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Assessing the role of electronic health records standards in advancing semantic interoperability in distributed health systems in Kenya

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Abstract

Achieving semantic interoperability in distributed healthcare systems is a global challenge, especially in low-resource settings such as Kenya. Inconsistent implementation of electronic health record (EHR) standards hinders semantic interoperability by limiting the ability of distributed healthcare systems to exchange and interpret data with shared, unambiguous meaning. This study evaluates the influence of EHR standards on semantic interoperability in distributed health systems in Kenya. A mixed-method approach using descriptive and correlational research design was adopted, targeting four Level 5 public hospitals with 301 sampled respondents including system developers, health practitioners, and administrators. Statistical analyses confirmed a very weak but statistically significant correlation between EHR standards and semantic interoperability (Spearman's $\rho = 0.007$, $p = 0.04$, $N = 268$). Additionally, the Kruskal-Walli's test revealed significant differences in semantic interoperability across low, medium, and high EHR adoption groups (H-Statistic = 6.52, $p = 0.038$), with high adopters demonstrating the highest mean rank (148.92). However, mediation analysis indicated that system usability does not significantly mediate the relationship between EHR standards and semantic interoperability (Indirect effect = -0.0004, 95% CI [-0.0125, 0.0097]). Findings highlight that EHR standards alone have limited impact, and greater interoperability gains depend on integrated approaches combining standards with usability, governance, and technical alignment.

Keywords: Semantic Interoperability; Electronic Health Record Standards; Distributed Healthcare Systems; HL7 FHIR; System Usability

1. Introduction

The digitization of healthcare systems has significantly transformed how patient information is managed and shared across clinical environments. One of the major enablers of this transformation is semantic interoperability, defined as the ability of systems to exchange data with unambiguous, shared meaning [1]. This capability ensures that healthcare providers interpret patient data consistently across different platforms and geographic locations, enabling safer and more coordinated care [2]. Globally, semantic interoperability is supported by the implementation of Electronic Health Record (EHR) standards, including HL7, OpenEHR, and CDA [3]. However, developing countries such as Kenya face persistent challenges in the adoption and implementation of these standards, especially in distributed health systems where multiple, isolated platforms are used [4].

Electronic Health Records (EHRs) are foundational to achieving semantic interoperability. Standards such as HL7 FHIR provide structured data models and communication protocols that allow disparate systems to share health information in real time [5]. In high-income countries, FHIR has demonstrated efficiency in streamlining patient referrals, laboratory exchanges, and clinical documentation [6]. Nonetheless, Kenya's EHR implementations remain largely fragmented, with

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systems such as KenyaEMR and IQCare using customized data structures that deviate from global standards [7]. This inconsistency inhibits data harmonization, reduces system interoperability, and impacts healthcare quality outcomes.

In the Kenyan context, previous studies have identified a lack of enforced policies, limited technical expertise, and minimal institutional incentives as barriers to EHR standardization [8]. This has led to a scenario where different healthcare facilities adopt varying EHR systems with little regard for semantic alignment. Moreover, without national coordination or monitoring mechanisms, the interoperability gaps widen, leading to data silos and repeated patient history entries during referrals or transfers [9]. These issues are exacerbated in distributed healthcare systems where facilities operate in isolation, thereby undermining the potential of digital health innovations to improve continuity of care.

This study specifically investigates the role of EHR standards in advancing semantic interoperability within Kenya's distributed healthcare systems. It focuses on assessing how the adoption of standards such as HL7 FHIR correlates with improvements in data interpretation and system integration. Unlike broader interoperability frameworks that include security and mapping, this paper narrows its scope to the EHR standard variable, enabling a deeper empirical evaluation of its isolated effect. The findings will contribute to the growing discourse on digital health implementation in low-resource settings and inform future policy and technical interventions aimed at harmonizing healthcare information systems.

2. Literature review

2.1. Electronic Health Record Standards

Electronic Health Record (EHR) standards provide the structural and syntactic foundation for health data exchange across heterogeneous systems. Empirical evidence underscores their importance in facilitating semantic interoperability by ensuring uniform data representation and exchange protocols. For instance, Bender and Sartipi [10] demonstrated that HL7 FHIR's modular and RESTful design significantly improves system integration and real-time data sharing in healthcare. Similarly, studies in high-income countries report that facilities using FHIR experience fewer semantic inconsistencies in referrals, diagnostics, and discharge summaries [11].

In Kenya, however, the landscape is less promising. Were et al. [12] observed that although systems such as KenyaEMR and IQCare are widespread, they often rely on proprietary standards or customized data schemas. This variation undermines semantic consistency across platforms. Ronoh et al. [13] found that the absence of centralized governance on standard adoption leads to interoperability breakdowns, especially during inter-facility patient transfers. Moreover, Ndlovu and Mars [14] noted that inconsistent implementation of EHR standards exacerbates data silos, reduces reporting accuracy, and limits the capacity for comprehensive health analytics.

2.2. Semantic Interoperability

Semantic interoperability extends beyond mere data exchange to encompass the preservation of meaning across health information systems. According to Lehne et al. [15], semantic interoperability ensures that clinical concepts retain their intended interpretation regardless of the receiving system's architecture. This is achieved through consistent use of terminologies like SNOMED CT and LOINC and adherence to data standards like HL7. Adler-Milstein and Holmgren [16] found that U.S. hospitals with high levels of semantic interoperability reported better patient outcomes and reduced medication errors.

Within the African context, achieving semantic interoperability remains a major challenge. Jawhari et al. [17] highlighted that healthcare systems in Sub-Saharan Africa, including Kenya, struggle with semantic alignment due to inconsistent use of ontologies and terminologies. Empirical studies by Mutai et al. [18] show that even when EHRs are implemented, lack of semantic structure hampers interoperability. Their findings revealed that only 12% of Kenyan county hospitals achieved any form of semantic consistency. This aligns with Braun et al. [19], who argued that ontology-based approaches and HL7 FHIR adherence are essential for enabling cross-platform semantic interoperability, particularly in distributed healthcare environments., who argued that ontology-based approaches and HL7 FHIR adherence are essential for enabling cross-platform semantic interoperability, particularly in distributed healthcare environments.

3. Research methodology

This study adopted a correlational research design to evaluate the relationship between security techniques and semantic interoperability in distributed healthcare systems. The design was chosen to quantify the strength and direction of associations between the independent variable (security techniques) and the dependent variable (semantic interoperability), while also assessing the mediating role of system usability.

The study population comprised healthcare professionals, systems administrators, hospital administrators, system developers, and records/data officers from four Level 5 referral hospitals in Kenya: Kisii County Referral Hospital, Nyeri County Referral Hospital, Nakuru Level 5 Hospital, and Coast General Teaching and Referral Hospital. These facilities were selected based on their advanced use of electronic health systems and distributed data exchange mechanisms.

A sample size of 301 respondents was determined using Yamane's formula at a 95% confidence level and a 5% margin of error [20]. Purposive sampling was used to select the four hospitals based on inclusion criteria related to interoperability readiness, while stratified random sampling was employed to ensure proportional representation across professional roles within each hospital.

Primary data were collected using a structured questionnaire, developed and validated by experts in health informatics and health information systems. The questionnaire measured perceptions and experiences related to the adoption and effectiveness of security techniques (e.g., access control, encryption, secure data exchange) and their influence on semantic interoperability. It also assessed system usability as a mediating factor. Supplementary data were gathered through interviews and focus group discussions, primarily for triangulating and validating quantitative insights.

Quantitative data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 25. The analysis began with descriptive statistics, including frequencies, percentages, means, and standard deviations, which were used to summarize the demographic characteristics of the respondents and their responses concerning the implementation of security techniques and the state of semantic interoperability within their institutions.

For inferential analysis, Spearman's rank correlation coefficient was employed to examine the strength and direction of the relationship between security techniques and semantic interoperability. To determine whether significant differences existed in semantic interoperability scores across institutions with varying levels of security implementation, the Mann-Whitney U test was applied. Additionally, to explore the mediating effect of system usability, a bootstrapped mediation analysis was conducted using 5,000 resamples. This approach provided a robust estimate of the indirect influence of system usability on the relationship between security techniques and semantic interoperability.

The instrument's validity was confirmed through expert review, yielding an average content validity score of 0.90. Reliability was tested through a pilot study involving 12 participants from a different Level 5 hospital (Kakamega County Referral Hospital). The internal consistency of the questionnaire was assessed using Cronbach's Alpha, which yielded values above 0.70 for all constructs, with an overall average of 0.823, indicating acceptable reliability.

Ethical clearance was obtained from the National Commission for Science, Technology and Innovation (NACOSTI) and the respective ethics committees of the participating hospitals. Written informed consent was obtained from all participants, who were assured of voluntary participation and the right to withdraw at any point. Data were anonymized, securely stored, and used exclusively for academic purposes to ensure confidentiality and data protection.

4. Results and Discussion

This section addresses the findings from the descriptive and inferential analysis conducted.

4.1. Descriptive Analysis on EHR Standards

Table 1 presents an analysis of the perceived impact of EHR standards on semantic interoperability.

Table 1 EHR Standards on Semantic Interoperability

Statement	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Total
The adoption of EHR interoperability standards (e.g., HL7, FHIR, CDA) has significantly improved data mapping accuracy.	35 (13.1%)	43 (16.0%)	83 (31.0%)	62 (23.1%)	45 (16.8%)	268 (100%)
The use of standardized EHR formats (e.g., FHIR, HL7) has reduced errors in data mapping.	22 (8.2%)	56 (20.9%)	75 (28.0%)	72 (26.9%)	43 (16.0%)	268 (100%)
The implementation of EHR interoperability standards has significantly decreased data inconsistencies and mismatches across healthcare systems.	14 (5.2%)	54 (20.1%)	72 (26.9%)	84 (31.3%)	44 (16.4%)	268 (100%)
The current EHR standards facilitate data exchange and mapping between different healthcare systems.	28 (10.4%)	75 (28.0%)	95 (35.4%)	50 (18.7%)	20 (7.5%)	268 (100%)
The standards used in our facility ensure data exchange and mapping across different healthcare systems.	27 (10.1%)	58 (21.6%)	76 (28.4%)	68 (25.4%)	39 (14.6%)	268 (100%)
The adoption of EHR standards has improved real-time data exchange between healthcare systems.	33 (12.3%)	50 (18.7%)	88 (32.8%)	61 (22.8%)	36 (13.4%)	268 (100%)

Table 1 presents the respondents' perceptions on the effectiveness of EHR standards in enhancing semantic interoperability in healthcare systems. The findings highlight the impact of interoperability frameworks such as HL7, FHIR, and CDA in improving data accuracy, reducing errors, and facilitating seamless information exchange across healthcare institutions.

The first statement, which assesses whether the adoption of EHR interoperability standards has significantly improved data mapping accuracy, reveals that 39.9% of respondents (Agree – 23.1%; Strongly Agree – 16.8%) perceive a positive impact. However, a notable 29.1% (Strongly Disagree – 13.1%; Disagree – 16.0%) disagree, indicating mixed opinions on the effectiveness of these standards in achieving precise data mapping.

Regarding the reduction of errors in data mapping, 42.9% (Agree – 26.9%; Strongly Agree – 16.0%) of respondents acknowledged improvements due to standardized EHR formats such as HL7 and FHIR. However, 29.1% (Strongly Disagree – 8.2%; Disagree – 20.9%) still believe that errors persist, suggesting that despite standardization, challenges in data mapping accuracy remain.

The statement evaluating whether EHR standards have significantly decreased data inconsistencies and mismatches received a 47.7% agreement rate (Agree – 31.3%; Strongly Agree – 16.4%), indicating that nearly half of the respondents recognize improvements in data consistency. However, 25.3% (Strongly Disagree – 5.2%; Disagree – 20.1%) reported that data mismatches still exist, possibly due to implementation gaps or system incompatibilities.

When asked whether EHR standards facilitate data exchange and mapping between different healthcare systems, a combined 26.2% (Strongly Agree – 7.5%; Agree – 18.7%) agreed, while a significant 38.4% (Strongly Disagree – 10.4%; Disagree – 28.0%) disagreed. The large proportion of neutral responses (35.4%) suggests that many respondents may be uncertain about the extent to which EHR standards support interoperability in their institutions.

Similarly, 40% (Agree – 25.4%; Strongly Agree – 14.6%) of respondents acknowledged that EHR standards ensure data exchange and mapping across different healthcare systems, while 31.7% (Strongly Disagree – 10.1%; Disagree – 21.6%) disagreed. The findings indicate a generally positive perception of the role of standards, though challenges in implementation and interoperability may still exist.

Finally, the effectiveness of EHR standards in improving real-time data exchange was positively acknowledged by 36.2% (Agree – 22.8%; Strongly Agree – 13.4%), while 31.0% (Strongly Disagree – 12.3%; Disagree – 18.7%) expressed skepticism. The presence of a relatively high proportion of neutral responses (32.8%) suggests that real-time data exchange remains a work in progress, with varying levels of success across different institutions.

4.2. Inferential Analysis: Association Between EHR Standards and Semantic Interoperability

Electronic Health Record (EHR) standards play a crucial role in facilitating semantic interoperability by ensuring consistent data representation, exchange, and interpretation across different healthcare systems. To assess the relationship between EHR standards and semantic interoperability, Spearman's Rank-Order Correlation was conducted. Table 2 presents the correlation results, highlighting the strength and significance of the association between the adoption of EHR standards and the level of semantic interoperability in distributed healthcare information systems.

Table 2 Correlation Between EHR Standards and Semantic Interoperability

			Semantic Interoperability	**EHR Standards**
Spearman's rho	Semantic Interoperability	Correlation Coefficient	1.000	.007
		Sig. (2-tailed)	.	.04
		N	268	268
	EHR Standards	Correlation Coefficient	.007	1.000
		Sig. (2-tailed)	.04	.
		N	268	268

Table 2 presents the results of Spearman's Rank-Order Correlation test assessing the relationship between EHR standards and semantic interoperability in distributed healthcare information systems. The correlation coefficient (Spearman's rho) is 0.007, with a p-value of 0.04, based on a sample size of 268.

The study sought to examine whether EHR standards influence semantic interoperability in healthcare information systems. The results indicate a very weak positive correlation (0.007) between EHR standards and semantic interoperability. However, the relationship is statistically significant ($p = 0.04 < 0.05$), suggesting that the association is unlikely due to random chance.

Despite the statistical significance, the very weak correlation suggests that EHR standards alone do not have a substantial impact on semantic interoperability. While EHR standards provide structured frameworks for data exchange, their effectiveness in enhancing interoperability may depend on additional factors, such as the extent of implementation, compliance with international standards (e.g., HL7, FHIR), system integration practices, and governance policies.

While the Spearman's rho correlation established a monotonic relationship between variables, further analysis was required to examine differences in semantic interoperability across distinct levels of EHR standards adoption (Low/Medium/High). The Kruskal-Walli's test, a non-parametric alternative to one-way ANOVA, was employed to compare median interoperability scores between these ordinal groups without assuming normal distribution of data. Table 3 presents the results of this analysis, revealing whether varying implementation levels of EHR standards correspond to statistically significant differences in interoperability outcomes.

Table 3 Kruskal-Wallis Test Results for EHR Standards and Semantic Interoperability

Ranks			
	EHR Standards	**N**	**Mean Rank**
Semantic Interoperability	Low (1.00)	54	122.14
	Medium (2.00)	103	130.73
	High (3.00)	111	148.92
	Total	268	
Test Statisticsa,b			
	Semantic Interoperability		

Kruskal-Wallis H	6.52
df	2
Asymp. Sig.	.038

a. Kruskal Wallis Test; b. Grouping Variable: EHR Standards

The Kruskal-Walli's test in Table 3 reveals a statistically significant but practically weak relationship between EHR standards adoption levels and semantic interoperability ($\chi^2(2) = 6.52$, p = 0.038). Post-hoc comparisons showed that institutions with high adoption levels (mean rank = 148.92) demonstrated marginally better interoperability performance than low adopters (mean rank = 122.14), while medium adopters showed no significant differences from either group. This suggests that while EHR standards adoption does influence interoperability outcomes, its standalone impact remains limited.

The findings imply that achieving meaningful interoperability improvements requires more than just EHR standards implementation. High-performing institutions likely benefit from complementary factors such as robust data governance, technical infrastructure, and semantic tools like ontologies and advanced mapping techniques. These results underscore the need for healthcare organizations to adopt a holistic approach to interoperability, combining standards compliance with other organizational and technical enablers to achieve substantial progress in seamless data exchange.

4.3. Inferential Analysis: Mediating Effect of System Usability on the Relationship Between EHR Standards and Semantic Interoperability

To examine whether system usability mediates the relationship between Electronic Health Records (EHR) and semantic interoperability, a mediation analysis was conducted using PROCESS Macro Model 4. The analysis involved 268 participants and utilized a bootstrap sampling procedure with 5,000 resamples to estimate the indirect effects. Table 4 presents the regression coefficients for each of the mediation paths, while Table 5 summarizes the direct, indirect, and total effects of EHR on semantic interoperability through system usability.

Table 4 Regression Analysis for the Mediation Paths (EHR Standards and Semantic Interoperability)

Path	**Coefficient (β)**	**Standard Error (SE)**	**t-value**	**p-value**	**95% Confidence Interval (CI)**
System Usability ← EHR (Path a)	0.3120	0.0421	7.4109	0.0007	(0.2292, 0.3948)
Semantic Interoperability ← System Usability (Path b)	0.2845	0.0387	7.3522	0.0001	(0.2084, 0.3606)
Semantic Interoperability ← EHR (Path c')	-0.0214	0.0298	-0.7181	0.4732	(-0.0801, 0.0373)

The regression analysis results presented in Table 4 examined the mediation pathway between Electronic Health Record (EHR) Standards and Semantic Interoperability through System Usability. The findings indicate that EHR Standards had a positive and statistically significant effect on System Usability (Path a: β = 0.3120, SE = 0.0421, p = 0.0007), suggesting that improved implementation of EHR standards is associated with enhanced usability of the system.

Additionally, System Usability positively and significantly influenced Semantic Interoperability (Path b: β = 0.2845, SE = 0.0387, p = 0.0001), indicating that higher levels of usability correspond to better semantic interoperability outcomes. However, the direct effect of EHR Standards on Semantic Interoperability, controlling for System Usability, was not statistically significant (Path c′: β = -0.0214, SE = 0.0298, p = 0.4732). This suggests that EHR Standards alone do not directly enhance semantic interoperability without the mediating role of usability.

Table 5 Direct and Indirect Effects of the Mediation Model (EHR Standards and Semantic Interoperability)

Effect Type	Effect Size	Boot SE	BootLLCI	BootULCI	Conclusion
Direct Effect (c')	-0.0024	0.0298	-0.0801	0.0373	Not Significant
Indirect Effect (a × b)	0.0887	0.0152	0.0601	0.1213	Significant (CI excludes zero)
Total Effect (c)	0.0673	0.0339	0.0006	0.1340	Not Significant

Table 5 provides a summary of the direct, indirect, and total effects in the mediation model. The direct effect of EHR Standards on Semantic Interoperability remained non-significant (β = -0.0024, Boot SE = 0.0298, 95% CI [-0.0801, 0.0373]), reinforcing the conclusion that EHR implementation alone does not directly impact interoperability outcomes.

Importantly, the indirect effect of EHR on Semantic Interoperability through System Usability was statistically significant (β = 0.0887, Boot SE = 0.0152, 95% CI [0.0601, 0.1213]). Since the confidence interval excludes zero, this confirms that System Usability significantly mediates the relationship between EHR Standards and Semantic Interoperability.

The total effect of EHR on Semantic Interoperability (β = 0.0673, Boot SE = 0.0339, 95% CI [0.0006, 0.1340]) was also not statistically significant, indicating that the overall influence of EHR implementation on semantic outcomes is primarily indirect

5. Conclusion

The study concludes that while EHR standards show a statistically significant relationship with semantic interoperability, their effect is weak when applied in isolation. The findings reveal that system usability plays a crucial mediating role, enhancing the impact of EHR standards on interoperability outcomes. This underscores that achieving meaningful semantic interoperability in distributed healthcare systems requires more than technical standard adoption, it necessitates a human-centered approach that integrates usability, supportive infrastructure, and policy alignment to enable accurate, consistent, and context-aware health data exchange.

Recommendation

Based on the empirical findings, the following recommendations are proposed to enhance semantic interoperability in distributed healthcare systems:

- EHR standards should be implemented alongside complementary enablers such as system usability, standardized ontologies (e.g., SNOMED CT), data governance policies, and mapping tools to ensure meaningful semantic alignment.
- The Ministry of Health should formalize a national interoperability framework mandating adherence to international EHR standards like HL7 FHIR. This should be accompanied by regular audits to monitor compliance across healthcare institutions.
- Health information systems must prioritize user experience, with features such as intuitive interfaces, clear prompts, efficient workflows, and effective training mechanisms to improve system usability and, consequently, semantic interoperability.

Continuous professional development programs targeting both technical personnel and healthcare workers should be institutionalized to promote the proper implementation, use, and maintenance of standardized, interoperable systems.

Compliance with ethical standards

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No conflict of interest to be disclosed.

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