A Systems Engineering Perspective on eHealth Implementations' Efficiency and Effectiveness: A Case Study involving suppliers

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Abstract.
The implementation of eHealth systems in South Africa did not generate the expected output. This paper investigates the impact of system engineering management (SEM) practices on the efficiency and effectiveness of eHealth system in two South African institutions in Gauteng and the Western Cape Province, respectively. The System Engineering Capability Model (SECM) is combined with the four major outcomes for eHealth systems as concepts in designing open ended questions for narrative enquiry adressing efficiency and effectiveness as part in the context of a result based development framework to collect stories from multidisciplinary teams in healthcare having varying knowledge of SEM. Three eHealth projects implemented in the two facilities show indications that the efficiency of eHealth projects is directly influenced by how well SEM is implemented. For this study, the environment capability category was the strongest contributor to efficiency for two projects and the technical capability category was the highest for the other one. Two of the eHealth projects were in the pilot phase and demonstrated low system outcome levels; however the third project in the operations phase showed a better system outcome level despite its low capability maturity level.

Introduction

Like many other African nations, the burden of disease is a major challenge in South Africa (WHO, 2010). The South African National Department of Health has launched initiatives to implement eHealth systems in order to improve the quality, access and efficacy of healthcare services for all citizens (Department of Health, 2012).

As defined by WHO (2010), eHealth is the use of Information and Communications Technologies (ICT) in healthcare. Amongst other, eHealth systems comprises of Electronic Medical Records (EMR), Telemedicine, mHealth and Genomic Medicine (DeNardis, 2011). Some of the expected benefits of eHealth systems are to extend geographic access, to improve diagnosis and treatment, to improve data management, to streamline financial transactions, and to mitigate fraud and abuse (Lewis, Synowiec, Lagomarsino and Schweitzer, 2012).

There are different opinions on the success of eHealth projects: some people believe that eHealth projects could not proceed beyond the pilot phase, and others comment on the poor ICT infrastructure of the country as a contributing factor in the failure of eHealth projects; yet, another is a lack of policy and guidance for eHealth systems integration and coordination, while others question the organization and workforce readiness to manage the required changes (Department of Health, 2012; Gulube & Wynchank, 2001; Mars & Seebregts, 2008).

According to WHO and ITU (2012) the four common stakeholders in the development of a national eHealth vision are:

- The broader stakeholders and general public.
- Key influencers.
- Engaged stakeholder.
- Decision makers.

These visions should guide eHealth system and product development processes for the stakeholders requirements analysis that forms part of the systems engineering process. The systems engineering process is applicable throughout the system life cycle, which includes the entire spectrum of activities for a given system, commencing with the identification of need and extending through the system design and development, production, utilization and maintenance and support, and retirement and disposal (Blanchard, 2008:15). During earlier phases of development, the systems engineering process considers the impact of later system lifecycle phases (production/construction, utilization, maintenance, support and disposal) on the final system (Blanchard, 2008:56).

Objectives

The preliminary investigation for this study suggests that some of the challenges with eHealth system implementations in South Africa are (Gulube & Wynchank, 2001; Mars & Seebregts, 2008):

- Lack of a national eHealth strategy.
- Limited capacity or capability within the public sector to implement eHealth.
- High connectivity price.
- Absence of national master patient index.
- Lack of coordination and interoperability.

This study intends to contribute to the debate on the implementation of eHealth systems in South Africa, which is perceived as unsuccessful by many stakeholders. The associated research questions are:

- Does a relationship exist between eHealth system efficiency and the execution of system engineering management principles?
- Do system engineering management practices have an impact on the implementation outcome of eHealth systems?

By answering the above research questions, the objective of this study is to determine how well system engineering management practices are applied in the implementation of eHealth systems in South Africa. Further, the study assesses the influence of effective execution of system engineering management practices on successful implementation of eHealth systems. The related objectives are:

- To determine the maturity level of system engineering management practices during eHealth systems implementation.
- To assess the influence of effective execution of system engineering management principles on the implementation outcomes of eHealth systems.

Concept for eHealth Systems Implementation

In evaluating healthcare technologies the primary focus should be the ability of technologies to increase throughput, namely an organization's ability to achieve its goals, and the ease of implementing accompanying process changes (Goldratt & Cox, 2004). The Theory of Constraints (TOC) argues that the system can only be improved by elevating the system constraint through strengthening the weakest link (Goldratt & Cox, 2004). These constraints can be physical, policy, operational procedure, or management policy constraints (Goldratt & Cox, 2004). Broens, Veld, Vollenbroek-Hutten, Hermens, Halteren & Nieuwenhuis (2007) classify the success determinants of telemedicine implementation into five major categories:

- Technology.
- Acceptance.
- Finance.
- Organization.
- Policy and legislation.

The above five categories have similarities with the Weeks (2012) attributes of healthcare services-support system described in the healthcare services-science model. The Technology and Acceptance determinants were the most reported of the identified determinants in the literature survey by Broens et al. (2007).

Based on the observations of an eHealth pilot project in Sri Lanka, Sudhahar, Vatsalan, Wijethilake, Wickramasinghe, Arunathilake, Chapman & Seneviratna (2010) concluded that eSolution is a promising solution that facilitates health consultation in rural communities of developing countries with less cost, minimum travel time and short traveling distances. Broens et al. (2007) noted that the focus of success determinants shifts from technology acceptance to financial and organizational factors as the project progresses from the pilot phase to a large-scale implementation phase. As a result, to determine the financial gain of the above mentioned eHealth system, it is critical to consider the large-scale system implementation cost of operations, maintenance and support phases.

In South Africa, the barriers identified during the implementation of eHealth are (Mars, 2012; Ruxwana *et al.*, 2010):

- Lack of ICT skill and knowledge.
- Unreliable equipment and Internet connection.
- Inadequate technical support and maintenance.
- Lack of adequate computer and communication devices.
- High cost of Internet bandwidth.

Monda et al. (2012) identified ensuring the quality of data stored in the EMR system as another eHealth implementation challenge. Lewis et al. (2012) identified other key impediments for most eHealth systems implementation programs are:

- Lack of necessary infrastructure.
- Initial and on-going cost of technology.
- Lack of familiarity with technology.
- Lack of cultural appropriateness.
- Lack of incentives to adopt new tools.

System Engineering Approach for Evaluating eHealth Systems

Efficiency in engineering is a measure ratio between the output and input of a system. An estimate of system or product efficiency can be acquired by measuring the capability maturity of the system engineering process that creates it (Elm, Goldenson, El Emam, Donatelli & Neisa, 2007) and is the basis for the efficiency parameter shown in Figure 1. Clearly defined goals and objectives of an organization is the first step of capability development (Blanchard, 2008). The System Engineering Capability Model (SECM) has focus areas that fall into the following three basic categories (Blanchard, 2008:404):

- Technical.
- Management.
- Environment.

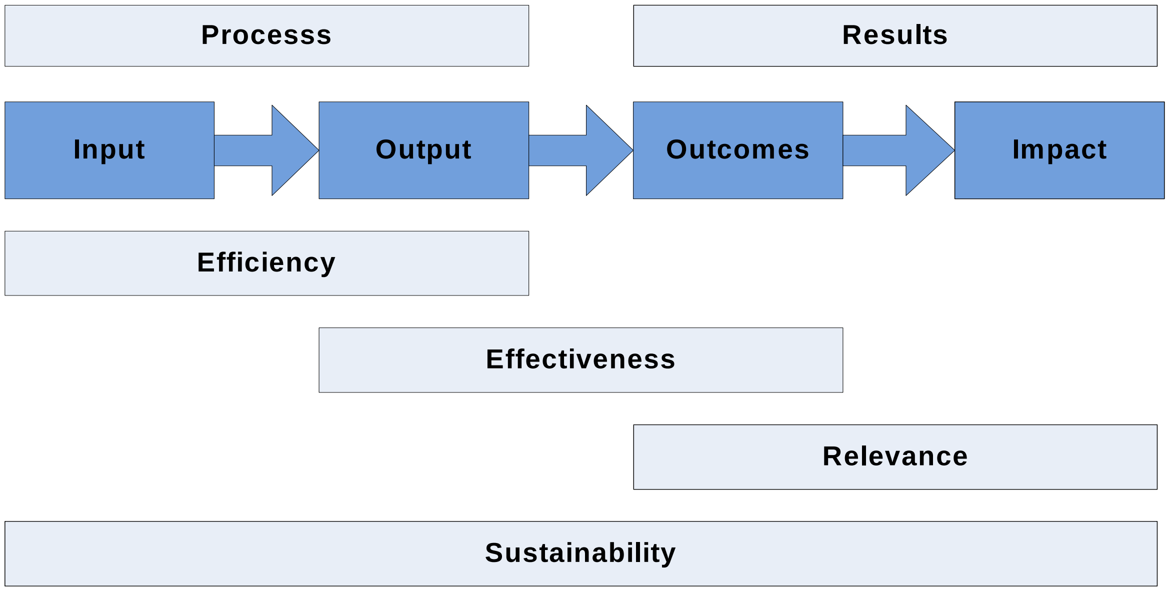

Figure 1: Result-based evaluation of development intervention (Nagel & Remmelzwaal 2010 in Erasmus, Poluta & Weeks, 2012:26)

The Technical category focuses on technical aspects of systems engineering (Blanchard, 2008:403). The Management category deals with cost-effective execution of the systems engineering processes through (GEIA, 2002):

- Planning.
- Control.
- Information management.

The Environment category supports the Technical and Management Focus Areas by enabling sustainability and ensuring the alignment of business goals with technology and process development processes (GEIA, 2002).

The levels of maturity ranging from 0-5, namely initial, performed, managed, defined, measured and optimized respectively, are used to measure the capability levels of the three system engineering management categories (GEIA, 2002). The criteria for each capability level are well defined and indicated with an integer number. A decimal number measurement, e.g. 2.7, is interpreted as implementing all the criteria of maturity level 2 and 70% of the criteria for level 3.

A system is sustainable when the combination of the system's input, output, outcome and impact is meeting favorable criteria as shown in the model in Figure 1 (Nagel & Remmelzwaal (2010) in Erasmus, Poluta & Weeks, 2012:26). System efficiency is achieved by a comprehensive process that is capable of producing the intended output from the given inputs. By measuring this comprehensive process and the organizational capability executing it, one can get an estimate of system efficiency. The Systems Engineering Capability Model (SECM) is an operative tool to conduct assessment of system engineering capability (GEIA, 2002). In this study, the SECM is adapted for the concept method to measure the efficiency of eHealth systems. The four major eHealth systems outcomes: System outcome, Users/Providers outcome, Management outcome, and Patient outcome, as categorized by Gruber, Cummings, Leblanc & Smith (2009) are adapted to measure the eHealth systems outcomes in this study. These outcomes are expected to improve the efficiency and effectiveness of healthcare services (Gruber et al., 2009). The system effectiveness measures the achievement of the general objectives of the introduced system or the system outcome as depicted in the result-based model in Figure 1. The other key determinant of system sustainability is the relevance of the system, which is the result of system impact based on the system outcome as indicated in the Figure 1 below. In this paper only the system or product efficiency and effectiveness are treated in the context of the sustainability definition shown in Figure 1.

Research Methodology

The number of companies in the South African eHealth industry is less than the required sample size to apply more proven research methodologies and statistical techniques delivering results with a high confidence level. Similarly, the number of people willing to take a survey from this industry is low.

The two broad categories of research methodologies are qualitative research and quantitative research (Leedy & Ormrod, 2010). It is believed that research studies could be enhanced by combining both quantitative and qualitative methods (Leedy & Ormrod, 2010). The triangulation approach combines qualitative and quantitative research methodologies to test propositions (Lee, 2012).

The researchers assume that most people in the healthcare services industry have limited technical knowledge and understanding of system engineering processes. As a result, a narrative enquiry with open ended guiding questions was used to collect data from technology suppliers within the healthcare environment. The research requires both a qualitative (interpretations) and quantitative (statistical description) research approach to analyze data and to report the findings that results from a mixed-method or triangulation research as shown in Figure 2. The researchers derived the quantitative data from the qualitative data by filling out SECM evaluation sheets based on the collected narratives.

Because of the sensitivity of healthcare information, accidental sampling was used to select a sample of eHealth projects based on the accessibility of research data. The eHealth-systems technology suppliers are summarized in the Table 1.

Table 1: eHealth-systems technology suppliers

No	**Health Facility**	**Location**	**eHealth System**	**Technology Supplier**
1	Hospital	Western Cape	Enterprise Content Management (ECM)	ECM Provider
2	Clinic	Gauteng	Electronic Medical Record (EMR)	EMR Provider
			Mobile Application	Mobile Solution Supplier

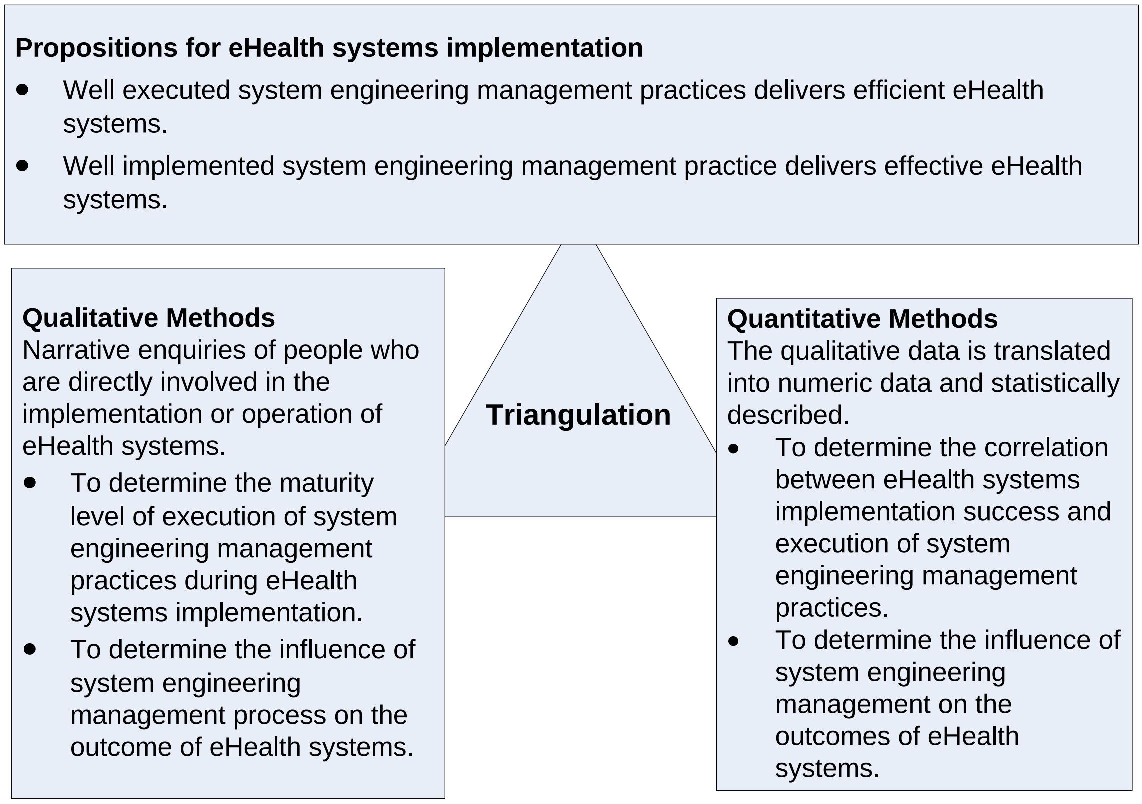

Figure 2: Research approach to investigate efficiency and effectiveness of eHealth systems

Results

The results of the investigation are discussed along the lines of the two objectives and corresponding propositions reported in the structure of the SECM model focus areas.

SEM practices during eHealth systems implementation

This section evaluates objective 1, to determine the maturity level of system engineering management practices during eHealth systems implementation, by analyzing the stories obtained during the interviews for emerging themes through the three focus area categories of system engineering and management tasks of the SECM, namely: technical, management and environment outputs.

Technical Outputs:

Requirements, defining solutions, verification and validation. The three technology suppliers seem to accept the importance of clearly defined requirements in the implementation of eHealth systems for their easy adoption. However, the approaches used to incorporate the user requirements appeared to be different for each of the three companies. The development of a mobile solution was a co-creation process with the client, whereas the supplier of the EMR system gathered the system requirements from past experience in the healthcare industry and the data captured and analyzed by the EMR system over time. On the other hand, the supplier of the Electronic Content Management (ECM) system could not gather the comprehensive needs of the clients, so most of the requirements were set based on the supplier’s observations.

Generally, one of the major gaps observed in the process of electronic systems introduction into the public health sectors was the limited engagement of stakeholders in the design and implementation process. Erasmus & Doeben-Henisch (2011a) indicates that the system engineering process starts from the problem of stakeholders that are a main actor of the system engineering process. Feedback and verification are important elements of system engineering management to define technical solutions (GEIA, 2002). It was observed that there was no available platform for EMR to receive feedback from its users. Blanchard (2008:21) states: "the system engineering process is continuous, iterative and incorporates the necessary feedback provisions to ensure convergence". The limited involvement of stakeholders and lack of incorporating feedback were the two key observed weaknesses of the solution defining process for the EMR system.

The respondents did not mention anything explicitly on how validation was addressed in the projects.

Technology assessment and selection. The applicable health facilities appeared to have appointed the ECM and EMR technology providers without considering a standard procedure for the technology assessment and selection process. The lack of clearly defined requirements and deliverables, as well as the informal invitation of technology suppliers to participate in the projects were some of the weaknesses noticed in the assessment and selection process of the eHealth systems.

Integration. All technology suppliers explained that their systems were capable of integrating with any legacy systems in real time or in a secured file sharing method. The technology and the standards are in place to ensure technical integration. The major challenge of systems integration was related to the management of the integration work as discussed by one of the technology suppliers. Integration requires an interaction through interfaces. Erasmus & Doeben-Henisch (2011b) discussed the three different interface types, namely the user interface, the environment interface and the system interface. "The user interface represents the required behavior of a user (which is not guaranteed), the environment interface represents the expected behavior of an environment (which is based on estimates), and the system interface represents the required behavior of the intended system, which is guaranteed if qualified" (Erasmus & Doeben-Henisch, 2011b). The interaction between the users and the system was limited because of insufficient training. The environment interface was also affected because of inaccurate assumption of the actual environment within the health facility. The respondents appeared to indicate that the user interface and the environment interface were two of the major problems in the integration of electronic solutions.

In summary, Department of Health (2012) put stakeholders' engagement as one of the priorities of eHealth strategies, but it is observed that that the involvement of interdisciplinary stakeholders in the design process was limited. Erasmus & Doeben-Henisch (2011b) discussed the significant role of interdisciplinary teams in system design to consider the life cycle needs of a system. According to the respondents, it seemed that the involvement of interdisciplinary teams was one of the missing pieces of the eHealth systems implementation. Ludwick & Doucette (2009) discussed the importance of an interdisciplinary approach in the implementation of eHealth system.

Management Outputs:

Change management. The possible causes of resistance to the adoption of eHealth systems as described by the respondents include:

- Lack of knowledge to use the technology.
- Lack of technical support to users.
- High work load.
- Fear of losing control over the benefits.
- Lack of strong leadership.

The possible cause of resistance from technology users were addressed through continuous training, leadership involvement, strong support to users, continuous communications through meetings and discussions, and dedicated data capturers other than clinicians. Ludwick & Doucette (2009) discusses the importance of proactive management of staff resistance to change. Continuous communication and training appeared to be important agents of the change management process. Mengistu (2010) mentioned that cultural appropriateness of a new electronic tool could be one of the possible impediments to the success of eHealth systems implementation. Similarly, it appears that the difference in the organizational culture between the private and public health sectors made the adoption of the EMR system difficult in the public health sector. Blanchard (2008) described early planning as a key to successful implementation of any programme. The lack of project deliverables for the ECM system was an indication of poor planning. Therefore, unable to plan the technical, management and environment aspect of systems as early as possible significantly degrade the implementation success of a system.

Risk management. The major risks described by the technology suppliers were related to project management including the weakness of project leadership, the unstructured involvement of multiple key players, informal involvement of technology suppliers and the dependency of the project on other people or projects' performance. The respondents further explained that the technical risks related to the technology had been mitigated successfully through redundancy and continuous improvement of technology. However, the project management risks were not easy to mitigate. Interestingly, a lack of ICT skills has not been mentioned as a concern by the technology suppliers that all appeared to believe that exposing users to the technology resolved the skill shortage challenges. Ludwick & Doucette (2009) mention that strong leadership, using project management techniques, establishing standards and training staff help to insulate the project from possible risks that can prevent implementation success. But the lack of some of these attributes to insulate the eHealth systems' implementation risks in the implementation of eHealth systems appeared to maximize the risk for failure. Smith & Merritt (2002) discuss that well designed risk management commences early in the project and proceeds as a monitor and follow-up effort throughout the project.

Data Management. The technology providers performed well to ensure the security of data and to define the data source, but the effort to ensure the quality of data was limited. Monda et al. (2012) states that the promised improved and efficient healthcare service delivery cannot be achieved without a high level of data quality.

Environment Output:

Competency. The technology suppliers used different approaches to deliver training to the technology users. It appeared that most of the technology users, except the nursing and older staff, were easily trainable when exposed to electronic systems. It was believed that training could address the skill shortage problem during the introduction of the EMR solution. The Department of Defense (2001) indicated that time and cost of training is a measure of system effectiveness. The eHealth systems studied in this research appeared to be effective in terms of training as users can learn the systems in a short period of time.

Technology and Organizational Support. The technology suppliers provided well-structured technical support. One of the concerns discussed by the ECM technology supplier was the absence of the technical IT team in the health facility, and the other concern mentioned by one of the clinical staff members was the absence of formal technical support agreements between the health facility and the technology providers.

Influence of SEM principles on implementation outcomes

The assessment of objective 2, to assess the influence of effective execution of system engineering management principles on the implementation outcomes of eHealth systems, is done by analyzing the stories obtained during the interviews for emerging themes through the use of the identified categories for the outcomes of Clinical Information Systems (CIS) implementation (Gruber et al. 2009):

- System outcomes.
- User outcomes.
- Management outcomes.
- Patient outcomes.

System outcomes refer to the results of a CIS implementation such as documentation. User outcomes refer to the end-users of a CIS who have interaction with the system in the course of providing patient care. Management outcomes refer to aspects of a CIS that assist in (Gruber et al. 2009):

- Managerial decision-making.
- Operational management,
- Meeting government regulations.
- Benchmarking organizational performance.
- Funding decisions within and external to the organization.

"Patient outcomes refer to those aspects of a CIS that are directly affected by the system's implementation for patients" (Gruber et al. 2009).

System and User Outcomes. All respondents from the technology suppliers mentioned that the technologies are easy to learn and use; moreover the technologies enable easy access to patient records. The reduction of work burden was one of the benefits of mobile application as indicated by the respondent from the Mobile solutions supplier.

Management and Patient Outcomes. The availability of patient information for informed decision-making was one of the major contributions of the electronic system. The respondents also claimed that building patient risk profiles by linking public health data to the patient record, removal of patients waiting time, removal of missing patient files, workforce management and early treatment of patients were some of the benefits to patients and management. The three major benefits of the ECM solutions to patients and management as described by the response from ECM supplier are:

- The patient centric benefit: the reduction of patients waiting time from 3.5 hours to almost nothing.
- The removal of missing file problem: the introduction of the ECM system benefited patients and management by removing the problem of missing patient files and other administrative records.
- Removal of legal fines: hospitals face legal fines for missing patients' medical records, but the ECM solution brought a remedy to that problem.

The ECM system was already operational and its outcome appeared to be better than the two other systems in the pilot phase (EMR and Mobile systems), but the better outcome of the ECM solution was not confirmed by the end-users of the system.

Descriptive Statistical Analysis. In Figure 3, the Mobile system demonstrated higher system engineering capability level than the EMR and ECM systems.

As shown in Figure 3, a high level of the system output for the mobile system does not correlate well with a high level of system outcome. The system output is the result of systems engineering process and appropriate SEM, hence executing system engineering successfully contributes to the output of eHealth systems but may not necessarily ensure success to the eHealth system outcome.

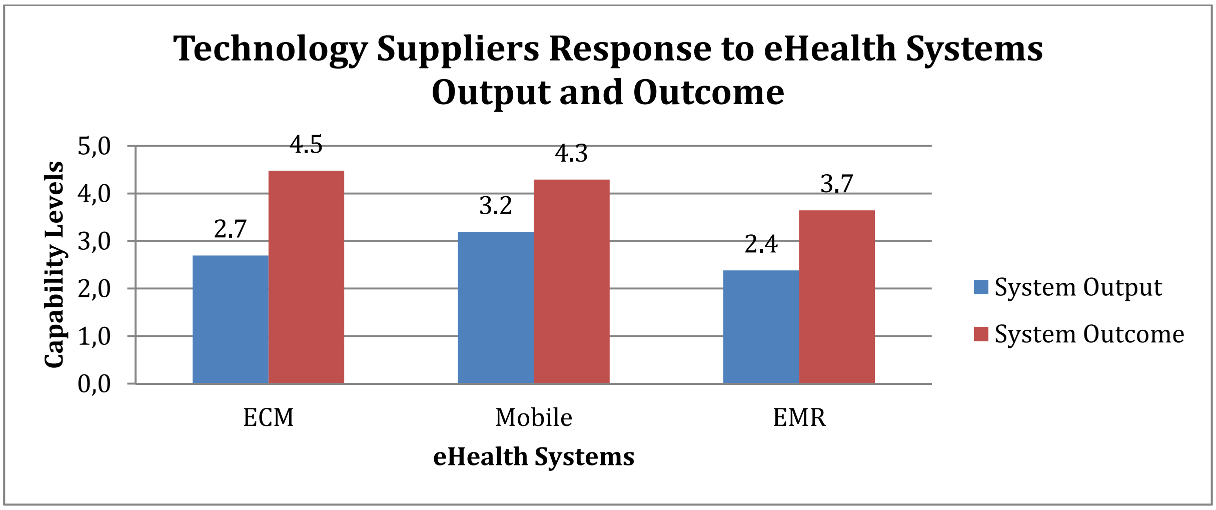

Figure 3: Technology suppliers' response to system engineering capability of eHealth systems output and outcome

The technology suppliers' response indicated that the mobile system demonstrated a higher system engineering capability level in the technical and management categories than ECM and EMR systems (Figure 4). This indicates that the mobile system was well defined and some quantitative measures were also established. For the management category, the mobile system was planned, tracked and verified but some of its processes were not well defined. Although all the eHealth systems showed higher system engineering capability in the environment category, level 3 and higher, the ECM demonstrated the best system engineering capability in the environment category compared to the other two eHealth systems as shown in Figure 4. This indicates that the environment output of the ECM system was well defined and quantitative controls were established to measure part of its processes. The quality of the ECM system outcome was above average in all the system, user, management and patient outcomes as shown in Figure 5. Although the mobile system showed high output, the ECM system demonstrated better outcomes, see Figure 3. This indicated that the output performance was not the only factor to influence the outcome performance. However, further study with a bigger set of sample data needs to be done in the future to prove the true relationship between the execution of SEM and system outcome.

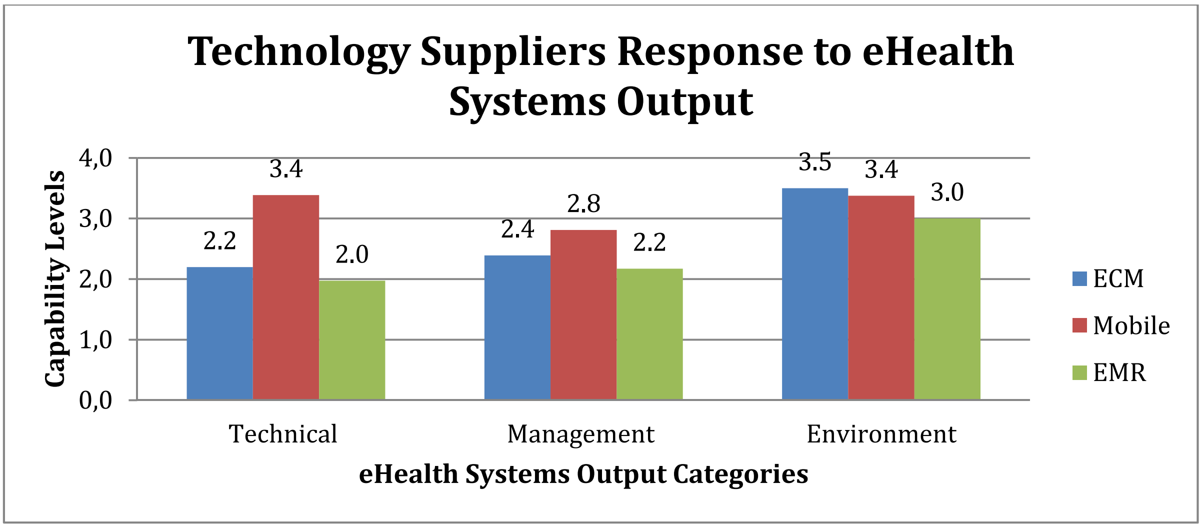

Figure 4: Technology Suppliers Response to the Output of eHealth Systems

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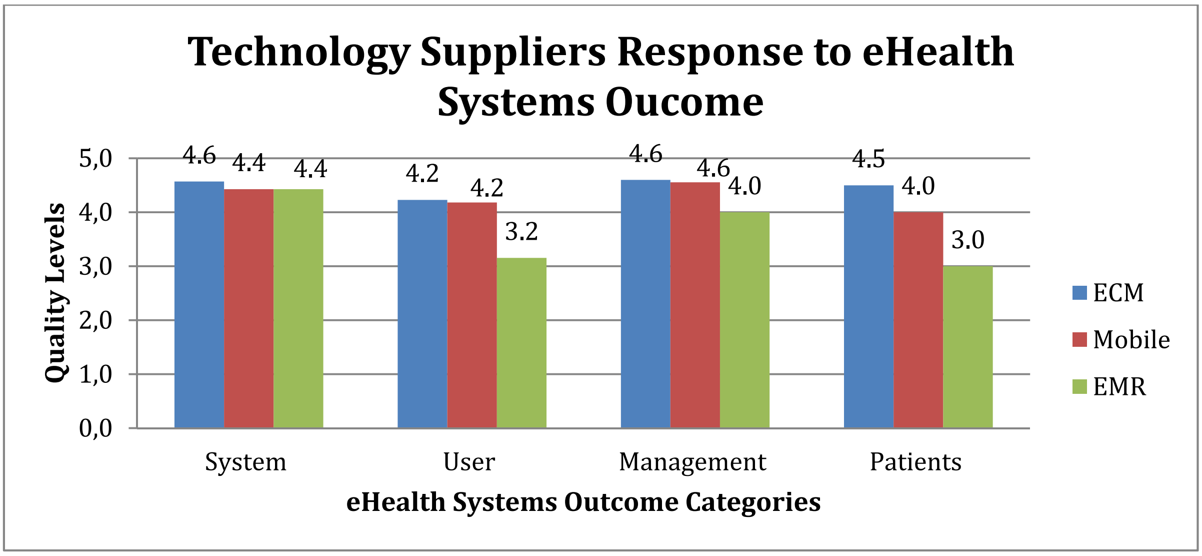

Figure 5: Technology Suppliers Response to the Outcomes of eHealth Systems

Conclusions and recommendations

The study found the Mobile and ECM systems implementations implicitly used more SEM practices than the EMR system implementation based on the descriptions from the suppliers' points of view. Part of SEM practices is the involvement of stakeholders and it is also recommended for eHealth projects (Department of Health, 2012). The qualitative study indicated that by not engaging all stakeholders in the design and implementation processes was the major challenge in the technical category for all three eHealth systems and this is a risk for project success (Ruxwana *et al.*, 2010).

The management category was challenged by the lack of strong leadership, absence of clear deliverables, poor change management approach, and data quality problems. From the qualitative study, it appeared that the management category was the major factor that limited the success of all three eHealth systems. However the quantitative analysis revealed a possible systems engineering capability shortage in the technical category of the ECM and EMR systems that is support in the lack of systems engineering discipline knowledge and the application thereof. This indicates the absence of practices in the system engineering management category could be the reason for failures of most eHealth systems' implementations in South Africa and future studies are needed to confirm this conclusively.

Both the qualitative and quantitative analyses indicated high capability levels in the environment category for the three studied eHealth systems. The challenges in the environment category were related to infrastructure capacity and absence of technical IT teams in health facilities. The study showed that executing system engineering management practices produce eHealth systems with better output.

The first proposition that efficient eHealth systems are achieved through system engineering process management practice appeared to be supported by the evidence gathered for the SECM adapted part of the model in the course of carrying out this research study. It can be concluded that a positive correlation exists between the implementation of efficient eHealth systems and execution of system engineering management practices in this case study.

Answering the second research question by measuring the eHealth systems outcome was a challenge as the mobile and EMR systems were both in pilot phase. Although the Mobile application demonstrated a high system engineering capability level, its outcomes were not as good as that of the ECM system. The quantitative analysis indicated a positive correlation between the eHealth system outputs and the system outcomes but it does not necessarily indicate that a high system output guarantees a high system outcome as demonstrated by the high level for the system output of the mobile system that did not guarantee a high level for the system outcome. The evidence suggests that successful execution of SEM practices directly contributes to the system effectiveness but it might not ensure success of the eHealth systems implementation outcomes. The mobile and ECM systems require a follow-up study when they are in the operations phase in order to assess the correlation strength between the effective execution of SEM practices and the implementation outcomes of the eHealth systems. Moreover, future studies should also address the end-users of the systems in order to understand their perceptions.

The second proposition, well-implemented system engineering management practices ensures the success of eHealth system outcomes, is not proven to be necessarily either true or false, but the data analysis demonstrated a positive correlation between eHealth system outcomes and system engineering management practices.

Eventually, two of the three eHealth projects investigated in this research study are currently in the pilot phase, they have not yet been proven to be effective. Although future research with a bigger sample size should confirm the efficiency and effectiveness of eHealth systems, the data analyzed in this research study gives some indication that the Mobile system is efficient and the ECM system is effective from the implementers' points of view.

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Biography

Getnet Bogale Fanta worked for 7 years in telecommunications and supply chain management sectors on Management Information Systems for local and international organizations. He received the B.Sc. degree in Electrical Engineering from Addis Ababa University and a graduated with Master Degree in Engineering Management from University of Pretoria. His interest is the application of systems engineering to ensure sustainability of projects; especially, to ICT projects in the healthcare sector.

Louwrence Erasmus worked for more than 20 years in academia, national and international industries on multi-disciplinary projects and is a Principal Systems Engineer at the CSIR since 2013. He graduated from the Potchefstroom University with the B.Sc., B.Eng., and M.Sc. degrees in 1989, 1991 and 1993 and awarded the Ph.D. degree in 2008 from North West University, Potchefstroom. He is a registered professional engineer with ECSA and a senior member of IEEE and SAIEE. His interest is formal structures using constructivist philosophy of science and their practical implications in the practice of systems engineering.