A Systematic Method for Evaluating Implementations of Electronic Medical Records Systems in Low- and Medium-Income Countries

Philomena Njeri Ngugi

Thesis for the degree of Philosophiae Doctor (PhD)
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Name: Philomena Njeri Ngugi

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To my husband Ngugi Gittao,

Our children Gitau, Ivy, Francis and Naomi.

Scientific environment

This research is a result of the collaboration between Moi University-Kenya, University of Bergen-Norway, and Makerere University-Uganda, under the Health Informatics Training and Research in East Africa for Improved Health Care (HI-TRAIN) project. HI-TRAIN project was supported by the Norwegian Programme for Capacity Building Development in Higher Education and Research for Development (NORHED), under the Norwegian Agency for Development Cooperation (Norad) that funded this PhD scholarship. Norwegian Research School of Global Health also offered PhD courses that contributed to the course credits as well as travel grants for scientific conferences.

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Table of Contents

List of tables

List of figures

Abbreviations

CDC	Centres of Disease Control
CIEL	Columbia International eHealth Laboratory
C&T	Care & Treatment
D&M	DeLone and McLean
DS	Design Science
DSR	Design Science Research
EHR	Electronic Health Records
EMRs	Electronic Medical Records system
FEDS	Framework for Evaluation in Design Science
FGD	Focus Group Discussion
HIE	Health Information Exchange
HTS	HIV Testing & Counselling Services
IL	Interoperability Layer
IS	Information System
ISO	International Organization for Standardization
ISU	Information system use
ICT	Information and Communication Technology
IT	Information Technology
KeHMIS	Kenya Health Management Information System
KHIS	Kenya Health Information System
LMICs	Low-and Medium Income Countries
MER	Monitoring, Evaluation and Reporting
MFL	Master Facility List
MMR	Mixed Methods Research
MoH	Ministry of Health
NASCOP	National AIDS and STI's Control Programme
NGT	Nominal Group Technique

OpenMRS	Open Medical Records System
PEPFAR	President's Emergency Plan for AIDS Relief
PMTCT	Prevention of Mother-to-Child Transmission (PMTCT
POC	Point of Care
RDE	Retrospective Data Entry
SDPs	Service Delivery Partners
SMART	Specific Measurable Achievable Realistic and Time-bound
SNOMED	Systematized Nomenclature of Medicine
SOP	Standard Operating Procedures
USAID	United States Agency for International Development
WHO	World Health Organization

Abstract

Background: Implementations of Electronic Medical Record systems (EMRs) in healthcare industry in Low- and Middle- Income Countries (LMICs) have been on the rise in recent years driven by the promise of improvements in quality of patient care, patient safety, and cost reduction. Several LMICs, including Kenya, Uganda, and Mozambique have rolled out EMRs within public facilities at a national level. By nature, EMRs implementations are complex, disruptive, costly, and have a potential to restructure workflow processes. Successful EMRs implementation depends on numerous factors, often going beyond a simple consideration of the technology used. While LMICs have embraced national-level EMRs implementations, little evidence exist on how to systematically evaluate success of these implementations. Hence, the aim of this research was to develop and apply a systematic method for evaluating the state of EMRs implementations based on Information Systems (IS) *use* construct.

Methods: This research was anchored on Design Science Research (DSR) methodology. We employed DSR process model by Vaishnavi et al. five steps in the development of the artefact, namely: awareness of problem, suggestion, development, evaluation, and conclusion. The development step comprised of three sub-cycles that included development of EMRs use indicators utilizing Nominal Group Technique (NGT) process, application of the resultant EMRs use indicators to assess the actual state of EMRs implementations in the case study, and qualitative inquiry to identify barriers and facilitators to EMRs use through Focus Group Discussions (FGD) technique. The application of the quantitative and qualitative phases of the study were synthesized to give the overall result of the state of EMRs implementations in real environment settings.

Results: A systematic method of evaluating the actual state EMRs implementations comprising of three sub-cycles was developed. The sub-cycles outputs were as follows: a set of fifteen indicators and metrics for monitoring and evaluating actual EMRs use, hinged on four dimensions namely: system use, data quality, interoperability, and reporting (sub-cycle 1); low system usage levels which pointed to salient challenges

such as poor management of EMRs user accounts (sub-cycle 2); and EMRs use facilitators such as ease of use, ease of learn, system functionalities, adequate training, timely technical support, and collegial support were identified. However, factors related to infrastructure such as lack of power backup plan and insufficient hardware, as well as EMRs operation mode remain significant barriers to EMRs use (sub-cycle 3). The findings of these sub-cycles were used to validate the proposed methods and framework.

Conclusion: Continuous monitoring and evaluation of information systems implementations for successful scale-up and sustainable initiatives remains paramount. The developed method to systematically evaluate the state of EMRs post-implementations can be applied in similar settings in developing countries. The study results provide relevant and actionable information that can benefit EMRs users, ministries of health, EMRs implementing partners, and funding agencies.

List of publications

This thesis is based on the following original papers, which were published in peer reviewed international conference proceedings as well as open access journals (CC BY and CC BY-NC licenses) :

I. Ngugi P, Were MC, Babic A (2018). Facilitators and Barriers of Electronic Medical Records Systems Implementation in Low Resource Settings: A Holistic View. Stud Health Technol Inform. 2018; **251**:187-190.

II. Ngugi P, Babic A, Kariuki J, Santas X,Naanyu V, Were MC (2021) Development of standard indicators to assess use of electronic health record systems implemented in low-and medium-income countries. PLoS ONE 16(1): e0244917. https://doi.org/10.1371/journal. pone.0244917. PMID: 33428656; PMCID: PMC7799790.

III. Ngugi P. N., Gesicho MB, Babic A, Were MC (2020). Assessment of HIV Data Reporting Performance by Facilities During EMR Systems Implementations in Kenya. Stud Health Technol Inform. 272:167-170. DOI: 10.3233/SHTI200520. PMID: 32604627.

IV. Ngugi P, Babic A, Were MC (2021). A multivariate statistical evaluation of actual use of electronic health record systems implementations in Kenya. PLoS ONE 16(9): e0256799. https://doi. org/10.1371/journal.pone.0256799.

V. Ngugi P, Were MC, Babic A. Users' Perception on Factors Contributing to Electronic Medical Records Systems Use: A Focus Group Discussion Study in Healthcare Facilities Setting in Kenya. (Manuscript) In Press – accepted for publication in BMC Journal.

Related Publication

1. Ngugi Philomena N., Milka B. GESICHO and Ankica BABIC. How introducing Electronic Medical Records (EMR) Systems affected HIV health data indicators reporting performance. In Press (Manuscript)

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Chapter 1

1. Introduction

1.1 Background

The proliferation of information technology in the recent past has seen many organizations spending large sums of money in implementing information systems to support their daily operations, with a view to gaining competitive advantage as well as enhancing performance among other benefits [1, 2]. In the healthcare industry, implementation of Information Systems (IS) is mainly driven by the need for evidence-based practice for quality patient care, patient safety and also cost reduction [3]–[5]. As a result, many health information systems for clinical decision support, diagnosis and patient management, such as Electronic Medical Record Systems (EMRs), have been implemented widely. EMRs are defined as computer-based health information systems that record and store medical and treatment history of patients in one practice [4, 6]. International Organization for Standardization (ISO) defines Electronic Health Record (EHR) as “a repository of patient data in digital form, stored and exchanged securely, and accessible by multiple authorized users” [7]. Thus, EHR systems (EHRs) goes beyond clinical data collected in one provider’s office. Electronic records systems in health care are named inconsistently in the literature and used interchangeably as EMRs or EHRs. For the purposes of this research, we used the term EMRs.

Generally, information systems implementation projects comprises of pre-implementation, implementation and post-implementation phases [8–10]. These phases involve interplay of people, processes, and technology. The pre-implementation phase is the intensive planning involving various stakeholders, including project leadership, implementing partners and system end-users [11]. At this stage, project planners decide on the systems to be implemented, select implementation sites, determine the implementation approach, procure materials and equipment, and prepare the site for implementation [12]. During the implementation phase, the actual installation and activation of the selected information system begins. Implementation often involves workflow redesign, initial user training and troubleshooting among other activities.

Post-implementation phase revolves around ensuring the smooth running of the implemented system by conducting regular maintenance and upgrades as needed [13]. Strengthening of the user capacity through structured mentorship and on-job-training are emphasized during this phase.

1.2 State of EMR Systems Implementations Globally

The adoption of EMRs in healthcare industry has been on the rise in the recent years driven by the promises of improved quality patient care, patient safety and cost reduction [4, 5, 14, 15]. Many of these potential improvements in care emanate from supporting day-to-day patient management and clinical decisions [16]. EMRs have been introduced widely in many countries worldwide. In the US, EMRs have been in use for over 30 years, with the adoption rates in non-federal hospitals increasing from 9.4% in 2008 to 96% in 2015 [17]. Similarly, Australia has had high rates of EMRs adoption with more than 90% of general practices having some form of EMRs [18] while in New Zealand, all general practices use EMRs [19]. In Denmark EHRs adoption has been part of national Information Technology (IT) strategy since 1990 while in the Nordic countries, the EHRs has become a standard tool for clinicians [20]. This adoption trend has been followed by majority of European countries.

Low- and medium-income countries have also been keen in adopting EMRs. The adoption efforts in India were not just focused on technology to achieve successful Health Information Exchange (HIE) but also important healthcare policy decisions crucial for daily operations [21]. According to a study conducted by Akanbi et al. [22], implementations of EMRs in Sub-Saharan Africa are largely driven by HIV treatment international programs such as President's Emergency Plan for AIDS Relief (PEPFAR) [23]. This is unlike in developed countries where EMRs implementations are majorly driven by governmental directives, incentives as well as advancement in technology use in service delivery [24].

Although adoption of EMRs in developing countries has been on the rise, the adoption rate especially in Africa is very slow compared to developed countries and their use are more in administrative rather than in clinical support [23]. A worldwide glimpse shows

EMR/EHR slow adoption rates in developing countries has been due to various issues such as prohibitive costs, security concerns, and interoperability among others [25, 26]. In fact, statistics in 2013 reveals struggle of EMRs implementations with an estimated 73% of the implementations “not using the system as intended 12 months after implementation” [4]. World Health Organisation (WHO) has however published a manual for guiding implementations of EMR systems in developing countries with a view to harness their potential in care delivery [27].

Adoption or implementation of a health information system, however, does not mean use or being used in the way it was intended. Evaluation is therefore necessary to determine success or failure of the implemented system [28, 29].

1.3 Evaluation Approaches

Evaluation is the systematic assessment of implementation of an object using standard social research methods to provide useful feedback, where the object can refer to a program, technology, or a policy [30, 31]. Evaluation involves a critical look at the implementation enablers and barriers in order to provide solutions that maximize benefits across the implemented system or system under evaluation [31]. In the context of health information systems, evaluation is defined as ‘the act of measuring or exploring properties of a health information system (in planning, development, implementation or operation), the outcome of which informs a decision to be made concerning that system in the specific context’ [32]. While conducting evaluation study, practical lessons are learned which may not be unique to the specific area under research.

While there are various types of evaluations, the most basic and distinct types are formative and summative [31]. Formative evaluation activity takes place during the process of development as well as implementation of IS [33]. This type of evaluation is aimed at providing feedback to system developers or implementers for adjustments/improvements to increase chances of project success. Conversely, summative evaluation, also referred to as outcome or impact evaluation, is conducted after system development and implementation [33]. It provides information that demonstrates implementation effectiveness and outcomes regarding initially set objectives or specified success criteria.

An Information System (IS) project is considered successful when it is completed on-time, on-budget and with all features and functionality as initially specified [34]. However, according to Standish Group Report (2020), 69% of IT projects in 2019 failed or had challenges [35]. Given this high failure rate and the enormous investment involved in system design and development, infrastructure, implementation, training and IT support in both IS acquisition and implementation, necessity for evaluation is recognised that can contribute greatly to information systems success [28, 36–38]. Consequently, it is recommended that evaluation should be carried out at the different phases throughout the system's development cycle, from feasibility study to system development, implementation and post-implementation to increase the chances of success [30, 31]. In particular, post-implementation evaluations are essential in demonstrating the effectiveness of implementations and as a way of measuring return on investment [8]. IS success concept is widely accepted throughout IS research as the principle criteria for evaluating information systems [39].

Despite the importance of evaluation in guaranteeing IS success, it is not an easy and straightforward task for two main reasons. Firstly, there exists a wide range of IS evaluation methodologies, each having their own strengths and limitations [33, 40]. Secondly, aims and focuses of evaluation varies due to the different stages of the IS lifecycle which are associated with different goals, changes, and outcomes. Confronted with these diversities and complexities, practitioners and evaluators may often find it difficult to select which methodology is the most suitable one for evaluating a particular IS project or a particular stage of the project. Previous EMRs evaluations studies have assessed several different factors including provider satisfaction, patient satisfaction, quality of the services provided or changes in the efficiency of service [41].

EMR systems implementations are complex, multi-faceted and impact healthcare organizations on many levels especially in workflows (business processes) [42, 43]. Consequently, there are high chances of dismal performance, which may be unknown especially in public healthcare facilities. On the other hand, given the significant up-front investments involved in EMRs implementations, stakeholders (sponsors, donors and the management) are demanding demonstrated value of the implementations to inform further or future investments as well as sustainability of the implementations [44]. Thus, evaluation research in this field is becoming important with a view to answer key questions regarding the implementation effectiveness and economic value. Nevertheless, Stylianides et al. point out that there is no ideal or specific way of evaluating information systems in healthcare [45].

A summative evaluation was chosen for this evaluation study, with the unit of analysis being *system use*, which could only be possible in the post-implementation phase. By the time of this study, EMRs implementations in healthcare facilities in Kenya had been going on since 2012. The study covered eight years of the adoption period (2012-2019).

1.4 Problem Statement (The gap)

Recognizing the role EMRs play in patient data management, the Government of Kenya Ministry of Health (MoH) with the support and technical assistance of international partners namely Centres of Disease Control (CDC) and United States Agency for International Development (USAID) have had over 1000 EMR systems implementations countrywide. The main EMR systems implementations are IQCare and KenyaEMR overseen by a local implementing partner; Palladium through KeHMIS II project as mandated by CDC [46, 47]. As mentioned earlier, EMR systems implementations involves a significant up-front investments in software design and development, infrastructure, implementation, training, clinic-level operating costs, and IT support, hence evaluation to determine success of the implementations is paramount [48]. Previously, clinical site readiness evaluation was conducted by the implementing partners between 2012-2014 preceding the EMR systems implementations as a measure towards successful implementations. Nevertheless, despite the mass rollouts of the EMR systems in clinical facilities countrywide, the state of knowledge regarding success or failure of the implementations was relatively minimal as no post-implementation evaluation have been conducted on their use in patient data management and care delivery.

While there exists many IS success models that have been validated using various information systems in developed countries, there is compelling evidence that IS success models need to be carefully specified in a context [40, 49]. There is need therefore for best approaches for post-implementation evaluation of EMR systems for developing countries due to their unique challenges such as inadequate computer to user ratio and power blackouts among others, which pose a challenge to expected daily systems' use in health care delivery. Therefore, this study set out to develop a systematic method for evaluating the state of EMR systems based on EMR system *use* construct of the validated DeLone and MacLean (D&M) IS success model (see Figure 3, sub-section 2.2.1). "*Use*" refers to partial or complete use of the EMR system to document patient information or for care delivery.

1.5 Justification of the study

While only 20 percent of an information system's value is created during the system development process, 80 percent of its value is realized during its subsequent use [50]. Furthermore, Doll & Gholamreza point out that both academics and practitioners recognize that the potential of IT depends on how it is used [51]. Consequently, "*use*" and its outcomes (net benefits) should be the primary focus of IS success measurement within organizations. Literature reveals substantial evaluations of EMR systems implementations in developed countries, while this is not the case for developing countries [6, 52–57]. Most of the EMR systems evaluations conducted in other settings are facility-based, hence lack national representation [58]. On the other hand, nationally endorsed indicators and metrics for measuring EMR systems *use* in developing countries context are largely unknown. The proposed research therefore provides an opportunity to avail these tools (EMR system use indicators) as well as knowledge, by conducting a comprehensive evaluation of the national EMR (KenyaEMR) implementations status in healthcare facilities in Kenya. André et al. point out that new knowledge is a source for innovation in an intellectual environment [59]. Thus, this research was conducted to gain new knowledge towards evaluation approaches in LMICs. In particular, the aim of this research was to collect new data to provide the basis for action and recommendation.

Hence, evaluating implementations of EMR systems in Kenya provided an extraordinary opportunity to disseminate best practices for evaluating EMR systems implementations in other similar settings with a view to ultimately mitigate negative effects and promote optimal performance. Consequently, this research provides Kenya with a unique opportunity to become a leader in evaluation studies of EMR systems implementations in low resource settings.

1.6 Context of the Study

The study was conducted in Kenya, a country in East Africa with approximately 50 million persons [60]. As mentioned earlier, MoH has had over in over 1,000 public health facilities countrywide implemented with EMRs. These systems mainly serve HIV, Tuberculosis (TB), and Maternal and Child Health (MCH) clinics, with a view to expanding them to other health care domains in future [61]. The implementation of these systems varies in the mode of operation from one healthcare facility to another. The modes include paperless, point of care (POC), retrospective data entry (RDE), and hybrid modes that include both POC and RDE within the same facility. While two EMRs (KenyaEMR and IQCare) provided by different vendors were initially endorsed for national deployment in support of HIV care, the country has since 2019 transitioned to supporting and deploying only KenyaEMR system (KeEMRs). As such, sites running IQCare are being transitioned to KeEMRs. It is for this reason that we decided to focus on the sole system to be used within the country moving forward.

1.6.1 The KeEMR system

KeEMR system, is an open-source electronic medical records system that supports HIV and TB care and treatment programs. The system is customized from the open source OpenMRS platform [62]. It is comprised of different modules used in the various sections of care by different categories of users. The KeEMR products include: mUzima which is a mobile phone and tablet platform used for HIV testing and counselling (HTS) in offline/online mode, interoperability layers (IL) which is used for data exchange between systems (e.g. Viral load system from National AIDS and STI's Control Programme (NASCOP) to EMRs), Text messages for adherence (ETS), ARV dispensing tool (ADT) and Data warehouse API (DWAPI) - an application interface that facilitates transmission of HIV indicator data from EMRs to the national data warehouse (NDW). Figure 1 shows the homepage of the EMRs under study.

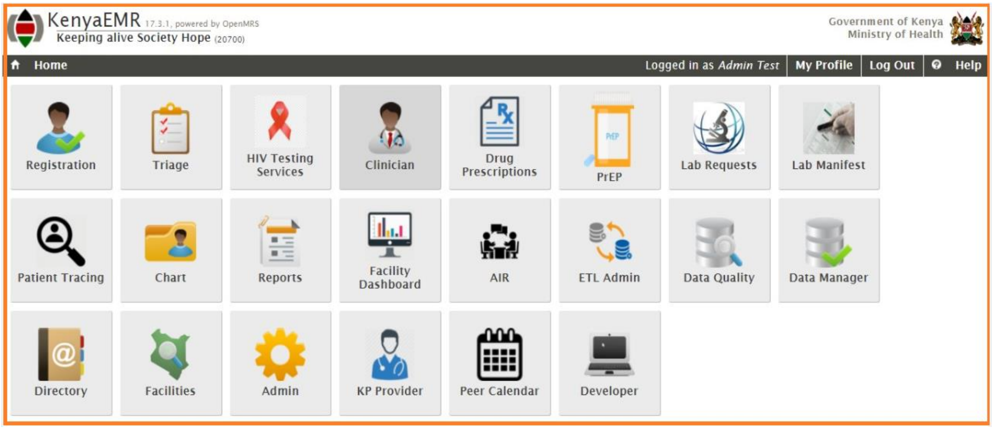

Figure 1: Screenshot of KeEMRs home page [63].

KeEMRs uses a communication layer referred to as interoperability layer (IL) to enable health data exchange with other health information systems such as pharmacy system (ADT). KeEMRs version 16.0.2 and above enforced the use of a nationally-endorsed 10-digit patient identifier number (five digits representing master facility list (MFL) code and five digits comprehensive care clinic number (CCCNo)) as from the year 2017 for unique patient identification.

1.6.2 KeEMR system implementation distribution

In Kenya, KeEMRs is implemented in facilities spread across 22 counties with varying numbers of sites per county (Figure 2). At the time of the evaluation, KeEMRs had been rolled out in over 370 public, non-governmental organizations (NGO) and faith-based healthcare facilities [47]. For efficiency in care delivery, these public facilities are organised into Kenya Essential Package for Health (KEPH) service levels as follows: Level 1 - community level; Level 2 - dispensaries and clinics; Level 3 - Health centres, maternity homes and sub district hospitals; Level 4 - primary facilities which include District hospitals; Level 5 - secondary facilities/Provincial hospitals; and Level 6 - Tertiary/ National hospitals.

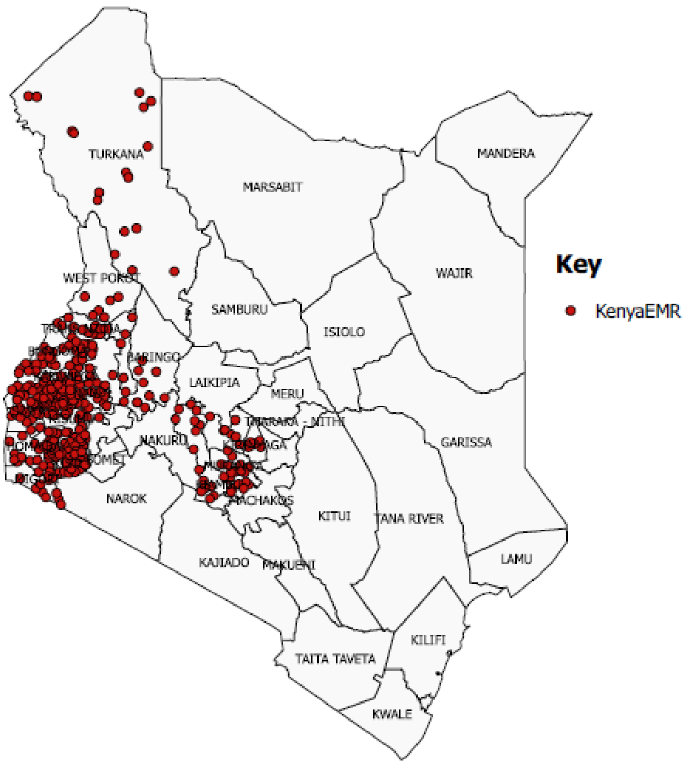

Figure 2: Distribution of KeEMRs implementations as of June 2020
https://dwh.nascop.org/#/

1.7 Research Contribution

This study has developed a systematic and practical method as well as framework for assessing state of IS post-implementation in healthcare environment. This contribution is realized through a generic three-step process using standard tools and validated IS success models.

The first contribution is a comprehensive approach that researchers can use to systematically develop standard information system use indicators/measures, that are appropriate for a given theoretical context **(Paper II)** [64]. The developed standard

EMRs use indicators were subjected to quality testing through Specific, Measurable, Achievable, Realistic and Time-bound (SMART) criteria by subject domain experts.

The second contribution is a novel approach to empirically determine success of IS implementations using objective data derived by means of multi-dimensional instrument (indicators) as reported in **(Paper IV)** [65]. The empirical findings were combined with qualitative study investigating EMRs users' perspective on facilitators and barriers to EMRs use for comprehensiveness **(Paper V)**. To our knowledge this is the first study to have used computer-generated data in a low resource setting.

The third contribution is the practical knowledge on the actual state of EMRs implementations in the study setting (Kenya) using empirical data, since first rollout in the year 2012. This provides decision makers (MoH, implementing partners and funding agencies) with accurate and actionable information for improving the performance of the introduced EMRs as well as scale-up initiatives. To our knowledge, no study exists that has used multiple approaches to understand actual use of EMRs implementations in resource limited settings **(Paper IV&V)**. Given the many shared characteristics between developing countries especially in sub-Saharan Africa, this thesis demonstrates that this evaluation method can be applicable in conducting IS evaluations in similar settings.

1.8 Structure of the Thesis

This thesis consists of a total of eight chapters. Chapter one introduces the role of health information systems implementation in healthcare and discusses the distinct information system implementation phases. The chapter also presents the state of EMR systems implementations globally followed by a review of general information system evaluation approaches. Subsequently it defines the research gap (research problem), justification of the study and research contribution. Finally, it presents the outline of the overall structure of the thesis.

Chapter two presents literature review on information system success evaluation models, information *system use construct* – conceptualizations and measures, dimensions of information system use, information system usage measures, and finally current approaches to assessing EHR/EMR usage.

Chapter three describes the theoretical framework that was used in this research.

Chapter four outlines the aims and objectives for this research and the corresponding research questions.

Chapter five presents the study methodology that was used to conduct the research. It starts by discussing the Design Science Research approach followed a discussion on the philosophical perspective of design science research. This is followed by a description of the study design clearly showing the study research phases and the resulting scientific papers. Finally, the chapter discusses the iteration stages of DSR process model and its application in the development of the study artefacts.

Chapter six reports the results of data analysis derived from the three sub-cycles followed in the development of the study artefact.

Chapter seven presents a detailed discussion of the study findings, linking them to the overall study objectives and research questions. It also discusses methodological consideration and limitations of the study.

Chapter eight concludes the study and finally makes recommendations for practical actions and for future research.

Chapter 2

2. Literature Review

"Success" is achieving the goals that have been established for an undertaking (Anon).

2.1 Introduction

Strategic value of information systems is only realized through successful implementations and utilization in the organization's business processes. How to measure the level of success of IS implementations has become a critical research issue over the past few decades. Researchers in this area seek to understand the compelling IS success constructs in relation to human, technical and organizational dimensions. As a result, a number of theories and models applied in a wide range of disciplines and research contexts have emerged.

2.2 Information System Success Evaluation Models

There is mounting interest in the use of theories, models and frameworks to gain insights into the mechanisms by which IS implementations are more likely to succeed [66]. Petter et al. argue that measurement of information system implementation success is both complex and never a straightforward task [67]. As a result, a range of evaluation methodologies and frameworks have emerged with divergent approaches, strengths and limitations [40]. Thus, evaluation methods can be complex, single or combined, and with a lot of variables [68].

2.2.1 DeLone and McLean (D&M) IS success model

D&M is a mature, validated model established since 1992 in measuring health information systems success. The model is a derivative of three basic theories which are the theory of communication [69, 70], the extension of theory of communication [71], and SERVQUAL [72] as reviewed by Mardiana et al.[73]. It is based on the premise that information system success is a dependent variable articulated by an interplay of six dimensions: *system quality, information quality, use, user satisfaction, individual impact* and *organisational impact* [74]. However the model was revised in

2003 based on the criticisms from researchers who used the model [73, 75, 76]. Hayrinen et al. applied the old model in their systematic review of Electronic Health Records which reported on structure, content, use and impacts of EHRs on selected papers from 1982 to 2004 [77]. In response to the critics of the 1992 IS success model, DeLone and McLean summarized the empirical findings from studies which had utilized the model and proposed an extended model IS success model (Figure 3). The revisions involved an additional construct; *service quality* and the separation of *use* and *intention to use* constructs to address the problem arising from unclear causality [75]. Thus, the dimensions of the revised model are *system quality, information quality, service quality, use, intention to use, user satisfaction* and *net benefits* where each dimension is part of success [73]. The model has been adopted in evaluating success of health information systems implementations on wide-ranging perspectives. Health Canada, in their review of evaluation models, earmarked D&M IS success model as a potential candidate for evaluating their electronic health records projects [78]. Berhe et al. in the year 2017 used this model to evaluate EMR effectiveness from a user's perspective in Ayder Referral hospital in Ethiopia where they utilized a couple of the dimensions to measure success [58]. Bossen et al. used the model in evaluating a comprehensive Electronic Health Record in two departments of a regional hospital in Denmark shortly after its implementation, where the evaluation outcome informed escalation of the implementation to its other five hospital branches [54]. Lau et al. used the revised D&M model in their review of fifty literature review publications describing health information systems evaluations studies with view to inform HIS practice and research [79].

One of the weaknesses of the model as highlighted by Yusof et al. is its failure to address organisational aspects or the environment (organisational culture and structure) in which the system operates, which are implicit success determinant factors [80].

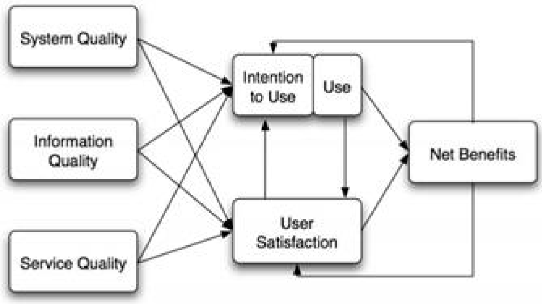

Figure 3:The updated DeLone and McLean IS success Model (2003) [74].

2.2.2 Van der Meijden and Colleagues contingent factors

In their systematic literature review of inpatient clinical systems, Van der Meijden et al. successfully applied the original D&M framework in assessing 29 systems report in the literature [81]. However, they identified a number of contingent factors that can affect success or failure of these systems [82]. They classified these factors into *system development*, *implementation attributes* and *organizational aspects* hence resulting to what is referred to as extended D&M revised framework. This extended framework was used by Lemai et al. in their review of literature of EHR implementations around the world and their impact [82].

2.2.3 MIT90s (IT-Organizational Fit Model)

Due to the complexity that comes with the development and implementation of information systems in health care, studies in health informatics have included the concept of 'fit' to advance implementation success [83]. In fact, Kaplan shows that poor fit between system developer's goals and clinician's cultural values contributes to user reluctance to use the implemented clinical decision support system [84]. IT and business relations are also key as enablers or inhibitors to implementation success. The MIT90s also known as IT-Organizational Fit framework is a renowned model which includes both internal and external elements of fit (Figure 4) [85]. The framework describes that success in managing the deployment of information technology in the organization as a balance of six factors: (1) external environment; (2) organization strategy; (3) individuals and roles; (4) organization structure; (5) technology and, (6) management process [85]. The framework is comprehensive as it includes human, technology and organization factors which are considered important in successful implementation of health information systems [86]. However, Yusof et al. suggest addition of more details to these factors to provide more specific evaluation dimensions [80].

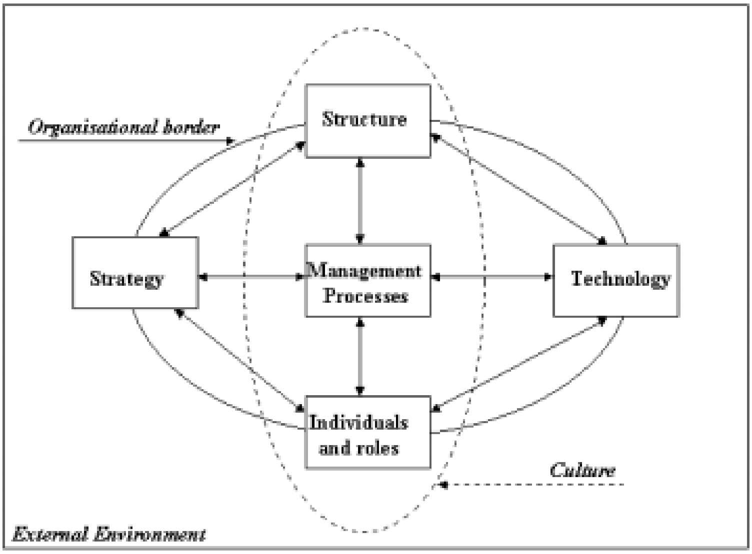

Figure 4: MIT90s Framework [85]

2.2.4 Human, Organization, and Technology (HOT -Fit) framework

HOT-Fit evaluation framework is a combination of the concepts of D&M model and IT-Organizational Fit Model developed by Yusof *et al.*[80] in response to the need for improvement of existing methods in evaluating information systems in healthcare settings to ensure implementation success [87]. IT-Organizational Fit Model complements the D&M model by featuring the concept of fit and organizational factors. Measures such as user involvement and organizational culture which are pertinent to information system evaluation do not match any of the dimensions of the D&M model [81]. Brender et al. in their study discovered that ‘soft issues’, i.e., human and organizational issues are emphasised more than technical issues in healthcare [88]. For instance, EMR systems are not useful unless the intended users use them. On the other hand, the users will not use them if there are barriers that impede the system use. In short, it is clear that human, organizational, and technological factors in regard to measuring system effectiveness or success are all important and hence are vital considerations in evaluation. At the same time, these factors should have a mutual alignment or fit in order to ensure successful HIS implementation as illustrated by HOT-Fit framework presented in Figure 5. In summary, the framework comprise the following dimensions: technological factor (system quality, information quality, service quality), human factor (system development, system use), organization factor (structure, environment), and net benefits.

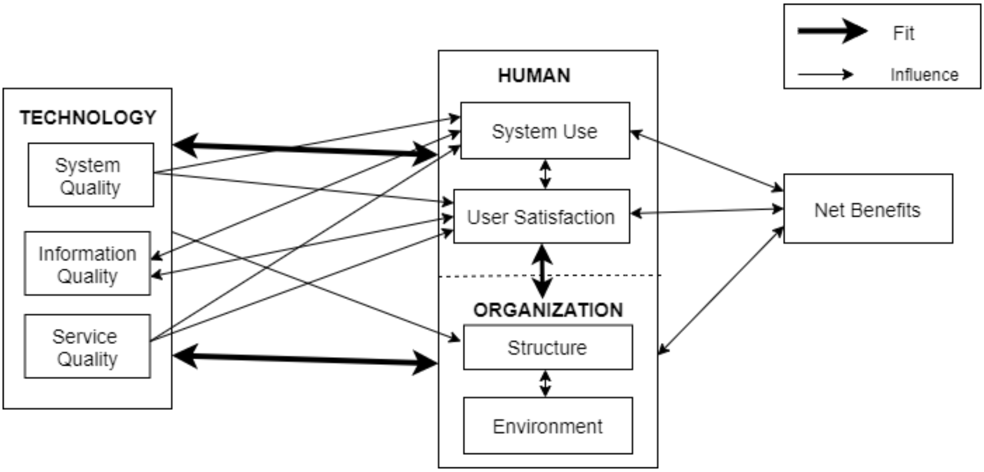

Figure 5: Human-Organisation-Technology Fit (HOT-Fit) framework [80]

A case study of a Fundus Imaging System (FIS) of a primary healthcare organization in the UK was used to validate the HOT-Fit framework as well as other system reviews [87]. The data collection methods employed in the case study were interview, observation and document analysis.

Erlirianto et al. successfully used the HOT-Fit framework to evaluate an EMR implemented in a hospital in Indonesia [86]. They developed a conceptual framework and 17 research hypotheses in line with the HOT-Fit framework of which they were able to prove. The framework has been refined progressively in terms of its dimensions, measures and sub-measures.

2.3 The Information System Use Construct – Conceptualizations and Measures

Researchers have extensively studied and suggested many constructs to determine IS success as discussed in the previous sub-sections. DeLone and McLean however recommended system *use* construct as the most appropriate variable for measuring the success of IS [73]. Furthermore, there is a widespread agreement among many researchers that system usage is a key variable as it is a requisite for deriving benefits of IT as well as in evaluating its impact and eventually a measure of IS success [74, 89]. In other words, it is not until a system is used in performing tasks it is designed for that its benefits can be realized either at individual, group, or organization level. Furthermore, survey analysis results demonstrate *use* as a mediator between the quality of IS and the impacts of IS on individuals [90]. According to Petter et al., the quality of the system, its services and its information, affect both its use and user satisfaction which, in turn, affect the perceived net benefits [67]. Nevertheless, it is important to note that a used system does not necessarily translate to its success nor its benefits to an organization [91, 92].

Information systems *use* is an essential part of the human behaviours in utilizing computers in organizations [75]. Researchers have used diverse terms for IS *use* construct including; IT/System usage [93, 94], IS continuance [95, 96], IT utilization [97], among others. However, system usage is commonly used. There are varied definitions of system usage. Cuellar et al. define system usage as '*utilization of information technology (IT) by individuals, groups or organizations to accomplish a set purpose'* [89]. Moreover, Goodhue and Thompson, define *use* as "*the extent to which the system is incorporated into the user's business processes or tasks across the phases of the lifecycle*" [98]. Thus, system usage is an activity that involves three elements: a user (the subject using the system), a system (the object being used), and a task (the function being performed) [67, 93, 99]. Other researchers have treated system usage as a technology acceptance measure [100–102]. In this research, we acknowledge that user acceptance and satisfaction are critical factors for successful IS/EMRs implementation. Drawing from these IS use concepts, elements and recognizing that information systems comprise of many features, in this study, system usage means *the utilization of one or* *more features of a system to perform a task*. This study also considered system usage as a dependent variable – a success measure and thus an indicator of implementation success.

Research on information system usage has been conducted at different levels: single-level (individual-level) [103], group-level [93], and organizational-level [104]. Burton & Gallivan however argue that studying this phenomena at one level leads to disjointed and skewed study outcomes which may not be a true representation of the state of IS implementation in the organization [93]. For instance, an organization may wish to understand the benefit of a new discussion platform. Individual-level studies may reveal that staff frequently use the system and hence claim the system a success. On the other hand, group-level studies may find absence of ongoing communities and hence judge the system a failure. Thus, multi-level studies can resolve such conflicting findings by examining and synchronizing the study outcomes [105].

Examining interrelationship of system usage with its immediate neighbouring constructs namely *intention to use*, *user satisfaction* and *net benefits* of D&M IS success model (Figure 1), there exists differing perspectives as to whether the relationships are causal or process related (sequence of events among the variables). Extant studies assume a process relationship where IS *use* leads to user satisfaction and further intent to use the system, which ultimately impacts individual/organizational benefits [75, 106]. A causal relationship (variance model), on the other hand is portrayed when a system of high quality is expected to lead to higher user satisfaction and consequently use, leading to positive impacts on individual productivity, and in turn organizational productivity improvements [106]. However, studies on IS success more often than not include an examination of a causal relationship between information system use (ISU) and individual performance or benefit [75]. D&M IS success model combines both causality and process model with all flowing in the same direction (Figure 3). However, Seddon argues inclusion of both leads to confusion and thus his effort in refinement of the model [74].

2.4 Dimensions of Information System Use

In their effort to derive suitable measures for IS *use*, DeLone & McLean [50] proposed four formative dimensions of *use* appropriate in measuring the incorporation of an information system into work processes namely:

i) *Extent* – This is the proportion of the available IS features used or utilized in the work processes [67]. This dimension measures level of usage of the implemented system. Alternatively, extent can be deemed as the proportion of the business processes encoded in the information system thus indicating the level of automation. However, automation level is not a direct measure of system *use*.

$$Extent\ of\ use = \frac{Number\ of\ features\ used}{Total\ number\ of\ features\ available\ and\ appropriate\ for\ use}$$

ii) *Frequency* – the rate at which IS functions are used by the users in their work. This dimension assesses the frequency with which the system is used hence the term frequency of use. It occurs at the level of the user and not the work processes.

$$Frequency\ of\ use = \frac{Number\ of\ times\ a\ function\ is\ used}{Number\ of\ times\ the\ function\ could\ be\ used}$$

Nevertheless, it is important to note that by simply measuring the amount of time a function is used does not properly capture the relationship between usage and the realization of expected results.

iii) *Thoroughness* - This dimension assesses optimal use of the utilized system functionality.

$$Thoroughness = \frac{Depth\ of\ use\ of a\ functionality}{possible\ depth\ of\ use\ of\ a\ functionality\ where\ the\ use\ is\ appropriate}$$

iv) *Attitude towards* use – This dimension involves a set of measures that assess the level of comfort, degree of respect, and the challenges arising from the system. It is a key determinant of users' likelihood to use the system in the future.

Other dimensions proposed by other researchers include nature, quality, and appropriateness of the system use [67, 107, 108]. DeLone & MacLean suggested that the nature of system use could be addressed by determining whether the full functionality of a system is being used for the intended purposes [108]. For instance, full functional use of an EMRs/EHRs may incorporate utilization of all the features included in the system design by the intended users in their work processes.

2.5 Information System Usage Measures

Measurement is the process of mapping the magnitude of an attribute to a numerical value [67]. Owing to the differing researchers' conceptualizations of IS *use* construct, diverse measures have emerged [102]. Further, system usage is an intricate construct and therefore it is unlikely that any one taxonomy is appropriate for all applications and purposes [51]. Since IS *use* simply means using the system, therefore resources such as human effort are consumed as the system is used. Consequently, IS *use* may possibly be measured in hands-on hours, frequency of use, number of users, or basically as a binary variable: use/non-use [109]. The most common forms of system usage measures can be classified into two: (1) subjective self-reported measures and (2) objective computer-recorded measures. Trice & Treacy pointed that "utilization can be measured effectively if the measures chosen correspond to the measures suggested by an appropriate reference theory" [110] .

2.5.1 Subjective measures

Subjective measures also referred to as self-report measures produce data based on user perception utilizing measures described by the manners of IS usage such as specificity, method, appropriateness of, and dependence on use [111]. Mostly, field-studies using self-reported measures collect data through questionnaires or interviews tools. In most of these studies, researchers basically ask respondents about their use of information system using Likert scale (five-point, seven-point, etc) by rating the measurement items [112]. The weakness of subjective measures such as use of questionnaires is that they are limited in revealing actual system use or a technology [113]. Possible explanations for this discrepancy could mainly be occasioned by subjects' exaggeration of the extent of usage to align with their superiors' expectations and difficulty in recalling their past usage, thus introducing bias in the measure. Devaraj & Kohli posited that technology impacts can be assessed by examining actual IT usage rather than self-reported IT usage [114].

2.5.2 Objective measures

Objective IS usage measures relate to actual job activities from where numerical data are extracted rather than obtaining verbal description only [115]. Thus, they generate system-based data derived mostly from the duration of use as well as some aspects of the extent of use such as number of systems, sessions, user-generated contents etc. [111]. The resulting measured data does not suffer bias commonly prevalent in self-report measures (subjective). Several studies used objective system-recorded data such as login times, connect time, and number of clicks (Table 1). One major advantage of computer-recorded data is the ability to inexpensively gather voluminous retrospective or longitudinal data thus enabling researchers to go beyond cross-sectional research [116]. Nevertheless, processing voluminous data requires a large budget, computer time, conversion of raw data into analysable data sets, and scarce expertise to program routines for customized reports .

Table 1 presents a list of studies applying both objective and subjective IS usage measures.

Table 1: Measures and methods for measuring IS usage in past research between (1978 – 2017) [50,102,107,110,111,117,118]

Broad dimension	**System usage Measures**	**Nature of variable**	**Instrument**	**Study/Reference**
Extent of use	Number of system accesses	Subjective	Questionnaire	Srinivasan (1985); Raymond (1990); Lu and Gustafson (1994);
Duration of use	Connect time, hrs per week	Objective	Computer logs	Ginzberg (1981); Srinivasan (1985); Venkatesh et al. (2002); Snitkin and King (1986)
Extent of use	Number of sessions, number of enquiries	Subjective	Questionnaire	Lucas (1978); Ginzberg (1981); Igbaria et al. (1989); Lu and Gustafson (1994), Devaraj et al. (2008);[110]
Extent of use	Number of data reports requested, and accessed	Objective	Computer logs	Schewe (1976); Benbasat and Schroeder (1978); Raymond (1990); Szajna (1993); Devaraj and Kohli (2000); Devaraj and Kohli (2003)
Frequency of use	Frequency of updates, number of times use the system (daily, weekly, etc)	Objective/ subjective	Computer logs/questionnaire	Robey (1979)
Frequency of use	Use of particular commands	Objective	Computer logs	Benbasat et al.(1981)
Extent of use	Number of system queries			King and Rodriquez (1978); DeSanctis (1983); De et al. (2010)
Extent of use	Actual time spent on the computer, frequency of use, number of packages used, level of sophistication of usage	Subjective	Questionnaire	Igbaria et al.(1989)
Extent of use	Number of communications (emails)	Objective	Computer logs	Szajna (1996); Klein (2007)
Proportion of use	Processing (CPU) time, number of reports executed, number of records accessed	Objective	Computer logs	Devaraj and Kohli (2003)
Proportion of use	Amount of downloaded data	Objective	Computer log/sales tracking software	Ahearne et al. (2004)

Frequency of use	Frequency of system use	Subjective	Questionnaire	Wu and Wang (2005)
Extent of use	Number of blog posts	Objective	Computer logs	Wattal et al. (2010)
Extent of use	Number of clicks	Objective	Computer logs	De et al. (2010); Brynjolfsson et al. (2011)
Frequency of use	Frequency of use of 12 core system functionalities	Subjective	Questionnaire	Tilahun and Fritz (2015)
Extent of use	Number of system functionalities used	Subjective	Questionnaire	Powell et al.(2017)

In summary, DeLone & McLean highlight eight key *use* measures that have emerged in the last three and half decades: *frequency of use, duration of use, nature of use, appropriateness of use, number of functions or features used (extent of use), thoroughness of use, attitudes toward use,* and *intention to reuse* [50]. Whether *use* variable is treated as subjective or objective is dependent on how the researcher packages the measurement tool. For example, a measurement like "the actual amount of time spent on the microcomputer system per day," can be measured through a survey using user-reported tool (questionnaire) asking the "total number of hours spent on the computer." Likewise, data for the same question can be obtained objectively by use of a query to extract the duration of time spent by a logged-in user from the system log. *Use* variable is however considered as a behaviour as it pertains to individuals using IT/IS in a work context to perform certain organizationally relevant functions and therefore most of its measures are based on behavioural assessment (subjective).

2.5.3 Eye tracking technology to measure IS usage

There are limitations of both objective and subjective measures of IS usage. Subjective measures are perceived to suffer response bias thus often perceived as not accurate enough to reflect actual usage of the system while objective measures in previous studies are limited mostly to system-based log data [102, 111]. To this end, Dimoka et al. proposed the use of brain imaging such as functional magnetic resonance imaging (fMRI) and psychophysiological tools such as eye-tracking, skin conductance for IS research in general and IS usage in particular [119]. This provides promising opportunities for deepening understanding and capture of IS usage behaviours in a more comprehensive and insightful manner. Thus, efforts to extend the objective IS usage measures based on psychophysiological tools such as eye-tracking device have emerged. Eye-tracking technology to extend IS use objective measures gauge exactly where and how long the human eyes look and focus on a certain stimulus or image on a screen (regions of interest) [111]. The results of this analysis reveal users' eye movement which is referred to as individuals' IS usage patterns. However, eye-tracking (psychophysiological tools) approach/technique is limited to an individual assessment (user interaction with an IS or individuals IS usage) [119].

2.5.4 Developing IS use measures

In the study of information system *use*, it is important to recognize the two salient natures of *use* common across all systems typologies namely: (1) *requisite use* and (2) *value-adding use* [90]. Requisite use is synonymous to mandatory or obligatory use of the system in performing basic business/work tasks. As such, requisite use is practical in cases where the system incorporates the main business workflow or all business processes, resulting into a fully automated environment. On the other hand, value-adding use entails additional use on non-core business functions [90]. Thus value-adding use is voluntary and meant to achieve a specific objective to enhance output or impact. A third type of *use* though rarely considered is *exploratory use* which occurs during the learning phase of either a new system or new users to a system [120]. Exploratory *use* captures how users explore IS/IT to accomplish their tasks. However, Abdinnour-Helm & Saeed point out that measures for exploratory use should be distinct from those of value-adding use as their goals of use are different [120]. In fact, McLean et al. argue that the measures for requisite use and value-adding use should also be different where each should capture a unique aspect of use [90]. Thus, measures of *frequency of system use* in general are appropriate for requisite use, while for value-adding use, measures that capture *depth / extent of system use* are appropriate [90].

Although researchers like Gable et al. argue that IS *use* should not be considered in measuring IS success in situations where IS use is mandatory, DeLone &McLean tend to differ [50, 121]. They argue that even where use is mandatory, variability exists especially in the intensity of this use and consequently likely to have a significant impact on the achievement of the anticipated system benefits. For example, users may utilize only a few of the system features (extent) leading to dismal desired outcomes. With some applications however, like social media and e-commerce, use is largely voluntary yet it is the most suitable variable to determine their success. Furthermore, system use varies in mandatory settings because some users are not willing to abide by the organizational directives. Thus, *use* remains an important success measure in both mandatory and voluntary environments.

Having in mind the differences in the three types of IS use discussed earlier, McLean et al. proposed a framework for choosing system use measures [90]. They pointed out that the types of information systems, their characteristics, system lifecycle, system configuration, user and user experience in information system success research should be put into consideration while making the selection. Table 2 presents a six-step framework for developing/selecting system use measures. Steps one to four focus on the considerations for system use while steps five and six determine the appropriate type of measure for the context.

Table 2: Steps in developing measures for System Use (framework) [90]

1. Determine the system typology (i.e., Function IT, Network IT or Enterprise IT)
2. Determine the level of automation (for e.g., High, Medium, Low)
3. Determine the characteristics of the key user groups (especially important for Enterprise IT)
4. Determine the phase of the system lifecycle or user experience (especially important for EIT)
5. Determine the type of usage you want to measure (i.e., requisite or value adding or both)
6. Select the appropriate type of measure (i.e., frequency based or depth / extent)

McAfee classifies system typology into three categories: function, network and enterprise IT [122]. *Function IT* (FIT) supports the execution of distinct tasks. Examples of this category are Word processors and spreadsheets. *Network systems* provides communication among systems. Network technologies include instant, blogs, messaging e-mail etc. However, use of network IT is optional. *Enterprise IT* (EIT) specifies business processes by defining tasks and processes. This includes applications such as Customer Relationship Management (CRM) and Supply Chain Management (SCM) as well as technologies, such as electronic data interchange.

The framework was validated empirically by conducting three separate investigations in three types of the systems (Enterprise, Functional and Networking systems) [90]. The survey questionnaire comprised of 15 questions capturing use, attitude, individual impact dimensions and their measures. Seven-point Likert scale was used to rate each question.

2.6 Current Approaches to Assessing EHRs/EMRs Usage

The wave of EMRs/EHRs implementations in the health sector globally has changed the dynamics of the clinical care in general including patient-clinician interactions, thereby creating new research opportunities [50,123,124]. IT systems in a healthcare facility operate in various dimensions, such as medical staff (e.g., doctors, nurses, and medical technicians), operational management (e.g., administrators, suppliers, accounting, and human resources), patients (e.g., electronic patient record, billing statement, and check-in or discharge), and business models (Telecare, U-care, Patient home monitoring, and mHealth by mobile devices) [99]. Some of the meaningful use of EMRs include creating, use, editing, and viewing of patients records by multiple care givers, e-order requests like laboratory tests, e-prescribing, and general improvement in patient data management [125, 126]. Center for Medicare and Medicaid Services refers to 'meaningful use'' as the need for health care providers to show their use of EMR technology in ways that can be measured significantly in quality and in quantity [127]. ''Meaningful use'' is comprised of two core requirements: adoption of certified EMRs and using them to accomplish specified objectives [128].

Preliminary research on EHRs/EMRs use studies reveal there are no specific measures for assessing their usage. However, a scoping review of literature on measuring EHRs use in primary care by Huang et al. revealed EHRs functions (e.g., patient registration, ordering laboratory tests etc) was the most prevalent metric with particular focus mainly on the use/non-use of the functions [129]. Nevertheless, Huang et al., argue that unidimensional/binary measures such as Yes/No answer, for instance asking if the EMRs is used or simply asking if a certain EMRs function is used, are inadequate to evaluate actual use [129]. They concluded that outcomes associated with EMRs adoption could be better gauged when multiple dimensions of EMRs use are considered. As such, most of the studies combine several IS success dimensions (constructs) to assess EMRs/EHRs implementation outcomes rather than just IS *use*. Table 3 lists a summary of some of the published approaches to evaluating EMR use in primary care setting, some of which influenced development of the conceptual model for this study.

Table 3: Studies on EHRs/EMRs use and approaches employed in measuring system usage

	Research Study	**Brief Description**	**Research Theory Used**	**Users**	**Country Setting (Developed/ developing)**	**Measures relevant to this study**
1	Linder et al.(2007) [92]	Assessed association between EHR use, as implemented, and the quality of ambulatory care in a nationally representative survey	-	Physicians/ clinicians	Developed (US)	• Number and percentage of ambulatory visits in which clinicians used an EHR
2	Wilcox et al.(2008)[130]	Categorization of system users according to how extensively they adopted the various capabilities of electronic health records (EHR)	Model of usage categories	Physicians	Developed (US)	• System accesses • Use of system features/functions
3	Li Zhou et al.(2009) [131]	Examined how the quality of care delivered in ambulatory care practices varied according to duration of EHRs adoption and usage.	Survey/no specific theory	Physicians	Developed (Massachusett s)	• Use and the extent of use of EMRs features (most or all of the time; some of the time; do not use)
4	Bowes WA III (2010)[132]	Measuring EHRs adoption through utilization of system functions through audit logs	-	System users	Developed (US)	• Count of Patient Records accessed through EHR functionality
5	Nan Xiao (2012)[133]	Examined how the meaningful use of EMRs would affect health care outcomes in outpatient settings	-	Care providers	Developed (US)	• Length of use was measured asked the respondents how long they have used current EMR in their offices • Extent of meaningful use was measured by the number of

						functionalities used and the corresponding use frequency
6	Makam et al.(2013) [134]	A survey with primary care providers (PCPs) about their use and satisfaction with performing common tasks	-	Primary care givers	Developed (Texas)	• Functions of the EHR used • Amount of time that physicians spent on clinical documentation
7	Hsiao et al.(2013) [135]	Used Electronic Health Records Survey to examine its adoption and use by physicians'	-	Physicians	Developed (US)	Yes/No response to: "Does this practice use electronic medical records or electronic health records (not including billing records)?"
8	Binyam and Fleur (2015)[107]	Assessment of EMR usage pattern, user satisfaction level and determinants of health professional's satisfaction towards implemented EMR system	D&M IS success model	physicians, nurses, lab pharmacists and HMIS staff	Developing (Ethiopia)	• EMR use rate • Use rate of core EMR functions.
9	Gordon et al.(2017)[136]	Use of the Rhode Island (RI) HIT Survey to characterize how primary care physicians used EHRs and examined trends in the use of specific functionalities over time.	-	System users	Rhodes Island	• System functionalities use rating - "almost always"
10	Maillet et al.(2018) [137]	A survey to assess the actual use of an EMR by acute care nurses at different adoption stages.	UTAUT	Nurses	Canada (Developed)	Summation of 14 items targeting five subdimensions of IT functions using: • duration of use • frequency of use • extent of use

2.7 Conclusion

Of the seven D&M IS success model constructs, this study adopted '*use*' construct to achieve its objectives. The choice was informed by, first, the need to establish the actual

EMRs use in the case study/study facilities. Second, drawing from the previous research studies, IS *use* is appropriate in IS success/use evaluation studies. We adopted the term *system usage* which means *the utilization of one or more features of a system to perform a task*. This study also considered system usage as a dependent variable – a success measure and thus an indicator of implementation success. In the quantitative part of the study, we employed computer-recorded measures because of the need to assess retrospective data since implementation of the respective EMRs under study. This approach allowed implementation and scaling of the evaluation of system use within implemented EMRs – given that it does not depend on much human input.

Chapter 3

3. Theoretical Framework

3.1 Introduction

In this chapter, we describe the approach and theoretical framework that informed the development of the systematic evaluation method in this thesis.

3.2 Theoretical background

Literature on Information Systems provides a wide-ranging definitions and measures of information system implementation success depending on the perspective(s) of the stakeholders in question (who is assessing the IS success). In the eyes of a software developer, a successful information system is one that is completed on time, within budget and specifications [34]. Users consider an IS successful if it improves their work performance, while organizations gauge success on its contribution to company's profits or creation of competitive advantage as Byrd et al. [138] put it. This raises the question, what are the critical factors necessary to consider in evaluating IS implementation success?

Success has many dimensions: effectiveness, efficiency, organisational attitudes and commitment, use, users' satisfaction and patient satisfaction, as revealed by the diverse frameworks [8,74,80,86]. Berg acknowledges the difficulty in having all the parties, internal and external of the organisation agree on which dimension(s) are most relevant and hence concludes that the question of system success is about the question of success for whom [139]. Furthermore, what is considered as success today may change tomorrow, hence making success a dynamic concept [30]. Stacie Petter et al. also point out that measurement of information system success is both complex and illusive [67]. While many evaluations studies do not explicitly define 'success', quantitative evaluation literature generally measures outcomes of EMR systems compared to their original goal [140].

There is, however, a general consensus by many IS researchers who treat IS success as a multidimensional construct in which multiple measures can be used [141]. In their quest for determining a dependent variable for information system success, DeLone & McLean (1992) postulated a comprehensive taxonomy comprising six major dimensions or constructs of IS success: *system quality, information quality, use, user satisfaction, individual impact*, and *organizational impact* [76]. However, Seddon et al. and other researchers claimed the model is incomplete and suggested inclusion of *net benefits* [109]. DeLone &McLean (2003) IS success constructs after revision are *system quality, information quality, service quality, use/intent to use, user satisfaction* and *net benefits*. Several evaluation research studies have examined these constructs and their relationships [142–144]. While many IS success frameworks and models have emerged incorporating the differing views, D&M IS success model remains dominant basis of IS success measurement [145].

In this research, we argued that concept of "*use*" is a good measure for determining EMRs post-implementation success within the first few years of its implementation and for an evaluator who is external to the organisation under evaluation. This was also based on the fact that most of system value is realized during its subsequent use [50]. Furthermore, this can provide feedback to continually adapt the implementation based on evidence, which was the anticipated outcome of this research.

3.2.1 Theoretical/Conceptual framework

DeLone and McLean point out that often the choice of IS success variables is a function of the objective of the study and the organizational context [108]. The indicators and metrics for this research were derived from the measurable characteristics of the *use* success dimension as shown in Figure 6. Each dimension in the framework is a part of IS success, either when applied partly or whole. In addition, Nominal Group Technique (NGT) consensus was employed to formulate EMRs *use* indicators as measures of implementations success.

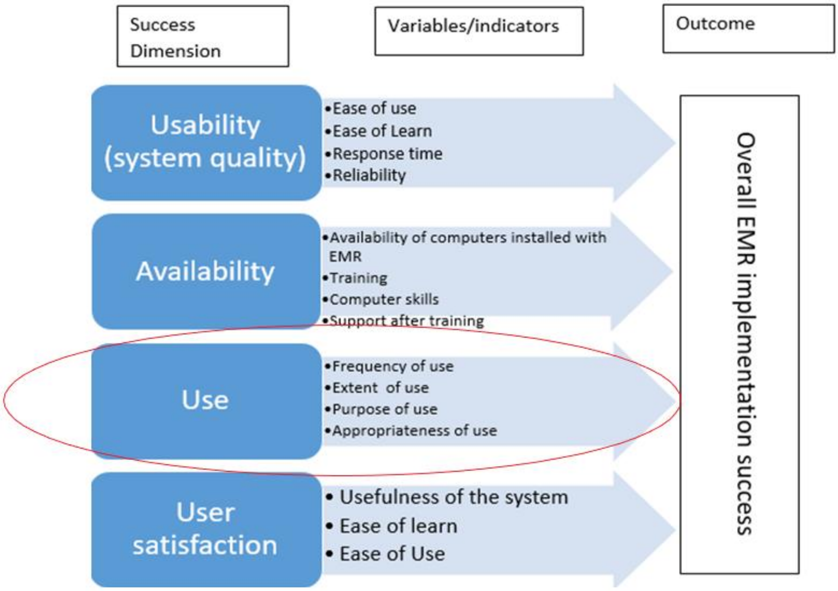

Figure 6: Conceptual framework derived from DeLone and McLean (D&M) IS success model [74]

3.3 Quality indicators

An indicator shows presence or state of a situation. While different disciplines use different indicators, there is no standard definition of indicators. Rather, extant scientific literature on indicators goes straight to discuss the qualities that make a good indicator in particular fields implicitly assuming the definition of an indicator is known. In the context of monitoring and evaluation, an indicator is a quantitative metric that provides information to monitor performance, measure achievement and determine accountability [146]. Indicators are described in depth by how well they relate to the underlying phenomenon they are trying to reveal.

3.3.1 Essential components of an indicator

When new indicators are being developed, they must be fully defined for clarity and concreteness. Monitoring and Evaluation Reference Group (MERG) identified a set of essential components for an indicator regardless of field of application [146]. These components comprise the metadata that determine the underlying viability of an indicator. The components for an indicator include:

Title – this is a brief heading that captures the focus of the indicator.

Definition – this entails a clear and concise description of the indicator.

Purpose - This entails an explanation of the reason why the indicator exists i.e., what is it for?

Rationale - The underlying principle(s) that justify the development and deployment of the indicator i.e., why the indicator is needed and useful.

Method of measurement - This is a description of the logical and specific sequence of operations used to measure the indicator.

Numerator – This is the top number of a common fraction, which indicates the number of parts from the whole that are included in the calculation.

Denominator – This is the bottom number of a common fraction, which indicates the number of parts in the whole.

Calculation. This entails the specific steps in the process to determine the indicator value.

Data collection method. This are the general approaches used to collect data (e.g. surveys, records, models, estimates).

Data collection tools - This entails a description of the specific tools used to collect data.

Data collection frequency – This entails the intervals at which data are collected e.g. quarterly, annually, bi-annually. It is important that frequency is consistent with the data collection methodology.

Data disaggregation - The relevant subgroups that collected data can be separated in order to understand and analyse the findings more precisely.

Guidelines to interpret and use data - Recommendations on how best to evaluate and apply the findings. For example, outlining what it means if the indicator shows an increase or a decrease in a particular measure.

Strengths and weaknesses - A brief summary of what the indicator does well and not so well.

Challenges - Potential obstacles or problems that may have an impact on the use of an indicator or on the accuracy/validity of its findings.

Relevant sources of additional information - References to information/materials that relate to the indicator, including background information on the development of the indicator, comparisons with previous versions of the indicator and lessons learned from the use of the indicator or similar indicators in various settings.

The development of the comprehensive details of the EMRs *use* indictors developed in this thesis followed the above guidelines and also aligned with the HIV Monitoring, Evaluation and Reporting (MER) 2.0 indicator template [147], of which EMRs implementations users are already familiar with.

Chapter 4

4. Research Aim and Objectives

4.1 Overall aim

The overall aim of this thesis was to develop and apply a systematic method for evaluating the state of Electronic Medical Records systems implementations in LMIC countries such as in Kenya. This contributes towards strengthening information systems evaluations with a view to support successful implementation scale-up and sustainable initiatives.

4.2 Specific Objectives

To achieve the overall aim, the following specific objectives were realized:

(1) Use Nominal Group Technique (NGT) and group validation technique to develop consensus-based metrics and indicators for determining EMR systems use.

(2) Assess the functional/operational status of the implemented KenyaEMR system in healthcare facilities in Kenya by using empirical data collected from all the implementations countrywide.

(3) Identify factors contributing to EMR systems use or non-use in healthcare facilities in Kenya.

4.3 Research Questions

The following questions guided the process of addressing the outlined research objectives:

1. What unique measures predict EMR system use in the healthcare setting in developing countries?

2. Can the existing frameworks and the validated EMR systems use indicators and metrics be leveraged to predict the status of EMR systems implementations in Kenya?

3. What factors influence the use of EMR systems in Kenya?

Chapter 5

5. Research Methodology

5.1 Introduction

This chapter describes the research process and methods that were used to achieve the research aims and objectives. The overall objective of this study was to extend the body of knowledge and understanding concerning evaluation of EMRs use post implementation in developing countries. In this chapter, we describe the design science approach and how we applied it in our work. We also discuss the study's philosophical perspectives and study design. Finally, we discuss DSR process models and their application in the study research process.

5.2 The Design Science Research Approach

Design science research (DSR) is a scientific methodology whose focus is on solving identified organizational problems through creation of artefact(s), guided by existing theories and knowledge [148]. Design science research also focuses on knowledge creation that can improve existing theories thus reducing the gap that exists between theory and practice [149]. Furthermore, DSR is concerned with evaluation of what has been created (artefact) and to communicate results to appropriate audiences with the purpose to improve existing information systems [150]. Hevner et al. notes that the DSR approach seeks to create new and innovative reality (artefact) which can include constructs, models, methods, instantiations, and improved design theories [151].

Success of a design science research is gauged on three main factors: relevance, rigor, and design. Figure 7 presents the design science research framework and the relationships between these factors. Generally, a problem perceived in practice (business) or anticipated by researchers provides the impetus for formulating the research effort. The problem area forms the environment and it is comprised of people, organization and technology [152]. In DSR, relevance is achieved when research activities are framed in such a way as to address the business need(s)/problem [151]. Therefore, in the relevance cycle the researcher is concerned with the existing environment of an IS, the people, technology as well as the organization that is intended to benefit from the artefact [152]. On the other hand, rigor is concerned with effective use of the available knowledge base regarding the subject matter, thus leading to the validity and reliability of the research findings (artefact) [148]. The rigor cycle is also concerned with the methods that should be sound and fitting to solve the problem while attempting to achieve innovative research that consequently contributes back, new and competent knowledge to the knowledge base. The knowledge base comprises of existing theories, models/frameworks, methods or techniques that can appropriately be used to build and evaluate the artefact [151]. The design cycle encompasses the actual development of the artefact in iterations, providing feedback back and forth the IS environment to refine the design and to the knowledge base as depicted in Figure 7.

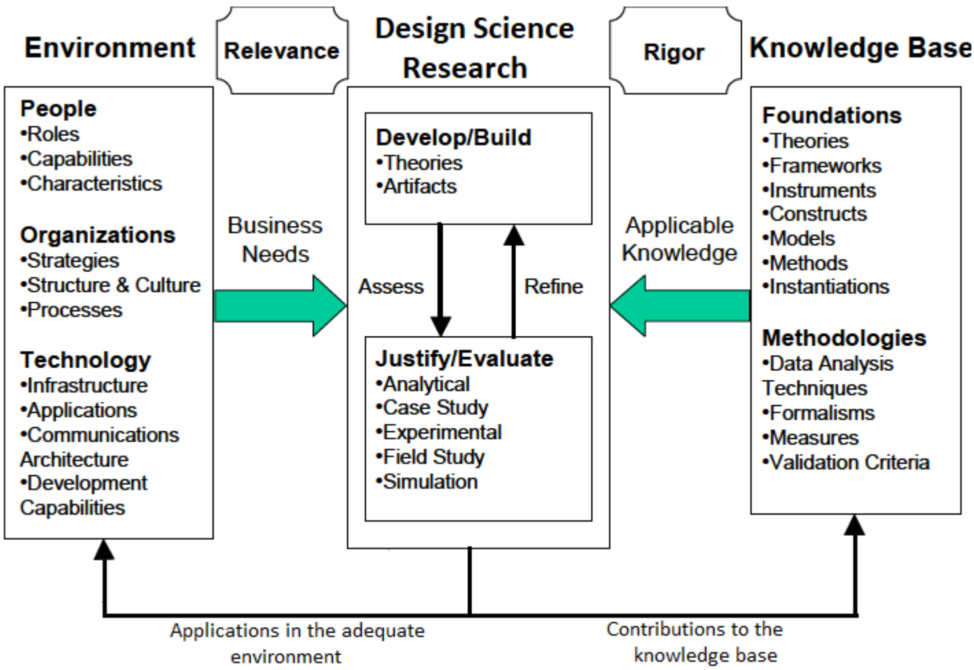

Figure 7: The design Science Research framework (Source: Hevner et al. 2004 page 80 [151]

Hevner et al. identified seven guidelines for DSR methodology as follows: (1) design as an artefact, (2) problem relevance, (3) design evaluation, (4) research contributions, (5) research rigor, (6) design as a search process, and (7) communication of research [151].

5.2.1 The Philosophical perspective in design science research

Philosophical underpinnings of research in general with respect to various research paradigms is comprised of four elements: ontology, epistemology, methodology and methods/axiology [153]. They encompass the basic assumptions, beliefs, norms, and values that each paradigm holds. Ontology is the branch of philosophy that is concerned with what is the form and the nature of reality and being, and that which exists that can be known about that reality [154]. Epistemology is the branch of philosophy that deals with the nature and sources of knowledge (deals with different methods of knowing) [155]. In any research, epistemology is preceded by ontology [156]. Once the researcher has settled on the type of reality (ontology), the next step is how to know and understand the reality (epistemology). Conversely, methodology refers to well-planned approaches and procedures to conduct investigation while methods are the specific means of collecting data for analysis guided by the research design and theoretical mindset of the researcher [156].

Design science research is guided by three paradigms namely, positivism, interpretivism and pragmatism [151].

a) Positivism

Positivism is a branch of philosophy that holds the believe that reality exists independently of humans but controlled by irrefutable laws [157]. Positivism assumes that truth and knowledge is 'out there to be discovered' through scientific method of investigation [155]. Positivists hold the position that the social world is similar to natural world and in nature, cause and effect of a phenomena are distinguishable which when established can be predicted with certainty in the future [156]. Positivism advocates the use of quantitative research methods. Ontology of positivists is realism, epistemology is objectivism while methodology is experimental [153]. The positivists assumption that application of scientific methods to a social phenomena leads to discovery of laws governing them independent of the knower has been criticized and termed as 'naïve' by many scholars [157]. Post-positivism is a by-product of addressing the weaknesses of the positivist paradigm. The ontological position of the post-positivism is critical realism which recognises the possibility of the researcher's beliefs and values can have effect on what is being observed [157].

b) Interpretivism

Interpretivism paradigm is the opposite of positivism where emphasis is placed on the viewpoint of the individual and their interpretation of the phenomena under study [155]. Therefore, the standpoint of interpretivists is that reality is socially constructed hence the other name for this paradigm is constructivism paradigm. Additionally, this paradigm stands on the belief that theory stems from the data generated from the research act. Ontological position of interpretivism is relativism meaning that reality is a subjective construction of the mind [158], alluding to subjectivist epistemological position. This means that the reality is revealed by the researcher hence the methodology is participation. Often, an interpretivist researcher relies on qualitative methods for data collection [153]. Some critics of interpretivism paradigm claim that the knowledge produced from interpretivism has limited transferability as it is based on highly contextualized data and hence lack generalizability [158]. Others criticize it of lack objectivity due to the involvement of the researcher and the participants in the research action [156].

c) Pragmatism

Pragmatism research paradigm advocates a pluralist and practical approach with a view to understand the phenomenon at hand. Therefore, the emphasis in this case is more on the research problem under study rather than the methods used [155]. Research conducted within pragmatism framework makes use of both qualitative and quantitative methods (mixed methods) thus putting into account multiple viewpoints, perspectives, positions and standpoints [159] depending on nature of the study (problem under study). This makes the research meaningful and legitimate[155]. Consequently, a mixture of ontology and epistemology is acceptable in this paradigm. The ontology of pragmatism is non-singular reality meaning that everyone has their interpretation of reality. On the other hand, epistemology of pragmatism is neither objective nor subjective but relational which means that the relationship is determined by the researcher at hand.

Philosophical assumption applied in this study

Pragmatism and interpretivism research paradigms influenced by critical realist and relativist ontological positions were adopted in this research. This standpoint is consistent with Bunge's believe that design science research is most effective when researchers shift between pragmatic and critical realist perspectives [160]. In this study, the researchers held the believe that the phenomenon under study would be explored best through multiple realities and meaning made out of them thus representing relativists ontology position. As such, the study adopted mixed methods research approach advocated by pragmatism paradigm.

5.3 The Study Design

Research designs are categorized broadly into three: quantitative, qualitative, and mixed methods. Quantitative methods often deal with data in form of numbers (quantification) in terms of their collection and statistics for analysis. Quantitative study often employs theories, mathematical model or hypothesis related to the phenomena under study [161]. Mostly, experiments and surveys methods are used for data collection. Qualitative research on the other hand is primarily explorative research that employs non numerical analyses and interpretations of observations to gain understanding of underlaying patterns, opinions, and motivations [162]. Common data collection methods include focus group, interviews, participation/observation, among others. Mixed method research (MMR) involves integrating both quantitative and qualitative approaches in a research study for enhanced insight into the phenomena under study as well as the research question(s) [163]. Green et al. highlight five notable purposes for mixing in mixed methods research namely; triangulation, complementary, development, initiation and expansion [164]. Regardless of the purpose of mixing, evaluation studies that use mixed methods are robust and more useful in medical setting [165]. Furthermore, Anderson & Aydin underscores the need for a combination of mixed methods to measure complex social interactions affecting technology use [166].

There are various approaches of mixed methods research [163], but the three primary ones include: (a) convergent parallel – This involves simultaneous collection, merge, and use of both quantitative and qualitative data, (b) explanatory sequential – This involves two phases: the first phase gathers quantitative data while the second gathers qualitative data based on the results from the first phase. The purpose of explanatory design is to enhance on the quantitative findings, and (c) exploratory sequential – This involves two phases: the first collects qualitative data to investigate a phenomenon and second uses the findings to gather quantitative data to explicate the qualitative findings.

DeLone and McLean IS success framework used in this study does not specify the methods or parameters to be used [74]. With the aims of this study in mind, we used explanatory sequential MMR where quantitative data was first collected followed by qualitative data to enhance the quality of the findings. Analyses results of the quantitative data provided the criteria for selecting study facilities to participate in the subsequent qualitative study. In overall, this research adopted mixed methods, retrospective observational study design for results validation as well as strengthening the study's conclusion [167]. In observational studies, observations are made without interventions of the investigator while in experimental studies, one or more factors are altered and the effects examined [168]. Retrospective studies are conducted at the present time and look at the past to examine events, trends, or outcomes of the phenomenon under study. Empirical data for the quantitative part of this study was collected retrospectively for the period January 2012 – December 2019.

5.3.1 Study subjects and methods

Table 4 presents study subjects and data collection methods for each specific study objective. The study specific objectives are described in Chapter 4 of this thesis.

Table 4: A summary of the number of study participants and facilities per study objective.

Specific objective	Study participants	Data collection methods
1	10 EMRs subject experts	- Literature review - Nominal group technique
2	213 EMRs facilities/KeEMRs champions	- Data extraction from KeEMR system & KHIS using queries
3	20 EMRs users	- Focus group discussion technique

Figure 8 illustrates the process that was followed in conducting the research and associated publications resulting from each phase. The problem to be addressed is clearly defined in Chapter 1 of this thesis. A detailed description of methods is found in the respective publications (see Appendices).

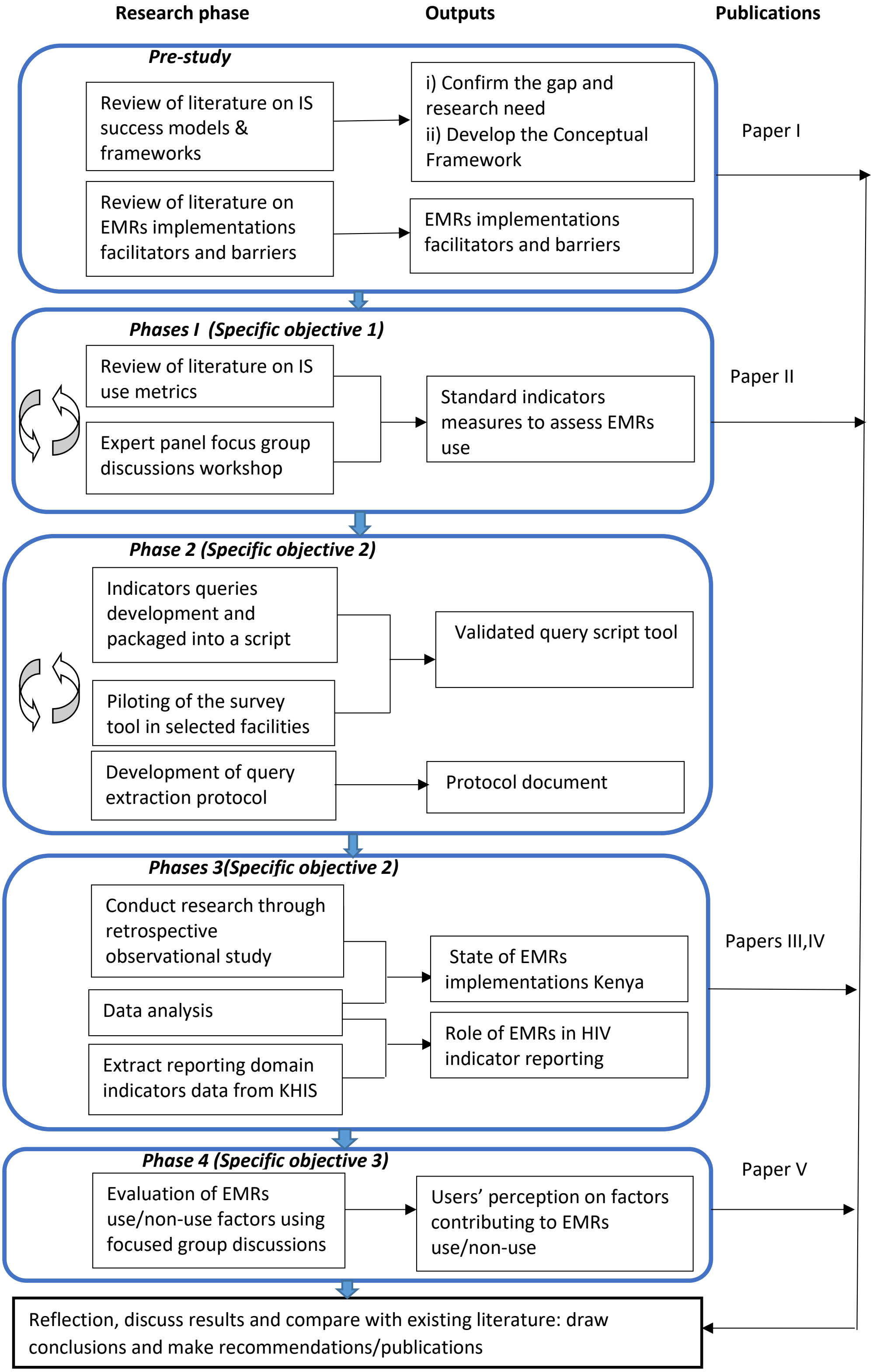

Figure 8:The research process used in this thesis

5.4 Application of Design Science Research Process (DSRP) Model

There are quite a number of process models of design science research processes readily available for researchers' selection based on the DSR project at hand [169][151][170]. However, the phases of these processes are somewhat similar where each begins with problem characterization though different names are used by each model. In this section, we discuss the iteration stages of DSR process model as proposed by Vaishnavi et al. [150] and its application in the development of the artefacts in this study. Vaishnavi et al. process model consists of the following stages: awareness of problem, suggestion, development, evaluation, and conclusion (Figure 9) [150].

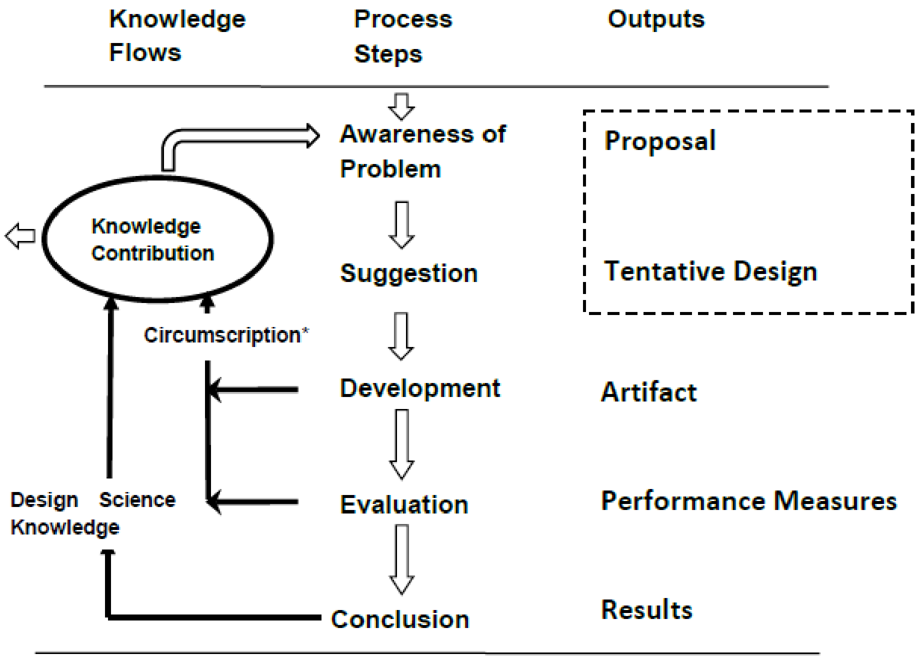

Figure 9: Design Science Research Process Model (DSR Cycle) [150]

5.4.1 Problem Awareness

This stage involves a clear identification and characterization of the research problem originating from the industry or a specific discipline. This awareness may be derived from multiple sources such as literature review, organizational documents such as policies and minutes, and discussions/meetings. The outcome of this stage results to outputs such as a proposal document. The awareness of the problem in this study originated from the MOH/funding partners while the environment was the healthcare facilities implemented with Electronic Medical Records systems (EMRs) under investigation.

This research was conceived out of an organizational need. The MoH, funding agencies and EMRs implementing partners needed to know the actual status EMRs use eight years post-implementation. This was the first investigation/study of its kind in a resource constrained setting. To clearly understand the problem and the environment, we conducted a pre-study systematic literature review on studies on facilitators and barriers of EMRs implementations in low resource setting. We searched for papers published in the period 2007 to 2017 and the findings published in **(Paper I)**. Subsequently, we conducted extensive literature review on IS success models, frameworks, and evaluation studies on IS implementations in order to determine the IS implementation success measure constructs [8,28,29,50,80,89,109]. These were evaluated and their inadequacy to sufficiently solve the current problem identified.

5.4.2 Suggestion

This stage entails envisioning a solution based on the problem awareness output and guided by existing theories and methods drawn from the knowledge base for the problem area [150]. A formal proposal is developed which contains tentative design (solution). In this study, new approaches of evaluating EMRs implementations were designed based on the problem awareness and the need to contextualize the solution to developing countries setting. The approach comprised of three specific objectives contained in the proposal document namely: (1) Use Nominal Group Technique (NGT) and group validation technique to develop consensus-based metrics and indicators for determining EMR systems use; (2) Assess the functional/operational status of the implemented KenyaEMR system in healthcare facilities in Kenya by using empirical data collected from all the implementations countrywide; and (3) Evaluate factors contributing to EMR systems use and underuse or non-use in healthcare facilities in Kenya (refer to Chapter 4).

5.4.3 Development

This stage entails creating the artefact which can range from theories, processes, constructs, models, methods or instantiations [151]. The developed artefact must be relevant to the environment for which it is created. Development derives its rigor from the knowledge base consisting of raw materials/resources such as theories, models or methods. The construction of the artefact can involve a number of iterations.

The development of the artefact in this study followed three sub-cycles each guided by the study's three specific objectives. Different approaches and techniques were employed to achieve each objective. These are described below according to each specific objective and associated publications resulting from each sub-cycle.

Sub-cycle 1: EMRs use indicators development (Paper II)

Objective 1: Use Nominal Group Technique (NGT) and group validation technique to develop consensus-based metrics and indicators for determining EMR systems use.

From the literature review exercise (see Figure 8, Phase 1), we gathered 14 candidate indicators and metrics of information system use. These proposed IS use indicators and metrics were subjected to a rigorous nominal group technique (NGT) process with multidisciplinary subject matter experts with knowledge of the development, implementation and use of EMRs to reach consensus on the final set of indicators for monitoring EMRs use. NGT is a ranking method that enables a controlled group of nine or ten subject matter experts to generate and prioritize a large number of issues within a structure that gives the participants an equal voice [171]. The candidate indicators were rated against quality using **s**pecific, **m**easurable, **a**chievable, **r**elevant, and **t**ime-bound (SMART) [172] dimensions using a five-point Likert scale for each dimension where 1= Very Low, 2=Low, 3=Neutral, 4=High, and 5=Very high level of quality. The NGT process involved five steps (see Figure 10). NGT allows for equal participation of members, and generates data that is quantitative, objective, and prioritized [173, 174]. Some of the original candidate indicators derived from literature were revised and new ones added based on team discussions/consensus. Finally, each participant was asked to rank the final list of the 15 indicators individually and anonymously in order of importance, with rank 1 being the most important and rank 15 the least important. The participants were also asked to group the 15 indicators by the implementation priority and sequence into Phase 1 or 2.

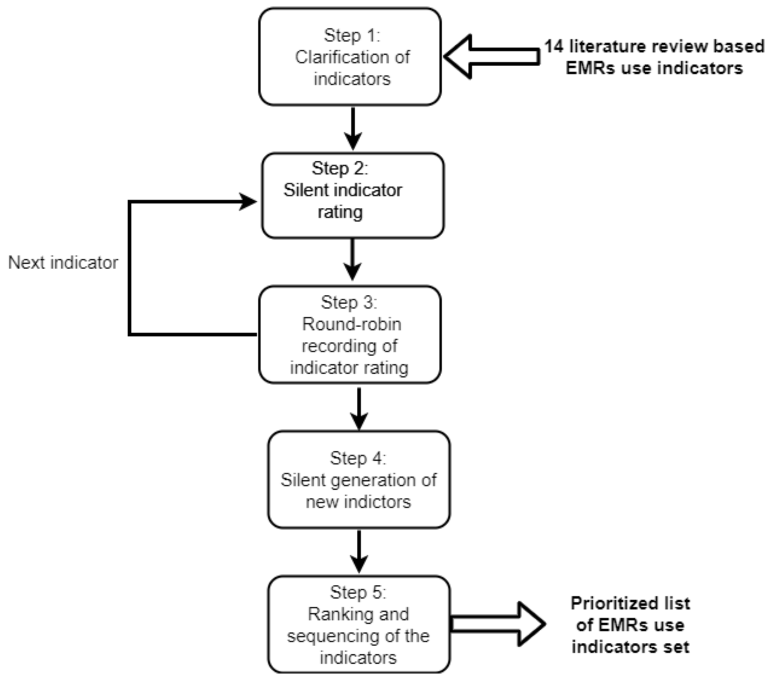

Figure 10: Nominal group technique process as applied in the development of the EMRs use indicators

Descriptive statistics were computed to investigate statistical differences on the rating of the 14 candidate indicators among the participants. Chi-square test was used to determine if there were statistically significant differences in rating of indicators across each of the SMART dimensions. Weighted mean for each SMART dimension across all the 14 indicators was calculated to identify how the participants rated various candidate indicators. For the final indicator list, descriptive statistics were computed to determine the average rank score for each indicator and to assign priority numbers from the lowest average score to the highest. Data analysis was done using SPSS version 25 [175].

Sub-cycle 2: Quantitative study - Evaluation of actual EMRs use (Papers III & IV)

Objective 2: Assess the functional status of the implemented KenyaEMR system in healthcare facilities in Kenya by using empirical data collected from all implementations countrywide.

The standard EMRs use indicators set developed in sub-cycle 1 was used in conducting a comprehensive assessment of the actual use of EMRs implementations in all healthcare facilities implemented with KenyaEMR system in Kenya. For the purposes of this study, 10 of the indicators were used in the assessment as they could be programmed and run as scripts within the EMRs implementation (environment). The remaining five indicators were excluded for the reason that they would have been too time consuming and resource intensive for the study.

Method

To collect primary data for each of the first seven indicators (see Table 7), we used queries with a view to eliminate bias normally introduced by self-reporting data collection tools such as questionnaires [51, 111]. The queries were developed in MySQL software and were designed to collect monthly server log data for each indicator from January 2012 – December 2019 per facility. This period covers the duration the EMRs were in use since the first implementation in the year 2012. We tested the queries for accuracy in a training server with the developers of the system under study. To ensure validity of the indicator outputs, we reviewed the data generated from the testing phase together with a data analyst and revised the queries accordingly. The seven queries were then combined and packaged into a script (Appendix I) that comprised the queries and Linux bash script for creating a zipped archive file as an output after running the script.

We also developed Standard Operating Procedure (SOP) instructions (protocol) detailing step-by-step process for executing the script (Appendix II) to guide the users in the query execution task. We conducted a pilot test in six facilities selected randomly in two counties to identify and address potential glitches in running the queries in a production environment (facilities). The pilot test was also intended to ensure that the protocol were understandable and easy to follow. Any issues raised during this phase were addressed and the script and protocol updated. The final script was shared via email to selected EMRs users in the study healthcare facilities (n=312). The resulting data collected from running the query script were emailed to the researchers in zipped form for consolidation, cleaning and analysis.

Monthly data for the last three EMRs use indicators (reporting rate, reporting timeliness and report completeness) were extracted from the aggregate Kenya Health Information System (KHIS) [176] also referred to as District Health Information System 2 (DHIS2), for the period 2011 to 2019 for the facilities understudy (n=312). This dataset comprised of HIV data on reporting rate, reporting timeliness, and report completeness for three programmatic areas (1) HIV testing & counselling (HTS), (2) Care & treatment (C&T), and (3) Prevention of Mother-to-Child Transmission (PMTCT). It is worth noting that all healthcare facilities are expected by the MoH to report a range of HIV indicator data into the KHIS system on a monthly basis. We consolidated and systematically cleaned the resulting datasets in readiness for analysis.

Mean values and standard deviations of the collective performance by facilities for each indicator were calculated. One-way ANOVA (with Tukey's b "post-hoc" test) were performed to measure the variance in variables means (*Staff System Use, clinical volume*, and *patient identification* indicators) across the counties. Correlation analysis was also performed to measure the relationship between selected indicators such as *staff system use* indicator and volume of the clinical data for insight on user productivity. Weighted mean of *Staff System Use* and *Patient Identification* indicators was computed to determine the overall performance of each facility (Appendix III). Finally, multiple linear regression model was fitted to establish how individual facility characteristics affected the use of the system (**Paper IV**).

Descriptive analyses were conducted to compare performance in reporting completeness and timeliness by the facilities during the period 2011 to 2018 for the three reporting indicators (reporting rate, reporting timeliness and report completeness) (**Paper III**).

Sub-cycle 3 - Qualitative study (Paper V)

Objective 3: Evaluate influencing EMR systems use in healthcare facilities in Kenya.

Qualitative inquiry was conducted based on facility performance analyses results obtained from sub-cycle 2 to explore users' perception on factors influencing EMRs usage. In addition, the original goal was to understand how the actual system users reflect on the state of EMRs implementations.

Method

A purposive sample of 20 facilities was selected to provide primary data for this study categorized as follows: best performers (top six), average performers (top seven), and poor performers (top 7) [177]. Purposive sampling is aimed at seeking depth and richness of information and rather than representativeness [178] that was of interest in this study. We conducted three focused group discussions (FGDs), each session lasted two hours. Focus group is defined as organized, highly interactive group discussions that aims to explore a specific topic or an issue to generate data [179]. The focus in our study was to uncover barriers and facilitators to EMR system use in the healthcare facilities as perceived by the actual users. Of the three groups, two groups comprised of 10 EMRs users (one per facility) while one group comprised of four EMRs implementations service delivery partners (SDPs). The aim of the group comprised of the SDPs was to explore EMRs management's perception on EMRs implementations. Purposive sampling method was used to select the 24 study participants [177]. The Focus Group Discussions (FGDs) sessions were conducted online via a secure Zoom video-conferencing enterprise platform [180].

Qualitative content analysis was performed using NVivo qualitative software after transcribing the audio-recording of the discussions (**Paper V**).

5.4.4 Evaluation

This stage involves assessing the developed artefact in the context of the utility it contributes to its environment using well-executed evaluation methods [151]. Thus, evaluation provides evidence that the developed artefact achieves the purpose it was designed for without which outcomes might be seen as unsubstantiated assertions [181]. At the end of the evaluation activity, the researchers can decide whether to iterate back to the problem awareness or suggestions stage (as indicated by the circumscription arrow in Figure 3 which describes the DSR process). Results of evaluation can be used to improve the effectiveness of the artefact or to continue on to conclusion and leave further improvement to further research.

Extant DSR literature suggests variety of different evaluation paradigms, methods, and activities. For example, Markus et al. evaluation framework designed for DSR Information and Communication Technology (ICT) artefacts use the three levels of semiotic in the evaluation namely pragmatic, semantic and syntax [169]. The framework considers utility and quality aspects in the evaluation due to the complex nature of the design processes from a build and evaluate perspective. Venable et al. (2016) also developed Framework for Evaluation in Design Science (FEDS) DSR project evaluation strategy that considers why, when, how, and what to evaluate [182]. Two dimensions (1) the functional purpose of the evaluation (formative or summative) and (2) the paradigm of the evaluation (artificial or naturalistic) represented on x-y axes respectively, form the basis of the FEDS framework.

The evaluation trajectory sought and followed in this study is the 2-by-2 framework proposed by Pries-Heje et al. to guide selection of evaluation strategy(ies) for a DSR project [183]. They posit that evaluation design needs to decide *what* will be evaluated, *when* it will be evaluated, and *how* it will be evaluated. The framework incorporates both *ex ante* and *ex post* orientations (answers the question, when to evaluate) as well as naturalistic settings and artificial settings (answers the question, how to evaluate). E*x ante* evaluation is performed before the development of the artefact in order to estimate and evaluate (predict) the impact of future situations [181]. Conversely, *ex post* evaluation takes place after development of the artefact for the purpose of assessing its value financial and non-financial measures [181]. Naturalistic evaluation explores the performance of an artefact in its real environment (real people, real systems, and real settings) [181]. Thus, it is always empirical and may be interpretive, positivist, and/or critical. On the contrary, artificial evaluation utilizes laboratory experiments, field experiments, and simulations instead [181]. Venable et al. (2012) improved Pries-Heje et al. framework and method by providing a guide to design science researchers on how to design the evaluation component of their DSR projects [181]. This was found lacking in most DSR evaluation frameworks [151,169,183].

The artefact from this research was evaluated *ex post* in a naturalistic environment. Real users, some of whom we included in this study can further evaluate the EMRs implementations guided by the approach suggested in this thesis.

5.4.5 Conclusion

This is the last stage of a research process which entails write up and dissemination of the research findings. Hevner et al. & Peffers et al. refer to this phase as communication and is aimed to diffuse the resulting knowledge [151, 184]. The knowledge gained can be solid facts that can be learned or repeatedly applied [150]. Nevertheless, a case of further research may arise if the knowledge is anomalous or incomplete. In this phase, the researcher reflects on what was learned, what worked, and what did not work to solve the problem. The findings from this study were published in peer reviewed journals and presented in international scientific conferences.

Chapter 6

6. Results

6.1 Introduction

In this chapter, we present a summary of the key findings and results from each phase of the research, and accomplishments through the three sub-cycles. The detailed explanation of the results are found in the respective publications (see Appendices). These will also be referred to in the text.

6.2 Problem awareness and suggestions

Electronic medical records systems have the potential to improve care management and reduce costs. As such, the Ministry of Health (MoH) in Kenya, with the support of international donor funding and local partners, embarked on development and implementation of EMRs, such as KenyaEMR and IQCare, in healthcare facilities since 2012 [185]. Further, EMRs implementations involve a significant up-front investments in software design and development, infrastructure, implementation, training, and IT support. Hence evaluation to determine success of these implementations is paramount. Nevertheless, no evaluations have been conducted to establish the status of the EMRs post-implementation to inform scale-up in the study and similar other settings. Details of the problem to be addressed is clearly defined in Section 1.4 in this thesis.

Various approaches used in studies evaluating EMRs implementations were identified. Based on the findings we have developed a method that incorporates the use of both quantitative and qualitative research approaches. The method entails evaluating the state of EMRs implementation in an LMIC setting employing D&M IS success use construct [74]. Further details on research theoretical background are contained in Chapter 3 of this thesis.

6.3. Sub-cycle 1: Development of standard indicators to assess use of electronic health record systems implemented in low-and medium-income countries. (Paper II)

The Nominal Group Technique (NGT) exercise reached a consensus to include a total of 15 EMRs use indicators in the final list of indicators (Table 5). These indicators were classified into four categories (Figure 11), namely:

(a) System Use – these indicators are used to identify how actively the EMRs is being used based on the amount of data recorded, number of staff using the system, and uptime of the system.

(b) Data Quality – these indicators are used to highlight proportion and timeliness of relevant clinical data entered into the EMRs. They also capture how well EMRs data captures an accurate clinical picture of the patient.

(c) Interoperability – given that a major perceived role of EMRs is to improve sharing of health data, these indicators are used to measure maturity level of implemented EMRs to support interoperability.

(d) Reporting – aggregation and submission of reports is a major goal of the implemented EMRs, and these indicators capture how well the EMRs are actively used to support the various reporting needs.

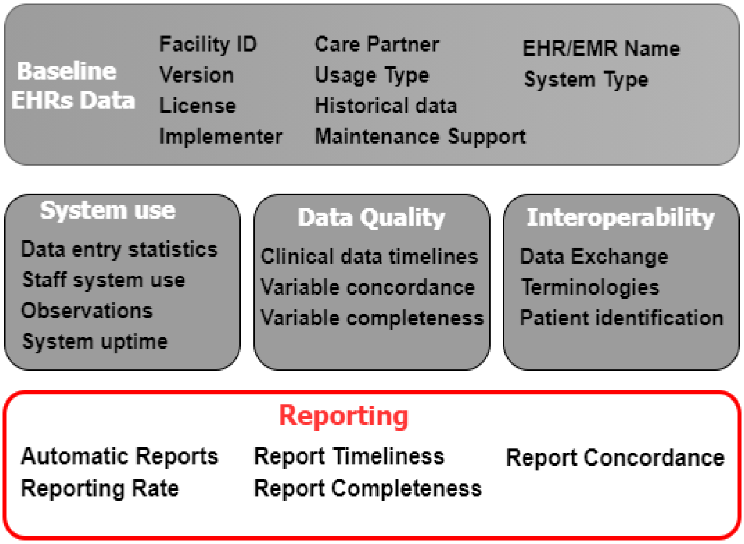

Figure 11: Infographic of key domains for EMRs use indicators

Table 5: The set of validated reporting indicators on EMRs use

#	Domain	Indicator Name	Description	Frequency[a]
1	System Use	Data entry statistics	Number and % of patient records entered into system during reporting period	Monthly
2	System Use	Staff system use	% of providers who entered data into system as expected for at least 90% of encounters	Quarterly
3	System Use	Observations	Number of observations recorded during period	Quarterly
4	System Use	System Uptime	% of time system is up when needed during care	Monthly
5	Data Quality	Clinical data Timeliness	% of clinical provider encounters entered into the EMRs within agreed time period.	Monthly
6	Data Quality	Variable Concordance	% concordance of data in paper form vs data in EMRs	Quarterly
7	Data Quality	Variable Completeness	% of required data elements contained in EMRs	Quarterly

8	Interoperability	Data Exchange	Automatic exchanging of data with different systems	Quarterly
9	Interoperability	Standardized Terminologies	% of terms that are mapped to standardized terminologies or national dictionary.	Yearly
10	Interoperability	Patient identification	% of nationally accepted patient identification instances in the EMRs.	Quarterly
11	Reporting	Automatic Reports	Proportion of expected reports generated automatically by system	In-line with PEPFAR[b] reports
12	Reporting	Reporting Rate	Proportion of expected reports that are actually submitted	Monthly
13	Reporting	Report Timeliness	Timeliness of expected reports to national reporting system	Monthly
14	Reporting	Report Completeness	Completeness of expected reports to national reporting system	In-line with PEPFAR reports
15	Reporting	Report Concordance	% concordance of data contained in paper-derived reports compare to report data derived from the EMRs	Biannual

[a]Frequency describes how often the data should be collected
[b]Monitoring, Evaluation, and Reporting [MER] indicators defined by PEPFAR initiated HIV programs [186]

As part of the NGT exercise, a detailed indicator reference guide including description of the indicator, the data elements constituting the numerator and denominator, how the indicator data should be collected, and what data sources would be used for the indicator, were also refined **(Paper II)**. Sub-cycle 1 output presents a detailed EMRs Monitoring and Evaluation Reporting (MER) document, with agreed upon details for each indicator provided (Appendix IV).

6.3.1 Indicator ranking and implementation sequence

The score and rank NGT exercise involving a total of 10 subject experts generated a prioritized consensus-based list of EMRs use indicators with a score of 1 (highest rated) to 15 (lowest rated) (**Table 6**). Nine of the 15 indicators were recommended for implementation in the first phase of the indicator tool rollout, while the other six indicators were recommended for Phase 2 rollout. Rollout assumes introducing the indicators into practice as a two-stage process for gradual adoption hence the two phases (1 & 2).

Table 6: Ranking of finalized EMRs use indicators

Indicator Ranking	**Indicator Name**	**Average Score** Mean (SD)	**Implementation Phase (1or2)**
1	Data Entry Statistics	2.78 (2.33)	1
2	System Uptime	4.56 (5.22)	1
3	EMR Variable concordance	6.44 (2.80)	1
4	EMR Variable Completeness	6.56 (3.32)	1
5	Report Concordance	6.67 (4.66)	1
6	Staff system use	6.78 (4.64)	1
7	Clinical Data Timeliness	7.33 (4.61)	1
8	Report Completeness	7.89 (2.98)	1
9	Patient Identification	8.00 (4.33)	1
10	Data exchange	8.67 (4.12)	2
11	Reporting timeliness	9.00 (3.61)	2
12	Automatic Reports	10.33 (2.83)	2
13	Observations	11.56 (4.12)	2
14	Standardized Terminologies	11.56 (2.87)	2
15	Reporting Rate	11.89 (2.76)	2

6.4 Sub-cycle 2: Assess the functional status of the implemented KenyaEMR system (KeEMRs) in healthcare facilities in Kenya by using empirical data collected from all implementations countrywide. (Papers III & IV)

Two hundred and thirteen facilities (213) out of the 312 assented to participate in the study responded (68.3%), spanning 19 counties in Kenya. The actual use of the implemented KeEMRs was assessed on various factors. First, we evaluated the spread of the EMRs implementations per county. We observed that KeEMRs was first rolled out in the year 2012 with only five implementations in four counties. Most of the EMRs implementations however, occurred in 2014 (113 implementations, 53.1%) followed by 2013 (91 implementations, 42.7%). No implementations occurred in the period 2015 – 2017 whilst there were only four new implementations (1.8%) between 2018 and 2019 in line with the country's planned implementation strategy **(Paper IV)**. Secondly, we assessed general facilities performance based on selected indicators as presented below.

6.4.1 EMR usage indicator results

Table 7 details the 10 indicators used in evaluating the state of EMRs implementations (sub-cycle 2) including a summary of the facilities average performance per indicator in percentages and counts.

Table 7: EMRs usage indicators evaluated in this study

#	Indicator (variable)	Domain	Indicator query description	Source of data	Average performance in % & counts
1.	Staff system use	System use	Defined by create, update, and delete actions around a patient record by an authorized EMRs user	EMRs	18 ± 13.3% ($p=0.001$)
2.	Clinical volume	System use	A count of the data captured by the 23 data elements* per patient encounter per month	EMRs	3363 ± 4249
3	EMR Variable completeness	Data quality	No query. Data elements* captured from RDQA report generated from EMRs	EMRs	100%
4	Data Exchange	Interoperability	Count of unique data exchange messages between EMRs and other sub-systems through interoperability layer.	EMRs	14.1%
5	Standardized Terminologies	Interoperability	Percentage mapping of EMRs concepts with the concepts_reference_map table	EMRs	97.6%
6	Patient Identification	Interoperability	Patient visits identified using 10-digit identifier vs total active patients during the reporting period	EMRs	50.5% ± 35.4% ($p< 0.001$)
7	Automatic Reports	Reporting	A count of the reports' generation requests	EMRs	**

8	Reporting Rate	Reporting	Derived from DHIS2 system lookup table	KHIS	(see table 8)
9	Report timeliness	Reporting	Derived from DHIS2 system lookup table	KHIS	(see table 8)
10	Report completeness	Reporting	Derived from DHIS2 system lookup table	KHIS	***

*The 23 data elements include: patient ID, sex, date of birth, date confirmed positive, enrolment date, initiation date, initial regimen, Current regimen, BMI at last visit date, TB screening at last visit, TB screening outcomes, IPT start date, IPT status, IPT outcome date, Second last VL result, second last VL date, most recent VL result, most recent VL date, last clinical encounter date, next visit date, Pregnancy assessment last date, Initial EID within 8 weeks, Infant prophylaxis.

**The query output for *Automatic reports* indicator returned zero and hence there was no data to compute. This was because the generated reports from KeEMRs and their transmission are not saved. The system is configured to refresh the database report tables daily. Thus, it could be recommended to calculate this indicator daily or have the system retain the contents of the report table for at least a month.

***We encountered a challenge in extracting the data for *Reporting completeness* indicator from KHIS system due to configuration issues. The system presents both missing reports and zero reports with a blank cell. Thus, it was impossible to tell when a facility has not sent their reports or when its reports=0. Thus, this data was not collected. However, we raised this anomaly to the relevant authorities.

The descriptive analysis of the evaluated EMRs use indicators revealed that the average mean of the staff system usage in the 19 counties was 18.2%. The findings showed that there was a significant mean difference on system users across the counties (p=0.001) (Table 5). On average, facilities captured 3363 (SD=4249) data elements (clinical volume) every month, for the 23 data types of interest for reporting in Kenya ranging from 251 (SD=167) to 28937 (SD=11356). We observed that the *EMR Variable Completeness* indicator was 100% across the study facilities, but this only represented the 23 key data elements that had to be captured on every patient. Majority of the facilities (183/213) lacked the interoperability layer (IL) module and hence had no capability to exchange health data with external systems. On average, 97.6% (52,098 out of 53,353) of KeEMRs concepts were mapped to the standardized (international) terminologies/concept dictionaries such as CIEL and SNOMED. Only 50.5% (SD=35.4%, p< 0.001) of the patient records had patients with IDs in the nationally-endorsed patient identifier format, i.e., 10-digit number (5 digits from Master Facility List (MFL) + 5 Comprehensive Care Clinic number (CCCNo.)) with a wide range of 3% to 100% conformity across the facilities.

6.4.2 Impact of EMRs implementation on reporting of HIV indicators (Paper III)

Table 8 shows reporting rates and timeliness in the year 2011 (pre-EMRs implementation) and in 2012-2018 (period when EMRs were progressively rolled out in the facilities). There was a steady improvement of reporting rate and timeliness across facilities during the study period. However, a noticeable drop in performance is seen in 2018 with an average drop of 13% in reporting rate and 11% in timeliness of reporting.

Table 8: MOH 731 Reporting rate and timeliness averages in %

Year	Indicator	HTS	PMTCT	C&T
2011		**n=74**	**n=71**	**n=49**
	Reporting rate	15.98 ± 8.71	14.9 ± 7.32	15.30 ± 7.88
	Reporting Timeliness	5.96 ± 7.99	5.51 ± 7.58	5.78± 8.02
2012		**n=4**	**n=4**	**n=4**
	Reporting rate	56.25 ± 27.55	41.68 ± 36.03	56.18± 25.90
	Reporting Timeliness	41.68 ± 34.03	37.50 ± 37.60	33.25± 34.08
2013		**n=104**	**n=105**	**n=103**
	Reporting rate	92.80± 12.97	93.25 ± 14.02	91.20± 14.82
	Reporting Timeliness	77.65 ± 23.53	72.21 ± 29.73	73.23± 24.70
2014		**n=260**	**n=258**	**n=259**
	Reporting rate	97.44 ± 6.97	98.64 ± 4.33	96.53± 8.87
	Reporting Timeliness	85.90 ± 17.53	65.07 ± 34.49	80.05 ± 21.30
2015		**n=261**	**n=260**	**n=260**
	Completeness	99.27 ± 2.86	99.39 ± 2.61	98.95± 3.74
	Timeliness	90.05 ±17.57	83.93 ±22.62	84.24 ± 22.36
2016		**n=260**	**n=260**	**n=260**
	Reporting rate	99.36± 2.43	99.10 ± 3.13	99.08± 3.00
	Reporting Timeliness	94.12 ± 9.48	89.81 ± 13.28	83.73 ± 20.29
2017		**n=260**	**n=259**	**n=259**
	Reporting rate	98.24 ± 5.22	98.01 ± 5.58	98.75 ± 3.85
	Reporting Timeliness	90.91 ± 12.72	88.13 ±15.18	85.01 ± 19.37
2018		**n=261**	**n=260**	**n=259**
	Reporting rate	70.10 ± 23.85	70.52 ± 23.72	69.38 ± 23.96
	Reporting Timeliness	67.01 ± 24.58	65.04 ± 24.87	62.47± 26.55

n = number of facilities

6.4.3 General performance of the healthcare facilities (Paper IV)

Using the weighted mean of the means scores of *Staff System Use* and *Patient Identification* indicators, facilities were benchmarked against each other using the "best performer" and "worst performer" approach. The weighted mean ranged from 9% to 65% across the 213 facilities. Appendix III presents facility performance list from the highest to the lowest. The top ten performing facilities had an average weighted mean of 61% (range 59-65%) while the bottom ten facilities had an average mean of 11% (range 9-12%).

6.4.4 Effect of facility characteristics on EMRs use (Paper IV)

Multiple linear regression modelling showed that the facility characteristics (level of facility, ownership, services, and mode of EMRs use) were significantly influencing the actual usage of the system with the exception of Mode of EMRs use characteristic (Table 9). Retrospective Data Entry (RDE) mode of EMRs use had the highest negative impact on the use of the system.

Table 9: Multiple linear regression model for staff system use and facility characteristics (Paper IV)

Facility Characteristics		Unstandardized Coefficients		Standardized Coefficients	t	P-value
		B	Std. Error	Beta		
(Constant)		0.354	0.084		4.213	<0.001
Facility level	Level 2 Level 3 Level 4	0.445	0.019	0.194	23.929	<0.001
Ownership	-Faith-Based Organisation -Ministry of Heath -Non-Governmental Organization	0.401	0.035	0.092	11.308	<0.001
Services	CT CT&HTS	0.392	0.015	0.206	25.351	<0.001
Mode of EMRs use	Hybrid POC RDE	-0.124	0.014	-0.074	-9.176	<0.001

Dependent Variable: Number of active system users; Independent Variables: KEPH level, ownership, mode EMRs of use, and services. p-value: when $p<=0.05$, there is statistically significant difference. B (coefficient) explains a change in dependent variable that can be attributed to a change of one unit in the independent variable.

6.5 Sub-cycle 3: Factors influencing EMR systems use in healthcare facilities in Kenya (Paper V)

6.5.1 Facilitators and Barriers to EMRs use

We identified six categories of EMRs use facilitators and barriers from the qualitative content analysis from the focus group discussions (FGDs) data namely: (1) System functionalities/capabilities, (2) training, (3) technical support, (4) human factors, (5) infrastructure, and (6) EMRs operation mode. We categorized the coded data as either facilitator or barrier of EMRs use or both (Table 10).

Table 10: EMRs use facilitators and barriers

	Facilitators	Barriers	Boundary factors
System factors	- Ease of use - Ease of learn - System implementation at all points of care (system integration) - Regular system upgrades enhancing the capabilities of the system. - Efficient Reports generations at click of a button ✓ sending routine reports direct to DHIS2 system ✓ Partners reports (SDP) - Readily available data to support in decision making at clinical and management level - Improved data quality	- Limited use of the EMR– only used for HIV care - Delayed updates on the EMR product releases e.g the most current - COVID-19 EMR - Delayed system upgrades by partners	
Training	- Adequate initial user training - Online (Zoom) training by partners - System champions trained on system upgrades.	- Training covers a few users of the system instead of all staff. - New staff not trained in good time. - Lack of training on system upgrades - new functionalities - Absence of regular follow-up/refresher user training or not as comprehensive - Little/lack of training on basic IT skills for backend tasks e.g running queries. - Lack of updates on MoH/NASCOP guidelines/SOPs e.g definition of LTF	- On-job-training (OJT) good/ incomprehensive
Technical support	- 24/7 help desk support from offered by system developer (Palladium) through a toll-free line - Very responsive technical team - System developer's site access provided to learn about the new system upgrades	- Delays in IT staff support within the facility	

EMR system operation mode	- Implementation at all points of care- Paperless & POC (patient data captured once) ✓ EMR data and paper register records 100% concordant at the point of care ✓ More time with patients and for other tasks	- Retrospective data entry (RDE) – (patient data captured on paper then transferred to EMR)	- Hybrid - mixed mode (POC & RDE)
Human factors	- Collegial support - OJT by experts to colleagues and new untrained staff. - Change of attitude on age factor – both young & old staff now using the system.	- High staff turnover - Negative attitude by MoH staff towards the system because of exclusion from training - Inadequate staff in cases of RDE mode leading to delays in updating patient records - Staff burnout due to repeated tasks in RDE mode - Negative attitude towards system -initially older staff dismissed system as meant for the young people who know computers.	- "Age attitude"
Infrastructure factors	- Integrated care through interconnectivity of service delivery points - Provision of additional updated hardware – tablets by partners	- Frequent power blackouts leading to RDE & hybrid modes of EMR operations - Lack of proper power backups - Lack of enough computers leading to RDE mode. - Local area network (LAN) and internet disconnections - Lack of system integration to other clinics for seamless flow of patient data in all points of care. - Slow and old computers ✓ Hardware replacement a challenge	

Patient data management	- Easy appointments managements - Flagging of patients due for viral loads - Easy way of defaulter tracing and lost to follow up (LTFs) - Easy management of indicators - Able to quickly tell current on care - Prompt and correct information to social department for patient follow-up.	- Multiple manual registers and reporting requirements	-

6.5.2 Recommendations for enhanced EMRs use (Paper V)

The study participants provided vital ideas that would address some of the barriers to EMRs use in order to encourage its usage. Table 11 presents a summary of the suggestions, rationale and the responsible stakeholder.

Table 11: Summary of the participants recommendations for enhanced EMRs use and rationale

Recommendation	Rationale	Responsible
MoH to take lead in the KeEMRs ownership and implementations instead of the funding agencies or partners	Guaranteed sustainability when the partners leave	MoH
Clear EMRs implementation structure with the roles of the county government (host of the EMRs implementations), EMRs developers, and Service Delivery Partners (SDPs) clearly defined	Efficacy in managing the roll outs, leading to increased likelihood of EMRs implementations success	MoH
Stable power backup plan (redundancy)	24/7 system availability is highly recommended in a healthcare setting	MoH
Hospital wide EMRs implementations	To avoid the undesirable shift from electronic to paper patient records	MoH/SDPs
Regular trainings (all inclusive)	Refresher trainings are necessary whenever there are system upgrades as well as to new staff (users) to competently use the EMR system. The training should include all staff (MoH & Project) to avoid negative attitude and secure common understanding of the EMRs functionality and goals	Implementing partners (SDPs)

Training to include IT content	Basic IT skills are necessary to enable system users perform basic back-end tasks like system backup, running queries, etc.	Developers/SDPs
- Drop paper registers in facilities with 100% concordance. - Review the mode of reporting (electronic instead of paper) or relax the current requirements.	Currently, mandatory registers such as Daily Register (DR) are paper-based which forces system users to transfer electronic data to paper (MoH registers).	MoH & NASCOP
Support all facilities to POC EMRs operation mode.	Most systems operated in hybrid mode which is time consuming and resulting to double work occasioned by retrospective data entry.	MoH/SDPs

6.6 Evaluation

What was actually evaluated? - A process (method) of evaluating state of EMRs implementations using IS *use* construct/dimension. The process described in this thesis is generalizable to any information system as well as to a class of similar problems.

How was it evaluated? - The evaluation was naturalistic in that it was conducted using a real system (KeEMRs) in a real organisation facing real problems. The groups discussions (NGT and FGD) involved real people who are experts in the subject matter [64]. The evaluation criteria was utility (ability to accomplish/achieve intended/stated purpose) [181].

When was it evaluated? -The artefact was evaluated ex post.

6.7 Dissemination of findings

The findings of this study were published in peer reviewed open-access journals and presented at international scientific conferences. Moreover, this thesis will be available in open-access university site (BORA).

Chapter 7

7. Discussion

7.1 Introduction

Evaluating success of information systems implementation involves use of theories, models and frameworks with divergent approaches. The state of EMRs implementations in Kenya had not been characterized. This research set out to systematically evaluate actual state of EMRs post-implementation in a low resource setting using computer-generated data via robustly developed EMRs usage indicator measures.

In this chapter, we discuss the main findings for each study specific objective in relation to respective research questions. A systematic method for evaluating the state of EMRs post-implementations in resource limited settings (artefact) resulted, following a combination of the research objectives performed iteratively in the development phase.

7.2 Discussion of the main findings.

7.2.1 Development of Standard EMRs use indicators

Given the importance of system usage as a crucial link between IS investments and IS outcomes, it is expected that advanced techniques and metrics for assessing system usage are employed in practice [117]. Nevertheless, preliminary research on EHR/EMR use studies reveal there are no specific measures for assessing their usage [8,28,29,50, 80,89,109]. Further, DeLone and McLean (D&M) IS success framework employed in this study does not specify the methods or parameters to be used [74]. With this in mind and the need to determine the state of EMRs implementations in the study setting, a set of fifteen indicators and metrics for monitoring and evaluating actual EMRs use, hinged on four dimensions namely: system use, data quality, interoperability, and reporting, were systematically developed [64] **(Paper II)**/(Table 5). This answers the first research question: ***What unique measures predict EMR system use in the public healthcare setting in developing countries?***

Systematic approaches in indicator selection/development have several advantages: (1) they rely directly on available evidence, complemented with expert opinion when necessary, (2) facilitate the development of quality indicators thorough experts consensus, and (3) generates data that is objective. Systematic methods such as NGT and the Delphi technique have been widely used for quality-indicator development in healthcare [64, 187]. In our research, a panel of experts (EMRs users, MoH representatives, system partners and developers) reviewed the indicators to ensure content clarity and validity.

The developed indicators take into consideration constraints within the LMIC's setting such as system availability, human resource constraints, and infrastructure needs. Ideally, an IS implementation is considered successful if the system is available to the users whenever and wherever it is needed for use [46]. Clear measures of system availability, use, data quality, and reporting capabilities ensure that decision makers have clear and early visibility into success and challenges facing system use. The developed indicators allow for aggregation of usage indicators to evaluate performance of systems by type, regions, facility level, and implementing partners (see Figure 11) in the results section.

The multidimensional indicators (system use, data quality, system interoperability, and reporting) developed in our study align with the three main components of Electronic Health Record (EHR) meaningful use, namely: (1) EHR must be used in the care processes such as prescribing, (2) EHR must encompass electronic health data exchange for improved health care quality and (3) EHR must support reporting of clinical measures [31,32]. This suggests multidimensional nature of any comprehensive EHRs/EMRs use measures. Doll & Torkzadeh in their research argued that multidimensional measures of system-use can facilitate research on the link between upstream causal factors of interest to management information systems professionals (for example, design features or development methods) and their downstream consequences (that is, the social and economic impacts of IT)[51].

One important consideration while developing the indicators was the source of the measure data. To avoid the biased nature introduced by self-reported measures through questionnaires and interviews, this research instead considered utilizing computer-recorded data generated through queries thus incorporating objectivity and repeatability into the measurements. Nevertheless, two of these indicators, *data entry statistics* and *variable concordance*, derive measure data from both facility records and computer logs data while *report concordance* indicator derive data from KHIS system **(Paper IV)** [65].

We developed the indicators in-line with the internationally renowned PEPFAR HIV Monitoring, Evaluation, and Reporting (MER) indicators Reference Guide [35]. This approach guarantees that the developed indicators are in a format well-familiar to most healthcare settings within LMICs. Thus, the learning curve to understanding and applying the indicators is significantly reduced. Nevertheless, short training time may be required for those unfamiliar, due to the simplicity of the format. These measures of EMRs use could be applied in a benchmarking activity to compare information systems in similar work systems (settings).

7.2.2 Status of EMRs systems in Kenya (case study)

Multidimensional instrument based on D&M IS success model *use* construct was adapted to reflect the current state of EMRs implementations [64]. This answered the second research question: ***Can the existing frameworks and the validated EMR systems use indicators and metrics be leveraged to predict the status of EMR systems implementations in Kenya?*** The packaging of the selected indicators in form of a query script in the second sub-cycle of the development stage supported collection of objective data that was independent of human beliefs or perceptions. This was beneficial in unearthing salient EMRs implementation challenges that would have otherwise remained unknown. For example, the very low rating on system usage (18.1%) across the facilities revealed existence of high numbers of dormant user accounts in the EMRs which gave a false high figure of total number of authorized users [65] (**paper IV**). This pointed to challenges in active management and monitoring of user accounts by the system administrators as well as possibility of system users sharing login credentials. A study investigating users' behaviour in password utilization revealed users share passwords for convenience as well as a show of trust [190].

There was no facility specific amount of clinical volume (patient data) that was anticipated over time due to several factors. These factors include patients' volume, frequency of patients' visits (encounters), EMRs mode of use, active usage of the system during care and the period since EMRs implementation. It is worth noting that all these factors are unique to each facility. Nevertheless, the study revealed there were some instances when the volume captured for a given month or period was as low as none (zero) **(paper IV)** [65]. This exposed challenges such as system failure/breakdown during the specific period or where retrospective data entry (RDE) had not actually been done in time or not at all, in times of power blackout. RDE mode of EMRs use was viewed as a barrier to use, which is consistent with other studies [107].

While some facilities had fully adopted use of the nationally endorsed patient identifier, others were lagging very much behind. The findings on this measure were consistent in both qualitative and quantitative approaches of this study **(Papers IV&V)** [65]. Thus, this shows it is possible to achieve 100% patient identifier use if enforcement measures by the relevant authorities are pushed a notch higher. This could be beneficial considering the role universal patient identifiers play in the realization of health data exchange among facilities and within departments [191]. Nevertheless, interoperability preparedness was quite low, with only a few facilities fitted with interoperability layer **(paper IV)** [65]. Apparently, the high mapping of EMRs concepts to international standard terminologies such as CIEL and SNOMED presented a level of interoperability preparedness with other systems for health information exchange. DeLone and McLean posit that integration with other systems is one of the system quality measures among ease-of-use, functionality, reliability and flexibility [74]. The qualitative part of the study confirmed that ease of learn and use motivated participants to use the implemented EMRs **(Paper V)**.

In spite of the implementation weaknesses/challenges exposed by most indicator measures in this study, the EMRs were configured to capture the expected HIV data elements as per the country's standard operating procedures reflected by 100% data variable completeness **(Paper IV)** [65]. This reflects data quality assurance, if other quality attributes such as integrity and completeness are adhered to during patients' data capture into the EMRs. Explicably, decisions grounded on quality data leads to better health outcomes [192].

While the monthly reporting of health data indicators with respect to reporting rate and timeliness by the study facilities across the counties showed considerable improvement, our study could not associate it directly to the KeEMRs implementations (**Paper III**) [61]. This was because at the time of our study (2012-2019), the data collected within the KeEMRs was not directly reported into the national reporting system (KHIS) electronically, since the two systems were not integrated. Nevertheless, the inbuilt reports generation functionality within KeEMRs could have facilitated in the collation of care & treatment data, which in turn expedites the reporting process for data officers to the KHIS. Other factors related to organizational, human, patient load, and financial resources could have as well improved the monthly reporting, which can be explored in future studies.

7.2.3 Facilitators and barriers to EMRs use

The qualitative study identified real issues around EMRs use which could not have been revealed through the use of the indicator measures, answering the question: ***What factors influence the use of EMR systems in Kenya?*** System users perceived EMRs implementation in healthcare facilities to have significantly improved patient data management resulting to quick access to patients' files, high quality data, efficiency in routine reporting, and generally freeing clinician to have more time with the patients **(paper V)**. Largely, all EMRs users regardless of job category were willing to use the system because of the perceived benefits. Most of the facilitators to EMRs use intimated by the users were similar to findings from other studies that pointed out facilitators such as ease of use, ease of learn, system functionalities, adequate training, timely technical support and collegial support [25, 26]. On the other hand, factors related to infrastructure such as lack of power backup plan and insufficient hardware remain significant barriers to EMRs use or demotivators as also reported in other studies in low resource [25, 26]. Nevertheless, EMRs operation mode of use was an outstanding problem limited to EMRs implementations in developing countries **(Paper V**). Retrospective data entry (RDE) mode and the shift from electronic records to paper forms were identified as main demotivators in EMRs use.

In summary the findings from this study revealed the wide-ranging maturity levels of the EMRs implementations nationwide. The facilities are still grappling with pertinent issues, despite over eight years since EMRs implementation in support of care and treatment. Thus, these findings highlight that simply counting number of EMRs implementations, as is currently the case, is highly inadequate in determining IS implementation success.

7.3 Methodological considerations

In this study, various factors were considered in the selection of the research approach, the methods and data availability. We discuss these in the subsequent sub-sections.

7.3.1 Design Science research approach

Design science research approach focus is to create artefacts relevant in addressing a clearly established problem, thereby contributing to the body of knowledge [151]. Hevner et al. proposed seven guidelines essential when conducting design science research: (i) Design as an artefact; (ii) Problem Relevance; (iii) Design Evaluation; (iv) Research Contributions; (v) Research Rigor; (vi) Design as a Search Process; and (vii) Communication of Research. This research was anchored on design science research approach [151]. We discuss these guidelines and how we addressed them in this research.

Design as artefact

The product of DSR approach is an artefact in the form of a construct, a model, a method, or an instantiation [151]. This research produced a three-step systematic method of evaluating the state of EMRs implementations in LMICs settings that is also applicable to a ‘class of similar problems’.

Problem relevance

The produced artefacts are designed to solve real and relevant organizational problems [151]. The state of the EMRs implementations (adoptions) in Kenya had not been characterized over eight years into rollout and despite the high investments on several factors as well. We found countrywide evaluation of the actual use of the implemented EMRs relevant to determine implementations success. This would consequently inform scale-up and sustainability of the implementations in similar low resource settings.

Design evaluation

Design evaluation entails use of well-executed evaluation methods to rigorously assess the utility, quality, and efficacy of a design artefact [151]. Hevner et al. further emphasize the criticality of evaluation activity in DSR [151]. We used real people and real system users in a real environment in all the three sub-cycles of the artefact development (naturalistic evaluation) [64, 65] (**papers II, IV&V**). The produced results from the indicator outputs (EMRs use measure data), reflect the state of KeEMRs implementation (environment), which is a good way to measure functionality and utility of the developed indictors and the process involved. Additionally, the developed standard EMRs use indicator set were subjected to quality testing through Specific, Measurable, Achievable, Realistic and Timebound (SMART) criteria by subject domain experts **(Paper II)**. Furthermore, before the data collection commenced, pilot testing of the query script was conducted in six facilities selected randomly in two counties (real environment) with the support of the EMRs implementing partner staff (real people), to ensure feasibility of data collection within facilities. Moreover, the perceived facilitators and barriers factors to EMRs use identified by the qualitative study have confirmed to a great extent the empirical findings of the quantitative study (**papers IV&V**) [65].

Research contribution

Successful design science research must provide clear and verifiable contributions in the areas of the design artefact, design foundations, and/or design methodologies. Our main contribution of this research is practical, methods and framework for assessing success of IS post-implementation in healthcare environment. This contribution is realized through a generic three-step process using standard tools and IS success models that are validated.

The first contribution is a comprehensive approach that researchers can use to systematically develop standard information system use indicators/measures, that are appropriate for a given theoretical context, from a critical realist position. The developed standard EMRs use indicators were subjected to quality testing through SMART criteria by subject domain experts.

The second contribution is a novel approach to empirically determine success of IS implementations using objective data derived by means of multidimensional instrument (indicators) as reported in (**Paper II**) [64]. Simply counting the number of IS implementations, as is currently done in many settings, remains a highly inadequate measure for evaluating EMRs implementations success. The empirical findings were combined with qualitative study investigating EMRs users perspective on facilitators and barriers to EMRs use for comprehensiveness. To our knowledge this is the first study to have used computer-generated data in a low resource setting.

The third contribution is the practical knowledge on the actual state of EMRs implementations in the study setting (Kenya) to inform relevant stakeholders (MoH, implementing partners and funding agencies) to support data-driven/evidence-based decision making. To our knowledge, no study exists that has used multiple approaches to understand actual use of EMRs implementations in resource limited settings (**Paper IV&V**).

Research rigor

Research rigor is dependent upon application of rigorous methods in both the construction and evaluation of the design artefact [151]. This research took the form of pluralistic inquiry, applying methods such as NGT and FGD, and IS success frameworks. Considering the identified EMRs implementation challenges unique to low resource settings, we utilized the validated DeLone & McLean IS success model ‘use’ construct. Consequently, we derived a wide range of measures that characterize EMRs use. Our choice of the EMRs *use* construct in evaluating EMRs implementations was backed by the fact that 80 percent of IS value is realized during its subsequent use after system development process [50]. We used Nominal group technique (NGT) approach (consensus method) with subject matter experts coupled with our own literature review to develop and validate the standard EMRs use indicators and metrics **(Paper II)** [64]. Within the NGT exercise, a panel of experts (EMRs users, MoH representatives, system partners and developers) reviewed the indicators to ensure content clarity and validity.

Further, focus groups discussion (FGD) technique, also a consensus method, was employed in investigating facilitators and barriers factors to EMRs use, as it was best suited to investigating experiences, attitudes and emerging ideas from the group (EMRs users) [193]. Lincoln and Guba (1985) recommend member (participants) checking, a positivist epistemological position, as a means to enhance rigor in qualitative research [194]. They proposed that credibility is inherent in the accurate descriptions or interpretations of phenomena. To this end, the transcribed data from the focus group discussions in our study were sent to the participants via email to read through and confirm correctness in order to ensure credibility thus trustworthiness of the data [195]. Transferability was realized through thick descriptions and deduced theory **(Paper V)** hence making possible applicability of the qualitative study findings to other settings implementing EMRs. All applied data analyses well established and validated methods chosen to suite collected data sets (type of data). The generated data were representative of the problems and study participants and were collected according to the methods requirements (amount, type of data, relevant data periods). Consequently, all this has contributed to the construct validity.

Design as research process

The search for an effective artefact requires utilizing available means to reach desired ends while satisfying laws in the problem environment [151]. The evaluation process to determine the state of EMRs implementations in the study setting followed DSR process model proposed by Vaishnavi et al. namely: Awareness of problem, suggestion, development, evaluation and conclusion [150]. Iterations were dependent on the type of data used and experts as well as efforts dedicated to developing the artefact. The three sub-cycles used in the development stage could be seen as iterations within DSR process. Sub-cycles were needed to accomplish different solutions since the success of EMRs implementation depend both on hard and soft issues of the environment.

Communication of the research

The last DSR guideline emphasizes the need to have research employing design science approach be presented effectively to both technology-oriented and management-oriented audiences [151]. Although the outcomes of this research were aimed at managerial audience (stakeholders including funding agencies and the ministries of health), the research provides useful guidelines to researchers in evaluations of information systems. As such, the findings of this research were presented in five scientific papers all of which are published in peer reviewed journals and presented in both regional and international conferences as well.

7.3.2 Mixed method approach

Mixed method research (MMR) involves integrating both quantitative and qualitative methods/approaches in a research study for enhanced insight into the phenomena under study as well as the research question(s) [163]. Several authors recommend mixed-methods approach, due to the disparate and diffuse effects of health informatics, to achieve diverse and insightful understanding of the causal links involved in the implementation and use of IT in health care [54,196,197]. Further, Caruth's review of literature on demystifying mixed-methods research design recommended methodological pluralism, including both qualitative and quantitative methods, in the evaluation of health care IT [30]. Determining the state of the implemented EMRS in our study setting required multiple measures from multiple views (both objective and subjective). As such, this evaluation research/study employed mixed-methods research approach, designed interactively, to provide rich, subtle information regarding actual EMRs use [105]. This study followed an exploratory approach as this investigation/evaluation was the first of its kind in a resource limited setting.

7.3.3 Generalizability

The goal of design science research is to create artefacts that address problems specific to organizations/society but at the same time be generalizable to a 'similar class of problems' [151]. This study aimed at solving a problem and transferring the lessons learned to a class of similar problems. The need to evaluate information systems implementations to establish their success cannot be overemphasized, especially considering the enormous investments involved. Thus, the systematic method (the process) for evaluating the state of EMRs post-implementations in resource limited settings can be generalized to similar settings (transferability). Nonetheless, the evaluation results of this study are specific to the setting understudy, thereby somewhat limiting generalizability of its findings to other settings. This, however, is a limitation of field studies in general [114].

7.4 Study Limitations

When assessing the contributions of the research study, it is important to recognize its limitations. In this sub-section we present limitations of this study.

i. While a multidisciplinary panel of 10 experts is considered adequate for most NGT exercises [198], the study noted a limitation in the representation of perspectives for indicators in the interoperability domain. The low ranking of *Data Exchange* and *Standardized Terminologies* indicators was an indication that the participants might have had limited knowledge or appreciation of interoperability domain and its role in enhancing system use. It is important to point out that interoperability remains a challenge in implementations of information systems, which could have influenced study participants' view.

ii. The study participants were drawn from one country (Kenya) and one type of EMRs (KeEMRs) investigated. Thus, the findings may not necessarily translate directly to other countries and systems. However, the study provides a demonstration case (a process) that can be modelled by other countries and systems to inform similar EMRs usage evaluations in similar settings – 'a class of similar problems'.

iii. Due to the social distancing and travel restrictions occasioned by COVID 19 pandemic, FGDs were conducted online via secure Zoom platform. The main methods of data collection during a focus group discussion include audio and tape recording, note-taking and participant observation [199]. The challenges of internet connectivity in the study setting has often limited the zoom platform sessions to only audio as video demands high bandwidth connections. Consequently, the study did not include observational data since it would not have been representative of the whole focus group.

iv. Mishra among other authors recommend a minimum of three to four focus group meetings for simple research topics to exhaustively discuss a topic (saturation) [200]. Nevertheless, in our study, only two focus groups comprising EMRs users were formed. This was again affected by the difficult time in the healthcare occasioned by COVID 19 pandemic and hence the targeted participants (clinicians, data clerks, etc.) were overwhelmed by work due to the COVID 19 cases in the country. The members of the focus group were recommended by the study sites as expert EMRs users. This notwithstanding, we are convinced the study identified all the factors within the groups formed. Discussions were truthful and rich in arguments and provided results that were sufficient for the analysis. Therefore, we applied saturation concept within the group discussions.

v. EMRs implementations in the study sites (n=213) took place at varied time in the period 2012-2016. Thus, EMRs usage analysis over time could not be performed.

vi. Four of the indicators were not included in the evaluation due to study time constraints as well as limited human resources needed to execute them. Additional resources are needed to collect the data via these indicator measures which was not possible at the current level of implementation/study.

Nevertheless, these limitations notwithstanding, the study provided insightful findings which contribute to expanding knowledge and understanding of evaluation of the state of IS post-implementation and factors that influence their use in public healthcare setting in developing countries. This can serve as a foundation to guide further research in this subject area.

Chapter 8

8. Conclusion and recommendations

8.1 Conclusions

This thesis contributes towards strengthening evaluation of health information systems in an effort to support successful EMRs scale-up and sustainable initiatives. As adoptions of EMRs in health care practice continue to rise at all levels (both regionally and nationally) and considering the associated high implementation costs, the need for continuous monitoring and evaluation for successful implementations is paramount. Evaluating success of information systems implementation involves use of theories, models and frameworks with divergent approaches [201]. Building on the system *use* construct and the rich literature focusing on information systems success/work, this research achieved the overall aim of developing and applying a systematic method for conducting rigorous evaluations of the state of EMRs implementations in a limited resource setting, a case of Kenya.

The multidimensional set of indicators developed in this research align with the relevant EHRs meaningful use dimensions namely: (1) EHRs must be used in the care processes such as prescribing, (2) EHRs must encompass electronic health data exchange for improved health care quality, and (3) EHRs must support reporting of clinical measures [188, 189]. Thus, this sheds light on how fully or effectively healthcare facilities are using IT, health data exchange readiness as well as performance in reporting requirements. Further, the indicators can allow for monitoring and aggregation of EMRs usage measures to ensure that appropriate and timely actions are taken at institutional, regional, and national levels to assure effective use of EMRs. Moreover, the indicators are not system-specific and hence can be used to evaluate usage of different types of information systems, including clinical, laboratory, radiology, and pharmacy information systems.

Packing the indicators in form of a query script is a novel approach for collecting objective primary data independent of human beliefs or perceptions, thus revealing actual state of IS under investigation. However, we recognize that differences exist in information systems database structure, hence, the queries to collect indicator measures using primary data from within each system will need to be customized and system-specific.

Following the three-step systematic information system evaluation method developed in this research, the state of EMRs implementations in Kenya has been characterized. The findings reveal wide-ranging maturity levels of the EMRs implementations nationwide. Although EMRs implementation endeavour has been on for over eight years, the findings demonstrate that there are many areas of improvement in EMRs use, as well as the need for continuous monitoring of EMRs use to inform timely interventions. Among the key areas identified revolved around availability of the EMRs, majorly attributed to EMRs mode of operation and frequent power blackouts. Good management of system user accounts was also found lacking.

The findings are of benefit to decision makers at different levels, including ministries of health, funding agencies and local implementing partners for successful EMRs implementations. Further, these findings highlight that simply counting number of EMRs implementations, as is currently the case, is highly inadequate in determining IS implementation success. The methods suggested in this research could easily be implemented using the proposed quantitative approach. User perspective could also be acquired in focus group forums that have in this research proven to be rich in information and useful as guidance for improvement especially in terms of the work organization and logistics.

8.2 Recommendations

This research has successfully developed a novel method to systematically evaluate the state of EMRs post-implementations. From our findings, the following aspects need attention at the system development level and/or management level as revealed in the study setting.

I. Currently, the EMRs implementation management structure in the study setting is not clear which has negatively affected rapid realization of implementations targets. The roles of the concerned stakeholders (MoH, County government and SDPs) around EMRs implementations and management need to be clearly defined. High quality project management and detailed planning is pivotal to successful information systems implementations, institutionalization and user acceptance.

II. Hospital wide information systems implementations (EMRs) that are linked (networked) to facilitate health data exchange would overcome the undesired shift from electronic to paper records, which was identified as a major barrier in the EMRs use. This was mostly experienced during the mandatory monthly reporting task. Thus, a link between the national aggregate system (KHIS) and the EMRs is highly recommended for direct and efficient reporting.

III. The data on *system uptime* indicator described by '*percentage of time system is up when needed during care'*, could not be calculated. This was because the system does not keep a log of uptime and downtime. Such data is vital in assessing systems' availability in the production environment. Therefore, it is highly recommend that the system be configured at the development level to respond to this need. Such log data can be maintained for quarterly review on system availability for use.

IV. The query output for *Automatic reports* indicator returned zero and hence there was no data to compute. This was because the generated reports from KeEMRs and their transmission are not saved. The system is configured to refresh the database report tables daily. Thus, it could be recommended to calculate this indicator daily or have the system retain the contents of the report table for at least a month.

V. The national aggregate system (KHIS) represents both missing reports and no reports with a blank cell. Thus, it was impossible to tell when a facility has not sent their reports or when it contains blank values. This poses a challenge in computing report completeness indicator described by the *number of mandatory report elements that are submitted as part of reports*. Thus, KHIS system needs to be revised at the development level to make this distinction.

8.3 Future work

Based on the findings of this research, there are still some aspects that would benefit from further exploration in future research as follows:

I. The derived set of indicators do not assess the "satisfaction of use" dimension outlined in DeLone & McLean IS success model [74] , which is a surrogate to system use. Future work should extend the indicators to explore this dimension.

II. Further, we will work with relevant partners to help integrate outputs and visualizations of the usage reports within the EMRs, and to provide various visualizations and dashboards for managers and decision-makers to increase visibility on system usage within and across facilities.

III. It is also recognized that continued usage of EMRs in the patient care processes do not necessarily lead to better work performance or improved care quality. As such, further research is needed to investigate impact of EMRs usage on care quality and outcomes as well to identify further barriers that are still unknown.

IV. We also recommend further research to establish user-computer ratio in the healthcare facilities to assess the challenges in terms of availability of hardware, work organization, type and level of facility, and the extent of information system implementation.

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Appendices

Publications

Paper I

Paper II

Paper III

Paper IV

Paper V

Appendices

Appendix I : Query Script

Appendix II: Standard Operating Procedure (SOP) instructions (protocol)

Appendix III: Facility Performance

Appendix IV: Detailed EMRs use indicators Monitoring and Evaluation Reporting (MER) document

Errata

Page	Changes made	Issue & Action
19	This adoption **trend** has been…	Misspelling: Tread to Trend
24	gain **new** knowledge towards….	Misspelling: Knew to new
40	…. it pertains **to** individuals using….	Bolded word was missing
41	… value-adding use **~~is~~** entails additional	Bolded word was deleted
41	…. where IS use ~~in~~ **is** mandatory…	Misspelling: in to is
42	…. includes applications such as ~~such as~~	Repetitive words deleted
50	what **is it** for?	Bolded words switched
54	creation of **art~~i~~efact**(s)	Bolded word changed to appear like other in the text: artifact to artefact
56	by-product **~~out~~** of addressing	Bolded word was deleted
61	discuss **~~of~~** results	Bolded word was deleted
66	… remaining **~~four/~~**five indicators	Bolded word was deleted
66	….(see Table **7**)	Wrong table reference: Table 1 to Table 7
75	(Papers III & IV)	*Typo correction of paper numbers III, V & VI to III & IV*

Appendix I: Indicators query script excerpt

/* Staff system use indicator: COUNT ACTIVE SYSTEM USERS AGGREGATED PER MONTH AND YEAR*/

/*denominator*/

```
select  '1 Year','month','Count'

union all

select theyear,themonths,users from(

select theyear,themonths,users from(

select *  from (select themonths,theyear,count(*) users from(select month(date_created) as themonths,year(date_created) as theyear from users) x group by theyear,themonths order by theyear,themonths) t

union all

select * from (select themonths,theyear,(count(*)*-1) users from(select month(date_retired) as themonths,year(date_retired) as theyear from users where (date_retired is not null or date_retired!='0000-00-00')  and retired=1) x group by theyear,themonths order by theyear,themonths) t1

) t2 order by theyear,themonths) t3 into outfile '/tmp/emr_usage_indicators/numberOfActiveUsersPerMonthAndYearD.csv' fields terminated by ',' enclosed by '"' lines terminated by '\n';
```

/*numerator*/

```
select  '1 Year','month','Count'

union all

select theyear,themonths,cnt from (

select count(distinct cnt) cnt,theyear,themonths from(

select * from(

select distinct creator cnt,month(date_created) as themonths,creator user,year(date_created) as theyear from encounter group by theyear,themonths

union

select  distinct changed_by cnt,month(date_changed) as themonths,changed_by user ,year(date_changed) as theyear from encounter  where (date_changed is not null or date_changed!='0000-00-00')  group by theyear,themonths

union

select  distinct voided_by cnt,month(date_voided) as themonths,voided_by user,year(date_voided) as theyear from encounter  where (date_voided is not null or date_voided!='0000-00-00') and voided=1  group by theyear,themonths

union

select distinct creator cnt,month(date_created) as themonths,creator user,year(date_created) as theyear from obs  group by theyear,themonths

union

select  distinct voided_by cnt,month(date_voided) as themonths,voided_by user,year(date_voided) as theyear from obs where (date_voided is not null or date_voided!='0000-00-00') and voided=1 group by theyear,themonths

union
```

.
.
.
.

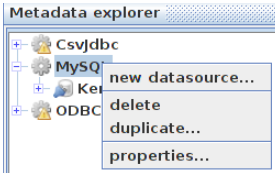
Appendix II: Standard Operating Procedures for Query Extraction

Objective: This Standard operating procedure outlines the procedure for extracting queries provided

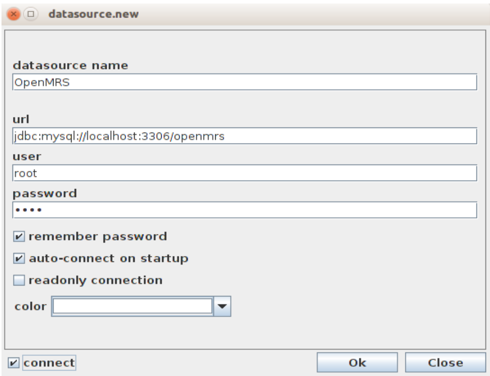
Context: *The query has been provided in a zipped folder/directory named Queryscript**.zip**. Extract it to the Desktop in ubuntu machine and use it to complete this exercise.*

Configure KenyaEMR Data Tool

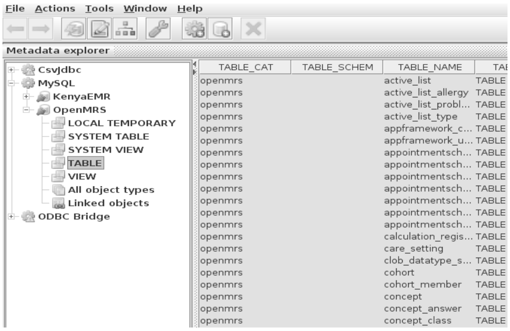
1. Launch data tool application on the desktop .
2. On the Metadata explorer right click on MySQL to create a new data source connection.



3. Select new datasource and enter the following details :
   a. Data source name: **"OpenMRS"**
   b. URL: **jdbc:mysql://localhost:3306/openmrs**
   c. User name: **root**
   d. Password: **test (Input the mysql password)**
   e. Check "**Remember Password**", "**Auto-connect on start-up**" and "**connect**" check boxes and click "**OK**"



4. Double click on the OpenMRS connection and click on the table to ensure the tables are displayed to the right window as shown below.



5. Navigate to the Desktop in the terminal by typing Cd Desktop then press enter. Then navigate to the combined -query folder and press enter .

6. Then type the following command and press enter
sudo chmod a+x run_query.sh
Enter password for Admin account

7.Then type sudo ./run_query.sh and press enter Enter mysql password for root and press enter.(NB:When you input mysql root password it will show on the terminal)

8. Once you have entered the password the query will start executing as shown below.

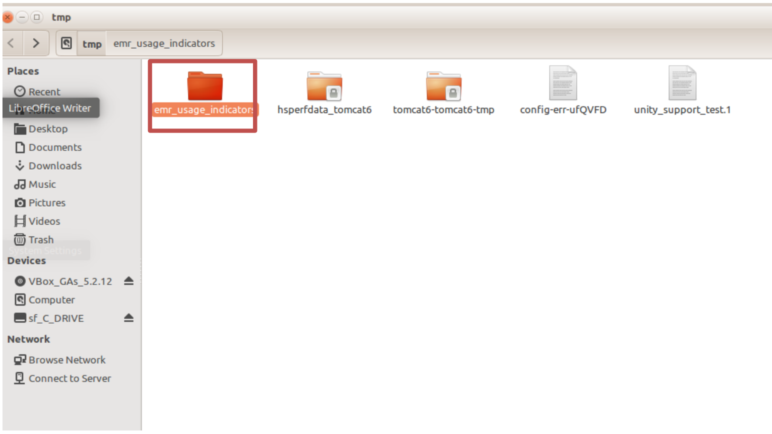
9. Wait for the query to complete execution then input mysql root password once again and press enter as shown below as shown below.(NB:Mysql root password will not show)

10. After inputting mysql root password, you will be prompted to input the password for the admin account. Input the password then press enter.

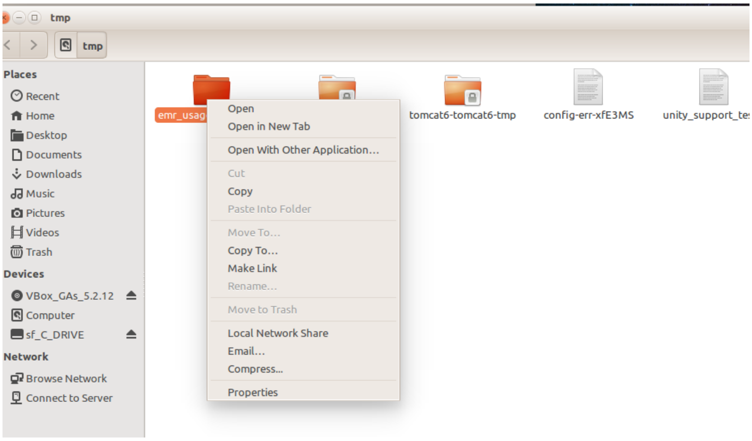
11. Wait for the queries to finish executing.

12. Navigate to the tmp folder.

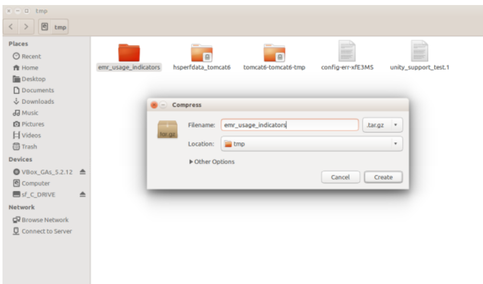
13. Open the tmp folder and get to a folder named **emr_usage_indicators**

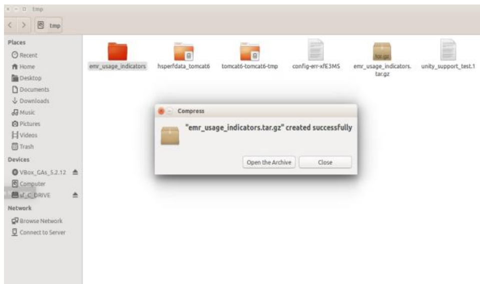


14. On right click you get these options

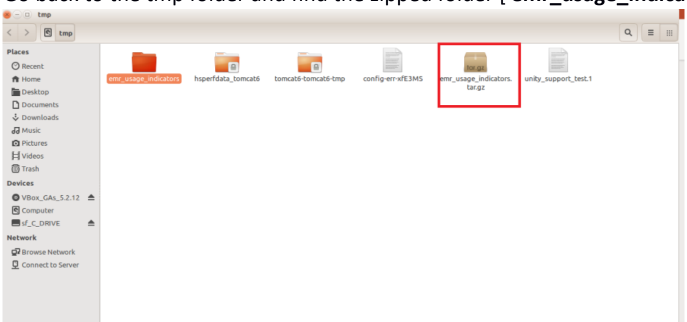


15. Select Compress then click create





16. Go back to the tmp folder and find the zipped folder [**emr_usage_indicators.tar.gz**]



17. Email the zipped folder **emr_usage_indicators.tar.gz** as an attachment to philomenangugi02@gmail.com. Should you have any problem running these queries, please call helpdesk on toll free number on **0800-722440**

<<END>>

Appendix III: Study facilities performance and characteristics (Top of the best, average and poor)

Performance position	County	Weighted Mean*	Keph level	Facility_type_category	Owner Type	EMRs Implementation Dates	Services	EMR mode
1	Migori	65%	Level 2	MEDICAL CLINIC	NGO	12.03.2014	CT&IL	POC
2	Kisumu	62%	Level 4	HOSPITALS	MoH	01.12.2018	CT	HYBRID
3	Bungoma	62%	Level 4	HOSPITALS	MoH	27.09.2013	CT	HYBRID
4	Kisumu	61%	Level 4	HOSPITALS	MoH	01.09.2018	CT&IL	POC
5	Kisumu	61%	Level 3	HEALTH CENTRE	MoH	01.02.2013	CT	HYBRID
6	Nandi	61%	Level 3	HEALTH CENTRE	MoH	04.07.2013	CT	RDE
92	Homa Bay	41%	Level 3	HEALTH CENTRE	MoH	18.09.2014	CT&HTS&IL	HYBRID
93	Kisii	40%	Level 4	HOSPITALS	MoH	02.07.2013	CT	RDE
94	Kakamega	40%	Level 4	HOSPITALS	MoH	25.09.2013	CT	POC
95	Nyandarua	40%	Level 3	HEALTH CENTRE	MoH	26.05.2014	CT	HYBRID
96	Kisii	39%	Level 3	HEALTH CENTRE	MoH	24.06.2014	CT	RDE
97	Vihiga	39%	Level 3	HEALTH CENTRE	MoH	04.08.2014	CT	HYBRID
98	Turkana	39%	Level 2	DISPENSARY	FBO	23.07.2013	CT	RDE
207	Kakamega	12%	Level 3	HEALTH CENTRE	MoH	20.08.2014	CT	HYBRID
208	Vihiga	12%	Level 3	HEALTH CENTRE	MoH	10.06.2013	CT	HYBRID
209	Kakamega	10%	Level 3	HEALTH CENTRE	MoH	20.08.2014	CT	HYBRID
210	Nandi	10%	Level 3	HOSPITALS	MoH	10.12.2013	CT	RDE
211	Vihiga	10%	Level 3	HEALTH CENTRE	MoH	17.04.2014	CT	RDE
212	Kiambu	9%	Level 2	DISPENSARY	FBO	06.11.2013	CT&HTS	HYBRID
213	Nandi	9%	Level 4	HOSPITALS	MoH	19.12.2012	CT	POC

Keph - Kenya essential package for health, NGO – Non Governmental Organization, MoH – Ministry of Health, FBO – Faith Based Organization, CT-Care & Treatment, HTS – HIV counselling & Testing services, POC – point of care, RDE-Retrospective data entry .

Green- best performing, yellow average performing and Red – poor performing gauged by *Weighted means of *Staff system use* and *Patient identification* indicators for the study period 2012-2019

Appendix IV : Excerpt from EMRs use indicator details document

INDICATOR NAME: STAFF SYSTEM USE				
Description:	Percentage of staff members who used the EMR system during the reporting period.			
Numerator:	Number of active users of the system during reporting period.	Individuals with privileges to use the system are expected to have logged into the system during the reporting period for a time duration that is deemed meaningful by the country.		
Denominator	Total number of staff members with privileges to use the system.	This includes all staff providers given privileges within the system.		
How to use:	This indicator is used to monitor how well people with privileges to use the system are actually using it.			
How to collect:	The country's standard operating procedures should define what meaningful duration of access to the EMR is. As an example, a country could define it as the total length of time an individual is logged into system (e.g. at least 2 hours during the reporting period), or the length of a session (e.g. they must be logged in for at least 10 minutes in a session during the reporting period). This indicator will be derived from EMR queries of log data. The numerator is often a query within the EMR to determine if a particular staff member accessed the EMR to meet the criteria defined by the country. The denominator is also derived from the EMR as the total number of providers with access to the system.			
PEPFAR MER Considerations	None. While HRH_STAFF and HRH_CURR under PEPFAR MER 2.0 could seem relevant, this current indicator is for any full or part-time provider offering HIV care services for which data is entered in to the EMR.			
Reporting level	Facility, district, national.			
How often to report:	Quarterly			
How to review for data quality:	Numerator ≤ Denominator. There is a risk of artificially inflated access to meet indicator goal. Getting distribution of access by provider could help highlight this discrepancy.			
How to calculate annual total:	Annual rate will be the average of quarterly reporting percentages.			
Data Elements (Components of indicator)	***Numerator (Required)**:* Number of active users of the system during reporting period.	**Disaggregate Groups** User Category Access Type -Clinical data entry -Patient chart review - Reporting **(Required)**	**Disaggregates**	**Description of Disaggregate** User Category defines the type of users who accessed the system - e.g. providers, managers, data entry clerks.

				Access Type: Access type defines what the access was for. Given a sense of what the access is used for.
	Denominator ***(Required)*** Total number of staff members with privileges to use the system.	**Disaggregate Groups**	**Disaggregates**	**Description of Disaggregate**
		Disaggregate Groups		

Revision after NGT Exercise:

- Team suggested that the original indicator was too difficult to actualize and proposed simplifying it.
- Changed from health care worker access to all provider access.
- Changed from proportion of patient records accessed during visit, to simply provider access to the system as this is easier to measure.
- The team suggested that the indicator should be changed to 'Number of Active Users of the System during Reporting Period'. We changed this to proportion, as we want to capture those who are not using the system - to help in understanding why.
- Meaningful use concept introduced - though this has to be defined by country. It could be total duration of time for system use during period, or length of session.

PLOS ONE

RESEARCH ARTICLE

Development of standard indicators to assess use of electronic health record systems implemented in low-and medium-income countries

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Abstract

Background

Electronic Health Record Systems (EHRs) are being rolled out nationally in many low- and middle-income countries (LMICs) yet assessing actual system usage remains a challenge. We employed a nominal group technique (NGT) process to systematically develop high-quality indicators for evaluating actual usage of EHRs in LMICs.

Methods

An initial set of 14 candidate indicators were developed by the study team adapting the Human Immunodeficiency Virus (HIV) Monitoring, Evaluation, and Reporting indicators format. A multidisciplinary team of 10 experts was convened in a two-day NGT workshop in Kenya to systematically evaluate, rate (using Specific, Measurable, Achievable, Relevant, and Time-Bound (SMART) criteria), prioritize, refine, and identify new indicators. NGT steps included introduction to candidate indicators, silent indicator ranking, round-robin indicator rating, and silent generation of new indicators. 5-point Likert scale was used in rating the candidate indicators against the SMART components.

Results

Candidate indicators were rated highly on SMART criteria (4.05/5). NGT participants settled on 15 final indicators, categorized as system use (4); data quality (3), system interoperability (3), and reporting (5). Data entry statistics, systems uptime, and EHRs variable concordance indicators were rated highest.

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Competing interests: The authors have declared that no competing interests exist.

Conclusion

This study describes a systematic approach to develop and validate quality indicators for determining EHRs use and provides LMICs with a multidimensional tool for assessing success of EHRs implementations.

Introduction

Electronic Health Record Systems (EHRs) are increasingly being implemented within low-and middle-income countries (LMICs) settings, with the goal of improving clinical practice, supporting efficient health reporting and improving quality of care provided [1,2]. System implementation is the installation and customization of information systems in organizations making them available for use to support service delivery, e.g. EHRs in healthcare [3,4]. National-level implementations of EHRs in many LMICs primarily aim to support HIV care and treatment, with funding for these systems coming from programs such as the US President's Emergency Plan for AIDS Relief (PEPFAR) [5,6]. Several countries, such as Rwanda, Uganda, Mozambique, and Kenya, have gone beyond isolated and pilot implementations of EHRs to large-scale national rollout of systems within government-run public facilities [7]. For example, Kenya has had over 1000 electronic medical systems (EMRs) implementations progressively since 2012 in both private and public facilities supporting patient data management mainly in HIV care and treatment [8]. With such large-scale EHRs implementations, developing countries are finding themselves in the unenviable position of being unable to easily track the status of each implementation, especially given that most of the EHRs implementations are standalone and are distributed over large geographical areas. A core consideration is the extent to which the EHRs implemented are actually in use to support patient care, program monitoring, and reporting. Without robust evidence of use of the implemented EHRs, it becomes difficult to justify continued financial support of these systems within these resource-constrained settings and to realize the anticipated benefits of these systems.

In LMICs, implementation of EHRs within a clinical setting does not automatically translate to use of the system. While the evidence is mounting on the benefits of EHRs in improving patient care and reporting in these settings, a number of studies reveal critical challenges to realizing these benefits [9–11]. Some of these challenges include: poor infrastructure (lack of stable electricity, unreliable Internet connectivity, inadequate computer equipment), inadequate technical support, limited computer skills and training, and limited funding [12–17]. Additionally, implementation of EHRs is complex and can be highly disruptive to conventional workflows. Disruption caused by the EHRs can affect its acceptance and use; this is more likely to happen if the implementation was not carefully planned and if end-users were not adequately involved during all stages of the implementation [18–21]. The use of the EHRs can also be affected by data quality issues, such as completeness, accuracy, and timeliness [22]. This is a particular risk in LMICs given the lack of adequate infrastructure, human capacity, and EHRs interoperability across healthcare facilities [23].

Although LMICs have embraced national-level EHRs implementations, little evidence exists to systematically evaluate actual success of these implementations, with success largely defined as a measure of effectiveness of the EHRs in supporting care delivery and health system strengthening [24–26]. Success of EHRs implementation depends on numerous factors, and these often go beyond simple consideration of the technology used [19,20]. Many information system (IS) success frameworks and models incorporate a diverse set of success measures, such as "effectiveness, efficiency, organizational attitudes and commitment, users' satisfaction, patient satisfaction, and system use" [27–34]. Among numerous IS success frameworks and models, "system use" is considered an important measure in evaluating IS success; IS usage being "the utilization of information technology (IT) within users' processes either individually, or within groups or organizations" [29,31]. There are several proposed measures for system use, such as frequency of use, extent of use, and number of system accesses, but these tend to differ between models. The system use measures are either self-reported (subjective) or computer-recorded (objective) [22,29,30].

There is compelling evidence that IS success models need to be carefully specified for a given context [34]. EHRs implementations within LMICs have unique considerations, hence system use measures need to be defined in a way to ensure that they are relevant, meet the EHRs monitoring needs, while not being too burdensome to accurately collect. Carefully developed EHRs use indicators and metrics are needed to regularly monitor the status of the EHRs implementations, in order to identify and rectify challenges to advance effective use. A common set of EHRs indicators and metrics would allow for standardized aggregation of performance of implementations across locations and countries. This is similar to the systems currently in use for monitoring the success of HIV care and treatment through a standard set of HIV Monitoring, Evaluation and Reporting (MER) indicators [35].

All care settings providing HIV care through the PEPFAR program and across all countries are required to report the HIV indicators per the MER indicator definitions. An approach that develops EHRs indicators along the same lines and format as HIV MER indicators assures that the developed EHRs system use indicators are in a format well-familiar to most care settings within LMICs. This approach reduces the learning curve to understanding and applying the developed indicators. In this paper, we present development and validation of a detailed set of EHRs use indicators that follows the HIV MER format, using nominal group technique (NGT) and group validation technique. This was developed for Kenya, however, it is applicable to LMICs and similar contexts.

Materials and methods

Identification of candidate set of EHRs use indicators

Using desk review, literature review, and discussions with subject matter experts, the study team (PN, MW, JK, XS, AB) identified an initial set of 14 candidate indicators for EHRs use [36–39] The candidate set of indicators were structured around four main thematic areas, namely: system use, data quality, interoperability, and reporting. System use and data quality dimensions broadly reflect IS system use aspects contained in the DeLone and McLean IS success model, while interoperability and reporting dimensions enhance system availability and use [39]. The focus was to come up with practical indicators that were **s**pecific, **m**easurable, **a**chievable, **r**elevant, and **t**ime-bound (SMART) [40]. This would allow the developed indicators to be collected easily, reliably, accurately, and in a timely fashion within the resource constraints of clinical settings where the information systems are implemented.

Each of the 14 candidate indicators was developed to clearly outline the description of the indicator, the data elements constituting the numerator and denominator, how the indicator data should be collected, and what data sources would be used for the indicator. These details for the indicators were developed using a template adapted from the HIV MER 2.0 indicator reference guide, given that information systems users in most of these implementation settings were already familiar with this template (S1 Appendix) [35]. Nevertheless, it will require short training time for those unfamiliar due the simplicity of the format.

Nominal group technique (NGT)

NGT is a ranking method that enables a controlled group of nine or ten subject matter experts to generate and prioritize a large number of issues within a structure that gives the participants an equal voice [41]. The NGT involves several steps, namely: 1) silent, written generation of responses to a specific question, 2) round-robin recording of ideas, 3) serial discussion for clarification and, 4) voting on item importance. It allows for equal participation of members, and generates data that is quantitative, objective, and prioritized [42,43]. Nominal group technique (NGT) was used in the study to reach consensus on the final set of indicators for monitoring EHRs use.

NGT participants

Indicator development requires consultation with broad-range of subject matter experts with knowledge of the development, implementation, and use of EHRs. With guidance from Kenya Ministry of Health (MoH), a heterogeneous group of 10 experts was invited for a two-day workshop led by two of the researchers (M.W. and P.N.) and a qualitative researcher (V.N.). Inclusion in the NGT team was based on the ability of the NGT participant to inform the conversation around EHRs usage metrics and indicators, with an emphasis on assuring that multiple perspectives were represented in the deliberations. The NGT participants' average age was 40 years where majority were males (69%). The participants included: the researchers acting as facilitators; one qualitative researcher (an associate professor and lecturer); two MoH representatives from the Division of Health Informatics and M&E (health information systems management experts); one Service Development Partners (SDPs) representative (oversees EHRs implementations and training of users); four users of the EHRs (clinical officers (2) & Health records information officers (2)); CDC funding agency representative (an informatics service fellow in the Health Information Systems); and two representatives from the EHRs development and implementing partners (Palladium and International Training and Education Center for Health (I-TECH)), who have been involved in the EHRs implementations and who selected sites for EHRs implementations [44,45]. The study participants were consenting adults, and participation in the group discussion was voluntary. All participants filled a printed consent form before taking part in the study. Discussions were conducted in English, with which all participants were conversant. For analysis and reporting purposes, demographic data and roles of participants were collected, but no personal identifiers were captured. The study was approved by the Institutional Review and Ethics Committee at Moi University, Eldoret (MU/MTRH-IREC approval Number FAN:0003348).

NGT process

The NGT exercise was conducted on April 8–9, 2019, in Naivasha, Kenya. After providing informed consent, the NGT participants were informed about the purpose of the session through a central theme question: "How can we determine the actual use of EHRs implemented in our healthcare facilities?" Participants were first given an overview on the NGT methodology and how it has been used in the past. Given that candidate indicators had already been defined in a separate process, we did not include the first stage of silent generation of ideas. Ten NGT participants (excluding research team members) evaluated the candidate indicators on quality using the SMART criteria on a 5-point Likert scale rating on each of the five quality components. The NGT exercise was conducted using the following five specific steps:

Step 1: Clarification of indicators. For each of the 14 candidate indicators, the facilitator took five minutes to introduce and clarify details of the candidate indicator to ensure all participants understood what each indicator was meant to measure and how it would be generated. Where needed, participants asked questions and facilitators provided clarifications.

Step 2: Silent indicator rating. The participants were given 10 minutes per indicator and were asked to: (1) individually and anonymously rate each candidate indicator on each of the SMART dimensions using a 5-point Likert scale for each dimension where 1 = Very Low, 2 = Low, 3 = Neutral, 4 = High, and 5 = Very high level of quality; (2) provide an overall rating of each indicator on a scale from 1–10, with 10 being the highest overall rating for an indicator; (3) indicate whether the indicator should be included in the final list of indicators or removed from consideration; and (4) provide written comments on any aspect regarding the indicator and their rating process. To help with this process, a printed standardized indicator ranking form was provided (S2 Appendix), and the indicator details were projected on a screen.

Step 3: Round-robin recording of indicator rating. Each participant in turn was asked to give their overall rating of each indicator and these were recorded on a frequency table. No discussions, questions, or comments were allowed until all the participants had given their ratings. At the end of the round-robin, each participant in turn elucidated his/her criteria for the indicator overall rating score. At this stage, open discussions, questions and comments on the indicator were allowed. The discussions were recorded verbatim. The participants were not allowed to revise their individual rating score after the discussion.

Step 4: Silent generation of new indicators. After steps 2 and 3 were repeated for all 14 candidate indicators, the participants were given ten minutes to think and write down any missing indicators in line with the central theme question. The new indicator ideas were shared in a round-robin without repeating what had been shared by other participants. These new proposed indicators were written on a flip chart and discussed to ensure all participants understood and approved any new indicator suggestions. The facilitator ensured that all participants were given an opportunity to contribute. From this exercise, new indicators were generated and details defined collectively by the team.

Step 5: Ranking and sequencing the indicators. After Step 4, with exclusion of some of the original candidate indicators and addition of new ones based on team discussions, a final list of 15 indicators was generated. Each participant was asked to individually and anonymously rank the final list of the 15 indicators in order of importance, with rank 1 being the most important and rank 15 the least important. The participants were also asked to group the 15 indicators by the implementation priority and sequence into Phase 1 or 2. Phase 1 indicators would be those deemed as not requiring much work to collect, while Phase 2 indicators would require more human input and resources to collect.

Selection of final indicators

All the individual rankings for each indicator were summed across participants and the final list of prioritized consensus-based EHRs use indicators was derived from the rank order based on the average scores. The ranked indicator list was shared for final discussion and approval by the full team of NGT participants. The relevant indicator reference sheets for every indicator were also updated based on discussions from the NGT exercise. No fixed threshold number was used to select the indicators for inclusion. Finally, the indicator details were reviewed (including indicator definition or how data elements are collected, and indicator calculated) as guided by the NGT session discussions, resulting in the final consensus-based EHRs use reference sheets with details for each indicator.

Data analysis

Descriptive statistics were computed to investigate statistical differences on the rating of the 14 candidate indicators among the participants. Chi-square test was used to determine if there were statistically significant differences in rating of indicators across each of the SMART dimensions. The ratings totals per SMART dimension from the crosstabs analysis output were summarized in a table (Table 1), indicating the p-value generated from the Chi-square output for each dimension. The variability between the SMART dimensions and the rating was tested using Chi-square since the parameters under investigation were categorical variables (non-parametric data). The totals include rating count and its percentage. Weighted mean for each SMART dimension across all the 14 indicators was calculated to identify how the participants rated various candidate indicators. For the final indicator list, descriptive statistics were computed to determine the average rank score for each indicator and to assign priority numbers from the lowest average score to the highest. As such, the indicator with the lowest average score was considered the most important per the participants' consensus. All analyses were performed in SPSS version 25 (IBM, https://www.ibm.com/analytics/spss-statistics-software). The indicators were also grouped according to implementation phase number assigned by the participants (either 1 or 2) to form the implementation order phases.

Results

SMART criteria rating for candidate indicators

The participants rated the collective set of the 14 candidate indicators highly (i.e. 4 or 5) across all the SMART dimensions (Table 1). However, a variation in the totals across the SMART components was due to some participants' non-response in rating some of the components.

From the analysis, the indicators were rated high for specific and time-bound SMART quality dimensions with a mean of 3.96 (p-value = 0.141) for specific and 4.17 (p-value = 0.228) for time-bound. However, the two dimensions did not show any statistically significant difference in how various participants rated them. Measurable, achievable, and relevant dimensions were also high, with the mean of 3.86(p-value = 0.009), 4.01(p-value = 0.039) and 4.27(p-value = 0.023), respectively, and showed statistically significant difference in how the participants rated them across all the indicators.

Individual indicator ratings

Table 2 shows the participants' overall ratings for each of the 14 candidate indicators on a scale of 1 to 10, reflecting lowest to highest rating respectively. Generally, the participants rated the candidate set of indicators highly with an overall mean rating of 6.6. Data concordance and automatic reports were rated highest with a mean above 8.0. However, the participants rated the observations indicator low with a mean of 3.8, while staff system use, system uptime, and report completeness indicators were moderately rated with a mean of 4.4, 5.9, and 5.8 respectively. The individual indicator ratings and ratings against SMART criteria served as a validation metric for candidate indicators.

Final indicators list

The NGT team reached a consensus to include all 14 candidate indicators in the final list of indicators, and added one additional indicator, report concordance, for a total of 15 EHRs usage indicators. The final set of indicators fell into four categories, namely (Fig 1 and Table 3):

Table 1. Summary of the indicators rating on the various SMART quality dimensions.

SMART Quality	Responses						Total	Mean[b]	P-value
		Rating[a] of SMART Survey							
		1	2	3	4	5			
Specific	Count	7	7	18	54	48	134	3.96	0.141
	Percent	5.2%	5.2%	13.4%	40.3%	35.8%	100.0%		
Measurable	Count	6	12	19	52	43	132	3.86	0.009
	Percent	4.5%	9.1%	14.4%	39.4%	32.6%	100.0%		
Achievable	Count	4	8	24	42	53	131	4.01	0.039
	Percent	3.1%	6.1%	18.3%	32.1%	40.5%	100.0%		
Relevant	Count	5	6	11	37	74	133	4.27	0.023
	Percent	3.8%	4.5%	8.3%	27.8%	55.6%	100.0%		
Time-bound	Count	5	3	15	51	59	133	4.17	0.228
	Percent	3.8%	2.3%	11.3%	38.3%	44.4%	100.0%		

[a] Rating Scale 1 = Very Low; 2 = Low; 3 = Neutral; 4 = High; 5 = Very high.
[b] Mean range 1.0–2.5 = Low; 2.6–3.5 = Neutral; 3.6–5.0 = High.

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Table 2. Candidate indicators overall rating.

#Indicator		Indicator overall rating										Total	Mean*
		1	2	3	4	5	6	7	8	9	10		
1	Data entry statistics	0	0	1	0	1	1	1	2	3	0	9	7.1
2	Staff system use	0	0	3	0	5	1	0	0	0	0	9	4.4
3	Observations	1	2	2	3	0	0	1	1	0	0	10	3.8
4	System uptime	0	0	1	1	2	3	1	1	1	0	10	5.9
5	Data timeliness	0	0	0	0	0	1	7	2	0	0	10	7.1
6	Data concordance	0	0	0	0	1	0	2	4	1	2	10	8.0
7	Data completeness	0	0	0	0	0	2	3	4	1	0	10	7.4
8	Automatic reports	0	0	0	1	0	0	0	5	3	1	10	8.1
9	Report timeliness	1	0	0	0	2	3	0	1	2	1	10	6.5
10	Report completeness	0	0	1	1	1	4	2	1	0	0	10	5.8
11	Reporting rate	0	0	1	0	1	0	4	1	0	2	9	7.1
12	Data exchange	0	0	0	0	1	2	4	2	0	0	9	6.8
13	Standardized terminologies	0	0	0	1	1	2	3	0	2	0	9	6.7
14	Patient identification	0	0	0	0	0	1	5	2	1	0	9	7.3
	Total	2	2	9	7	15	20	33	26	14	6	134	6.6

* Mean ranges 1.0–4.0 = Low 4.1–6.0 = Neutral 6.1–10.0 = High

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1. System Use—these indicators are used to identify how actively the EHRs is being used based on the amount of data, number of staff using the system, and uptime of the system.
2. Data Quality—these indicators are used to highlight proportion and timeliness of relevant clinical data entered into the EHRs. They also capture how well EHRs data captures an accurate clinical picture of the patient.
3. Interoperability—given that a major perceived role of EHRs is to improve sharing of health data, these indicators are used to measure maturity level of implemented EHRs to support interoperability.

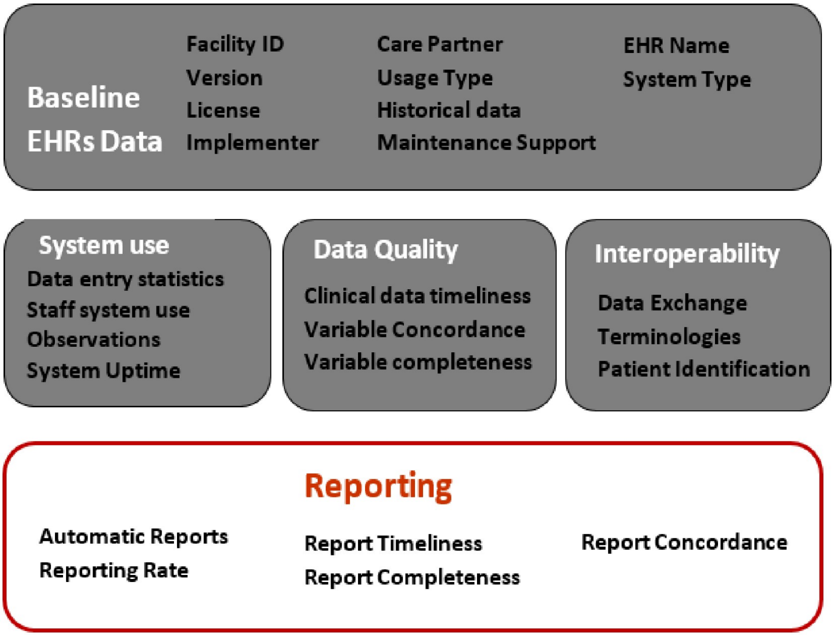

Fig 1. Infographic of key domains for EHRs use indicators.

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Table 3. The set of validated reporting indicators on EHR system use.

#	Domain	Indicator Name	Description	Frequency
1	System Use	Data entry statistics	Number and % of patient records entered into system during reporting period	Monthly
2	System Use	Staff system use	% of providers who entered data into system as expected for at least 90% of encounters	Quarterly
3	System Use	Observations	Number of observations recorded during period	Quarterly
4	System Use	System Uptime	% of time system is up when needed during care	Monthly
5	Data Quality	Clinical data Timeliness	% of clinical provider encounters entered into the EHRs within agreed time period.	Monthly
6	Data Quality	Variable Concordance	% concordance of data in paper form vs data in EHRs	Quarterly
7	Data Quality	Variable Completeness	% of required data elements contained in EHRs	Quarterly
8	Interoperability	Data Exchange	Automatic exchanging of data with different systems	Quarterly
9	Interoperability	Standardized Terminologies	% of terms that are mapped to standardized terminologies or national dictionary.	Yearly
10	Interoperability	Patient identification	% of nationally accepted patient identification instances in the EHRs.	Quarterly
11	Reporting	Automatic Reports	Proportion of expected reports generated automatically by system	In-line with PEPFAR[a] reports
12	Reporting	Reporting Rate	Proportion of expected reports that are actually submitted	Monthly
13	Reporting	Report Timeliness	Timeliness of expected reports to national reporting system	Monthly
14	Reporting	Report Completeness	Completeness of expected reports to national reporting system	In-line with PEPFAR reports
15	Reporting	Report Concordance	% concordance of data contained in paper-derived reports compare to report data derived from the EHRs	Biannual

[a] Monitoring, Evaluation, and Reporting [MER] indicators reporting by PEPFAR initiated HIV programs

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Table 4. Ranking of finalized EHRs use indicators.

Indicator Ranking	Indicator Name	Average Score Mean (SD)
1	Data Entry Statistics	2.78 (2.33)
2	System Uptime	4.56 (5.22)
3	EHR Variable concordance	6.44 (2.80)
4	EHR Variable Completeness	6.56 (3.32)
5	Report Concordance	6.67 (4.66)
6	Staff system use	6.78 (4.64)
7	Clinical Data Timeliness	7.33 (4.61)
8	Report Completeness	7.89 (2.98)
9	Patient Identification	8.00 (4.33)
10	Data exchange	8.67 (4.12)
11	Reporting timeliness	9.00 (3.61)
12	Automatic Reports	10.33 (2.83)
13	Observations	11.56 (4.12)
14	Standardized Terminologies	11.56 (2.87)
15	Reporting Rate	11.89 (2.76)

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4. Reporting—aggregation and submission of reports is a major goal of the implemented EHRs, and these indicators capture how well the EHRs are actively used to support the various reporting needs.

As part of the NGT exercise, the details of each of the indicators was also refined. S3 Appendix presents the detailed EHRs MER document, with agreed details for each indicator provided. In this document, we also highlight the changes that were suggested for each indicator as part of the NGT discussions.

Indicator ranking

The score and rank procedure generated a prioritized consensus-based list of EHRs use indicators with a score of 1 (highest rated) to 15 (lowest rated). As such, a low average score Mean' meant that the particular indicator was on average rated higher by the NGT participants. Table 4 presents the ordered list of ranking for the indicators as rated by nine of the NGT participants as one participant was absent during this NGT activity. Data Entry Statistics and System Uptime indicators were considered to be the most relevant in determining EHRs usage, while Reporting Rate indicator was rated as least relevant.

Indicator implementation sequence

Nine of the 15 indicators were recommended for implementation in the first phase of the indicator tool rollout, while the other six indicators were recommended for Phase 2 rollout (Table 5). The implementation sequence largely aligns with the indicator priority ranking by the participants (Table 4). The indicators proposed for Phase 1 implementation are a blend from the four indicator categories but are mostly dominated by the System Use subcategory.

Discussion

To the best of our knowledge, this is the first set of systematically developed indicators to evaluate the actual status of EHRs usage once an implementation is in place within LMIC settings.

Table 5. Recommended implementation sequence of the EHRs use indicators.

Implementation sequence	Indicator name	
	Phase 1	**Phase 2**
1	Data Entry Statistics	Standardized Terminologies
2	System Uptime	Observations
3	EHRs data concordance	Automatic Reports
4	EHRs Data Completeness	Report timeliness
5	Staff system use	Reporting Rates
6	Clinical Data Timeliness	Data Exchange
7	Report Concordance	
8	Reporting Completeness	
9	Patient Identification	

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At the completion of the modified NGT process, we identified 15 potential indicators for monitoring and evaluating status of actual EHRs use. These indicators take into consideration constraints within the LMIC's setting such as system availability, human resource constraints, and infrastructure needs. Ideally, an IS implementation is considered successful if the system is available to the users whenever and wherever it is needed for use [46]. Clear measures of system availability, use, data quality, and reporting capabilities will ensure that decision makers have clear and early visibility into success and challenges facing system use. Further, the developed indicators allow for aggregation of usage indicators to evaluate performance of systems by type, regions, facility level, and implementing partners.

An important consideration of these indicators is the source of measure data. Most published studies on evaluating success of information system focus on IS use indicators or variables such as ease of use, frequency of use, extent of use, and ease of learning, mostly evaluated by means of self-reporting tools (questionnaires and interviews) [19,39,47]. As such, the resulting data can be subjective and prone to bias. We tailored our indicators to ensure that most can be computer-generated through queries, hence incorporating objectivity into the measurement. However, a few of these indicators, such as data entry statistics as well as those on concordance (variable concordance and report concordance) derive measure data from facility records in addition to computer logs data.

Although the NGT expert panel was national, we are convinced the emerging results are of global interest. First, we developed the indicators in-line with the internationally renowned PEPFAR Monitoring, Evaluation, and Reporting (MER) indicators Reference Guide [35]. Secondly, the development process was mainly based on methodological criteria that are valid everywhere [48,49]. Furthermore, the indicators are not system-specific and hence can be used to evaluate usage of other types of EHRs, including other clinical information systems implementations like laboratory, radiology, and pharmacy systems. However, we recognize that differences exist in systems database structure; hence, the queries to determine indicator measures data from within each system will need to be customized and system-specific. It is important to also point out that these indicators are not based on real-time measures and can be applied both for point of care and non–point of care systems.

The selected set of indicators have a high potential to determine the status of EHRs implementations considering that the study participants rated all five SMART dimensions high (over 70%) across all the indicators. Further, the indicators reference guide provides details on "how to collect" and the sources of measure data for each indicator (S3 Appendix). This diminishes the level of ambiguity in regard to measurability of the indicators. Nonetheless, some of the indicators need countries to define their own thresholds and reporting frequencies. For instance, a country would need to define the length of acceptable time duration within which a clinical encounter should be entered into the EHRs for that encounter to be considered as having been entered in a timely fashion. As such, the indicator and reference guide need to be adapted for specific country and use context. Despite staff system use and observations indicators low overall rating (4.4 and 3.8 respectively), they were included in the final list of indicators after consensus-based discussions as part of the NGT exercise. We believe this is due to the indicators' direct role in determining system usage and the fact that they were scored highly in the SMART assessment. Further assessment with a wider group of intermediate system users would be beneficial to estimate the value of the indicators in question before rendering them irrelevant.

This study has several limitations. It was based on a multidisciplinary panel of 10 experts, which is adequate for most NGT exercises, but still has a limited number of individuals who might not reflect all perspectives. On average, 5–15 participants per group are recommended depending on the nature of the study [50,51]. The low ranking of Data Exchange and Standardized Terminologies indicators indicate that the participants might have limited knowledge or appreciation of certain domains and their role in enhancing system use. Further, all participants were drawn from one country. Nevertheless, a notable strength was the incorporation of participants from more than one EHRs (KenyaEMR and IQCare systems) and a diverse set of expertise. In addition, the derived indicators do not assess the "satisfaction of use" dimension outlined in Delone & McLean mode [39] and future work should extend the indicators to explore this dimension.

A next step in our research is to conduct an evaluation on actual system use status for an information system rolled-out nationally, using the developed set of indicators. We will also evaluate the real-world challenges of implementing the indicators and refine them based on the findings. We also anticipate sharing these indicators with a global audience for input, validation, and evaluation. We are cognizant of the fact that the indicators and reference guides are living documents and they are bound to evolve over time, given the changing nature of the IS field and maturity of EHRs implementations.

Conclusion

An NGT approach was used to generate and prioritize a list of consensus-based indicators to assess actual EHRs usage status in Kenya. However, the indicators can be applicable to LMICs and similar contexts. This list of indicators can allow for monitoring and aggregation of EHRs usage measures to ensure that appropriate and timely actions are taken at institutional, regional, and national levels to assure effective use of EHRs implementations.

Supporting information

S1 Appendix. System usage indicator template.
(PDF)

S2 Appendix. Indicator rating form.
(PDF)

S3 Appendix. Monitoring, Evaluation and Reporting (MER v1.0): Electronic Health Record (EHR) system usage indicator reference guide.
(DOCX)

S1 File.
(XLSX)

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Assessment of HIV Data Reporting Performance by Facilities During EMR Systems Implementations in Kenya

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Abstract. There is little evidence that implementations of Electronic Medical Record Systems (EMRs) are associated with better reporting completeness and timeliness of HIV routine data to the national aggregate system. We analyzed the reporting completeness and timeliness of HIV reports to Kenya's national aggregate reporting system from District Health Information Software 2 (DHIS2) for the period 2011 to 2018. On average, reporting completeness improved to 97% whilst timeliness increased to 83% in 2017 with similar performance for the facilities under study that implemented either KenyaEMR or IQCare. However, in 2018, the reporting rates dropped by 13% for completeness and 11% for timeliness most likely due to changed reporting procedures. This suggests that besides EMRs, there are other factors influencing reporting such as reporting routines, which need to be assessed separately. Nonetheless, the EMRs have facilitated the collection of HIV data for submission to the DHIS2, which in turn facilitates the reporting process for the data officers.

Keywords. KenyaEMR, IQCare, HIV data, reporting, timeliness, completeness

1. Introduction

Many healthcare facilities in developing countries are increasingly using Electronic Medical Record Systems (EMRs) during patient care, despite challenges of unstable power supply and human capacity[1]–[3]. Mostly, the EMRs implementations in these settings are as a result of the President's Emergency Plan for AIDS Relief (PEPFAR) initiatives with a view to support HIV patient data management[4]. As such, the EMRs majorly support HIV services encompassing prevention, testing, care and treatment. Due to socio-technical challenges in developing countries, adoptions of the EMRs in the healthcare facilities differ in maturity levels. This has led to varying modes of operation with some settings using paperless, point of care approaches, retrospective data entry, or a hybrid approach[5][6]. These approaches potentially have variable impacts on the intended EMRs benefits.

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KenyaEMR and IQCare are among the major EMRs accredited to support HIV healthcare delivery services within facilities under the Ministry of Health (MoH) in Kenya[7]. On the other hand, the District Health Information Software Version 2 (DHIS2), a web-based open source system, supports collection and analysis of both routine and non-routine aggregate reporting health services data drawn from healthcare facilities countrywide [8].

With the prevalence of EMRs implementations in countries like Kenya, it remains unclear what their contribution is to quality of aggregate data in support of data-driven decision-making. This paper explores the impact of EMRs implementation efforts on quality of reporting of HIV indicators in developing countries with particular focus on completeness and timeliness of reports to DHIS2 maintained by Kenyan MoH.

2. Materials and Methods

Facilities are required by the MoH to submit HIV routine data on six programmatic areas based on a summary reporting tool for HIV referred to as MOH731 by the 15th day of every month. DHIS2 aggregate system was used to obtain HIV routine data reports for the period 2011 to 2018 on HIV counselling and testing (HTS) and care and treatment (C&T) programmatic areas for all healthcare facilities in Kenya. Systematic procedures were used to clean the data. The data sets generated and analyzed in this paper are available in the national DHIS2 online database https://hiskenya.org/dhis-web-commons/security/login.action. The EMRs were implemented in the facilities on varying dates from November 2012 to September 2014 for KenyaEMR and August 2012 to July 2016 for IQCare.

Descriptive analyses were conducted to compare performance in reporting completeness and timeliness by the facilities during the period 2011 to 2018. Timeliness refers to whether reporting facilities submit their reports according to the timeline set by the MoH. Completeness is the extent to which the expected reports are successfully submitted to the national reporting system. The facilities (n) included in the study were those which submitted MOH731 reports to DHIS2 and progressively implemented either KenyaEMR or IQCare systems. The variations in n was due to the establishment of new facility sites during the years under study. All analyses were conducted using SPSS.

3. Results

Table 1 shows the rates of reporting completeness and timeliness in 2011 (pre-EMRs) and in 2012-2018 when facilities progressively rolled out EMRs. There was a steady improvement of reporting timeliness and completeness across facilities with and without EMRs during the study period. In the year 2012, significant reporting rates are seen when only a few EMRs were introduced averaging around 56% and 40% in reporting completeness and timeliness respectively. On average, reporting completeness improved to 97% whilst timeliness increased to 83% by 2017 with similar performance for the facilities implemented either KenyaEMR or IQCare. However a noticeable drop in performance is seen in 2018 with an average drop of 13% in completeness and 11% in timeliness of reporting. Anecdotal evidence suggests that there was a change in reporting routines, which could have negatively affected reporting on the two programmatic areas.

Table 1. MOH 731 Reporting completeness and timeliness averages in %

Year	HTS				C&T			
	KenyaEMR		**IQCare**		**KenyaEMR**		**IQCare**	
			Pre-EMR Implementation					
	n=74		**n=57**		**n=49**		**n=41**	
2011 Completeness	15.98 ± 8.71		16.95 ±9.19		15.30 ± 7.88		17.08±9.50	
Timeliness	5.96 ± 7.99		5.41 ±6.96		5.78± 8.02		4.87± 6.98	
EMR Implementation status	**With EMR**	**Without EMR**	**With EMR**	**Without EMR**	**With EMR**	**Without EMR**	**With EMR**	**Without EMR**
	n=4	**n=226**	**n=3**	**n=223**	**n=4**	**n=219**	**n=2**	**n=214**
2012 Completeness	56.25 ± 27.55	71.17± 25.18	58.33± 44.13	70.00± 25.10	56.18± 25.90	65.76± 25.65	70.85± 29.49	65.01± 26.05
Timeliness	41.68 ± 34.03	58.33± 25.15	38.9± 34.70	51.90± 25.71	33.25± 34.08	52.69± 26.05	45.85± 29.49	45.71± 23.53
	n=104	**n=152**	**n=105**	**n=137**	**n=103**	**n=152**	**n=105**	**n=126**
2013 Completeness	92.80± 12.97	91.41± 14.35	92.31± 12.92	89.91± 16.85	91.20± 14.82	87.23± 21.06	88.74± 15.77	87.72± 19.66
Timeliness	77.65 ± 23.53	81.47± 19.87	76.36 ±22.92	78.54±22 .88	73.23± 24.70	73.49± 27.38	64.10± 30.17	69.44± 27.71
	With EMR n=260		**n=227**	**n=15**	**With EMR n=259**		**n=225**	**n=15**
2014 Completeness	97.44 ± 6.97		95.60 ± 8.88	97.79± 3.80	96.53± 8.87		95.45± 10.61	93.34± 17.03
Timeliness	85.90 ± 17.53		83.09 ±19.30	75.03±27 .29	80.05 ± 21.30		75.44± 26.75	71.11± 27.93
	n=261		**n=239**	**n=2**	**n=260**		**n=241**	**n=2**
2015 Completeness	99.27 ± 2.86		97.88 ± 7.03	79.15± 29.49	98.95± 3.74		97.10± 7.81	75.00± 35.36
Timeliness	90.05 ±17.57		81.33 ±26.11	62.50± 5.94	84.24 ± 22.36		78.07± 23.79	54.15± 5.87
	n=260		**With EMR n=241**		**n=260**		**With EMR n=243**	
2016 Completeness	99.36± 2.43		97.76± 5.83		99.08± 3.00		98.33±4.80	
Timeliness	94.12 ± 9.48		87.52± 14.04		83.73 ± 20.29		75.16± 24.87	
	n=260		**n=243**		**n=259**		**n=244**	
2017 Completeness	98.24 ± 5.22		96.27 ± 8.68		98.75 ± 3.85		96.56± 9.06	
Timeliness	90.91 ± 12.72		83.17 ± 16.26		85.01 ± 19.37		73.67± 24.67	
	n=261		**n=243**		**n=259**		**n=243**	
2018 Completeness	70.10 ± 23.85		66.30± 23.34		69.38 ± 23.96		66.48±23.37	
Timeliness	67.01 ± 24.58		60.48 ±23.99		62.47± 26.55		57.74± 26.50	

4. Discussion

The descriptive statistics concerned the two major EMRs implemented in Kenya, namely KenyaEMR and IQCare. The study looked at the two most common HIV services as required by the MoH, which are HTS and C&T. Since the systems are used at the front end of the data management, it was of interest to understand their contribution to the mandatory national monthly reporting of the HIV indicators to DHIS2 system over time. The data collected within the EMRs is not directly reported into the DHIS2 and therefore the analyzed data can only provide evidence about reporting in general terms. The increase in reporting performance in 2013 could be attributed probably to the EMRs, but the best evidence for that would be anecdotal. Nevertheless, the inbuilt reports generation functionality in EMRs could have facilitated in the collation of HIV data, which in turn expedites the reporting process for data officers to the DHIS2. Additionally, some benefits could have arisen from the user support and e-learning resources offered by the implementing partners [9]. The method applied in this study can be replicated to data from other disease types.

The study reported here did not investigate aspects such as organizational factors, human resource, patient load factors, and financial resources. It is less clear what reporting routines were established prior to the introduction of the electronic records. However, it seems that the routines and procedures contributed to the improvement in the completeness and timeliness of reporting.

5. Conclusions

The study investigated the performance in HIV indicators reporting using descriptive statistics that included two EMRs namely; IQCare and KenyaEMR. The completeness and timeliness of reporting rate was high. However, it is easier to assume than approve that EMRs solely contribute to the success of reporting since there are other factors to consider such as organizational, human, patient load, and financial resources, which can be explored in future studies.

Ethical approval and Acknowledgements

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RESEARCH ARTICLE

A multivariate statistical evaluation of actual use of electronic health record systems implementations in Kenya

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Abstract

Background

Health facilities in developing countries are increasingly adopting Electronic Health Records systems (EHRs) to support healthcare processes. However, only limited studies are available that assess the actual use of the EHRs once adopted in these settings. We assessed the state of the 376 KenyaEMR system (national EHRs) implementations in healthcare facilities offering HIV services in Kenya.

Methods

The study focused on seven EHRs use indicators. Six of the seven indicators were programmed and packaged into a query script for execution within each KenyaEMR system (KeEMRs) implementation to collect monthly server-log data for each indicator for the period 2012–2019. The indicators included: *Staff system use*, *observations (clinical data volume)*, *data exchange*, *standardized terminologies*, *patient identification*, and *automatic reports*. The seventh indicator (*EHR variable Completeness*) was derived from routine data quality report within the EHRs. Data were analysed using descriptive statistics, and multiple linear regression analysis was used to examine how individual facility characteristics affected the use of the system.

Results

213 facilities spanning 19 counties participated in the study. The mean number of authorized users who actively used the KeEMRs was 18.1% (SD = 13.1%, p<0.001) across the facilities. On average, the volume of clinical data (*observations*) captured in the EHRs was 3363 (SD = 4259). Only a few facilities(14.1%) had health data exchange capability. 97.6% of EHRs concept dictionary terms mapped to standardized terminologies such as CIEL. Within the facility EHRs, only 50.5% (SD = 35.4%, p< 0.001) of patients had the nationally-

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endorsed patient identifier number recorded. Multiple regression analysis indicated the need for improvement on the mode of EHRs use of implementation.

Conclusion

The standard EHRs use indicators can effectively measure EHRs use and consequently determine success of the EHRs implementations. The results suggest that most of the EHRs use areas assessed need improvement, especially in relation to active usage of the system and data exchange readiness.

Introduction

Electronic Health Records systems (EHRs) have been introduced widely into medical processes in many countries worldwide, making patient data readily available for treatment, care and analysis [1–3]. These EHRs implementations promise to improve quality of patient care, patient safety and to reduce costs [4–6]. For instance, introduction of Electronic Medical records systems (EMRs) in health care has shown improvement in time dependent events such as patient waiting time, time to processing specimen in the laboratory from test request to results reporting among others benefits [7,8]. Moreover, a systematic review on utilization of EHRs for public health in Asia revealed their ability to help identify and predict seasonal outbreaks and high risk areas and prevent infections or diseases, leading to better health outcomes [9]. Schoen *et al*. noted an overall increase in EHR adoption and a significant variation in the growth rate across countries in their survey of primary care doctors in health reforms [10]. Despite the infrastructural and technical challenges experienced and reported in developing countries, the uptake of EHRs in healthcare processes have also been on the rise [2,11]. However, adoption of EHRs in Sub-Saharan Africa are largely driven by HIV treatment international programs such as President's Emergency Plan for AIDS Relief (PEPFAR) to support patient data management [11,12].

EHRs implementations involve a significant up-front investment in software design and development, infrastructure, implementation, training and IT support [13]. Sponsors, donors and management are demanding demonstrated value of EHRs implementations to inform investments and sustainability of the implementations [14,15]. Furthermore, EHRs implementations are complex, multi-faceted and impact healthcare organizations on many levels [15,16]. Consequently, chances of dismal performance of these systems are high, which may be unknown especially in public healthcare facilities. Therefore, it becomes necessary to evaluate information systems to provide evidence on system functional status and its fitness for purpose with a view to inform future deployments. Maximum benefits of information systems (IS) implementation can only be realized if the systems are deeply used in the post-adoption phase [17]. As such, evaluation of actual use of EHRs once implemented provides vital information relevant to informing approaches to improve success of existing and subsequent implementations.

Assessment of information system (IS) implementation success is both complex and never a straightforward task [18]. Thus, a range of evaluation methodologies and frameworks have emerged with divergent approaches, strengths, and limitations [19,20]. DeLone & McLean (D&M) IS success model is a mature and validated model for measuring health information systems success that was established in 1992 and revised in 2003 [21]. The model has been used to evaluate implementation success for a wide range of health information systems. Berhe *et al*., recently used the model to evaluate EMRs effectiveness from a user's perspective in Ayder Referral hospital in Ethiopia [22]. Cho *et al*. also used the model to evaluate the performance of newly-developed information systems in three public hospitals in Korea [23].

The revised D&M model has seven dimensions used to measure IS implementation success, namely: *System quality*, *Information quality*, *Service quality*, *System Use*, *intention to use*, *User satisfaction* and *Net benefits*. Of these dimensions, '*System Use*' was identified as the most appropriate variable for measuring the success of IS [21,24]. *System use* is the utilization of an IS in work processes by individuals, groups or organizations [11]. A number of studies have measured the actual EHRs use in terms of extent, frequency, duration of use and functions of the system based majorly on behavioural response of users through questionnaires, interview and/or focus group discussions [2,11,17,25,26]. However, only limited evaluation studies utilizing computer-generated data to assess EHRs use are available. This study was conducted to fill this gap by evaluating actual use of a national level EHR system implemented in healthcare facilities in Kenya, as a demonstration of how similar approaches could be applied across other low- and middle-income countries (LMICs) to evaluate use.

In most LMICs, measure of success of EHRs scale-up often relies on simple counts of the number of EHRs implementations. This study demonstrates that: (a) through use of standardized indicators [27], key new insights and gaps on actual status of EHRs implementations within countries use can be identified; (b) aspects of national-level EHRs usage assessments need not be time- or resource-intensive, as assessments can be automated using data already within the EHRs; and (c) mechanisms that allow efficient EHRs usage assessments offer insights to enable any identified EHRs usage gaps to be addressed in a timely manner.

Materials and methods

Study setting

This evaluation was conducted in Kenya, a country in East Africa with approximately 50 million persons [28]. Recognizing the role that EHRs play in patient data management, the government of Kenya through the Ministry of Health (MoH) and in collaboration with its development partners, namely Centres of Disease Control (CDC) and United States Agency for International Development (USAID), has implemented EHRs in over 1,000 public health facilities countrywide [29]. These implementations mainly support HIV care and treatment programs. While two EHRs (KenyaEMR and IQCare) by different vendors were initially endorsed for national deployment in support of HIV care, the country has since 2019 transitioned to supporting and deploying only KenyaEMR system (KeEMRs). In Kenya, KeEMRs is implemented in facilities spread across 22 Counties with varying numbers of sites per county (**S1 Appendix**). This study evaluated the actual use of KeEMRs within the facilities in which the system is deployed to inform actual EHRs usage across the country, based on computer-generated data. The study was conducted using census method with all 376 facilities that had KeEMRs implemented between 2012–2019 eligible to participate. For efficiency in care delivery, these public facilities are organised into Kenya Essential Package for Health (KEPH) service levels as follows: Level 1—community level; Level 2—dispensaries and clinics; Level 3—Health centres, maternity homes and sub district hospitals; Level 4—primary facilities which include District hospitals; Level 5—secondary facilities/Provincial hospitals; and Level 6—Tertiary/National hospitals.

EHR system

KeEMRs is an implementation and adaptation of the open source OpenMRS system platform, which is widely deployed in many countries in Africa [30]. KeEMRs supports both

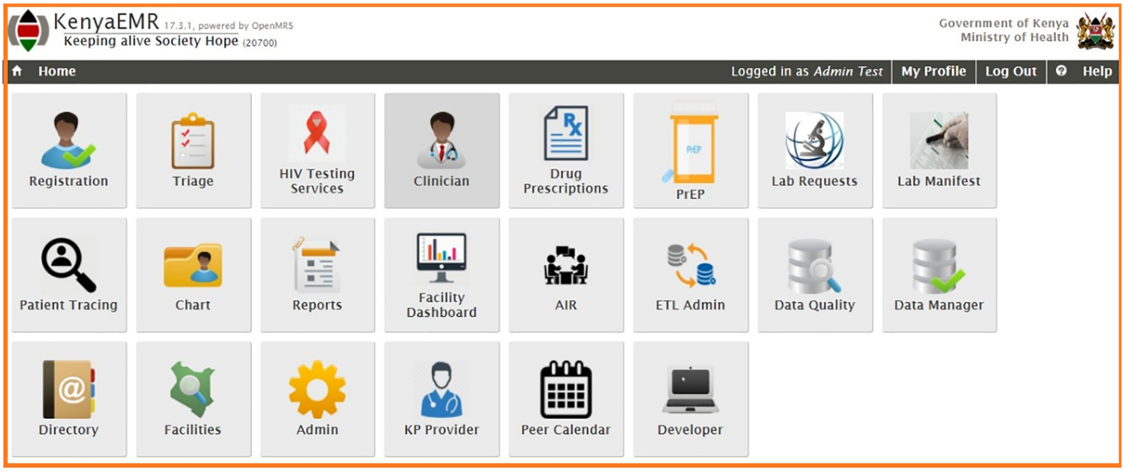

Fig 1. Screenshot of KeEMRs home page. Reprinted from [33] under a CC BY license, with permission from The Palladium Group- KeHMIS II Project, original copyright 2012.

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retrospective and point-of-care data entry (RDE & POC) with most of the facilities equipped for POC implementation. It was designed and developed(customized) by International Training and Education Center for Health (I-TECH) in the year 2012 to support care and treatment of HIV/AIDS [31]. Currently, Kenya Health Management Information system II (KeHMIS II) project supports the implementation of KeEMRs in over 370 health facilities throughout Kenya [32]. **Fig 1** shows the homepage of the EHRs under study.

KeEMRs uses a communication layer referred to as interoperability layer (IL) to enable health data exchange with other health information systems such as pharmacy system (ADT). KeEMRs version 16.0.2 and above enforced the use of a nationally-endorsed 10-digit patient identifier number (five digits representing master facility list (MFL) code and five digits comprehensive care clinic number (CCCNo)) as from the year 2017 for unique patient identification.

EHRs usage indicators

The EHRs use indicators used for this study are detailed in Ngugi et al [27]. The 15 rigorously derived indicators are modelled after the HIV Monitor, Evaluation and Reporting (MER) indicators, that facilities and implementations providing HIV care would be well-familiar with [34]. This study specifically focussed on the subset of the indicators that could be generated from within the implemented EHRs. This was because the ultimate goal is to have a module within the EHRs that can automatically generate indicators without human input for reporting and sharing with relevant stakeholders. The subset of the seven EHRs indicators included are outlined in **Table 1**. Three of the eight excluded indicators (namely *Reporting rate*, *Report timeliness* and *Report completeness*) rely on data in the national data aggregate system, the Kenya Health Information System (KHIS), and had already been evaluated and reported in a different study [29]. The other five excluded indicators (namely: *Data entry statistics*, *System Uptime*, *EHR Variable concordance*, *Report Concordance* and *Clinical Data timeliness*) required a level of human input to generate based on how the indicators are defined [27].

Table 1. EHRs usage indicators evaluated.

#	Indicator (variable)	Domain	Indicator Measure	Indicator query description	Source of data
1.	Staff system use	System use	Percentage of facility staff members who used the EHRs during the reporting period.	Defined by create, update, and delete actions around a patient record by an authorized EHRs user	EHRs
2.	Observations (Clinical Volume)	System use	Number of mandatory HIV-related clinical data elements recorded for patients in the EHRs during the reporting period.	A count of the data captured by the 23 data elements* per patient encounter per month	EHRs
3	EHR Variable completeness	Data quality	The extent to which all required data elements for a patient are contained within the EHRs	No query. Data elements* captured from RDQA report generated from EHRs	EHRs
4	Data Exchange	Interoperability	Percentage of specified systems with which the EHRs can automatically exchange all required data with.	Count of unique data exchange messages between EHRs and other sub-systems through IL	EHRs
5	Standardized Terminologies	Interoperability	The proportion of key terminologies that are mapped to standard terminology services or use a nationally endorsed concept dictionary	% mapping of EHRs concepts with the concepts_reference_map table	EHRs
6	Patient Identification	Interoperability	Use of a nationally accepted patient identification method.	Patient visits identified using 10-digit identifier vs total active patients during the reporting period	EHRs
7	Automatic Reports	Reporting	The proportion of expected reports and sub-reports to the national level that are automatically generated and transmitted to the national reporting system.	A count of the reports' generation requests	EHRs

*The 23 data elements include: Patient ID, sex, date of birth, date confirmed positive, enrolment date, initiation date, initial regimen, Current regimen, BMI at last visit date, TB screening at last visit, TB screening outcomes, IPT start date, IPT status, IPT outcome date, Second last VL result, second last VL date, most recent VL result, most recent VL date, last clinical encounter date, next visit date, Pregnancy assessment last date, Initial EID within 8 weeks, Infant prophylaxis.

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EHRs indicators queries

Queries were developed using MySQL to generate monthly indicator reports for the evaluated indicators except *EHR Variable Completeness*. These queries were programmed to be run within each EHRs implementation and were tested for accuracy in a training server prior to deployment. The data generated from the testing phase were reviewed by the researchers together with a data analyst to ensure validity of the indicator outputs (data) and needed revisions made to the queries. The resulting six queries were then combined and packaged into a script that comprised the queries and Linux bash script for creating a zipped archive file as an output after running the script. Pilot testing of the script was conducted in six facilities selected randomly in two counties to ensure feasibility of data collection within facilities. The final script was distributed to the study healthcare facilities, with accompanying instructions detailing the step-by-step process (S2 Appendix) for executing the script. Data for the *EHR Variable Completeness* indicator (key data elements related to HIV care and treatment) were derived from routine data quality assessment (RDQA) report that were already being generated from the EHRs.

Data collection and analysis

All the 376 facilities implemented with KeEMRs were approached to participate in the study. Nevertheless, data collection script was distributed to 312 sites that gave authority for the commencement of the study and had used the EHRs for at least six months. Experienced system champions at each facility ran the query script as per the outlined protocol (S2 Appendix). Further support on running the query and generating the report was provided through a toll-free line to the EHRs developers helpdesk as needed. Monthly indicator data were generated from each EHRs implementing facility from January 2012 (the earliest possible time for system deployment) to December 2019. Generated reports (data) were transmitted electronically to the research team for consolidation and data cleaning thereby enforcing data quality. No personal identifiable information were contained in the resulting indicator reports. All the EHRs implementations used the same terminology service, hence assessment of the *Standardized Terminologies* indicator evaluated the proportion of terms in this dictionary that mapped to standard terminologies such as SNOMED and ICD [35,36]. Data collection for this study occurred over a period of eight weeks between April and June 2020.

Facility characteristics (KEPH levels, facility-type-category, ownership, services and mode of EHRs use) data were derived from Master Facility List (MFL) website maintained by the MoH. These data were summarized using descriptive statistics. Mean values and standard deviations of the collective performance by facilities for each indicator were calculated. One-way ANOVA (with Tukey's b "post-hoc" test) were performed to measure the variance in variables means (*Staff System Use*, *clinical volume*, and *patient identification* indicators) across the counties. Correlation analysis was also performed to measure the relationship between *staff system use* indicator and volume of the clinical data for insight on user productivity. Weighted mean of *Staff System Use* and *Patient Identification* indicators was computed to determine the overall performance of each facility. The two indicators assumed a weighting mean of 1, hence each was assigned a weight of 0.5 in order to have an unbiased mean. A summation of the weighted mean of the two indicators for each facility was then computed and finally ranked in descending order. The two indicators were chosen because they are the key variables that show EHRs utilization in the facility. Data exchange indicator data were treated and analysed as dichotomous data (presence or absence) of interoperability layer (IL) software that facilitates data exchange with external systems.

Finally, we fitted multiple linear regression model to establish how individual facility characteristics affected the use of the system. The dependent variable was number of active system users while the covariates were the facility characteristics (KEPH level, ownership services and mode of EHRs use). All analyses were performed using IBM SPSS statistics 25 [37].

The primary outcome of interest for this study was to determine the collective performance by facilities on each of the seven indicators over the period of KeEMRs implementation in Kenya, as a measure of overall EHRs usage. In addition, this study had several secondary outcomes of interests, namely: (a) evaluation of variability in EHRs usage between counties, (b) relationship between number of active users of systems and the clinical volume for insight on user productivity, and (c) the effect of facility characteristics on EHRs use.

Ethical statement

The study was approved by the Institutional Review and Ethics Committee at Moi University, Eldoret (MU/MTRH-IREC approval Number FAN: 0003348). Permission to collect data was also obtained from Ministry of Health (MoH), County Directors of Health of each county, as well as Service Delivery Partners (SDPs) responsible for EHRs implementations and HIV data at the facility level. Permission to collect data from 312 (out of 376) facilities in 19 counties were granted. All participants filled a consent form before taking part in the study. No personal identification data were collected from either patient records/system database or the healthcare facilities or personnel who executed the queries.

Results

Organizational characteristics of the responding facilities

Out of the 312 facilities that assented to participate in the study, 213 (68.3%) spanning 19 Counties responded. Characteristics of the responding facilities are detailed in **Table 2**. The

Table 2. Frequency distribution for the facility characteristics (n = 213).

Characteristics	Count	%	P-value
KEPH Level			
Level 2	28	13.10%	0.092
Level 3	100	46.90%	
Level 4	85	39.90%	
Total	213	100.00%	
Facility type category			
Dispensary	26	12.20%	0.057
Health Centre	99	46.50%	
Hospitals	86	40.40%	
Medical Clinic	2	0.90%	
Total	213	100.00%	
Ownership			
Faith Based Organizations	21	9.90%	0.001
Ministry of Health	189	88.70%	
Non-Governmental Organizations Private	3	1.40%	
Total	213	100.00%	
Services			
CT*	161	72.30%	<0.001
CT&HTS**	52	13.60%	
Total	213	100.00%	
Mode of use			
HYBRID	112	52.60%	<0.001
POC	20	9.40%	
RDE	81	38.00%	
Total	213	100.00%	

* Care & Treatment service (CT)

**HTS–HIV counselling and testing service.

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responding facilities were largely between KEPH levels 2 and 4, as these were the ones offering HIV services and in which the EHRs was deployed. Most of these facilities offered care and treatment (C&T) service 161(72.3%). Over 86% of these facilities were either Health Centres or Hospitals and were largely owned and run by the Ministry of Health (88.7%). Only 9.4% of the facilities were completely paperless, with slightly over a third of the facilities (38.0%) still doing retrospective data entry (RDE) fully.

The total number of responding facilities with EHRs implementation varied by county, with the lowest county having three while the highest had 25. Most of these implementations occurred in 2014 (113 implementations, 53.1%) followed by 2013 (91 implementations, 42.7%) (S3 Appendix). No implementations occurred in the period 2015–2017 whilst there were only four new implementations (1.8%) between 2018 and 2019 in line with the country's planned implementation strategy.

EHRs usage indicator results

Staff system use. An average of 18.1% (SD = 13.1%) staff members with EMRs access rights used the system in any given period. The best and worst facilities had a mean usage of 46.8% (SD = 23.3%) and 7.3% (SD = 3.3%) respectively (p< .001) (S4 Appendix).

Observations (clinical data volume). On average, the facilities captured 3,363 (SD = 4,249) patient-related data elements (clinical data volume) monthly, based on the mandatory 23 data types of interest for HIV reporting in Kenya [38] showing there was high dispersion in the data collected (**S4 Appendix**). The facility with highest mean monthly volume captured 28,937 (SD = 11,356) data elements while the least had 251 (SD = 167). There was a weak positive correlation between *Observations* (*Clinical data volume*) and *Staff System Use* indicators (coefficient r = 0.01).

EHR variable completeness. We observed that all the 23 data elements required for HIV patients by the MoH were contained within the records for each patient in the EHRs. Hence the *EHR Variable Completeness* indicator as per the country's standard operating procedures (SOP) was 100% across the study facilities.

Data exchange. Majority of the facilities (183/213) lack the interoperability layer (IL) module and hence had no capability to exchange health data with external systems (**S5 Appendix**). Of the 14.1% facilities which had data exchange capability, 56.7% of them were in one county. None of the facilities (n = 108) in 13 of the 19 counties had data exchange capability.

Standardized terminologies. On average 97.6% (52,098 out of 53,353) of KeEMR system concepts were mapped to the standardized (international) terminologies/concept dictionaries such as CIEL and SNOMED.

Patient identification. Only 50.5% (SD = 35.4%, $p < 0.001$) of the patient records had patients with identifiers in the nationally-endorsed patient identifier format (10-digit number = 5 MFL+5 CCCNo.) (**S4 Appendix**). There was a wide range of 3% to 100% conformity across the facilities, indicating the need for further investigation on why such low conformity rates. Three of the healthcare facilities fully adopted the approved patient identifier (100%) while 28 facilities had an average mean of < 10% conformity in the use of the national patient identifier.

Automatic reports. KeEMRs is configured to generate monthly Ministry of Health routine reports (MoH 731) for transmission to the national reporting system (KHIS). However, by the time of this study, we could not capture the data to compute automatic reports indicator (the proportion of expected reports to the national level that are automatically generated and transmitted to the national reporting system). This was because the records of the generated reports and their transmission are not saved, with tables refreshed on a daily basis.

Performance of the facilities

Using the weighted mean of the means scores of *Staff System Use* and *Patient Identification* indicators, facilities were benchmarked against each other using the "best performer" and "worst performer" approach. The weighted mean ranged from 9% to 65% across the 213 facilities. **S6 Appendix** presents facility performance list from the highest to the lowest. The top ten performing facilities had an average weighted mean of 61% (range 59–65%) while the bottom ten facilities had an average mean of 11% (range 9–12%).

EHRs use against facility characteristics

The relationship between the facility characteristics and the number of active system users assessed by the multiple linear regression analysis was statistically significant (p = 0.000) for all the covariates (**Table 3**). The characteristics influenced system usage positively, with the exception of Mode of EHRs use characteristic. RDE mode of EHRs use had the highest negative impact on the use of the system.

Table 3. Multiple linear regression model for staff system use and facility characteristics.

Facility Characteristics		Unstandardized Coefficients		Standardized Coefficients	t	P-value
		B	Std. Error	Beta		
(Constant)		0.354	0.084		4.213	0.000
KEPH Level	Level 2 Level 3 Level 4	0.445	0.019	0.194	23.929	0.000
Ownership	-Faith-Based Organisation -Ministry of Heath -Non-Governmental Organization	0.401	0.035	0.092	11.308	0.000
Services	CT CT&HTS	0.392	0.015	0.206	25.351	0.000
Mode of EHRs use	Hybrid POC RDE	-0.124	0.014	-0.074	-9.176	0.000

Dependent Variable: Number of active system users; Independent Variables: KEPH level, ownership, mode EHRs of use, and services. p-value: When $p< = 0.05$, there is statistically significant difference. B (coefficient) explains a change in dependent variable that can be attributed to a change of one unit in the independent variable.

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Discussion

To our knowledge, this is the first national-level study that has systematically evaluated actual EHRs use post-implementation utilizing computer-generated real-time data based on robustly developed EHRs usage indicators. A systematic review on measuring EHRs use in primary care revealed that most studies measured use through assessing the utilization of individual EHRs functions [26]. The findings from our study highlight the fact that simply counting number of EHRs implementations is highly inadequate in determining IS implementation success. Multidimensional set of indicators for evaluating EHRs use in this study align with the three main components of EHRs meaningful use, namely: (1) EHRs must be used in the care processes such as prescribing, (2) EHRs must encompass electronic health data exchange for improved health care quality and (3) EHRs must support reporting of clinical measures [39,40]. In this study, indicators reflecting system use and interoperability domains indicated low measures, suggesting the need for further improvement.

Measuring system-use at the application level sheds light on how fully or effectively organizations are using IT [41]. In our study, the overall *Staff System Use* was very low across all the facilities regardless of the period of EHRs implementation. The study established existence of many dormant user accounts in the EHRs across all facilities portraying a high number of users authorized to use the system (denominator) compared to actual number of users (numerator) hence the low average mean. Another possibility of low mean could have been occasioned by shared login credentials or shared computers resulting into multiple users on one user account. This presented a scenario like only one user performed activities around patients' files i.e., create, update or delete, which were the assessed *Staff system use* indicator measures. Consequently, this compromised the accuracy of the numerator count. A study investigating users' behaviour in password utilization revealed users share passwords for convenience as well as a show of trust [42]. The finding from our study warrants deeper assessment on user credentialing processes and account usage patterns (such as sharing of credentials). It also highlights the need to re-emphasize good password practices to the system users and active monitoring of user accounts by the system administrators. We also recommend further research to establish user-computer ratio in the healthcare facilities.

While our results show KeEMRs' readiness to interoperate with other external systems due to high mapping rate of its concepts to standard terminology services like CIEL [38,43], the study established a slow incorporation of the interoperability layer (IL) within the EHRs. Integration with other systems is one of system quality measures among ease-of-use, functionality, reliability and flexibility [44]. The low data exchange indicator findings from this study suggests the need for investigation on other system quality measures. Technological barriers, such as functionality and compatibility issues, and non-user-friendliness can limit system use [45]. The actual uptake of the nationally-accepted patient identifiers was average although with large variations in uptake levels between facilities and between counties. Several studies reveal lack of interoperability as a well-known impediment to EHRs successful adoption and use [46–49]. As such, interoperability layer should be incorporated into all EHRs implementations as well as concerted efforts towards nationwide adoption and use of unique patient identifier, which promises to improve patient safety and care efficiency [50].

The study expected a strong positive correlation between *Staff System Use* and *Observations (*clinical data volume) recorded in the EHRs, which was not the case. This could be attributed to the possibility of users sharing login credentials as intimated earlier. Several factors determine facility clinical volume such as patients' volume, frequency of patients' visits (encounters), EHRs mode of use and active usage of the system during care, all unique to each facility. Ideally, facilities entering data retrospectively should efficiently transfer paper records into the EHRs in a timely fashion for 100% concordance. However, a study on EHRs use and user satisfaction by Tilahum and Fritz revealed retrospective data entry as a major cause of dissatisfaction of EHRs use among users, especially when the same individuals collecting the data are tasked to enter it into the system later [2]. Indeed, our study revealed that point of care (POC) and hybrid modes of data capture were associated with increased system usage compared to retrospective data entry. Thus, EHRs implementors should aim at point of care mode of operation right from initiation.

Study strengths and limitations

The key strength of the study was the use of empirical data extracted directly from EHRs hence not subject to bias normally introduced by human judgment prevalent in self-reports such as questionnaires. Boon *et al* in their study on antecedents of continued use and extended use of enterprise systems strongly recommended use of system log file data to overcome human related response bias [51]. Secondly, the study period (2012–2019) was long enough to reveal the state of the EHRs use in the health care facilities. Also, the study results are reliable due to the use of census method in the collection of the primary data. Furthermore, these facilities had diverse range of characteristics in terms of ownership and facility levels and covered broad geographic area of Kenya. The study does, however, acknowledge a few limitations. It was only conducted in one country (Kenya) and the findings do not necessarily translate directly to other countries. However, the study provides a demonstration case that can be modelled by other countries to inform similar EHRs usage evaluations. Finally, this study only focused on facilities where the EHRs were in actual use, without mention of locations where the EHRs were implemented and actually failed. Attention needs to be paid to failed implementations, to ensure that usage rates are not being over-reported.

In the next step of our research, we will conduct qualitative assessments to better understand the observed findings. This will be done through Focus Group Discussions (FGD) and semi-structured interviews with EHRs users and key stakeholders. Further, we will work with relevant partners to help integrate outputs and visualizations of the usage reports within the EHRs, and to provide various visualizations and dashboards for managers and decision-makers to increase visibility on system usage within and across facilities. It is also recognized that continued usage of EHRs in the patient care processes do not necessarily lead to better work performance or improved care quality. Further research is needed to investigate impact of EHRs usage on care quality and outcomes.

Conclusion

Assessment of actual use of implemented EHRs within LMICs is important. The systematically generated standard EHRs usage indicators can be adopted and used successfully within facilities across countries. Results from this study demonstrate that there are many areas of improvement in EHRs use, as well as the need for continuous monitoring of EHRs use to inform timely interventions. Simply counting number of implementations, as is currently done in many settings, remains a highly inadequate measure for evaluating EHRs implementations success.

Supporting information

S1 Appendix. Distribution of KeEMRs implementations as of June 2020.
(PDF)

S2 Appendix. Standard operating procedures for query extraction.
(PDF)

S3 Appendix. KeEMRs implementations distribution in the period 2012–2019 across the counties (n = 19).
(PDF)

S4 Appendix. Facilities descriptive statistics for staff system use, observations & patient identification indicators.
(XLSX)

S5 Appendix. Interoperability layer (IL) module (data exchange) presence/absence in facilities across the counties.
(PDF)

S6 Appendix. Facilities performance using weighted means.
(XLSX)

S7 Appendix.
(XLSX)

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Users' Perception on Factors Contributing to Electronic Medical Records Systems Use: A Focus Group Discussion Study in Healthcare Facilities Setting in Kenya

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Abstract

Background

Electronic Medical Records systems (EMRs) adoption in healthcare to facilitate work processes have become common in many countries. Although EMRs are associated with quality patient care, patient safety, and cost reduction, their adoption rates are comparatively low. Understanding factors associated with the use of the implemented EMRs are critical for advancing successful implementations and scale-up sustainable initiatives. The aim of this study was to explore end users' perceptions and experiences on factors facilitating and hindering EMRs use in healthcare facilities in Kenya, a low- and middle-income country (LMIC).

Methods

Two focus group discussions were conducted with EMRs users (n=20) each representing a healthcare facility determined by the performance of the EMRs implementation. Content analysis was performed on the transcribed data and relevant themes derived.

Results

Six thematic categories for both facilitators and barriers emerged, and these related to (1) system functionalities; (2) training; (3) technical support; (4) human factors; (5) infrastructure, and (6) EMRs operation mode. The identified facilitators included: easiness of use and learning of the system complemented by EMRs upgrades, efficiency of EMRs in patient data management, responsive Information Technology (IT) and collegial support, and user training. The identified barriers included: frequent power blackouts, inadequate computers, retrospective data entry (RDE) EMRs operation mode, lack of continuous training on system upgrades, and delayed IT support.

Conclusions

Users generally believed that the EMRs improved the work process, with multiple factors identified as facilitators and barriers to their use. Most users perceived system functionalities and training as motivators to EMRs use, while infrastructural issues posed as the greatest barrier. No specific EMRs use facilitators and/or barriers could be attributed to facility performance levels. Continuous evaluations are necessary to assess improvements of the identified factors as well as determine emerging issues.

Keywords

EMRs use, facilitators, barriers, users' perception, system users

Background

Adoption of Electronic Medical Records systems (EMRs) has been on the rise in both developed and developing countries [1,2]. EMRs are a repository of patient data in digital form in one practice [3] while Electronic Health Record systems (EHRs) store and securely exchange clinical data, among multiple authorized users beyond one provider's office [4]. While EMRs adoption rates in developed countries have grown tremendously, in developing countries, the growth rate has been slow and their use is more in administrative rather than for clinical purposes [5]. For example, in the US, EMRs have been in use for over 30 years, with the proportion of hospitals having at least basic EHR functions increasing from 58.9% in 2014 to 80.5% in 2017 [6]. Similarly, Australia has had high rates of EMRs adoption with more than 90% of general practices having some form of EMRs [7]. In New Zealand all general practices use EMRs [8]. On the contrary, studies reveal EMRs adoption has been slow in developing countries due to various factors such as prohibitive costs, security concerns, and interoperability issues among others [9,10]. However, despite the challenges, many low- to middle-income countries (LMICs) including Ghana, Kenya, Lesotho, Mozambique, Rwanda, Sierra Leone, Tanzania, Uganda, and Zimbabwe have been working on National EMR systems according to a WHO survey [11].

By nature, healthcare organizations are complex and introduction of EMRs can bring further complications, which can lead to rejection of the system or failure of the implementation regardless of the setting [12]. As an example, users are likely to embrace systems that do not interfere with their workflow [13]. Consequently, successful EMRs implementations require careful planning and balancing of service delivery needs in order to optimize the anticipated benefits.

Information system (IS) use is the utilization of information technology (IT) within users' processes either individually, or within groups or organizations [14]. Implementation of a health information system does not necessarily mean that the system will be used in the way it was intended or used at all. Many factors affect the use of implemented information systems which vary among system users [15]. While these factors may perhaps be generalized regardless of the settings, organizational and user needs can be different due to cultural factors and unique challenges such as inadequate computer to user ratio and power blackouts, among others [9]. Further, the culture of not using information systems for the wider organizational processes (e.g., during health care delivery) may affect their use [16]. Such challenges jeopardize the system's availability when required for daily use in health care delivery.

While many health professionals generally believe that information technology can eliminate the burden of paper-based documentation such as delays in retrieval of patient records (especially in emergency situations), users get easily discontented if the adopted system or support does not meet their expectations [1,17,18]. Further, a study by Myongho revealed that physicians shun systems that interfere with their workflow and how they attend to their patients [19]. Furthermore, several studies have also reported comparatively low adoption rates of EMRs despite broad consensus on the potential benefits such as improved quality of care, patient safety and cost reduction [19–22]. Oftentimes, users hold first-hand knowledge on what can contribute to or limit the use of EMRs implementations as they incorporate these into their work environments [12,23].

Although there is a corpus of studies conducted to explore barriers and facilitators to EMRs implementations [9,24–27], only a limited number of evaluation studies are available concerning EMRs use in work processes once the systems are implemented in constrained resource settings [10,28]. To the best of our knowledge, none of the previous studies have looked at the increasingly deployed national-level EMRs systems in LMICs. Given the significance of users in information system utilization, users' perceptions are critical in exploring the facilitators and barriers to EMRs use [23]. To this end, this qualitative study set out to identify facilitators and barriers to the nationally-deployed KenyaEMR system (KeEMRs) use in a resource-constrained setting. Facilitors refers to the factors deduced from the participants perspective as motivators to the use of the EMRs in their work process while barriers are factors that hinder use of the system either partially or totally [29]. The goal of this study was to inform EMRs implementations and scale-up strategies in similar settings, considering the high costs involved in such endeavours. This is of interest to various stakeholders including funding agencies and the ministries of health. In this context, 'use' refers to a full and/or partial use of the EMRs in all activities relevant to patient care as enabled by the EMRs [14]. This study is part of an ongoing evaluation study on the state of EMRs implementations in Kenya [30].

Methods

Study design

A qualitative study design was used to explore perceptions of the users of the electronic medical records system, KeEMRs. The focus was to uncover barriers and facilitators to system use in the healthcare facilities.

Study Global Setting for Kenya Health System

This study was conducted in Kenya, a country in East Africa with 47 administrative counties and approximately 50 million persons [31]. The Kenyan healthcare system is split into four subsystems namely: Public sector with the major player being Ministry of Health (MoH), Commercial and Non-Governmental Organization (NGO), Private sector, and Faith Based Organisations (FBOs) [32]. The National Health Sector Strategic Plan II introduced the Kenya Essential Package for Health (KEPH), which categorized health service delivery into six levels, which include (i) level 1 - community services, (ii) level 2 - dispensaries/clinics, (iii) level 3 - health centres, (iv) level 4 - sub-county hospitals, (iv) level 5 - county referral hospitals, and (vi) level 6 - national referrals hospitals [33].

Study Specific Setting

In 2012, the Ministry of Health (MoH) in Kenya, with the support of international donor funding and local partners, embarked on development and implementation of EMRs in public healthcare facilities with a view to improve patient data management [34]. Five different types of EMRs developed by separate vendors have been implemented across the country. They include KeEMRs, Ampath Medical Record System (AMRS), eCare, IQCare, and OpenMRS [35]. Nevertheless, KeEMRs and IQCare are the main EMRs accredited to support HIV healthcare delivery services within facilities under the MoH in Kenya [35]. These two EMRs have been rolled out in over 1,000 healthcare facilities countrywide [34]. They are mainly deployed in HIV, Tuberculosis (TB), and Maternal and Child Health (MCH) clinics, with a view to expanding them to other clinical units in future [36]. The country has since 2019 transitioned to supporting and deploying only KeEMRs. As such, sites running IQCare system are being transitioned to KeEMRs. It is for this reason that this study focused on KeEMRs only.

The healthcare facilities in this study are located in the rural parts of Kenya, spanning eleven counties. They were determined from facilities' EMRs use performance assessment, conducted in our ongoing evaluation study on the actual use of EMRs implementations in healthcare facilities in Kenya [30]. The assessment utilized computer-generated EMRs *use* empirical data based on various EMRs use indicator measures as outlined in Ngugi et al. [37]. In that study, facility performance was determined by weighted mean calculated from the empirical data of two EMRs use indicators: *Staff System Use* (proportion of active system users) and *Patient Identification* (percentage of patient records with national identification number). From the resulting descending order ranking, facilities were categorized as best performers, average performers and poor performers.

A purposive sample of 20 facilities was selected to provide primary data for this study. Purposive sampling is aimed at seeking depth and richness of information and not representativeness [38]. Drawing from previous studies, a minimum sample size of at least 12 is recommended to reach data saturation for qualitative studies [39,40]. As such, a sample size of 20 was deemed sufficient for the qualitative analysis and scale of this study as well as accounting for nonresponse. The study facilities were categorized as follows: best performers (top six), average performers (top seven), and poor performers (top seven). Hence, the type of sampling was stratified purposeful sampling. This criteria ensured representation of views and perspectives from facilities at all performance levels. Table 1 presents the characteristics of the 20 healthcare facilities under study.

Table 1: Study facilities performance (Top: best, average and poor) and characteristics

Facility Performance position*	County No.	Weighted Mean**	Keph level	Facility_type_category	Owner Type	EMRs Implementation Dates	Services	EMRs mode
1	044	65%	Level 2	MEDICAL CLINIC	NGO	12.03.2014	CT&IL	POC
2	042	62%	Level 4	HOSPITALS	MoH	01.12.2018	CT	HYBRID
3	039	62%	Level 4	HOSPITALS	MoH	27.09.2013	CT	HYBRID
4	042	61%	Level 4	HOSPITALS	MoH	01.09.2018	CT&IL	POC
5	042	61%	Level 3	HEALTH CENTRE	MoH	01.02.2013	CT	HYBRID
6	029	61%	Level 3	HEALTH CENTRE	MoH	04.07.2013	CT	RDE

92	043	41%	Level 3	HEALTH CENTRE	MoH	18.09.2014	CT&HTS&IL	HYBRID
93	045	40%	Level 4	HOSPITALS	MoH	02.07.2013	CT	RDE
94	037	40%	Level 4	HOSPITALS	MoH	25.09.2013	CT	POC
95	018	40%	Level 3	HEALTH CENTRE	MoH	26.05.2014	CT	HYBRID
96	045	39%	Level 3	HEALTH CENTRE	MoH	24.06.2014	CT	RDE
97	038	39%	Level 3	HEALTH CENTRE	MoH	04.08.2014	CT	HYBRID
98	023	39%	Level 2	DISPENSARY	FBO	23.07.2013	CT	RDE
207	037	12%	Level 3	HEALTH CENTRE	MoH	20.08.2014	CT	HYBRID
208	038	12%	Level 3	HEALTH CENTRE	MoH	10.06.2013	CT	HYBRID
209	037	10%	Level 3	HEALTH CENTRE	MoH	20.08.2014	CT	HYBRID
210	029	10%	Level 3	HOSPITALS	MoH	10.12.2013	CT	RDE
211	038	10%	Level 3	HEALTH CENTRE	MoH	17.04.2014	CT	RDE
212	022	9%	Level 2	DISPENSARY	FBO	06.11.2013	CT&HTS	HYBRID
213	029	9%	Level 4	HOSPITALS	MoH	19.12.2012	CT	POC

Keph - Kenya essential package for health, NGO – Non Governmental Organization, MoH – Ministry of Health, FBO – Faith Based Organization, CT-Care & Treatment, HTS – HIV counselling & Testing services, POC – point of care, RDE-Retrospective data entry, IL – Interoperability Layer

* Positions **1-6**: best performing, **92-98**: average performing and **207-213**: poor performing gauged by **Weighted means of *Staff system use* and *Patient identification* 'EMRs use' indicators for the study period 2012-2019. Weighted mean were computed as follows: The two indicators assumed a weighting mean of 1, hence each was assigned a weight of 0.5 in order to have an unbiased mean. A summation of the weighted mean of the mean scores of the two indicators for each facility were then computed and finally ranked in descending order. The two indicators were chosen because they are the key variables that demonstrate EMRs utilization in the healthcare facilities [30].

The KeEMRs

KeEMRs is an open-source electronic medical records system, that is a customized distribution of OpenMRS developed in Java language [41]. The database (back-end) is developed in MySQL while the user interface (front-end) is developed in JavaScript and Hyper Text Mark Up Language (HTML). The front-end connects to the back-end via rest Application Interface (APIs). Since it is open-source software, it uses Linux operating system Ubuntu version 16 and above distribution. OpenMRS is supported by a large global network and used in at least forty countries worldwide [42]. KeEMRs was originally developed by International Training and Education Centre for Health (I-TECH). I-TECH is a global network that works with local partners to develop skilled health care workers and strong national health systems in resource-limited countries [43]. Currently, KeEMRs is supported by Palladium Group through Kenya Management Information System (KHMIS-II) project [44]. Palladium group is an international consulting firm that works in various industries to provide customized solutions [45]. KHMIS-II is a President's Emergency Plan for AIDS Relief (PEPFAR) funded project under the cooperative agreement with Centres for Disease Control and Prevention (CDC) for the period October 2016 to September 2021. The project's main objective is to support the Ministry of Health, County Health Management teams, and Service Delivery Partners (SDPs) in developing and maintaining Health Information Systems (HIS) innovations in Kenya. There are 31 SDPs in Kenya whose mandate is to deploy EMRs and train users in the healthcare facilities at the county level to support HIV care and treatment. At the time of the study, four of these SDPs were responsible for deploying KeEMRs in the study facilities. Of the trained system users, the facilities selected data staff (mostly health records information officers (HRIOs)) as system champions responsible either at the county or facility level. The selection criteria was based on competency in EMRs usage, enthusiasm, resourcefulness and willingness to learn.

KeEMRs is comprised of different modules to serve various sections of care (majorly HIV and TB clinics) by different categories of users. The main modules include Registration, Triage, HIV testing services, Clinician module, Drug Prescription, Laboratory requests, Patient tracing, Pre-Exposure Prophylaxis service (PrEP), and Reports. The KeEMRs products include: mUzima which is a mobile phone and tablet platform used for HIV testing and counselling (HTS) in offline/online mode, interoperability layers (IL) used for data exchange between systems (e.g. Viral load system from National AIDS and Sexually Transmitted Infections (STI's) Control Programme (NASCOP) to EMRs), Text messages for adherence (ETS), ARV dispensing tool (ADT), and Data warehouse API (DWAPI) - an application interface that facilitates transmission of HIV indicator data from EMRs to the national data warehouse. An illustration of the national reporting system in Kenya is shown in a supplementary figure [see Additional file 1].

At the time of this study, KeEMRs had been rolled out in over 370 public, non-governmental organizations and faith-based healthcare facilities on varying dates in the period 2012 to 2018 [43]. The plan of the MoH is to expand the system to all other public facilities and other sections of health care. It is important to note that the implementations of KeEMRs varies in the mode of operation from one healthcare facility to another. The modes include paperless, point of care (POC), retrospective data entry (RDE), and hybrid mode which is a combination of both POC and RDE within the same facility.

Study Participants

A total of 20 participants were recruited from the 20 study sites. Criteria for inclusion in the study was the ability of the participant to inform the conversation around KeEMRs usage, and facilitators and barriers to usage. Thus, the participants were selected by the in-charges of the study sites, as they were well-informed regarding system users suitable to participate in the study. Emphasis was placed on assuring that multiple perspectives were represented in the deliberations. With this in mind, the participants', who in this study are the units of analysis, included all categories of KeEMRs users including (1) Clinical staff, (2) Nursing staff, (3) Health Records Information Officers (HRIOs), (4) Data entry clerks, and (5) IT staff. Table 2 presents detailed socio-demographic characteristics of the participants.

Table 2. Characteristics of the EMRs users participants expressed in frequencies and % (n=20)

Gender	Male	9(45%)
	Female	11(55%)
Age (years)	20-30	10(50%)
	31-40	10(50%)
Profession	Data clerk	1(5%)
	Health records information officer (HRIO)	15(75%)
	IT staff	2(10%)
	Clinical officer (Clinician)	1(5%)
	Other	1(5%)
Work experience (in years)	<2	1(5%)
	2-5	10(50%)
	6-10	8(40%)
	>10	1(5%)
KeEMRs use experience (in years)	<2	3(15%)
	2-5	13(65%)
	>5	4(20%)

Four additional participants were drawn from the four SDPs organizations overseeing EMRs implementations in the study facilities. The aim of including this category of participants was to get the management's perspective, owing to their role in EMRs implementations mentioned earlier. All potential study participants were contacted via telephone and email.

Data Collection

Data were collected through Focus Group Discussions (FGDs) sessions conducted online via a secure Zoom video-conferencing enterprise platform [46,47]. The choice to use online platform was inevitable due to the social distancing and travel restrictions occasioned by COVID 19 pandemic. However, Reisne et al. purport that online FGDs allows participation across a wide geographical coverage, providing the potential for greater diversified views, among other advantages [48]. Focus group is defined as organized, highly interactive group discussions that aims to explore a specific topic or an issue to generate data [49]. Previous studies have reported varied numbers of participants considered sufficient for an FGD, with the numbers ranging from four to fifteen [50,51]. Generally, ten participants are considered large enough to gain a variety of perspectives and adequate participation while at the same time small enough to control [52]. We chose this methodology because focus groups are quite suitable for investigating experiences, attitudes and emerging ideas from the group [49]. Additionally, we desired to have an interactive environment where participants would discuss and comment on each other's experiences and points of view for richness of data (quality).

The 20 participating EMRs users from the study facilities were randomly assigned into two focus groups, each group comprising of 10 participants while the four SDPs representatives formed a third group. There was no specific order of conducting the three FGDs. The group discussions were conducted in English. Each FGD session lasted two hours. The primary researcher (PN- PhD candidate), with FGD training, moderated the FGDs assisted by AB (Associate Professor). The discussions were recorded after explicit permission to record and consent was obtained from each participant. All participants filled a consent form via email before taking part in the study [see Additional file 2].

A list of key questions were used to guide the discussions process [see Additional file 3]. The FGDs were initiated by asking all participants to reflect and share briefly on their experiences in supporting care to patients in their respective capacities/roles since the introduction of the KeEMRs in their facilities. This ensured that all participants had a chance to share their views. After this introduction, the moderator's questions guided the rest of the groups' discussions.

The participants were refunded the cost of internet connection charges incurred to connect to the Zoom platform. All data were collected in July 2020.

Data Analysis

The recorded discussions were downloaded and transcribed verbatim by the researcher, then re-played once to verify accuracy and authenticity. Any participant identifiers or other identifying information were stripped from the data to ensure confidentiality. The anonymized and validated transcripts were then analysed using qualitative content analysis. Content analysis is a systematic analysis of text commonly used in social science [53,54]. The content analysis process involved coding of the transcribed data followed by categorization into major themes, in line with the questions asked [55]. Through an inductive process, common themes linking codes to categories emerged. Illustrative quotations were abstracted to ground categories, subcategories and themes. The coded data were then categorized as either facilitator or barrier (or both) to EMRs use. Eventually, recommendations towards improvement in EMRs implementation and use were also categorized and summarized. NVivo ver12 qualitative data analysis tool was used to facilitate the data analysis [56]. The study followed consolidated criteria for reporting qualitative studies (COREQ) guidelines. COREQ comprises 32-item checklist developed to promote explicit and comprehensive reporting of interviews and focus groups (57) [see Additional file 4].

The study followed Guba and Lincoln's criteria of dependability and authenticity [58]. To ensure credibility of the data, the contents of the transcribed data from the focus group discussions were sent to the participants via email to read through and confirm correctness [59]. During the data collection and analysis, the researchers applied reflexivity to avoid biases associated to their own experience on the phenomenon under study by not being actively involved in the discussions (no reactions to participants responses) except guiding the process [60]. To ensure dependability and confirmability, an audit trail was established by keeping a research log of all the activities, developing a data collection record, and clearly recording data analysis procedures. Peer debriefing was also carried out between the FGD sessions and during analysis(58). Transferability was realized through thick descriptions hence making possible applicability of the findings to other settings implementing EMRs [59].

All methods were carried out in accordance with relevant guidelines and regulations.

Results

Facilitators and Barriers to EMRs use

From the qualitative analysis of the FGDs data, we identified six categories: (1) System functionalities, (2) training, (3) technical support, (4) EMRs operation mode, (5) human factors, and (6) infrastructure. Results presented below are organized according to the different themes derived from the qualitative content analysis (Fig. 1).

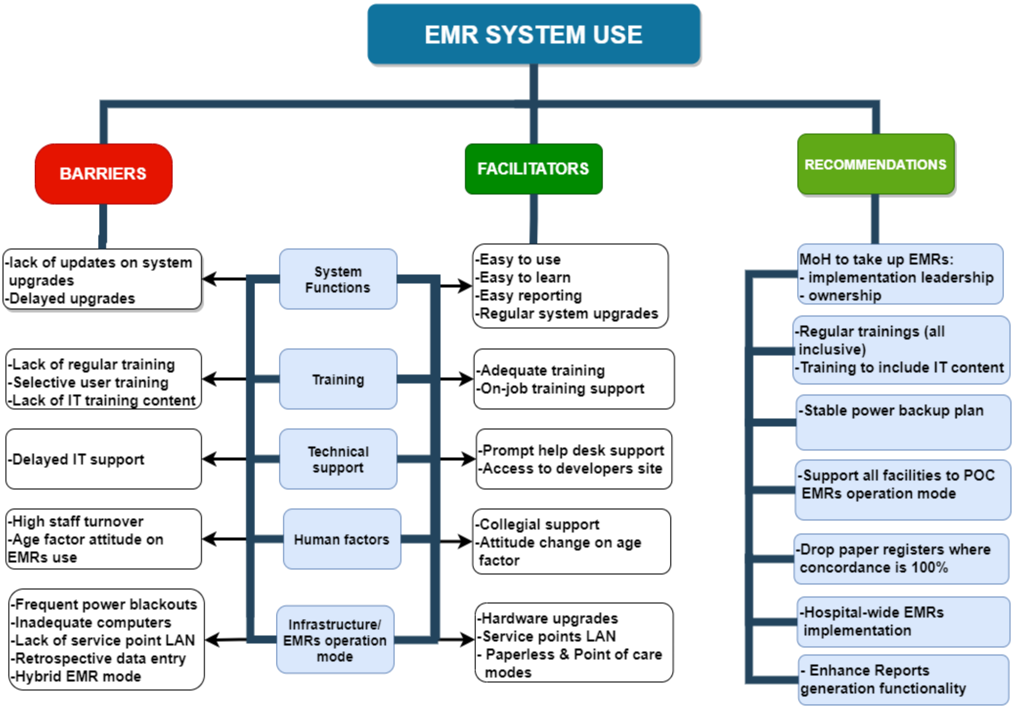

Fig. 1 Summary of codes and categories, and recommendations that emerged from the content analysis

System functions

Some of the KeEMRs functions include patient registration, patient tracing, ordering laboratory tests, drug prescribing etc. The participants generally believed that KeEMRs is loaded with lots of benefits and it is easy to learn and use. Thus, introduction of the EMRs has been of tremendous help in improving patient care. Before the EMRs implementation in the facilities, patient care was marred with delays and frustrations due to misplaced patient files, wasted time in patient files retrieval and clinicians sieving through the patients' files thereby constraining time spent with a patient. Staff suffered burn-out occasioning to 'cooking of data' in an effort to meet the mandatory monthly reporting requirement to the national MoH aggregate system.

G1: "……before we started using the system, we had a lot of challenges like patients' files were missing sometimes. Actually, they were not missing because they were lost, but they were misplaced. So, when a client came, it was very hard to find that file [and as such] the delays were there."

R3: "So after that we started using KenyaEMRs, actually we realised that we are taking a lot of time with the patients, asking patients what is really going on and things are very easy."

Further perceived benefits as a result of introducing the EMRs in care delivery include improved patient data management and consequently monthly routine reporting. This has been made possible by the intuitive functions inherent in the system. These includes easy retrieval of patients who have missed appointments, flagging of patients due for viral load, easy way of defaulter tracing and lost to follow-up patients (LFT), management of indicators such as viral loads, and ability to quickly tell current on care and those in differentiated care model. Furthermore, the EMRs users are able to provide prompt and correct information to social department for patient follow-up.

R7: "Before EMRs, it was difficult to retrieve file if the patient returns after a while - could be after 2 or 3 years. The introduction of EMRs has made it possible to get the patient file by the click of a button (...) we are able to conduct defaulter case management, trace lost to follow-up after they miss clinical visits, pull a list of those patients who have missed appointments, tell the number of days the patients have missed, so we submit the list to the social worker department where they are able to contact the patients so they can come back up to the clinic. The EMR version 17.1.1 is able to give us a list of patients active on care and those who are on differentiated care model."

R1: "Currently what I am appreciating is the management of appointment keeping which we have the calendar in the system which is able to support us as clinical staff. We are able to see how many patients we have booked, what days, so that we do not overbook and under-book on certain days. This has been a very good thing."

Additionally, the system users perceived that the EMRs have greatly helped in timely routine reporting as required by both the Ministry of Health (MoH) and service delivery partners (SDPs) based on very reliable data. Facilities are required by the MoH to submit HIV routine data on six programmatic areas based on a summary reporting tool for HIV referred to as MoH731 by the 15th day of every month. The programmatic areas are (i) HIV Counselling & Testing, (ii) Care and Treatment, (iii) Prevention of Mother to Child Transmission, (iv) Voluntary Male Circumcision, (v) Post-Exposure Prophylaxis, and (vi) Methadone Assisted Therapy. The reports are sent to the national aggregate system, District Health Information

Software Version 2 (DHIS2), maintained by MoH [see Additional file 1]. On the other hand, Data for Accountability Transparency and Impact (DATIM) reports are required by supporting partners such as SDPs on quarterly basis.

Most participants indicated that EMRs' data and paper register records are 100% concordant at the point of care. Concordance refers to the extent to which data contained in paper forms compare to that in the EMRs exuding quality data [61]. Concordance assessment is performed at the facility level by HRIOs. Quality data has gone a long way in supporting decision making at all management levels.

G4:"Without the EMRs, generating reports like the quarterly and the semi-annual reports could be so tedious. We could spend a whole day in a single facility trying to generate a report for a single quarter. Now our MoH 731 and DATIM reports do not keep changing because we have all these data in place."

G5: "The good thing is we had moved to point of care and our concordance is at 100%."

G1: "*I want to appreciate the guys working with KenyaEMRs because at [facility name], we have gone very far. We are even sending our reports direct to DHIS2. Actually, we have no problem with reporting (……). We are using DWAPI to send our data to the national data warehouse. We are using the system to send our MoH 731 report direct to DHIS2 whereby nobody can enter it manually it just goes automatically."*

G3: "*With my experience, KenyaEMRs is a good to use. It is really making our work easier and gives us data quality that we can use for decision making at any level."*

Continuous improvement of the system through regular system upgrades with enhancements of the system's capabilities was perceived a great motivator in the usage of the system. At the same time, the upgrade process was perceived as non-disruptive.

G2: "*I would like to thank the KenyaEMRs developers for continuous upgrading. We came from version 16.0 ……now we are in version 17.1.1 which has come up with various improvements that were missing from the previous versions. For example, we used to have problems generating the LTF patients which initially included other factors…now all that has been sorted."*

U3:"it [upgrades] is done within a few minutes; it is done and then you are able to continue with your work normally."

Nevertheless, despite the frequent enhancements of the EMRs as a result of additional new features, the study participants explained that most of the implementing partners delayed in performing the system upgrades at the facilities. Mostly the system enhancements are as a response to users' demands arising from the need to accomplish their job demands more efficiently through the system. Thus, delays in upgrades may trigger negativity towards the system. This eventually have implications on system use. For example, lack of updates on the EMRs products releases, e.g., the most current - COVID-19 EMR module, was perceived as a usage barrier.

U6: "The upgrading issue solely lies on the implementing partners, how fast they are."

U3: ".....the modules that were added were not many but this one for COVID 19 I am not sure if it is there because the champions have not been told about it....."

Training

Use of the EMRs in care delivery involves masterly of the system. Thus, users need training to effectively use the system. The study participants perceived the initial training offered at the introduction of the system in facilities, supplemented by on-job-training (OJT) for new untrained staff by colleagues, equipped them with relevant skills necessary to use the EMRs.

G6: "We had a very thorough training of three days including clinicians, nurses and all the users."

R1: "As much we are getting new staff, the trained ones are able to do OJT to them. Therefore, it has not been difficult for the new staff coming into the facility."

While some participants perceived the training they received on how to upgrade the EMRs as a good experience, others had contrary experiences and have to depend on SDPs for the upgrade task. In such situations, the system users lack such skills probably due to either inadequate training or SDPs failure to involve them while conducting such tasks as stated below. As mentioned earlier, SDPs are responsible for system implementation and upgrades tasks at the facilities as well as training.

U3: "I have been taken through doing the upgrade, and it is a good experience."

G2: "Our implementing partner has done it (upgrade) in the whole [County name]with the new version, it is done within a few minutes and then you are able to continue with your work normally. However, they do not take time to explain to you what has been added."

G1: ".... they (SDPs) just come do the installation or do the upgrades, then they quit and the team who are back there in the facility, they don't know how to use it."

Consequently, many participants expressed the need to have regular trainings in line with the EMRs upgrades as well as refresher sessions. While on-job-training was perceived a good stop gap measure in equipping untrained users, the participants reported that it was not as comprehensive which hamper morale in using the system. Further, the participants explained that it was unclear who should organize for the (re)trainings occasioned by the regular changes in the EMRs implementation structures by the MoH.

G5: "When the EMR is upgraded, there should be a training for the staffs, all the staffs in the facility. Because you see when it is upgraded some data sets increase and then there is no OJT from the program maybe from [organization name]. So, there should be that regular training to continue giving us morale."

G6: "I don't know who is to organise all these trainings. Because like right now I can say that almost three years we have never seen something like training but everything is changing."

Furthermore, the participants perceived little or lack of IT skills a barrier in executing simple technical or back-end system tasks such as running queries.

G2*: "If something happens, we have to wait for the IT guys to come to our aid on very basic tasks. If at all we had a little background training on the IT, then we can actually perform tasks and make the system up and running and the facility can always continue. So, I think as the champions we should get IT training so that the EMRs can keep on running whether the IT person is around or whether they are not around."*

Finally, lack of updates by MoH/NASCOP on standard operating procedures, guidelines and definitions such as the period (number days/months) that a patient is considered lost to follow (LTF), which is configured in the system, was identified as a barrier to effective use of the system. As such, the differences in definitions could have effect on decisions made based on erroneous data.

U7: "KenyaEMR is defining LTF as those who have missed their appointments up to 90 days while in other cases is defined as those missed appointment 29-30 days. These are some of the discrepancies that should be sorted in the system by the supporting partners or NASCOP have to come up with the clear definition of LTF."

Technical Support

Another important motivator in the use of the EMRs was the prompt technical support provided at two levels. Level 1 is facility level support where a system error or issue is resolved within the facility by the system champions. If the issue is unresolved it is escalated to the SDPs. However, if the supporting partners are unable to resolve the issue, then it is escalated to KHMIS project level (level 2 support). Level 2 support is provided either through the help desk or by system developers depending on its extent. Level 2 support priority is dependent on the EMRs operation mode where paperless mode is given the highest priority. The participants' felt prompt support addressed their needs in time and at the same time added to their technical skills.

Further the participants explained access to developer's website provided information on new system upgrades as well as general support. However, some participants expressed dissatisfaction with IT support within facilities, especially on response time.

U6: ".....but even before the implementing partners had upgraded, I had already seen there is a package in the KeEMRs website supported by [organization name-EMR developers]."

U2: "Actually the challenges that I incur is that there is that error that normally come which takes most of our time. But I want to thank XX from [organization name- EMR developers] who really helped sort that problem. I am also able to sort out some challenges alone without seeking help from [organization name- EMR developers]."

Human factors

Participants reported collegial support as a motivator in the use of the system where untrained colleagues learned to use the system through on-job-training (OJT) by colleagues on need basis. The EMRs were initially perceived as a reserve for the young users but through training and teamwork that changed the attitude and now both the young and old are competently using the system.

R3: "I think everybody in the facility and within the sub-county where I'm working are okay. …I've conducted OJT and they are using the EMRs."

G1: "*So there were bad attitudes towards the system from some of our guys. But actually, after training and having some internal meetings and making sure that the old guys like the facility in charge, she was very old, she was saying she didn't even know how to touch even the mouse, but actually through the encouragement by colleagues, they have changed … right now, everybody likes the system."*

Nevertheless, high staff turnover was perceived by most of the participants as a barrier in the use of the system. Those who came in as replacements mostly lacked the capacity to use the system. This was further compounded by the delays in conducting training. Some participants further explained there existed negative attitudes towards the system by staff who are not part of the HIV program hence dismissing it as preserve for specific staff. As such, they were not ready to use the system.

R7: "The other thing is staff turnover. A staff who is trained on the system could be transferred to another facility. So, we get staff from other facilities who are not trained on the usage of the system. They could be new staff all together."

U5: "As our colleague has said, there has been an attitude that the EMRs is for records personnel only. But I think training should be done not only to the program staffs but should cover all the staff of the facilities....."

Infrastructure and EMRs operation mode

The participants perceived the implementation of the EMRs at all points of care (records, triage, consultation, pharmacy & laboratory) a motivator to system use as it provided seamless flow of patient data in all sections of HIV-care. It also enabled paperless or point of care (POC) EMRs operation modes which meant less work for the system users.

G1: "We are using KeEMRs in the Comprehensive Care Center (CCC) alone...like in HIV testing and counselling. Counsellors are also using it for testing any person that comes into the facility, even the 'boda boda' people (slang for motorcycle riders) and the TB clients. We are also enrolling clients who are HIV positive, even expectant mothers (both positive and non-positive) and children both exposed and non-exposed. It helps us even get the immunization records (....). The system is capturing quite a lot."

However, where the EMRs were deployed for use in HIV care only, the participants perceived this a hindrance to its full acceptance and use as they have to revert to paper records while attending to the patients' other ailments like TB or Malaria.

G2: "However, it is mostly used in the CCC department. So, you find for example, somebody who is at the mother and child health (MCH) clinic will see only CCC clients using the KenyaEMRs and then revert to paper for the other clients."

While some participants reported computer hardware upgrades a boost in ensuring system availability, others felt enough was not done to address breakdowns occasioned by hardware failures. Further, lack of enough computers at every point of care was identified a barrier to EMRs use. In such situations, EMRs operate in RDE mode, where patient data is captured on paper and transferred later to the EMRs. Affected users perceived this as cumbersome arising from the double work hence demotivating use. Furthermore, lack of local area network to link service delivery points for seamless data flow as well as care with other clinics within a facility was cited as a barrier.

R1: "...but recently we have been supported with tablets in the facility, therefore point of care has a tablet where every client (patient) being seen at different delivery points have their details entered in the system."

U3: "..... there are some machines that need to be repaired and some computing part have failed, so I don't know what is the way forward."

G3: "The only challenge is the replacement of hardware and RAM is slow- speed of the machine. Otherwise, if we can improve on that I am ok. If it can be upgraded am somehow ok."

Finally, the most important perceived barrier echoed by participants that cut across nearly all facilities, was lack of appropriate power backup arrangement due to frequent power blackouts. The facilities' inability to have standby power supply force the users of the system to revert to paper documentation and consequently retrospective data entry. This means double/repeated work, culminating to negative attitude towards system use.

G3: "The main challenge I experience in my facility is power surge and during that power surge we do not have proper backups in our facility so you will have to wait till the power is back …. This finds you when you have even 2-3 days' work. Network is also an issue at times….I wish we can have power backup so that we do not depend on electricity only."

U6: "We wish we could get a power backup so that we can move from hybrid to POC because as much as I am getting my reports from EMRs, I do that retrospectively, …."

R5: "We don't have back up, and at the same time we are doing RDE so most of the time we have blackout, like right now we don't have power so the files are pending until the day power will be back even if it is after one month so it's really giving us a hard time."

Recommendations for enhanced EMRs use

The study participants provided vital ideas that would address some of the barriers to EMRs use in order to improve its usage. We present these recommendations under the categories of the relevant EMRs implementation stakeholders responsible to act.

Ministry of Health (MoH)

The participants highly recommended that the MoH, being at the national level, take up KeEMRs ownership and lead in its implementations instead of the funding agencies or partners. This will ensure sustainability when the partners leave. Further, MoH should make clear EMRs implementation structure, with the roles of the county governments (hosts of the EMRs implementations), EMRs developers, and SDPs clearly defined. Lastly, the MoH in consultation with NASCOP, should allow facilities with 100% Routine Data Quality Assurance (RDQA) concordance to drop some of the paper-based registers to avoid duplication of work, to make EMRs role in routine reporting relevant.

Service Delivery Partners (SDPs)

Participants strongly recommended that all facilities be supported in running the EMRs in paperless or POC mode to avoid duplication of work associated with RDE and hybrid modes.

Thus, EMRs implementations should be extended to other points of care not just in HIV clinics. Additionally, proper power backup plan (standby generators or solar power) should as well be put in place to address the power blackout challenges, which can last even 2-3 working days halting usage of the system.

All-inclusive training (for both program & MoH staff) was recommended by almost all the participants to eliminate the negative attitude towards the system in terms of who should use the system. To address the user skills gaps in system usage, regular refresher trainings at the facility level as well as system users' inter-facility forums to share real/practical experiences were recommended. Moreover, the training content should be revised to include basic IT content to enable system champions perform basic back-end staff like running queries at the command prompt.

KHMIS-II project

While the participants expressed satisfaction with the system functionalities, they did however suggest some improvements especially on reports generation. Currently, the system is designed to generate MoH reports such as MoH 731 (a mandatory summary form for collecting facility HIV-indicator data on monthly basis) by a click of a button. Nevertheless, it is quite cumbersome to generate adhoc reports requested by SDPs using the system. The users have to run a number of other reports to gather data for the requested report. As such, they suggested improvement in reports functionality to support adhoc report generation e.g., through use of queries.

Discussion and Conclusions

This study set out to explore the EMRs users' perceptions on factors influencing EMRs use in healthcare facilities. Factors related to (1) system functionalities, (2) training, (3) technical support, (4) human factors, (5) infrastructure, and (6) EMRs operation mode were identified as barriers or facilitators to EMRs use. The study findings did not reveal any relationship between the identified factors and the study facilities performance levels.

The EMRs users perceived EMRs implementation in healthcare facilities to have significantly improved patient data management resulting to quick access to patients' files, high quality data, efficiency in routine reporting, and generally freeing clinician to have more time with the patients. Users perception that EMRs support routine reporting is consistent with Ngugi et al.'s recent study on assessment of HIV data reporting performance by facilities during EMRs implementations in Kenya [36]. Largely, the perception was that all EMRs users were willing to use the system because of the perceived benefits.

EMRs functionalities were perceived adequate in supporting the users perform their tasks. Mostafa et al.'s study in Iran focusing on users' views and attitudes towards the key elements of successful implementation of hospital information system revealed functional system features as the most important critical success factor [12]. Conversely, systems with missing features and poor performance features are a use barrier [12]. However, variations of clinical functionalities in EMRs implementations is not unusual even in developed countries [62]. Our study demonstrates easy to use and learn qualities of the EMRs coupled with regular system upgrades to address missing functionalities can influence users' attitude in using the system as posited in other studies [15,29]. Nonetheless, users reject systems that interfere with the workflow leading to non-use [13].

Several studies emphasize the importance of training as a precursor to information system use regardless of the type [24,25,63]. Indeed, the participants in this study elucidated that training gave them the capacity to use the implemented EMRs, which was in some cases conducted informally (on-job training). Nevertheless, the study identified a skills gap among the participants on the capacity to use some functionalities inherent in the system. In fact, some participants were not even aware of existence of certain system functionalities hence a barrier to optimal use. A case in point, some participants indicated they were unaware of COVID 19 EMRs module released to support in the COVID 19 pandemic statistics at the county level. Holden's study on physicians' challenges on EMRs use emphasizes unfamiliarity with specific features of a system a barrier to using the EMRs fully, which may possibly be attributed to the quality of training (29). Further, Pole, in his study of EMRs implementation in Sri Lanka, states that "*the main secret of success was continuous training of hospital staff over a 2 or 3 year period"* (13). Actually, most of the participants underscored the need for continuous user training especially on the releases of EMRs upgrades. The study also revealed regular trainings that are all inclusive (all staff), can overcome human factor related EMRs use barriers occasioned by high staff turnover and negative attitude.

While results of many studies highlight information system infrastructure challenges such as computers, reliable power supply and networking capabilities, these are however more prevalent in low and medium income countries [9,27,64–67], and as well identified in this study. The findings from this study revealed that the challenge of infrastructure did not only affected EMRs availability but also the mode of its operation. Frequent power blackouts resulted into most facilities using the EMRs in RDE or hybrid modes perceived as barriers due to double work (transfer of paper documentation to EMRs when power supply resumes) [see

Table 1]. The solutions recommended by the study participants including installation of multiple power supplies (e.g. solar, generator, & uninterrupted power supply) and computers at all points of care, are consistent with recommendations by several other studies [28,65,66]. Furthermore, since hospital workflows are interconnected where activity in one department (clinic) affects the other, there is need to implement the EMRs in all departments to avoid the undesired shift from EMRs to paper documentation in the process of patient care.

This study identified a gap in the management of the EMRs implementations. The roles of MoH, County government and SDPs around EMRs implementations and management are unclear. This pose a challenge in the implementations leadership and EMRs ownership. For instance, the participants were unsure who should organise for the trainings as well as replace old and slow computers. Further, some facilities were yet to have their EMRs upgraded to latest release. Ismail et al. highlights the importance of high quality project management and detailed planning for successful IS implementations, institutionalization and user acceptance [68].

A key strength of the study was the inclusion of participants from facilities at different performance levels (best, average, and poor) whose characteristics are across-cutting [see Table 1]. Further, the participants represented all potential users of the system; clinicians, data clerks, HRIOs and IT staff. This ensured that all possible EMRs implementation and views were well represented. The inclusion of the SDPs in the study also added value in understanding their role in EMRs implementations and in supporting use of the EMRs. The interview guide and appropriate probes ensured that all participants were measured using the same standards (i.e., same environment and use of the same interview guide) [69]. The study FGDs forum made the participants realize the need for similar forums in supporting each other for optimal use of the EMRs features leading to better patient data management.

Nevertheless, there were several limitations to this study. First, due to COVID-19 pandemic, FGDs were conducted using an online modality and therefore we did not collect observational data. Secondly, the two focus groups analysed in this study were the only ones formed and thus the concept of saturation was not applicable [49]. However, enough time was spent within the discussions until there was saturation, with no new information shared [49]. Lastly, the study is limited in generalizability of its findings due to the fact that it was conducted in only one country Kenya, and with one type of EMRs, KeEMRs [70]. Rather, we seek transferability to LMICs contexts similar to this study [59]. Limitations notwithstanding, our study offers crucial important information that will be helpful to decision makers at different levels, including: MoH, funding agencies and local implementing partners for successful EMRs implementations.

It is notable that the MoH of Kenya plans to expand the KeEMRs to all other health facilities. Thus, it is expected that the results of this study will shed light on areas that need attention for optimal use of these systems across the country and in similar settings. In particular, power blackout challenges and user training should be given more attention to motivate system usage. Further, the need for clear EMRs implementation structure cannot be over emphasized.

The factors affecting EMRs uptake in resource-constrained settings are complex and need to be better characterized [27]. Thus, continuous assessments are also necessary in order to determine improvements and recurrent of similar issues as well, based on previous assessments. This assessment has also complemented other quantitative analyses related to this study [30].

Abbreviations

ADT	Antiretroviral Dispensing Tool
API	Application Interface
CCC	Comprehensive Care Centre
CDC	Centres for Disease Control and prevention
COREQ	Consolidated Criteria for Reporting Qualitative studies
DATIM	Data for Accountability Transparency and Impact
DHIS2	District Health Information Software Version 2
DWAPI	Data Warehouse Application Interface
EHR	Electronic Health Record
EMR	Electronic Medical Records
ETS	Text Message for Adherence
FBOs	Faith Based Organizations
FGD	Focused Group Discussion
HRIOs	Health Records Information Officers
HTML	Hyper Text Mark Up Language
HTS	HIV Testing and Counselling
IL	Interoperability Layer
IS	Information System
IT	Information Technology
KeEMRs	KenyaEMR system
KEPH	Kenya Essential Package for Health
LFT	Lost to Follow Up
LMIC	Low- and Medium-Income Countries

MCH	Mother and Child Health
MoH	Ministry of Health
NASCOP	National AIDS and STI Control Programme
NDW	National Data Warehouse
NGO	Non-Governmental Organization
OJT	On-Job-Training
PEPFAR	President's Emergency Plan for AIDS Relief
POC	Point of Care
RDE	Retrospective Data Entry
RDQA	Routine Data Quality Assurance
SDPs	Service Delivery Partners
STIs	Sexually Transmitted Infections
TB	Tuberculosis
WHO	World Health Organization

Declarations

Ethical Approval and Consent to participate

The study was approved by the Institutional Review and Ethics Committee at Moi University, Eldoret (MU/MTRH-IREC approval Number FAN:0003348). The Ministry of Health (MoH) also approved the study. Permission to collect data was obtained from County Directors of Health of each county as well as Service Delivery Partners (SDPs) responsible for EMRs implementations and HIV data at the facility level. Participants were informed that participation in the focus group was voluntary and they were free to leave the discussion at any time. Privacy and confidentiality were ensured by not revealing the identities of the participants, nor the facilities and SDPs organizations that took part in the study.

Consent for Publication

Not applicable.

Availability of Data and Materials

The data analyzed in this study is in the custody of the researchers and is available on request.

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Competing Interests

All authors report no competing interests to declare.

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Authors' Contribution

P.N. and A.B. conducted the focused group discussions. P.N transcribed the recorded discussions. P.N. and A.B. participated in content analysis and derivation of relevant themes. M.W participated in the validation of the study process. All authors provided critical feedback and helped shape the manuscript.

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