Enhancing Interoperability: Exploring Data Exchange Standards in SaaS Laboratory Management Systems

***Vicrumnaug Vuppalapaty**, Technical Architect, CodeScience Inc. USA*

DOI: 10.55662/JST.2023.4607

Abstract:

In the ever-changing environment of health care, smooth information exchange among different systems is significant to ensure efficiency and high-quality patient care. This is also important in laboratory management, where time and accuracy are critical for patients' diagnosis and treatment choices. Nevertheless, interoperability is still a big issue, with SaaS laboratory systems being the primary concern.

This study focuses on the importance of interoperability in contemporary healthcare systems, with particular emphasis on laboratory management. It shows the significance of an uninterrupted data flow between SaaS laboratory management systems and other healthcare I.T. systems, such as E.H.R.s and HIEs. Existing data exchange standards and frameworks for interoperability among SaaS laboratory management systems are discussed, including the challenges of achieving interoperability.

A quantitative research approach-based questionnaire was deployed to assess the interoperability requirements and processes of the genetic testing laboratories in the survey. Investigations point to different levels of compatibility among SaaS lab management systems in terms of features offered as well as the challenges faced by the latter. Challenges include different data formats, communication protocol standards, and data model incompatibility.

The study emphasizes the critical role of interoperability and data exchange in SaaS laboratory management systems and the entire healthcare industry. The methods of overcoming the interoperability problem are investing in education, creating collaborative partnerships, promoting integration frameworks, and establishing incentives for obedience to standardized data exchange format.

Introduction:

In modern-day healthcare, with its constant transformation, the direct interoperability of data between various systems has become the key to the success of achieving high standards of patient care. These systems merge into a holistic picture where immediate and correct analytics by laboratory management provide the basis for accurate diagnoses, decisions about treatment,

and overall patient management. Nevertheless, the interoperability between these SaaS management systems is the main obstacle in the path to it (Tashkandi, 2019).

Interoperability in modern-day healthcare systems is the most critical factor for improving the process of laboratory management. Interoperability is the glue that binds together different healthcare I.T. subsystems into a single system and allows healthcare providers to access information in time and in a desirable environment. In the laboratory sphere, where laboratory test results are generated speedily and error-free, they are crucial in determining patient outcomes, and interoperability becomes inevitable.

Interoperability between SaaS lab management systems and other E.H.R. applications, as well as H.I.T.s such as Health Information Exchanges (HIEs), must be enhanced to improve patient care delivery and optimize healthcare systems (Kim & Kim, 2012). Despite the interoperability, as mentioned above level, providing multiple benefits, it is faced with various challenges, ranging from the differences in database formats and network protocols to the system architecture disparities. These are but a few of the challenges that must be dealt with if laboratory data is to be used successfully to guide clinical decisions and achieve good patient results.

Research Objectives:

This research aims to:

- Evaluate the importance of interoperability in modern healthcare systems, paying more attention to its central position in laboratory management.

- Data exchange must be seamless among SaaS laboratory information systems and other

healthcare I.T. solutions, including E.H.R.s and HIEs.

● Identify the existing data exchange standards and interoperability frameworks applicable to the field of SaaS-based laboratory management systems.

● Highlight the challenges and impediments to laboratory management systems interoperability.

● Bring new strategies and recommendations to raise interoperability and data exchange standards in SaaS laboratory management systems.

Structure of the Article:

The article reviews interoperability and data exchange standards inside the SaaS laboratory management systems as well as the healthcare context of contemporary times. This essay will begin with an introduction presenting the necessity of interoperability in laboratory management. In the subsequent part, it will discuss the issues and standards that currently exist. The methods part details the research strategy, data obtaining, and analysis approach. The results demonstrated different levels of interoperability among SaaS systems, but the discussion interprets these findings recognizing the impact of healthcare stakeholders. In conclusion, interoperability and data exchange are emphasized by the need for close partnerships and encouraging teamwork to meet challenges and improve patient care.

Literature Review

SaaS is one of the following cloud subscriptions: SaaS, IaaS, and PaaS. It enables businesses to use the programs by making them available without any host on the servers. This platform has become very popular because companies do not have to buy servers and other resources and employ a dedicated team to ensure everyone is well-maintained (Al-Marsy et al., 2021). On the contrary, SaaS solution vendors put hosted applications in place and provide SaaS security and maintenance. Unlike most business product givers, Oracle Financials, for example, also provides cloud implementations for its software applications.

Interoperability difficulties and data exchange standards in laboratory information

management systems (LIMS) have been given quite a lot of attention in scientific literature, with some focus on healthcare I.T. systems integration. The following is a summation of those studies, frameworks, and industries that relate to the given topics (Loutas, Kamateri, & Tarabanis, 2011).

Interoperability Challenges in LIMS:

A study rooted various interoperability issues faced by LIMS, including different data types used by the various systems, the absence of standardized communication protocols, and inconsistency in data models. Complexities such as interoperability with other health I.T. systems are among the paramount problems that lead to reduced efficiency in data transfer and care coordination (Rezaei et al., 2014a).

Data Exchange Standards:

While many data exchange standards are already in place to solve the LIMS interoperability problem, some are still being developed. The HL7 International (HL7) standard is very popular, and these HL7 Version 2. x and HL7 Version 3 standards are widely used for the transmission of clinical and administrative data to the LIMS and other I.T. systems in healthcare (Rezaei et al., 2014b). Furthermore, the Interoperability Promoting Initiative of Integrating the Healthcare Enterprise (I.H.E.) introduces standard-based frameworks (HL7 Fast Healthcare Interoperability Resources) that enable data sharing between LIMS and the electronic health records (E.H.R.) systems.

Frameworks for Interoperability:

Interoperability frameworks can create a common interface for different kinds of LIMSs, allowing a multi-adapter system to use different storage systems. Then, systems rules can be created and applied by the multi-adapter system. The Healthcare I.T. Interoperability Framework, designed by the National Institute of Standards and Technology (NIST), describes the key components and standards of interoperability relevant to LIMS collaboration with other healthcare I.T. systems (Lim & Ryu, 2020). In addition, the I.H.E. organization makes available the profiles and implements guides for the interoperability function and interaction of LIMS and E.H.R. systems via standard interfaces and communication protocols.

Health standards (Health Level Seven - or HL7)

HL7, which has been around for 35 years since its establishment in 1987, is a non-profit community of experts involved in the development of standards for information systems. As the decades have passed, it has developed from a local community of health information specialists into a worldwide group of health information experts that take part in developing standards that encourage the interoperability of health information exchange systems (Bouzerzour et al., 2020).

HL7, literally Health Level Seven, is a universal part of standards designed for the electronic exchange, integration, sharing, and retrieval of health information. Outlining the parameters, formats, and protocols for the interaction and interoperability of healthcare I.T. devices and systems within and between organizations. HL7 format is a collective term that specifically stands for HL7 Version 2. This version is a widely used standard and has already achieved proliferation all over healthcare facilities worldwide. It electronically connects separate computer systems that make up the health information systems, for example, those that include electronic health records systems, laboratory information systems, pharmacy systems, and other healthcare systems (Ochian et al., 2014). The HL7 V2 standard specifically offers a structured format for data expression in the healthcare domain and a messaging container scheme for data transmission to various systems. It speaks a common language at the message type and segment level to allow the message construction to bring specific health information.

Fig 1: Exploring HL7 Standards

These messages may entail various data that refer to patient demographics, clinical observations, laboratory results, medication orders, and other relevant information. This Categorical standard also demonstrates how the messages are formed, including the use of separators and data types to maintain consistency and interoperability (Amokrane et al., 2018). Besides, HL7 V2 gives all rules for data interchange, message sequence, and error handling that are needed to ensure transmission safety and accuracy of health information. The utilization of HL7 V2 by healthcare organizations makes their system-to-system communication more effective and promotes interoperability between healthcare systems. It makes it possible to transfer direct information from one application to another, not only on paper classic prescriptions, laboratory tests, and electronic medical records but also from other clinical information sources. It fosters the availability of the necessary care for a certain period, improves communication between the health care providers, and advances effective and accurate decision-making processes (Gómez et al., 2022a). One must understand that the development of HL7 did not stop at Version 2 but rather continued through subsequent releases of HL7 Version 3 (V3) and Fast Healthcare Interoperability Resources (FHIR) standards. Every edition is designed to solve one or more problems with healthcare data exchange with HL7 V2

continuing to be significantly used, thus occupying the main position for electronic health record interchange. This was an indication that doctors have agreed on data exchange standards about teleophthalmology, especially store-and-forward teleophthalmology, and the authors also looked ahead in this area (Dixon et al., 2023). The authors emphasize the importance of standards and best practices in achieving smooth interoperability and the exchange of medical ocular images and related data among relevant stakeholders involved. The research deals with several standards like I.H.E., HL7 FHIR, DICOM, and medical terminologies and analyses their role in ophthalmology information systems (I.S.).

Fast Healthcare Interoperability Resources Standard (FHIR)

FHIR is a terminology defined by Health Level Seven International, which is an N.G.O. This standard supports different forms of objects and elements, which are represented as resources in the JSON format. They can be implemented by using an API Rest, which makes the process simple and allows the communication of medical data entities with different health systems through real-time connection (Gómez et al., 2022b). This pace can be used to fine-tune the pin-pointing specific information and help the various models to improve. The authors describe a novel technique for the unattended discovery of the endocardial border on cardiac M.R.I. images. A subdivision of the left ventricle in M.R.I. images is a key element in the interpretation of cardiac function and in recognizing abnormalities. The proposed method provides the sectioning based on level set segmentation. The initial mask of the algorithm is obtained by thresholding the initial image. An automatic technique for the identification of the left chamber of the heart using the assessment of the roundness of objects is proposed (Loutas, Kamateri, Bosi, et al., 2011).

Through the Rest API, like "INSOMNIA," the POST method is used to either send in a new resource or a list of FHIR resources in the JSON or XML format. Generating an I.D. based on this technique will then identify each resource. Secondly, it will use the G.E.T. method to look for them from the Rest server. In the "search parameters" section at the beginning of the link, the type of the "Patient" example resource is provided. At the same time, the resource observing against the Rest server (I.D., name, etc.) could be done (Li et al., 2020). It can alter, for instance, patient information by including the "observation" value for the "Resource Type" element instead of using the P.U.T. transaction. It can identify the kind of resource it deals with, like

"patient" in the URL before the P.U.T. transaction of the resource. Subsequently, it can use G.E.T. transactions to fetch the complete history of the resource, including all the versions where the changes were made. Another point is that the FHIR standard can be added to the list of resources that have already been loaded into Rest API. Alternatively, it will produce them with the aid of the Profile resource. Next, it can create a profile in the same format as the group of resources that are already on an FHIR server. For instance, "Hapi FHIR" will produce a link that will show the structure of the profile, the format being the one for each resource. The elements must be present in all of them (Vorisek et al., 2022). Similarly, a set of constraints must be introduced in the form of the cardinality of each element. What follows is copying the URL of the profile that one creates after applying it to a resource. This time, we will be accessing the Rest API and copying the URL without missing the step of changing the resource type value to the structure definition as the value. All operations are undertaken on transaction post. Finally, it is made sure that the resource is flexible to the new structure specified in profile FHIR to harmonize the structure of all the resources and resources of similar types. However, the options transaction can also visualize all the possible operations on any resource by the Rest API.

Figure 2 illustrates the above-mentioned (Ballentine, 2022). They suggested an FHIR solution that is intended to improve the process and storage of imaging data in the medical sector. Utilizing FHIR resources with the inclusion of Diagnostic Reports, Imaging Studies, Observation, and other resources that are easy to use and interconnected, reports, findings, annotations, and DICOM images can be combined. For example, an Imaging Study could be a Diagnostic Report, or the latter could be linked to the former. The ensuing sentence summarises (the findings/observation). In the Box, references can also carry other observations with annotation data. It proposes using SVG format for image annotations that are then encoded within Observations using FHIR Resources.

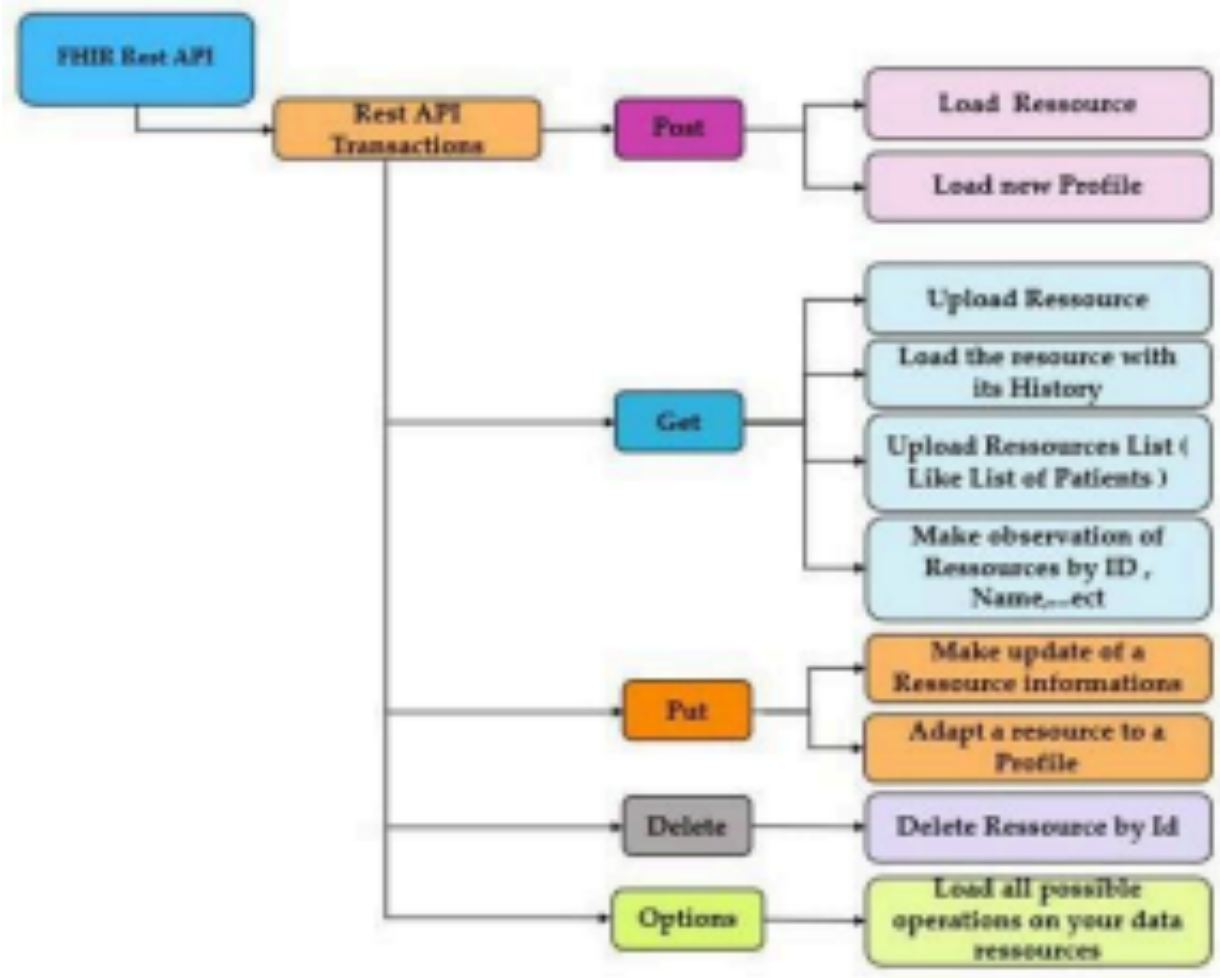

Figure 2. Block diagram of the FHIR standard.

Methodology

Data Collection Method:

To delve into the details of interoperability standards in Biomedical Informatics (B.M.I.), particularly dealing with HL7 standards, the quantitative method was selected. That included conducting a questionnaire, which allowed for participating in the needs and processes between interoperability and laboratory management systems (Sousa et al., 2023).

Lab Review and Recruitment:

To begin with, we came up with U.S. genetic testing labs from the National Centre for Biotechnology Information Genetic Testing Registry. The additional labs were found through

the internet applications. Each lab's webpage was scrutinized to determine its business category (e.g., commercial, university-affiliated, reference labs), key personalities, and status of the services (Roe, 2020). We did not consider such labs as research labs or those not dealing presently. Next, solicitation emails were created and sent out to the prospective labs, summarizing the chosen research topic and encouraging the participating labs to complete a pre-questionnaire. Customized questionnaires based on lab-prior E.F. survey responses were used to ensure relevance and efficiency. At the end of each, participants were asked to rate their interoperability level, choosing from three options: Primarily, Syntactic, and Semantic Interoperability (Gao et al., 2018). The participant spelled out the implications of each option to ensure comparability across the questionnaire

Sample Selection Criteria:

Genetic testing laboratories based in the United States were chosen as the example group, using the Genetic Testing Registry of the National Centre for Biotechnology Information and Internet Research. Labs were grouped by their business category to ensure there is a variety of the industry in the listing (Moreira et al., 2018). Exclusion criteria were intended to maintain relevance and current operating status.

Analysis Procedures:

Analysis was utilized to derive patterns and themes within the questionnaire data. The transcribed data were methodically examined, and emerging themes were extracted to appreciate the shades of the challenges and solutions of interoperability (Iftikhar et al., 2012). This helped develop a comprehensive understanding of the ecosystem.

Assessment of Interoperability Capabilities:

Interoperability capacities were evaluated using participant self-ratings during the questionnaire which shed light on the level of interoperability by each laboratory. Participants were directed to opt between the questionnaire options, reinforcing their grasp of their current capabilities and challenges (Balakrishna & Thirumaran, 2020).

Evaluation Criteria for Data Exchange Standards Compliance:

Compliance with standard exchange formats, particularly HL7, was evaluated by comparing the laboratory's use of predefined structures and computationally recognizable content. The questionnaires were meticulously designed to retrieve answers that reflect the extent of adherence to these standards and provided an insightful assessment of data exchange procedures (Wu et al., 2015).

Results

Participating labs:

Besides, we detected 302 genetic testing Labs. As sending emails to the 188 laboratories after exclusions, A.K. and S.M.H. sent invitations by email. The participation rate after the questionnaire reached 13 laboratories. However, the final participation rate only reached 10 laboratories (5.3%). The end participants included four private labs, seven specialized labs, five national reference labs, six hospital-based labs, and six university labs. The term lab may be ambiguous to some extent and have multiple meanings (Tsai et al., 2014). Specially labs do a particular type of genotyping such as Karyotyping or pharmacogenetics testing. Private labs are a point of concern as they may be a social problem for the company or its affiliates. Most of the participants had 3 to 5 years in the current position of the laboratory environment and had worked in the industry for 6 to 10 years. For the next labs, the lab manager/C.I.O. inferred which participant would most fit the study objectives with a deeper knowledge of the subject and research scope. Among the eight participants, four had a background in informatics and information technology, four had a background in genetics, and those with a background in biology, medicine, and chemistry completed the list (Zhou & Liu, 2013). Other individuals are elucidated in the Additional material that you may refer to. The questions for the questionnaire are given in Appendix 1; the following is the result obtained from the questionnaire.

Understanding	**Response**
Interoperability	

Definition of interoperability	Ability to integrate various healthcare I.T. platforms.
Key challenges hindering interoperability	Diverse data formats, Lack of standardized communication protocols, Incompatible data models.

Insights on SaaS Laboratory Management Systems	**Response**
Encounter or utilization of SaaS LIMS	Yes
Level of interoperability observed	Mixed - Some systems have advanced interoperability, while others lack it.
Strategies to enhance interoperability	Utilizing advanced systems supporting standardized data exchange formats like HL7 and FHIR.

Implications and Strategies	**Response**
Potential benefits of improving interoperability	Improved patient care delivery and enhanced communication between healthcare systems.

Strategies to overcome interoperability challenges	Education and training programs, Collaborative partnerships, Implementation of interoperability frameworks, Regulatory incentives, and Continuous improvement efforts.

Interoperability Status of SaaS Laboratory Management Systems:

On the other hand, this study disclosed a limp grip of different degrees of interoperability between Software as a Service (SaaS) laboratory management systems (LIMS). However, while some systems have proven this feature, it still needs to be improved during the integration of other healthcare I.T. platforms. It includes everything principally supported by standardized data exchange formats such as HL7 and FHIR (Lijun & Jianchao, 2013).

From the labs reporting to have SaaS LIMS with advanced interoperability, they can utilize strategies to allow E.H.R.s, HIEs, and other healthcare I.T. systems to freely exchange data and information seamlessly. Similar computer-interoperable systems were also proven regulatory-compliant with existing data exchange standards, thereby boosting smooth information transmission, which is critical to patient care.

While a large part of the SaaS LIMS was incapable of becoming interoperable, the main reasons for this were the difference in the data formats, the lack of a standard data exchange mode, and incompatible models (Almorsy et al., 2012). The Hippocratic systems are another constraint that limits the optimal function of the laboratory systems, which makes data flow less efficiently, so data coordination and patient care service delivery are subtle.

Support for Seamless Data Exchange:

Some SaaS LIMS showed efficacy in the data transfer process by using advanced systems to guarantee uninterrupted information exchange within the healthcare digital networks, whereas others experienced a bottleneck taking data transfer opportunities from the air. Systems with cutting-edge interoperability harness the established healthcare data exchange formats like HL7 and FHIR protocols to allow seamless communication with EHRS, HIEs, and other health

systems (Loutas, Kamateri, & Tarabanis, 2011).

Therefore, in the case of the Implementation of SaaS LIMS, it has been observed that a few models faced hindrances in supporting seamless data transfer instances due to various limitations, such as communication interoperability framework and protocols (Amokrane et al., 2018). Many of them were mostly interested in the manual handling of the error to translate data and lacked auto-driven mechanisms for its processing and exchange.

Challenges and Gaps Identified:

A SaaS laboratory management system study was found to have multiple issues and important standards for data exchange compliance (Ouchaou et al., 2022).Key challenges included:

● Diverse data formats and outdated data models have caused fragmentation and a lack of communication between the other healthcare apps.

● The absence of standardized communication protocols slowed down the efficient transfer of data between SaaS LIMS clients and other systems.

● The Lack of adequate frameworks integrating interoperability hindered SaaS LIMS compliance with exchange data standards that are widely used, such as HL7 and FHIR.

These issues demonstrated that complete approaches to interoperability system development and data exchange process optimization were required in the SaaS laboratory management systems market (Pace et al., 2016). Solving these problems is mandatory because it is necessary to provide the best care possible for patients and use laboratory data to the fullest for making medical decisions.

Discussion

Interpreting Results in the Context of Healthcare Interoperability: The results of our study demonstrate the value of interoperability for contemporary healthcare systems, especially for laboratory management. While some SaaS laboratory management systems showed the ability to exchange vital data with other healthcare I.T. systems, several of them were unable to do that. The findings corroborate that the process is complicated and raises the issue of records

normalization and technological alignment (Tashkandi, 2019).

Within the more extensive landscape of health information interoperability, the research findings highlight the significance of linking technology attributes with industry standards to enable computerized exchange. It has become a vital part of healthcare ecosystems to promote interoperability among stakeholders using Health Level Seven (HL7) standards and Integrating the Healthcare Enterprise (I.H.E.) frameworks (Caminero et al., 2015). On the other hand, the research brings to light some inconsistencies in the use and Implementation of these standards, pointing to a need for vigorous commitments from medical facilities, I.T. vendors, and regulators to rectify interoperability barriers.

Implications for Healthcare Organizations, I.T. Vendors, and Regulatory Bodies: This research points out the relevance of assessing the interoperability capacity of the SaaS laboratory management systems before purchasing for healthcare providers. First and foremost, organizations should choose systems that support adhering to industry standards and could exchange data easily with E.H.R.s, HIEs, and other healthcare I.T. platforms. Besides, healthcare institutions have to spend money on training and equipment to make the employees use the interoperable systems skillfully (Mandal et al., 2015).

The study suggests that for I.T. vendors to remain competitive, they have to develop interoperable solutions that are based on existing data exchange standards. Vendors should implement interoperability by designing and implementing the systems using standardized communication protocols and data formats compatible with other healthcare I.T. systems. Also, it is worth mentioning that cooperation with industry and participation in interoperability programs would increase the credibility and competitiveness of vendors (Gavrilov et al., 2018).

Strategies for Overcoming Interoperability Challenges:

● **Education and Training:** Health institutions must emphasize the need for staff training to broaden the use of interoperable systems.

● **Collaborative Partnerships:** To meet market needs, vendors must work with different industry players, e.e. healthcare institutions, some regulation organizations, and standards-developing institutions, to build interoperable solutions that attain the industry´s standards.

● **Interoperability Frameworks:** Medical institutions should use interoperability frameworks such as HL7 and I.H.E. to prevent any problems in transforming disparate platforms into a single platform (Khan et al., 2012).

● **Regulatory Incentives:** Regulatory bodies should encourage public and private health institutions and I.T. developers to use interoperable solutions and common data interchange conventions.

● **Continuous Improvement:** Healthcare providers and I.T. vendors working together should always be in a state of redevelopment, collecting feedback from the end users of the health facility and other stakeholders. They then refine their interoperability capabilities with other health facilities to keep up with fast-changing challenges.

Through a collaborative effort, healthcare stakeholders can address the issue of interoperability and facilitate the development of a more interconnected healthcare system, leading to a higher standard of patient care delivery and outcomes (Lim & Ryu, 2020).

Conclusion

The study proves that interoperability in modern healthcare systems is crucial, especially in lab management, where rapid and precise data sharing is necessary. The study reveals the complexities and avenues underlying interoperability within Software as a Service lab management systems (LIMS) by analyzing the existing data exchange standards, interoperability frameworks, and quantitative research involving US-based genetic testing laboratories (Gómez et al., 2022b). Research results indicate diverse degrees of interoperability among SaaS LIMS, ranging from robust systems with integrated capabilities to others that struggle to provide seamless data exchange with other healthcare I.T. platforms. Challenges in the field have been identified, including various data formats, a shortage of standardized communication protocols, and limited support for interoperability frameworks (Ballentine, 2022). These could be successfully addressed with collective efforts.

This research suggests interoperability techniques such as education and training, coalition building amongst healthcare stakeholders and I.T. vendors, integration of interoperability frameworks, regulatory incentives, and continuous optimization. Healthcare organizations, I.T.

vendors, and regulatory bodies should implement these strategies collaboratively, making this ecosystem more interoperable (Ouchaou et al., 2022).

References

Al-Marsy, A., Chaudhary, P., & Rodger, J. A. (2021). A model for examining challenges and opportunities in the use of cloud computing for health information systems. *Applied System Innovation*, *4*(1), 15.

Almorsy, M., Grundy, J., & Ibrahim, A. S. (2012). Tossma: A tenant-oriented SAAS security management architecture. *2012 IEEE Fifth International Conference on Cloud Computing*, 981–988. https://ieeexplore.ieee.org/abstract/document/6253613/

Amokrane, N., Laval, J., Lanco, P., Derras, M., & Moala, N. (2018). Analysis of data exchanges and contribution to data interoperability assessment. *2018 International Conference on Intelligent Systems (Is)*, pp. 199–208.

Balakrishna, S., & Thirumaran, M. (2020). Semantic interoperability in IoT and big data for health care: A collaborative approach. In *Handbook of data science approaches for biomedical engineering* (pp. 185–220). Elsevier.

https://www.sciencedirect.com/science/article/pii/B9780128183182000076 Ballentine, P. (2022). *Implementing a Flexible, Modern, and Repeatable FHIR-based E.H.R. Integration Framework for Predictive Analytics*.

https://www.academia.edu/download/88691613/Implementing_a_Flexible_Modern_and_Repeatable_FHIR_based_EHR_Integration_Framework.pdf

Bouzerzour, N. E. H., Ghazouani, S., & Slimani, Y. (2020). A survey on the service interoperability in cloud computing: Client‐centric and provider‐centric perspectives. *Software: Practice and Experience*, *50*(7), 1025–1060. https://doi.org/10.1002/spe.2794

Caminero, A. C., Ros, S., Hernández, R., Robles-Gómez, A., Tobarra, L., & Granjo, P. J. T. (2015). Virtual remote laboratories management system (tutores): Using cloud computing to

acquire university practical skills. *IEEE Transactions on Learning Technologies*, *9*(2), 133–145.

Dixon, B. E., Broyles, D., Crichton, R., Biondich, P. G., & Grannis, S. J. (2023). Architectures and approaches to manage the evolving health information infrastructure. In *Health Information Exchange* (pp. 199–215). Elsevier.

Gao, F., Thiebes, S., & Sunyaev, A. (2018). Rethinking the meaning of cloud computing for health care: A taxonomic perspective and future research directions. *Journal of Medical Internet Research*, *20*(7), e10041.

Gavrilov, G., Jakimovski, B., Chorbev, I., & Trajkovik, V. (2018). *Cloud-based electronic health record for health data exchange*. https://repository.ukim.mk/handle/20.500.12188/26130 Gómez, D., Romero, J., López, P., Vázquez, J., Cappo, C., Pinto, D., & Villalba, C. (2022a). Cloud architecture for electronic health record systems interoperability. *Technology and Health Care*, *30*(3), 551–564.

Gómez, D., Romero, J., López, P., Vázquez, J., Cappo, C., Pinto, D., & Villalba, C. (2022b). Cloud architecture for electronic health record systems interoperability. *Technology and Health Care*, *30*(3), 551–564.

Iftikhar, S., Khan, W. A., Ahmad, F., & Fatima, K. (2012). Semantic interoperability in E-health for improved healthcare. *Semant, ACTION-APPLICATIONS Scenar*, *107*. https://books.google.com/books?hl=en&lr=&id=sROeDwAAQBAJ&oi=fnd&pg=PA107&dq=Interpreting+Results+in+the+Context+of+Healthcare+Interoperability,SaaS&ots=brQ39x-X9f&sig=5tvAR1VJScB-HVUTWO_B5gH9tnI

Khan, W. A., Hussain, M., Khattak, A. M., Amin, M. B., & Lee, S. (2012). Saas-based interoperability service for semantic mappings among health-care standards. *8th International Conference on Innovations in Information Technology*, *29*.

Kim, T.-W., & Kim, H.-C. (2012). A healthcare system as a service in the context of vital signs: Proposing a framework for realizing a model. *Computers & Mathematics with Applications*, *64*(5), 1324–1332.

Li, S., Gao, X., Wang, W., & Zhang, X. (2020). Design of smart laboratory management system based on cloud computing and internet of things technology. *Journal of Physics: Conference Series*, *1549*(2), 022107.

https://iopscience.iop.org/article/10.1088/1742-6596/1549/2/022107/meta Lijun, W., & Jianchao, C. (2013). The identification service in health information exchange. *2013 IEEE 16th International Conference on Computational Science and Engineering*, 1161–1166. https://ieeexplore.ieee.org/abstract/document/6755353/

Lim, B.-C., & Ryu, K.-S. (2020). A Study on How to Build a Cloud-based Laboratory Information Management System and Provide SaaS (Software as a Service). *Proceedings of the Korea Information Processing Society Conference*, 327–329.

Loutas, N., Kamateri, E., Bosi, F., & Tarabanis, K. (2011). Cloud computing interoperability: The state of play. *2011 IEEE Third International Conference on Cloud Computing Technology and Science*, 752–757.

Loutas, N., Kamateri, E., & Tarabanis, K. (2011). A semantic interoperability framework for cloud platform as a service. *2011 IEEE Third International Conference on Cloud Computing Technology and Science*, 280–287.

Mandal, A. K., Sarkar, A., & Chaki, N. (2015). Flexible Cloud Architecture for Healthcare Applications. In R. Chaki, K. Saeed, S. Choudhury, & N. Chaki (Eds.), *Applied Computation and Security Systems* (Vol. 304, pp. 103–121). Springer India. https://doi.org/10.1007/978-81-322-1985-9_8

Moreira, J., Pires, L. F., van SINDEREN, M., & Daniele, L. (2018). SAREF4health: IoT Standard-Based Ontology-Driven Healthcare Systems. *FOIS*, 239–252.

https://books.google.com/books?hl=en&lr=&id=eI1xDwAAQBAJ&oi=fnd&pg=PA239&dq=Fast+Healthcare+Interoperability+Resources+Standard+(FHIR)+,+SaaS&ots=JYbvnuhCY5&sig=d_h03_QXqHVOeOtOAGAun0YmfLw

Ochian, A., Suciu, G., Fratu, O., Voicu, C., & Suciu, V. (2014). An overview of cloud

middleware services for interconnection of healthcare platforms. *2014 10th International Conference on Communications (COMM)*, 1–4.

Ouchaou, L., Nacer, H., & Labba, C. (2022). Towards a distributed SaaS management system in a multi-cloud environment. *Cluster Computing*, *25*(6), 4051–4071.

Pace, P., Aloi, G., Gravina, R., Fortino, G., Larini, G., & Gulino, M. (2016). Towards interoperability of IoT-based health care platforms: The INTER-health use case.

Proceedings of the 11th E.A.I. International Conference on Body Area Networks, 12–18. https://dl.acm.org/doi/abs/10.5555/3068615.3068621

Rezaei, R., Chiew, T. K., Lee, S. P., & Aliee, Z. S. (2014a). A semantic interoperability framework for Software as a service system in cloud computing environments. *Expert Systems with Applications*, *41*(13), 5751–5770.

Rezaei, R., Chiew, T. K., Lee, S. P., & Aliee, Z. S. (2014b). A semantic interoperability framework for Software as a service system in cloud computing environments. *Expert Systems with Applications*, *41*(13), 5751–5770.

Roe, R. (2020). Making the case for cloud: ROBERT ROE CONSIDERS THE LATEST CLOUD AND SAAS TECHNOLOGY, AND THE BENEFITS IT CAN PROVIDE TO LABORATORIES WITH TODAY'S WORKFLOWS AND AI INITIATIVES. *Scientific Computing World*, *170*(170), 10–13.

Sousa, R., Peixoto, H., Abelha, A., & Machado, J. (2023). Implementing a Software-as-a-Service Strategy in Healthcare Workflows. In S. Ossowski, P. Sitek, C. Analide, G. Marreiros, P. Chamoso, & S. Rodríguez (Eds.), *Distributed Computing and Artificial Intelligence, 20th International Conference* (Vol. 740, pp. 347–356). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-38333-5_35

Tashkandi, A. (2019). A design and experiment of automation management system for the platform as a service. *2019 Federated Conference on Computer Science and Information Systems (FedCSIS)*, 711–715. https://ieeexplore.ieee.org/abstract/document/8860045/

Tsai, W., Bai, X., & Huang, Y. (2014). Software-as-a-service (SaaS): Perspectives and challenges. *Science China Information Sciences*, *57*(5), 1–15.

Vorisek, C. N., Lehne, M., Klopfenstein, S. A. I., Mayer, P. J., Bartschke, A., Haese, T., & Thun, S. (2022). Fast healthcare interoperability resources (FHIR) for interoperability in health research: Systematic review. *JMIR Medical Informatics*, *10*(7), e35724.

Zhou, B., & Liu, W. (2013). Study on library automation management system of SaaS. *Proceedings of 2013 3rd International Conference on Computer Science and Network Technology*, pp. 144–147. https://ieeexplore.ieee.org/abstract/document/6967082/

Appendix

Interoperability in Healthcare Systems Survey

Instructions:

Please respond to the following questions based on your experiences and knowledge. Your input is valuable in addressing the challenges and improving interoperability in healthcare systems.

Section 1: Participant Information

1. Name (Optional):

2. Position/Role:

3. Healthcare Institution/Organization:

4. Years of Experience in Healthcare Industry:

Section 2: Understanding Interoperability

How would you define interoperability within healthcare systems, especially in laboratory management?

- [ ] Seamless exchange of data between different systems.

- [ ] Ability to integrate various healthcare IT platforms.

- [ ] Ensuring efficient communication between laboratory systems and other healthcare components.

- [ ] Other (Please specify): _____

From your perspective, what are the key challenges hindering interoperability in healthcare systems? (Select all that apply)

- [ ] Diverse data formats.

- [ ] Lack of standardized communication protocols.

- [ ] Incompatible data models.

- [ ] Limited support for interoperability frameworks.

- [ ] Other (Please specify): _____

Section 3: Insights on SaaS Laboratory Management Systems

Have you encountered or utilized Software as a Service (SaaS) laboratory management systems?

- [ ] Yes

- [ ] No

If yes, please rate the level of interoperability you observed with these SaaS laboratory management systems:

- [ ] Basic

- [ ] Syntactic

- [ ] Semantic

- [ ] Not applicable

What strategies have you observed or implemented to enhance interoperability with SaaS laboratory management systems and other healthcare IT platforms?

Section 4: Implications and Strategies

In your opinion, what are the potential benefits of improving interoperability in healthcare systems, particularly in laboratory management?

What strategies do you believe would be effective in overcoming interoperability challenges? (Select all that apply)

- [ ] Education and training programs.

- [ ] Collaborative partnerships between stakeholders.

- [ ] Implementation of interoperability frameworks (e.g., HL7, FHIR).

- [ ] Regulatory incentives for compliance with standards.

- [ ] Continuous improvement efforts.

- [ ] Other (Please specify): _____

Section 5: Additional Comments

Do you have any additional comments, insights, or suggestions regarding interoperability in healthcare systems, particularly in laboratory management?

Thank you for participating in this survey. Your feedback is invaluable in advancing our understanding and efforts to enhance interoperability in healthcare systems. If you have any further questions or would like to provide additional feedback, please feel free to contact us.