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ADOPTING AN OPEN SOURCE HOSPITAL INFORMATION SYSTEM TO MANAGE HEALTHCARE INSTITUTIONS

Youssef Bouidi
Laboratory of Informatics, Modeling and Systems (LIMS), University of Sidi Mohamed Ben Abdallah (USMBA), Fez, Morocco
y.bouidi@gmail.com

Mostafa Azzouzi Idrissi
Laboratory of Informatics, Modeling and Systems (LIMS), University of Sidi Mohamed Ben Abdallah (USMBA), Fez, Morocco
mostafa.azzouziidrissi@usmba.ac.ma

Noureddine Rais
Laboratory of Informatics, Modeling and Systems (LIMS), University of Sidi Mohamed Ben Abdallah (USMBA), Fez, Morocco
noureddine.rais@usmba.ac.ma

Abstract

Our paper is a comparative study of different Open Source Hospital Information Systems (OSHISs). We chose open source because of problems in healthcare management like budget, resources and computerization. A literature review did not allow us to find a similar comparison, which explains the great interest of our study. Firstly, we retrieved nine OSHISs: MediBoard, OpenEMR, OpenMRS, OpenHospital, HospitalOS, PatientOS, Care2x, MedinTux and HOSxP. Then, we used the DeLone & McLean model to evaluate information systems qualities and the SQALE method for the technical evaluation. Finally, we get OSHISs activities using open source

community statistics. In application, we used SonarQub as a SQALE implementation. As results, we get six characteristics for MediBoard (respectively OpenEMR, OpenMRS, OpenHospital, HospitalOS, PatientOS, Care2x, MedinTux and HOSxP), with a technical debt of 42.16% (respectively 53.23%, 54.5%, 65%, 66.1%, 65.2%, 56.96%, 52.13% and 75.5%). Activities statistics prove the MediBoard potential with 2381 commits and 12 contributions in 2016. Based on these results, we chose MediBoard as a solution to adapt in healthcare organizations. It is also a challenge to prove open source power in health management. As a future work, we will implement and test MediBoard modules in a real case.

Keywords

Health System, Hospital Information System, Open Source, SQALE, Technical Debt.

1. Background

Healthcare systems suffers from several problems and obstacles that disrupt the evolution of the healthcare sector. The health organization has three levels, depending on the means, the patient states and the locality. In this work, we treat the first and second level. Our study focuses on rural clinics (RC), health centers (HC), provincial hospitals (PH) and regional hospitals (RH).

This study is only one part of the integration of a HIS with the main problems affecting the health sector, such as lack of computerization, lack of budget and lack of resources. Indeed, it is a comparison of the OSHISs to choose the one that meets our needs and adopt it in healthcare institutions.

2. Introduction

Healthcare system complexity defines an organizations management problem. Therefore, it is necessary to use an Information System (IS) to make healthcare institutions management easier. Developing countries have not yet computerized its public healthcare service. This is because of the lack of resources and budget. The World Health Organization (WHO) released a report confirming the weakness of resources, the lack of investment, a very limited budget dedicated to care and the absence of a comprehensive strategy for public health research management and governance (World Health Organization, 2016). However, this service requires an IS that manages its various institutions and organizations. Nevertheless, the IT market offers us several solutions: commercial IS, free IS, complete IS, incomplete IS and open source IS. From there, we came up with the idea of using an open source solution.

The computing world has an increase in Open Source activity. Several software, Enterprise-Resource-Planning (ERP) and IS are developed under open source license to ensure freedom of use, modification and redistribution. Healthcare sector has also experienced several IT solutions. Here we are talking about the Hospital Information System (HIS), a set of technological tools that manage hospital data, such as patient information, services, doctors, nurses and logistics data. According to (Hannah & Ball, 2004), HIS is an application developed to manage the medical, administrative, legal and financial aspects of the hospital.

Open Source contribution in healthcare has given birth to OSHISs which are defined in the same way as in the HIS (Hannah & Ball, 2004), but they enjoy the benefits of activities freedom. Currently, there are several OSHISs with different qualities. Indeed, there is a divergence between OSHISs in terms of services, functional coverage, types and licenses. For this reason, we will have to compare OSHISs and choose the one adapted to our needs. However, a bibliographic study did not allow us to find any reference to an old comparison. This is the great interest of our study.

In this paper, we start by presenting a literature review, stating the history of these systems and some research cases and real experiences. Especially, the Malian experience, made by Cheick Oumar Bagayoko (Cheick-Oumar, Dufour, Chaacho, Bouhaddou, & Fieschi, 2010). Then, in the materials section, we present the OSHISs that we will compare using the detailed method in the specified section. In fact, we use the DeLone & McLean Model of IS quality (DELONE & MCLEAN, 2003) and the SQALE Method for the technical debt (Letouzey J. L., 2012) using the Sonar platform as SQALE implementation. We used also Open Source activities statistics. After the comparison, we discuss the results and give interpretations and explanations. Finally, the last section, we conclude our article with a global and final synthesis, and then declare our future work.

3. Literature Review

The first HIS was developed in 1965 by Lockheed Martin when he initiated a project to collect information on these systems (Lockheed Aircraft Corporation, 1965). Lockheed has built a HIS prototype called the Medical Information System (MIS) and tested by El Camino Hospital (Lockheed Aircraft Corporation, 1965) (Gall, Norwood, & Hospital, 1977). Initially, HIS was limited in personnel and finance management. He then began to integrate the medical

aspect of health care institutions by creating the Medical Information System (MIS), also known as the Clinical Information System (CIS) (Degoulet, 1998) (Ashish, 2008). In the 1970s and 1980s, other hospitals around the world used HIS (Krobock, 1984) with integrated capabilities such as instrument planning, recording and automation (Rubinoff & Yovits, 1977). In the 1990s, Japan used HIS to the maximum extent of hospital activities, including the preparation of health recovery insurance. In 1991, 81.6% of all Japanese hospitals used health informatics technology (Yoshikawa & Ishikawa, 1995) (Miyake, 1987). The integration of HIS with insurance association systems has also been prototyped, creating the potential for more comprehensive databases on patient medical records (Yoshikawa & Ishikawa, 1995). During this period, hospitals and developers focused on two specific objectives: Adapting the system to the clinical environment and establishing communication between HIS and other external entities (Yoshikawa & Ishikawa, 1995). The integration of HISs was still difficult because of the diversity of tasks, technical limitations, preference for departmental systems and the philosophy of developers. In this integration process, another important key was the execution of synchronous updates between heterogeneous systems and the management of communication servers (Smith, 1999) (Lenz, Blaser, & Kuhn, 1999) (Stuewe, 2002). During the 2000s, component-based, communication, distributed systems and network architectures enabled the development of a new type of HIS that improves communication standards and provides an interoperable environment for electronic health records (EHR) (Van de Velde & Degoulet, 2003).

The African experience with OSHISs has also been present in several countries. OpenMRS was the challenge of Paul Biondich and Burke Mamlin to guarantee health care access in Kenya and to fight diseases that destroy the lives of its citizens. The health situation in Kenya in 2004 prompted Paul and Burke to adopt Open Source as a solution in front of the country's financial situation and lack of resources (OpenMRS LLC, 2014). In Mali, adopting an OSHIS was a project in which Cheick Oumar Bagayoko was able to test MediBoard in 2010 (Cheick-Oumar, Dufour, Chaacho, Bouhaddou, & Fieschi, 2010). Bagayoko has proved the entirety of OSHIS by comparing the MediBoard's functionalities with the complete HIS used by the University Hospital of Marseille in France that we present its results in appendix 1. After installing it on two servers, one for testing and validation and the other for implementation and deployment, Cheick Oumar evaluated aspects of the ease-of-use and the user's (Cheick-Oumar,

Dufour, Chaacho, Bouhaddou, & Fieschi, 2010). Bagayoko obtained, as result of this experiment, five fully implemented modules as shown in Table 1, and a widely accepted system that we show the rates of obtained responses in Table 2.

Table 1 : *The implemented modules of MediBoard - Mali (Cheick-Oumar, Dufour, Chaacho, Bouhaddou, & Fieschi, 2010)*

Modules implemented in MediBoard
Management of the Patient's Medical Record
Management of the Patient Administrative Record
Tracking Practitioners' Activities
Infrastructure Management
Billing System (Entirely Developed)

Table 2 : *The use feedback of MediBoard - Mali (Cheick-Oumar, Dufour, Chaacho, Bouhaddou, & Fieschi, 2010)*

System Criteria	**Rate of responses**
Useful system	77%
Easy system	85%
Increased reliability of data	100%
Continuation of the experiment	100%

4. Materials

In this study, we choose nine OSHISs to compare their quality and define the best of them. We retrieved their source code using the SourceForge platform (SourceForge, 2017), their documentation using their official websites and their statistics using the OpenHub platform.

OpenMRS: It is a collaborative project designed to manage healthcare, especially, in developing countries. OpenMRS was a response to many challenges like the serious diseases (HIV, Malaria). Paul Biondich and Burke Mamlin from the Indiana University School of Medicine created this system in 2004. They had this idea after their academic visit to Kenya for offering them an access to health care project. It has many collaborators in different specialties as volunteers. OpenMRS exist actually in many countries around the world for research, clinical use, development, evaluation and other uses. (OpenMRS LLC, 2014)

OpenEMR: It is an Electronic Health Record for a medical practice management. It is ONC Complete Ambulatory EHR Certified with international uses. It was originally developed by Syntech organization in 2001 as Medical Practice Professional like version 1.0. Actually, the

system is on version 5 since 2017 and its code repository was migrated to the GitHub (OpenEMR Project, 2012)

MediBoard: It is an open source web application designed to manage health establishments. It is a Hospital Information System created by Thomas Despoix and Romain Ollivier. This HIS is actually until version 0.4.0 developed by the OpenXtrem organization. It is a modular system based on web technologies to handles all patient files, workflows and planning of all health establishment activities. (MediBoard, 2014)

HospitalOS: It is a HIS and a research / development project designed to every small-sized hospital. Hospital OS was created and developed for Thailand community. It is actually until 3.9 version and it is featured especially by the treatment of patients. (Webster, 2011)

Care2x: It is an integrated HIS started as "Care 2002"project in 2002. The first official release was until version 1.1 in 2004. In 2003, the project name was changed to Care2x. The last stable release was in 2012 until version 2.6.29. Its design can handle both of medical and non-medical services. Care2x has many features that include especially the smart search and the multiple custom languages. (care2x, 2013)

OpenHospital: It was developed by Informatici Senza Frontiere, in collaboration with students of Volterra San Donà di Piave Technical highschool, in 2005. It was implemented at St Luke's Hospital, Angal, in Nebbi District, Northern Uganda. It was used also in Kenya, Afghanistan, Benin and Congo. Actually, this HIS is at its seventh release, which is multi-user, has an extended patient database, has a historical integrated patient and gives an internal communication, reports and statistics. (Informatici Senza Frontiere, 2014)

MedinTux: It was initiated by the doctor Roland Sevin since ten years. It is distributed under the CeCiLL V2 license which is equivalent to the GPL license adapted to the French legislation. It was originally written for French emergency services, it can be used in a multi users environment and offers many features like consultations, prescriptions, real time visualization and statistics (MedinTux, 2012)

HOSxP: It is a HIS used in over 70 hospitals in Thailand. It was called KSK-HDBMS. Its development started in 1999 by Suratemekul to be continued by employers of its company Bangkok Medical Software. It is distributed under a GPL license and free only for its Primary Health Care Unit version. (SourceForge, 2002)

PatientOS: It is a HIS for small hospitals and clinics. It is a web-based application under the GPL license. (SourceForge, 2007)

5. Method

After collecting the source code of the OSHISs, we move to the stage of examining them. This comparative study concerns their qualities, so we will evaluate them to select the best one to adopt. The DeLone & McLean model offers three dimensions of IS quality evaluation. Initially, in 1992, this model defined only the system and information quality as the two only dimensions that judged the IS quality (DELONE & MCLEAN, 2003).

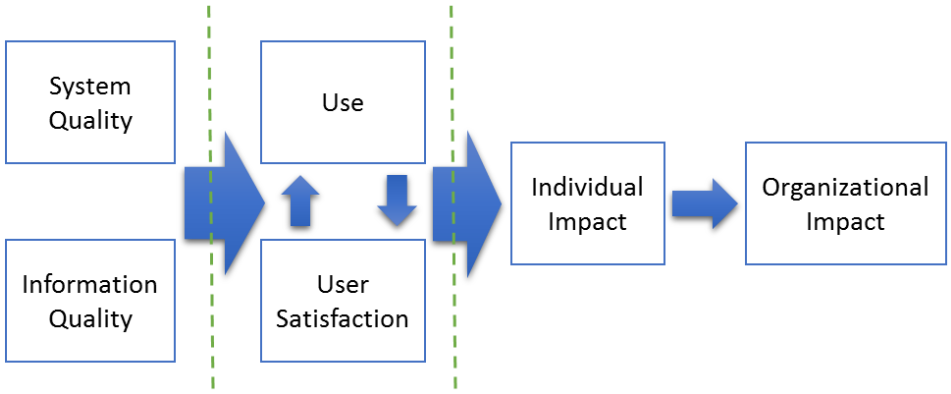

Figure 1: *The first model of DeLone & McLean (DELONE & MCLEAN, 2003)*

An easy access, a short response time and practical tools for users determine the system quality, which contributes to a more efficient work. The information quality produced is determined by information accuracy, accessibility, completeness and reliability.

However, as the figure 1 shows, this model cannot judge the IS quality without use, examination of user satisfaction and verification of impact on the concerned organization. For this reason, this model was improved in 2003 by adding a third dimension concerning quality of service (DELONE & MCLEAN, 2003).

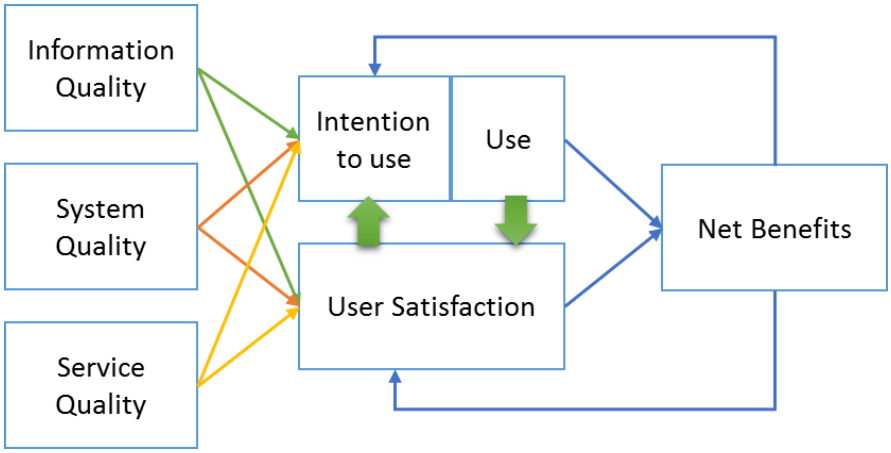

Figure 2: *The improved model of DeLone & McLean (DELONE & MCLEAN, 2003)*

This model was implemented in another one that specify clearly the third dimension. As mentioned in the figure 3, directly or indirectly, the service quality plays an essential role in IS quality evaluation. It is defined directly by the IS technical support and indirectly by the system and the information qualities. (Bharati & Berg, 2005)

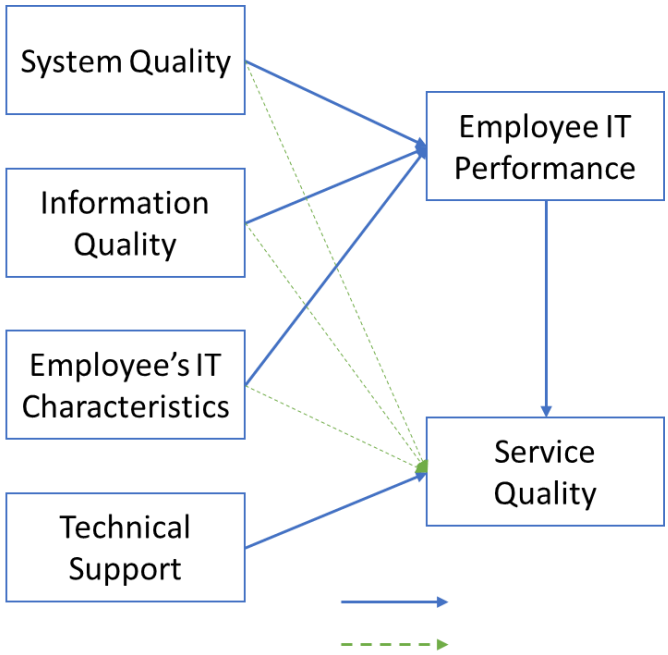

Figure 3: *The service quality Model of a management information system (Bharati & Berg, 2005)*

Technically speaking, the technical measures of an IS define directly the provided service to final users. SQALE method is a method that measures technical quality using technical debt

concept. The system and information define also, indirectly, the service quality through the IT performance of the organization's employees.

The SQALE method is based on the technical debt concept, which consists of measuring the quality indices of the technical IS characteristics after having analyzed them. The quality indicators present these measures by defining the technical debt that characterizes each of IS characteristics. (Letouzey J.-L. , 2016)

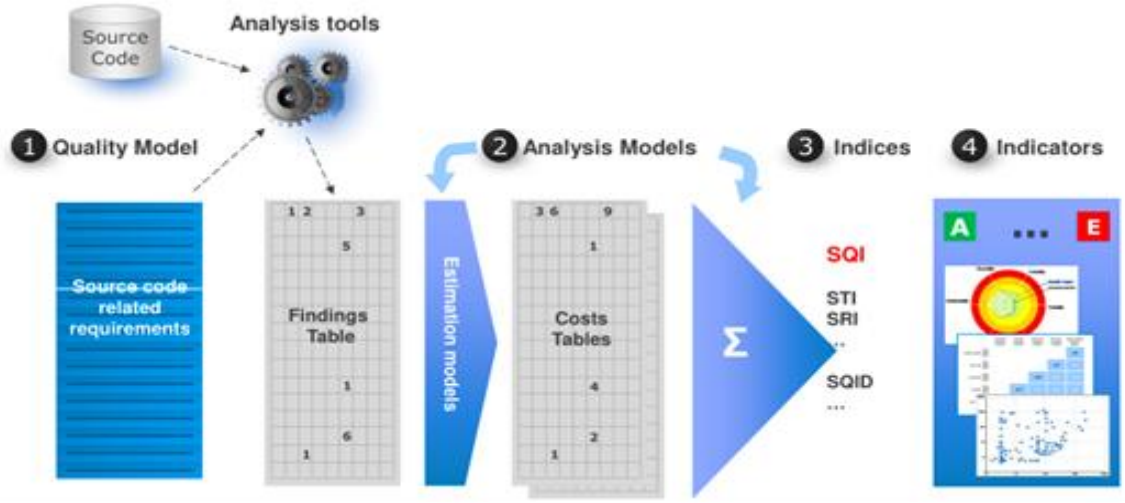

Figure 4 : *The SQALE method structure (Letouzey J. L., 2012)*

The quality model proposed by this method aims to organize the non-functional requirements related to the quality of the code. It is organized in three hierarchical levels. The first level is composed by derived characteristics coming from quality standards as factors to describe the source code quality, such as stability, reliability, changeability, efficiency, security, maintainability, portability and reusability. The second level, called sub-characteristics, used to combine requirements groups in two types: those that correspond to life cycle activities and those generally recognized as taxonomic results. The third level includes the requirements of the internal source code attributes. (Letouzey J.-L. , 2016)

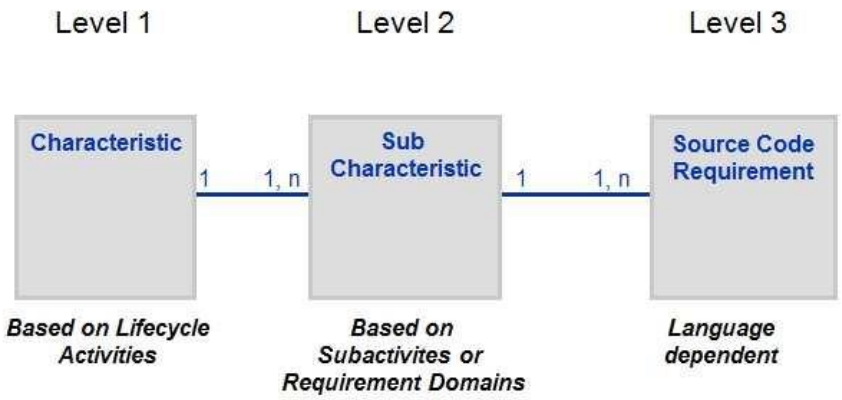

Figure 5 : *The quality model levels of the SQALE Method (Letouzey J.-L. , 2016)*

Figure 6 : *The characteristics of SQALE quality (Letouzey J.-L. , 2016)*

According to Jean-Louis Letouzey (Letouzey J.-L. , 2016), the SQALE analysis model performs two main tasks: the first applies rules to standardize measures by transforming them into costs and the second sets rules to aggregate these standardized values. The SQALE method defines the cost aggregation rules either in the quality model tree or in the artefact hierarchy of source code.

The indices of this method represent the costs and they are measured on the same scale in order to manipulate all authorized operations for this kind of scale. Jean-Louis Letouzey confirmed that the characteristic indices of SQALE are the Testability Index (STI), Reliability Index (SRI), Changeability Index (SCI), Efficiency Index (SEI), Security Index (SSI), Maintainability Index (SMI), Portability Index (SPI) and Reusability Index (SRuI) (Letouzey J.-L. , 2016).

By summing all remediation costs, related to all quality model requirements, the remediation cost of all quality model characteristics can be estimated. This measure is the SQALE Quality Index: SQI. The SQALE quality index is an implementation of the associated technical debt concept to the source code.

The SQALE method defines four indicators related to the quality characteristics, allowing a highly synthesized representation of the IS quality (Letouzey J.-L. , 2016). The SQALE rating consists to produce a derived measure or an ordinal scale subdivided in five levels from A (Green) to E (Red). The Kiviat diagram consists to present the SQALE evaluation in concentric areas and targeting the quality of each project according to its values. It presents in the same diagram all compared projects characteristics ranking according to the quality model. The SQALE pyramid helps to make appropriate decisions with considering the dependence between quality characteristics model and the IS life cycle. The fourth indicator is the SQALE Debt Map, which represents the artefacts of the assessment scope drawn on two dimensions: the first is the technical debt (SQI) and the second is the business impact (SBII). (Letouzey J.-L. , 2016)

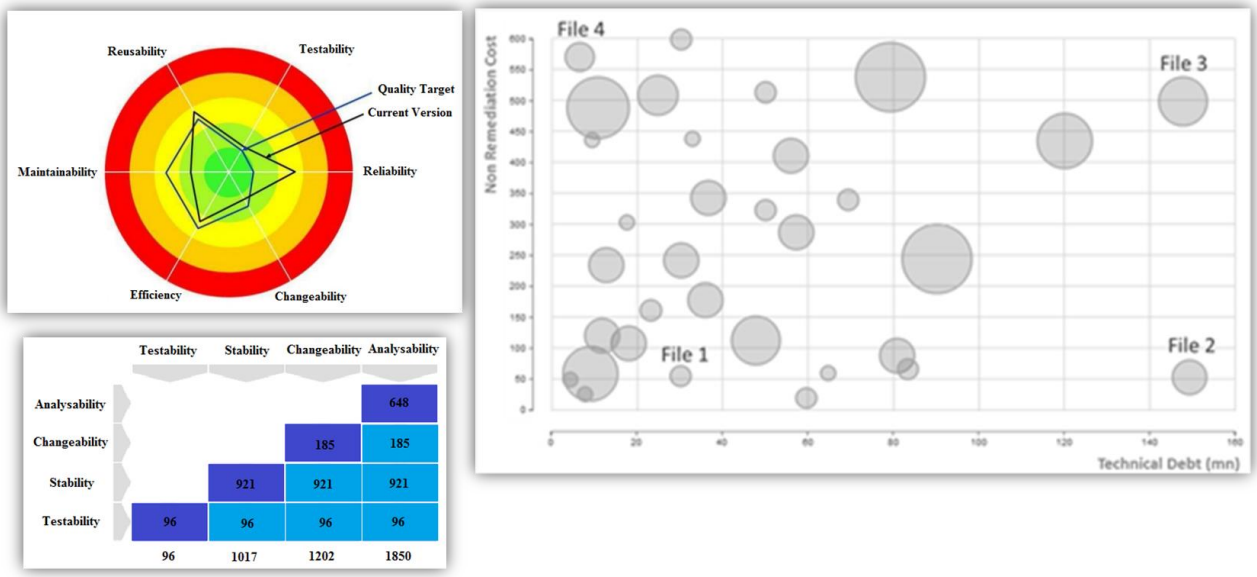

Figure 7 : *The quality indicators of SQALE method (Letouzey J. L., 2012) (LETOUZEY, 2014)*

To implement this method we used the SonarQub platform (SonarSource, 2017). It has a scanner that analyzes the source code to determine the characteristics and attribute them their technical debt scores. This platform respects the Client-Server architecture. In the server, the SQALE method is implemented in order to evaluate the source codes and to send to the Client

the measures to be presented in indices form and indicators that allow us the subtraction of the according technical debt to each characteristics.

Concerning system and information quality measurements, there are several models that implement the DeLone & McLean model. The implementations DeLone & McLean (2003, 2004) and Holsapple & Lee-Post (2006) have confirmed the criteria that allow the system and information evaluation. These judgments have to be recovered from the final users of IS.

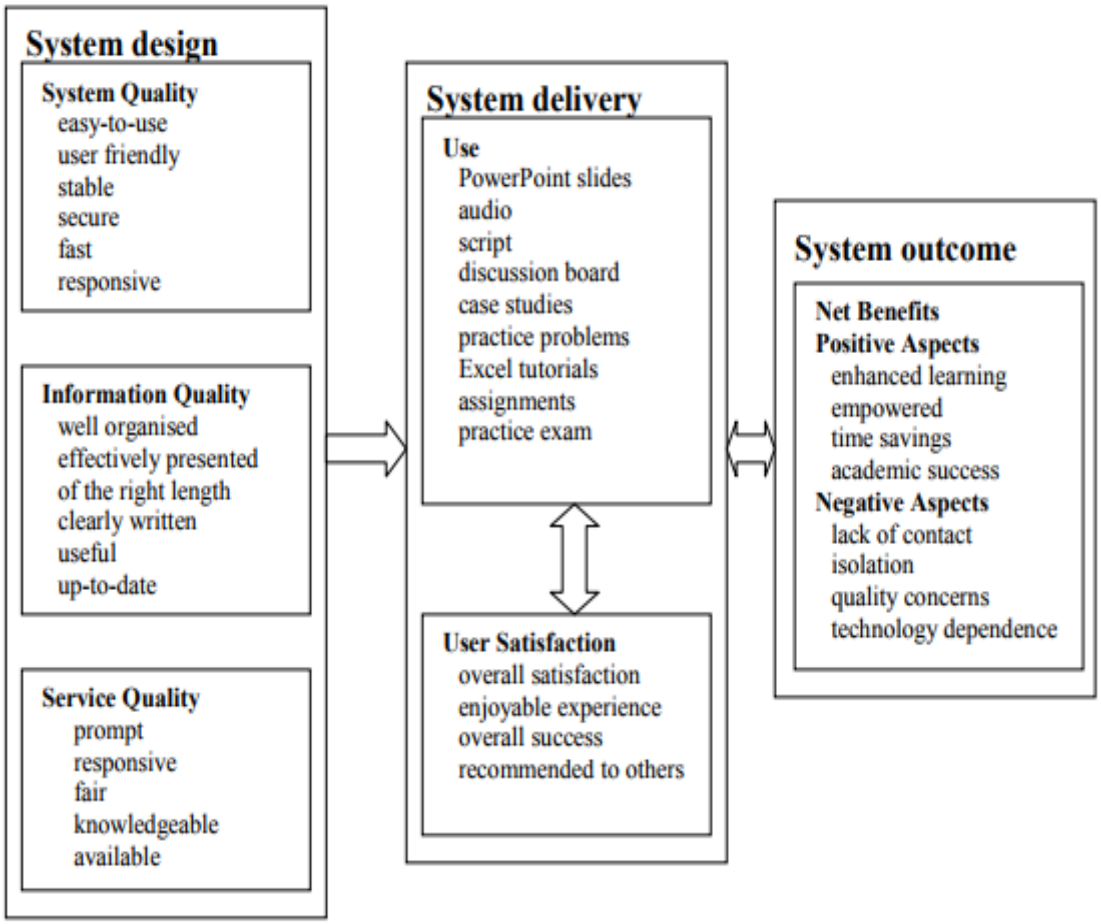

Figure 8 : *Holsapple & Lee-Post model (Dorobat, 2014)*

In our work, we will only examine the technical side in order to compare the OSHISs and judge their service qualities. After loading the source code in the SonarQub platform, we analyzed each of the measurements retrieved by the Sonar server that implements the SQALE method. Subsequently, we recovered the measures and indicators that we will present in the next section and discuss them in order to confirm the choice of the good OSHIS.

On the other hand, because we are working on open source solutions, it is necessary to compare the OSHISs activity. To accomplish this step, we used the OpenHub platform, which presents the Open Source community feedback by statistics form. Its statistics set up two important criteria; we are talking about contributions and commitments. Therefore, to examine the OSHISs activity, we will compare the two criteria retrieved directly from the Open Source community. (Black Duck Software, 2016)

6. Results

The method mentioned in the previous section allowed us to have a set of results that prove the technical potential of MediBoard among other OSHISs. The measurements obtained from the SonarQub platform were Reliability, Security, Maintainability, Complexity, Documentation and Rules Compliance.

Technically speaking, the SQALE method implementation, SonarQub, has determined six characteristics that have been evaluated for MediBoard (respectively OpenEMR, OpenMRS, OpenHospital, HospitalOS, PatientOS, Care2x, MedinTux and HOSxP) with a debt of 42.16% (respectively 53.23%, 54.5%, 65%, 66.1%, 65.2%, 56.96%, 52.13% and 75.5%) for the SQALE Quality of Technical Support. In Table 3, we present the details of the obtained results recovered from the SonarQub for each OSHISs.

Table 3: *Classification of OSHISs according to their SQALE quality debts*

OSHISs	Reliability	Security	maintainability	RC	Complexity	Documentation	SQ
MediBoard	36,4%	24,8%	21,4%	70,8%	2,4%	97,2%	42,16%
MedinTux	60,6%	43,2%	27%	80,2%	23,2%	78,6%	52,13%
OpenEMR	62%	42,8%	25%	89%	4,2%	96,4%	53,23%
OpenMRS	58,4%	65,4%	26,8%	58,4%	20,6%	97,4%	54,5%
Care2x	56%	80,6%	24,4%	83%	38,8%	59%	56,96%
OpenHOspital	64,6%	62,4%	74,6%	95,4%	13,6%	79,4%	65%
PatientOS	73,4%	62,8%	43,4%	72,8%	48,6%	90,2%	65,2%
HospitalOS	74,2%	56,4%	63,6%	65,4%	41,4%	95,6%	66,1%
HOSxP	92%	84%	41,4%	77,4%	60,2%	98%	75,5%

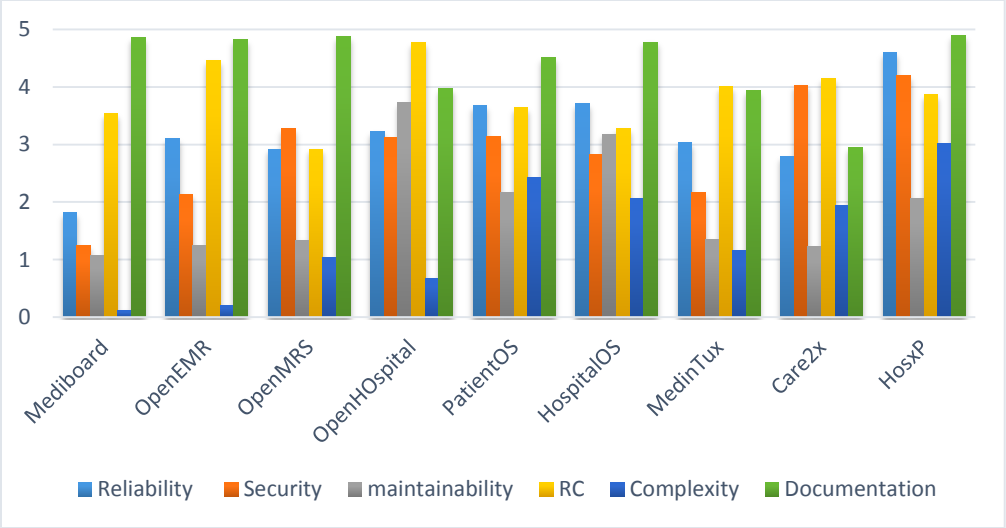

Figure 9: *The technical debts of the SQALE characteristics of the OSHISs*

These results have proved the technical potential of MediBoard. Indeed, its minimal debt with a complexity of 2.4%, a maintainability of 21.4% and a reliability of 36.4 and a security of 24.8%; We conclude that this OSHIS insured the technical support, i.e. MediBoard has won the third dimension challenge, which directly affects the IS service quality according to the DeLone & McLean model.

This technological aspect in the IS presents a basis for the rest of the dimensions. Indeed, the technical test allowed us to examine implicitly the other axes that constitute the IS. The reliability and security of data proves the MediBoard advantage of health information. Because hospital information is sensitive and requires a degree of confidence and protection, the examined characteristics prove the power of the MediBoard quality in front of the rest of the OSHISs. Not only the information quality, but also MediBoard has won the system evaluation challenge by the technical examination of complexity and maintainability. This OSHIS proves its strength by a minimal technical debt in the most complicated difficulty of the health system and the management of its institutions. In other words, MediBoard marks its advantage by reducing the complexity of the system.

Being an HIS is an obligation to respect international health standards. The HL7 standard and others play an essential role in the patient circuit management in healthcare facilities and in the information interoperability. The results obtained by SonarQub have selected the legal compliance in all rules and standards as one of the examined characteristics. According to the same characteristic, MediBoard, technically speaking, was in third place behind OpenMRS and

HospitalOS. The table in appendix 2 shows that MediBoard dispose of interoperability as a detected criterion on its transport layer, connected collaboration servers and internationally respected formats.

Finally, the evaluation of the Open Source Activity of each OSHISs was based on the measurement of contributions and commitments. This study showed the potential of MediBoard in the open source community by 2381 commitments and 12 contributions in 2016. This proves that MediBoard has ensured its value and interest for the developers who contribute to its improvement. These results, retrieved from the confirmed statistics of the OpenHub platform, Affirms that the quality of HIS can be measured by focusing on the interest that presents this HIS to developers and users.

Table 4: *Open Source HIS Activities in 2016 (Black Duck Software, 2016)*

HISs	Commits	Contribution
OpenEMR	1566	58
OpenMRS	522	81
MediBoard	2381	12
Open Hospital	70	2

7. Conclusion

The adoption of Open Source has been a challenge to manage first and second levels of healthcare institutions despite problems of which suffers this sector. Our study was more than a comparison between the chosen OSHISs; we proved also the power and quality of these ISs as well as their services.

In this study, we proved that MediBoard is the best OSHIS to adopt. However, this confirmation is only a result of all bibliographic study, technical evaluation and a statistical study. According to the DeLone & McLean model and its implementations seen previously in this paper, we still have to evaluate the information and the system qualities, by user's feedback, in order to confirm the total service quality.

Therefore, as a future work, we will implement completely MediBoard, propose it to a hospital for testing its functionalities, offer the users a questionnaire that implements the DeLone & McLean model and, finally, study the obtained results to adapt this solution following their needs and suggestions and to improve its quality.

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APPENDICES

Appendix 1: Functional requirements of Marseille's University Hospital versus MediBoard

(Cheick-Oumar, Dufour, Chaacho, Bouhaddou, & Fieschi, 2010)

Standard HIS features	MediBoard
Care Management	
Registration	X
Appointments & Scheduling	X
Management of Movement (Transfers)	X
Care Plan Management	X
e-prescription (acts, medicine)	X
Nursing	X
Report and Mail Management	X
Logistics	X
Resource Management (stocks, human, materials)	X
Clinical Research, Epidemiology, Statistics and Education	X
Health Information Exchange	X
Laboratory management (orders)	
Pharmacy management	X
Imaging	X
Exploratory Procedures	
Emergency Department	X
Surgery Department	X
Admin functions	
Patient identity management	X
Outpatient Visits, Admissions, Stays	X
Bed Management	X
Evaluation of production activities (French PMSI Management)	X
Billing	X
Facility Management	
Access Management Rights/Entitlements	X
Activity Management	X
Medical Economics Management	X
Accounting and Record	X
Human resources	X
Equipment Management	X
Purchasing/Inventory	X
HIS Environment Management	
HIS Infrastructures	
Monitoring and Planning Tools	
Communication Management	X
Repositories and Terminology Management	X
Other Features	
Clinical Decision Support	

Digital Work Space	X
Data Warehousing	
Quality of Care Assessment	X

Appendix 2: The characterizing criteria and indicators of MediBoard (MediBoard, 2014)

Indicators			Results
activity	**Contributors**		23
	Commits		30834
interoperability	**EAI**	**Formats**	HL7, HPRIM, MB-HPRIM
		Collaborations	Patient Identity Server Server of Patient Mouvement Actes Server
		Transport layer	FTP, SOAP
	IHE		PAM, PDQ, DEC
traceability	**Journaling**		logs systems
			Access logs
			Users logs
Code	**PHP**		57,5%
	XML		14,3%
	HTML		16,5%
	XML Schema		5,4%
	JS		4,1%
	Other		2,2%
language	**code**		common.php , [module].php
	application		Maintenance of translation Translation of modules
	standard		Strategy of Internationalization and localization
security	**server**		LDAP
	application		Authentication
	Management		user permission
Usability	**France**		Today, more than four million patient files are managed with MediBoard. With more than 30,000 users and 60 facilities, the deployment covers nearly 6,000,000 stays and 4,500,000 patients.
	Switzerland		
	Belgium		