The sharing over such different platforms leads to loss of data, corruption of data, that may not be understood by the doctor or health expert. Hence, challenges are mentioned, later solutions available to overcome the interoperable issues, benefits also demonstrated when sophisticated interoperable platforms are provided.

Table 1. Challenges of having interoperable over diverse platform

Challenge	Description
Technical Complexity	Integrating diverse health information systems is technically challenging. Many organizations use customized EHR systems that lack standardization, leading to compatibility issues and fragmented patient data.
Data Harmonization	Healthcare data originates from various sources with different structures and terminologies. Harmonizing this data to ensure consistency and accurate interpretation across systems is complex and prone to errors.
Privacy and Security	The sensitive nature of health data requires stringent security measures to prevent unauthorized access and breaches. Compliance with regulations like HIPAA adds complexity to data-sharing practices.
Governance and Collaboration	Effective governance involves establishing clear policies for data sharing and ownership. Collaboration among stakeholders is essential but can be complicated by differing priorities and interests.
Communication Gaps	Variations in technological adoption and organizational culture can create communication gaps, impeding information flow and delaying patient care. A unified approach to data sharing is often lacking.
Technological Fragmentation	Many healthcare organizations use technologies that do not integrate well, resulting in siloed data. This fragmentation makes it difficult to access a comprehensive view of a patient's health.

The above issues of Table 1 are to be overcome by sticking to standards that improves data sharing as well as to provide care and safety to the patient's information.

Table 2. Solutions for overcoming interoperable issue

Mechanism	**Description**	**Drawbacks**
1.Health Level Seven (HL7)	A standard for exchanging clinical and administrative data, providing messaging protocols.	Complexity: Difficult to implement; requires technical expertise. Versioning Issues: Compatibility problems due to different HL7 versions.
2. Fast Healthcare Interoperability Resources (FHIR)	A modern standard that simplifies data exchange using web technologies and RESTful APIs.	Adoption Variability: Inconsistent adoption across healthcare organizations. Security Concerns: Potential vulnerabilities from web technologies.
3. Digital Imaging and Communications in Medicine (DICOM)	A standard for sharing medical imaging data across devices and systems.	Limited Scope: Focuses only on imaging data; lacks integration for clinical notes. Integration Challenges: Difficult to connect with non-imaging systems.
4.Direct Messaging	A secure email-like protocol for sending patient information directly between providers.	Interoperability Limitations: Does not support real-time data exchange or complex data types. User Adoption: Effectiveness is dependent on widespread use
5.Common Clinical Data Set (CCDS)	A standardized set of data elements for sharing patient information. .	Data Completeness: May not encompass all relevant patient data. Implementation Variability: Different interpretations lead to inconsistencies
6. Application Programming Interfaces (APIs)	Allows software applications to communicate, integrating various health data systems.	Development Costs: Building and maintaining APIs can be expensive. Interoperability Gaps: Not all APIs are designed for easy interoperability

The possible standards in Table2 are recommended to use to overcome interoperability over diverse vendors involvement during health records data sharing.

The benefits are demonstrated in Table 3, when stable interoperable standard is ensured over diverse vendors.

Table 3. Benefits of using inter-operable standard over diverse source vendors

Added value Feature	**Description**
Enhanced Patient Care	Ensures access to comprehensive patient data, enabling informed clinical decisions and improved patient outcomes.
Reduced Medical Errors	Minimizes the risk of errors due to incomplete or inaccurate information, preventing medication errors, duplicate testing, and other potential harm.
Efficient Healthcare Workflow	Streamlines administrative processes, reducing manual effort and allowing healthcare professionals to focus on patient care.
Coordinated Care	Facilitates care coordination among multiple providers and specialists, ensuring seamless communication and preventing fragmentation of services.
Patient Engagement	Empowers patients by providing access to their health data, fostering active participation in care decisions and enhancing patient-provider communication.

To handle inoperable issues, and atomate management activities, a framework is required which is a smart health data hub, that functions as a cohesive system that combines both software and hardware elements to enhance data sharing and management in the healthcare ecosystem.

Table 4. Features of smart health data hub

Features (SHDHs)	**Description**
Interoperability	Enables seamless integration and communication between various health information systems, allowing effective data sharing across different vendors.
Data Governance	Implements robust frameworks to ensure compliance with legal and ethical standards, including data access control, consent management, and auditing mechanisms.
Real-time Data Access	Provides immediate access to health data, crucial for timely decision-making in clinical environments, supporting dynamic data sharing among stakeholders.
Scalability	Designed to manage large volumes of data from multiple sources, accommodating the increasing amount of health data generated.
Data Analytics and Insights	Includes advanced analytics capabilities that allow users to extract insights from data, informing clinical practices and health policies.

From Table 4, data to be shared effectively among diverse health information systems that ensures interoperability, effective governance, timely-decision making, manage large data volumes, and extract useful insights for further processing.

Table 5. Significant benefits of using Smart health data hubs

Benefits	**Description**
Enhanced Patient Care	Offers healthcare providers a comprehensive view of a patient's medical history, enabling informed and personalized treatment decisions, thus improving patient outcomes.
Accelerated Research and Innovation	Facilitates research initiatives by aggregating diverse health data, allowing researchers to identify trends and develop new treatments more efficiently.
Cost Efficiency	Reduces redundancy in testing and procedures, leading to lower healthcare costs and streamlining administrative processes for better resource allocation.
Improved Collaboration	Fosters collaboration among healthcare providers, researchers, and public health organizations, enhancing the overall healthcare ecosystem.
Support for Learning Health Systems	Contributes to the development of learning health systems, where continuous data use improves care practices and health outcomes based on real-world evidence.

The advantages out of suing smart health data hubs from Table 5, such as provide more care based on available history of medical data, recommend for new treatments, lower healthcare costs, effective collaboration among different entities, and continuous learning would improve patient health.

LITERATURE REVIEW

In the health systems, a standard to be followed that would prevent loss of data as well as maintain the data in structured manner, that helps to do easy decision making. The studies on health systems that interoperable issues are demonstrated for refinement of our work. From Alvarez-Romero, C. et al (2023) [1], the best practices such as central management, tools for error finding, techniques for quality control, Agreements, Suitable data format, a consistent User interface for different sources, and efficient governance model are listed, and demonstrated for efficient functioning. From Jotterand, F. et al (2022) [2], three adopted mechanisms is designed for the role of AI in medicine preparation and clinical setting. Many combination virtues for which required medicine is useful, and the experimental approach helps to invent specific patient goal. From Eimo Martens, Hans-Ulrich Haase et al (2024), the data of various sources which are to be brought into structured format for CVD, and the original data when integrated leads many interoperable issues. This challenge is taken and addressed in this study. Mahnuma Rahman Rinty et al (2022), demonstrate interoperability problems of health systems of developing countries, need to make that in HL7 standard but still face fewer vulnerabilities that are not countable, and this mechanism is less cost expensive than other models. The distributed health system would be easily portable from one server to another without interoperable issues. From Sreenivasan M. et al (2021), need to address interoperable issues using syntactic as well as semantic in which semantic EHRs would be effective in the interpretation of data coming from different sources, and would fit data appropriately in the required format. This effort helps in easy

decision-making. In this, challenges are also addressed that might be mitigated through best practices. From Edmond Li et al (2022), practical tasks demonstrated as well as studies on interoperability, and its issues in high-income countries. The studies from 2010 to 2022 were analyzed on those impacted patient safety, and their care. From David J. Ranney (2024), demonstrates the challenges, and future pathways of interoperability in health records. The EHRs would be accessible anywhere, anytime but safety to be addressed and ensured. Mostly, unauthorized access is avoided so that new data added should be interpreted by the authorized entity for easy understanding, and provide health recommendations. From Yin Yang et al (2021), demonstrate 3 advancements in the usage of modern technology in which AI, and data science would be integrated with metaverse which would benefit cost savings in addition to improving patient care as well as minimizing administrative tasks. From Syed Raoof et al (2022), demonstrate the challenges in assisting smart health in terms of gaps associated with automation, and report generation. The combination of cloud, deep learning, and IoT plays a key role in making automation. This combination is to be used in many applications supply chains, inventory, etc. From this, health care is taken as research due to different organs to be analyzed and interpreted for better decision-making. From Anastasia Levina et al (2024), demonstrate on the flow of data that would fit in a meaningful manner from devices, equipment software systems, and applications, then to the experts for review, and then to the doctors for a prescription. Sometimes, may also recommend personalized medicine as per the patient's demand. It is moving towards smart hospital where all analysis, drug suggestion and invention are in the process. From Nourse R et al (2022), demonstrate of people having chronic diseases, and assigning health professionals for follow-up. the patient care is the top priority using AI and helps to easy decision making as well as analysis. This addresses management of disease from beginning to the recovery stage.

From Mahmoud Nasr, Md. Milon Islam et al (2021) [12], discussed on use of AI in the health systems that would monitor the health using sensors, disease detection using ML methods, and usage of robots for social assistance. The pitfalls of existing methods, and propose hybrid approach for efficient handling of health data with safety. Soon Hyeong Jeong, Jun-Hong Shen et al (2021) [13], demonstrated usage of blockchain technology and IoT for ensuring security over data transmission as well as for monitoring health status using sensors. The base taken on which health report generated are bio-signals and ECG report. From Gupta, A., Singh, A. (2023), demonstrates several technological advancements as one integrity platform to analyze the health data, and noted a set of challenges, complexities on which research professional can work, and come up with possible findings in th field of smart healthcare. Fei Yan, Nianqiao Li et al (2023), demonstrates advanced security, and privacy principles on the health data extracted from medical images, and preserve these images from possible threats. The analysis is carried out on enhancing the SHSs. From Rahman, A., Hossain, M.S. et al (2023), the combination of FL and AI would be used for decentralized management, which provides features such as reliability, security, and privacy whereas traditional systems would follow centralized management that raise risks and results many challenges to overcome. From Amir Torab-Miandoab et al (2023) [17], demonstrated the challenges, issues with interoperability among different health systems in the countries where lack of technology is there. Hence, effort to convert paper-based reports to EHRs, and sharing those among diverse systems over channel, requires standard format that would be understandable by the doctor and expert. From J. Tummers, B. Tekinerdogan et al (2021), the specific obstacles around 69 were demonstrated, and specific standards to maintain between different health systems are addressed. The categorization on stakeholders as well as classification of features is demonstrated with challenges. From Antony G. Musabi et al (2024), discussed on kenya's health system in terms of challenges, and the best practices. This study recommended few practices to overcome challenges mentioned and listed reasons on how to improve health records sharing securely and with standard. From Dr. Naheed Ali (2022), the challenges are addressed, and also solutions given. The improvement would be achieved over cloud usage, APIs usage, and Blockchain usage. From Epizitone A, Moyane SP et al (2022) [21], ensuring the standard of health practitioners as well as experts who would assess and recommend prescription to the patients. The efforts are towards making consistent during global platform. From Donel Richemond et al (2023) [22], demonstrates the challenges like human errors, machine errors, lack of systematic management, and etc, and vulnerabilities such as implementation cost and compromise of sensitive information stealing. From [23], the issues of local and global load traffic issues are demonstrated and are optimized with best practices. Regarding [24], to handle traffic issues over a cloud, a hybrid framework is demonstrated for distributing the load. These two studies might help current study in which load issue supposed raises, would able to minimize the unavailable service risk.

PROPOSED METHODOLOGIES

The effective approach is derived from functionalities such as SOA principles, standard protocols, data formats, established connectors, data exchange efficiency monitoring tools, and assess accuracy of the model. PS1 is defined in terms of these significant activities embedded to achieve the robustness of the system.

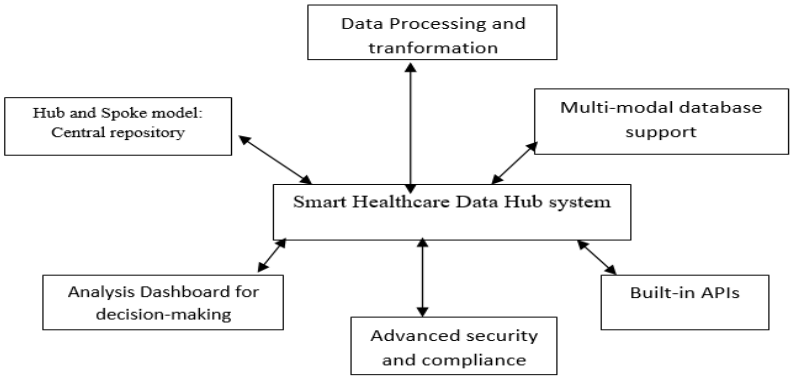

Fig.1. Central Repository of the proposed system: SHDH

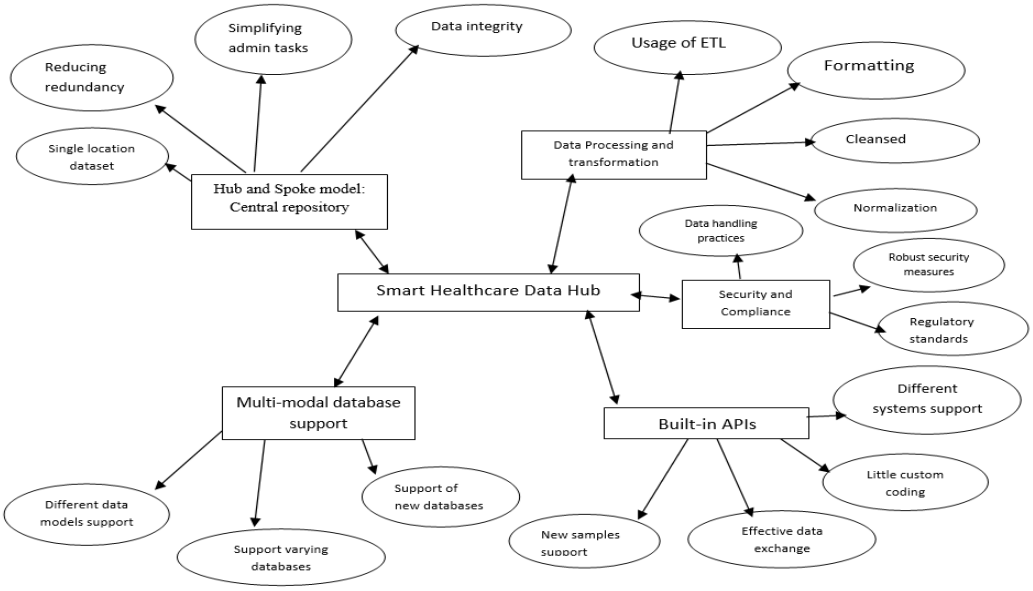

Fig.2: ER Diagram for effective interoperability of SHDH system

Fig.1 demonstrates the central module with its significant modules such as Hub and Spoke model, Data preprocessing, multi-database support, APIs usage for specific functionality, Best Security practice, and Decision-making based on time-series.

Fig.2 demonstrates the ER model of the proposed model SHDH on which significant entities and their activities are mapped for effective monitoring and goal.

Fig.3 demonstrates the flow of activities involved for effective delivery of the health system without inconsistencies and abnormalities.

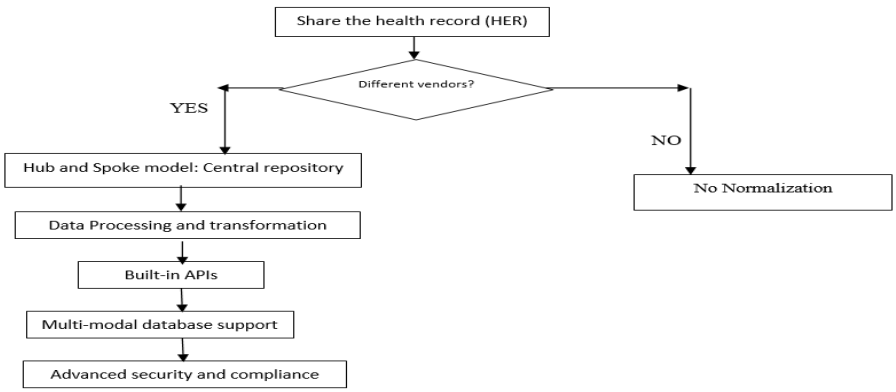

Fig.3. Flow of activities of SHDH system

PS1 pseudo procedure is considered a comprehensive approach to developing a reliable interoperable Smart Healthcare Data Hubs platform. By leveraging Service-Oriented Architecture, current industry standards, and goal-oriented semantic layers, the architecture aims to enhance data exchange among various healthcare systems, ultimately leading to improved healthcare delivery and patient outcomes. The using Smart Healthcare Data Hub consists of SOA principles, HL7 and FIHR protocols support, JSON and XML support data formats, Connectors, Failover mechanisms support, and Data exchange monitoring tools.

Table 6. Purpose of services used in SHDH system

Service	**Purpose**
SOA Principles	Facilitates a modular and flexible architecture that allows for the integration of diverse services and systems, promoting scalability and reusability.
HL7 and FHIR Protocols Support	Provides standardized frameworks for exchanging electronic health data, ensuring interoperability and consistency across different healthcare applications.
JSON and XML Support Data Formats	Enables the use of widely accepted data formats for data representation and exchange, ensuring compatibility and ease of integration among various systems.
Connectors	Acts as interfaces that link different data sources and systems, allowing for seamless data retrieval and submission across diverse healthcare platforms.
Failover Mechanisms Support	Ensures system resilience by providing backup systems and processes that maintain operations during failures or disruptions, thus enhancing reliability.
Data Exchange Monitoring Tools	Monitors the performance and efficiency of data exchanges, allowing for real-time tracking of data flow and identification of issues to ensure data integrity and quality.

PS1: Pseudo Procedure Effective_Integration_Interoperability_SHDHs (dataset[][]):

Input: Patient database

Output: Interoperability

Step1: Identify diverse cloud platforms where data to be shared

Step2: Take third-party standards to communicate between those diverse cloud platforms or define customized format

Step3: Make use of SOA principles for efficient data exchange

3.1 Adopt Modularity and reusable services for making flexible environment

Step4: For compatibility, use a combination of HL7 and FHIR protocols, formats such as JSON and XML

4.1 HL7 is preferred for legacy systems, and FHIR for modern and cloud-based systems

4.1.1 Enabled backward compatibility

4.1.2 Enabled Future proofing for new technologies

4.1.3 Holistic Interoperability

Step5: Make use of repositories that support ontologies and controlled vocabularies

5.1 Ensures semantic interoperability means data from different systems are interpreted correctly

5.2 Ontologies define the relationship between the concepts, resulting in a structure for understanding data.

5.3 Controlled Vocabulary brings standardization on similar concepts as the same terms.

Step6: Make use of connectors that extract and keep in the required format

6.1 Data is extracted, transformed, and formatted correctly, enabling seamless communication.

6.2 Act as intermediaries that bridge the heterogeneous systems by extracting data from one system and transforming it into a format that is compatible with another.

Step 7: Automation is initiated for timely decision-making on the exchange of data.

Step 8: Make use of redundant and fail-over mechanisms to handle service disruptions.

8.1 Use load balancers to ensure availability.

8.2 Use backup systems for ensuring failure scenarios.

Step 9: Use effective monitoring tools to assess data exchange efficiency

9.1 New Relic or Dynatrace are tools to monitor the performance of applications and services.

9.2 SolarWinds or Nagios track network performance and issues, ensuring data exchange.

Step10: Compute

Accuracy=True Positives+True Negatives/ Total Number of Cases

Where True Positives (TP): The number of correctly identified relevant data points, True Negatives (TN): The number of correctly identified irrelevant data points, Total Number of Cases: The sum of true positives, true negatives, false positives, and false negatives.

The dataset used is taken from the source of Kaggle specifically https://www.kaggle.com/datasets/prasad22/healthcare-dataset, as well as also relatively fit on government health dataset specifically https://healthdata.gov/stories/s/d84g-3yzd.

RESULTS

In this, Table 7 demonstrates on specific measures intensity over considered models such as Health Information Exchange, Electronic Health Records, External APIs, Centralized Data warehousing, Cloud-based strategy, Messaging and Communication Tools, and SHDH. From which, SHDH is the only method ensuring better-oriented measures. The evaluated measures are demonstrated in Table8 for these considered models. From this, SHDH is the only method having best outcomes. Table 9 demonstrates error rates of considered methods, from which SHDH is the only method that guaranty the effectiveness. The demonstration of Fig.4 and Fig.5 represent SHDH has efficiency in terms of parameters such as accuracy, performance, robustness in terms of less error rate, and security.

Table 7. Demonstration of considered methods against specific measures

Method	Accuracy	Performance	Robustness	Security
Health Information Exchange (HIEs)	High	Moderate	High	High
Electronic Health Records (EHR)	High	High	High	High
External Application Programming Interfaces (APIs)	Moderate	High	Moderate	Moderate
Centralized Data Warehousing and Analytics	High	Moderate	High	High
Cloud-Based Solutions	Moderate	High	Moderate	Moderate
Secure Messaging and Communication Tools	High	Moderate	Moderate	Very High
Smart Healthcare Data Hub (SHDH)	High	High	High	High

From Table 7, SHDH is having best value measure in terms of % due to its significant functionalities compared to other models.

Table 8. Evaluated measures against considered models

Method	**Accuracy**	**Performance**	**Robustness**	**Security**
Health Information Exchange (HIEs)	85	70	80	75
Electronic Health Records (EHR)	90	85	75	70
External Application Programming Interfaces (APIs)	75	90	70	80
Centralized Data Warehousing and Analytics	88	80	85	85
Cloud-Based Solutions	70	85	75	80
Secure Messaging and Communication Tools	90	75	80	95

Smart Healthcare Data Hub (SHDH)	95	92	95	98

From Table 8, among considered models, SHDH has the best values in terms of %, which makes its processing more effective.

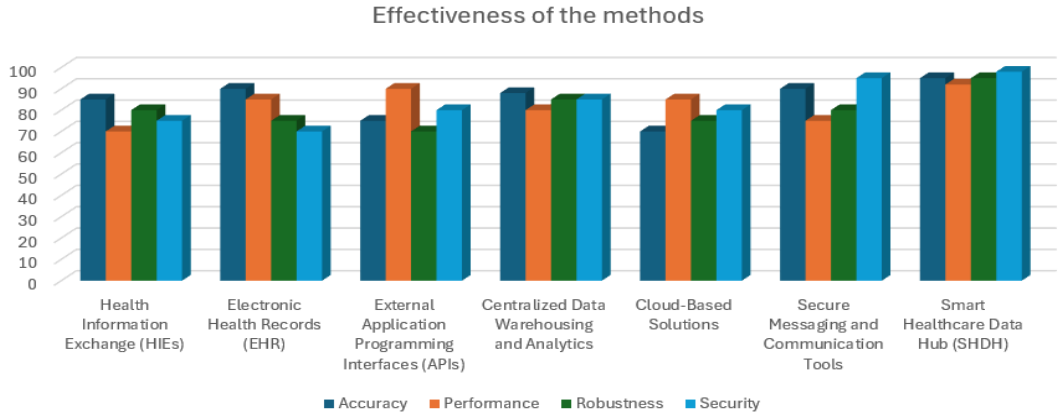

Fig.4. Effectiveness of methods based on specific metrics

Table 9. Error rates of considered methods

Method	**Error rate(%)**
Health Information Exchange (HIEs)	10
Electronic Health Records (EHR)	8
External Application Programming Interfaces (APIs)	12
Centralized Data Warehousing and Analytics	5
Cloud-Based Solutions	15
Secure Messaging and Communication Tools	7
Smart Healthcare Data Hub (SHDH)	4

From Table 9, SHDH has a lower error rate than other models and ensures more reliability and comfort than other models.

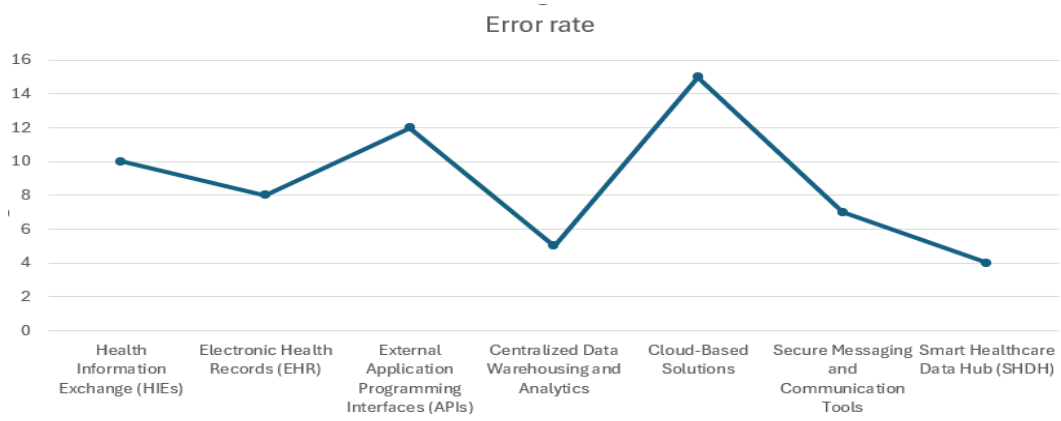

Fig.5. Error rate of considered approaches

From Fig.5, the effectiveness is found and identifies SHDH as having less error rate than other models. Hence, it is the best model among the considered models.

CONCLUSION

In the realm of healthcare data sharing, an effective method to be selected hinges on a careful evaluation of key attributes such as robustness, accuracy, performance, and security. Each method, whether it be Health Information Exchanges (HIEs), Electronic Health Records (EHRs), APIs, centralized data warehousing, cloud-based solutions, secure messaging

tools, or Smart Healthcare Data Hubs (SHDH), presents unique advantages and challenges. HIEs and EHRs stand out for their high accuracy and security, ensuring reliable data exchange while protecting sensitive patient information. APIs and cloud solutions offer flexibility and high performance but may face challenges related to data integrity and security. Meanwhile, centralized data warehousing provides a robust framework for analytics, albeit with potential delays in data access. Secure messaging tools excel in maintaining confidentiality, while SHDHs leverage advanced technology to integrate and analyze data comprehensively. Ultimately, the choice of method should align with the specific needs of healthcare organizations, considering their priorities in data management, regulatory compliance, and the overarching goal of enhancing patient care through effective information sharing.

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