University of Pretoria

Dynamics of Technology Acceptance to the Sustainability of eHealth Systems in Resource Constrained Environments

Getnet Bogale Fanta

PhD Engineering Management

Supervisor: Prof. Leon Pretorius
Department Engineering and Technology Management
Faculty of Engineering, the Built Environment and Information Technology
University of Pretoria
Pretoria
South Africa

Co-supervisor: Dr. Louwrence Erasmus
Department Engineering and Technology Management
Faculty of Engineering, the Built Environment and Information Technology
University of Pretoria
Pretoria
South Africa

October 2019

ABSTRACT

Healthcare in developing countries is confronted with a shortage of skilled healthcare workforce, medical errors, inequity and inefficient healthcare service delivery. Although significant progress has been made towards health-related Millennium Development Goals (MDGs) in the past years, developing countries still lag in achieving these targets. Innovative ways of solving healthcare problems through Information and communication technology (ICT) can improve the efficiency, effectiveness, access and quality of the healthcare system. Despite highly anticipated benefits of eHealth system to improve the efficiency of healthcare delivery, the healthcare had barely begun to take advantage of ICT mainly in a resource-constrained environment. The implementation of eHealth systems in developing countries could not proceed beyond the pilot phase to demonstrate sustainability in a large-scale rollout.

The majority of stakeholders recognized the importance of eHealth in providing support for the management of patient records; hence many developing countries embarked into implementing donor-driven eHealth projects. However, the desired outcomes could not be achieved essentially in developing countries because of issues such as high costs, underdeveloped infrastructure, and lack of technical expertise. Several eHealth pilot projects in developing countries failed to progress to full-scale implementation due to rejection by the end-users and poor settings of a system environment. The limitations of infrastructure and resources, lack of funding and shortage of trained workforces are some of the barriers to the wide-scale adoption and use of eHealth systems.

The ecosystem of sustainable eHealth implementation covers wider ranges of factors in technological, social, organizational and economic dimensions to promote the meaningful and sustained use of information in healthcare settings. However, most eHealth implementation frameworks are linearly modelled without capturing the complex relationship among each element of the ecosystem to ensure sustainable eHealth implementations. The sustained use of eHealth is influenced by the dynamic and nonlinear interactions of eHealth success factors that create complexity in the implementation of eHealth systems.

The evidence of eHealth implementation in the resource-constrained settings indicated that donor-driven eHealth systems struggled to progress beyond the pilot phase to demonstrate sustainability. As a result, there were several eHealth pilot projects in the developing world; sometimes referred to as “pilotitis” of the eHealth systems. Furthermore, eHealth technologies that showed some level of success in the developed world could not replicate the same result in developing countries due to the differences in the system environment.

The general research problem in this thesis focuses on how factors of eHealth implementation interplay to influence technology and information use to ensure the long-term sustainability of eHealth in resource-constrained settings. Systems thinking and system dynamics modelling method were used to handle complexity in the implementation of eHealth. Moreover, sustainability theory, technology acceptance model (TAM) and IS success models were used to develop a system dynamics model of sustainable eHealth implementation. The socio-technical, techno-organizational and techno-economic factors of sustainable eHealth systems are discussed to address the research objectives. The system dynamics simulation model of sustainable eHealth implementation is developed, verified, validated and tested.

This applied research study focused on addressing the problems of sustainable eHealth systems implementation in resource-constrained environments. The model-based theory building research study followed in this thesis aimed at enhancing the understanding of sustainable eHealth implementation in a resource-constrained environment to maximize the acceptance of eHealth by the end-users.

The dependency of sustainable eHealth implementation on the context and settings of healthcare organization supported the ontological assumption of the constructivist paradigm. Ontological assumption argued that reality was limited to the context, space, time and individuals in a given situation. The epistemological assumption of the research agreed with the subjectivity of knowledge and social constructionism. Both the ontological and epistemological assumptions of this research study supported the position of the constructivist research paradigm.

Methodologically, this study mainly applies qualitative research methodology which is common in the interpretive approach. Healthcare is recognised as a complex system. Hence, systems thinking and system dynamics modelling approach was used to handle the complexity associated with the implementation of eHealth systems within healthcare organizations. A qualitative case study, descriptive quantitative research design and systems dynamics simulation models were used to address the research questions.

Structured and semi-structured questionnaires were used to elicit information from purposefully sampled eHMIS and SmartCare health facilities in Ethiopia. All interview data from the end-users were analysed and described statistically. Field notes, document review, interview and focus group discussion data were analysed using ATLAS.ti software. Vensim DSS Version 6.3D was used to model and simulate the system dynamics model. Preferred

Reporting Items for Systematic Review and Meta-Analysis (PRISMA) approach was followed in the systematic literature review of techno-economic factors.

The long-term future of eHealth technology is associated with the fit between the technology, economic, social and organizational factors. One of the original contributions of this research study is the assessment of the sustainability of eHealth systems through acceptance of technology, quality of information product, and end-user satisfaction simultaneously. The socio-technical and techno-organizational system dynamics model and equations were developed by the author originally in Vensim as a unique contribution of this simulation research study.

The influence of socio-technical factors on the sustainable eHealth system was described by the dynamic hypotheses of four feedback loops (three reinforcing and one balancing loops). The strong influence of ‘individuals’ intention to use’ on the simulated ‘acceptance rate’ of eHMIS in the early years and the growing impact of social influences of ‘promoters’ and ‘inhibitors’ in later years of implementation was another unique contribution of this research study. The simulation results confirmed that the ‘effectiveness of training’ was a dominant factor to improve the ‘acceptance rate’ of eHMIS and SmartCare. The simulated ‘information quality’ of eHMIS and SmartCare was strongly influenced by ‘system quality’ followed by the satisfaction of users. The ‘performance improvement rate’ showed a stronger impact on the simulated ‘satisfied users’ compared to other model parameters. These are the original contributions of this simulation research study in the socio-technical dimension of sustainable eHealth implementation.

The adequacy of ICT and healthcare workforce within eHealth implementing facility and end-users’ familiarity with digital technology showed a stronger influence on the ‘acceptance rate’ of both eHMIS and SmartCare systems in the techno-organizational dimension. ‘Average workforce turnover’ strongly influenced the simulated ‘acceptance rate’ of both eHMIS and SmartCare systems. Whereas the impact of ‘familiarity with electronic systems’ on the simulated ‘information quality’ of eHMIS and SmartCare was stronger than other techno-organizational factors. Moreover, both ‘average workforce turnover’ and ‘familiarity with electronic systems’ demonstrated significant and growing influence on the simulated ‘satisfied users’ of eHMIS and SmartCare. These are original contributions to the study of technology acceptance dynamics to the sustainable implementation of eHealth systems in the techno-organizational dimensions.

The systematic literature studies in the techno-economic dimension of sustainable eHealth implementation highlighted the lack of adequate techno-economic studies in developing countries. Yet, literature studies indicated the importance of economic factors to ensuring the long-term sustainability of eHealth technology. The original contribution of the systematic review includes identifying potential system dynamic model parameters of a techno-economic model of eHealth acceptance. An economic incentive, funding duration, funding amount, funding source and economic benefit are identified as techno-economic factors that influence the long-term sustainability of eHealth projects. Furthermore, the techno-economic studies of eHealth systems are specific to the economic settings of the country, the type of eHealth application, the type of health problems addressed by eHealth intervention, and the perspective of stakeholder groups.

The focus of this research study was the acceptance of technology by end-users and not the adoption of technology by healthcare organizations. The techno-economic dimension of this research study was only limited to a systematic literature review due to a lack of primary data and adequate secondary data. As a result, the system dynamics model of techno-economic factors was not included in the simulation model but the candidate model variables were identified through a systematic review study. Therefore, future research studies may use these techno-economic variables together with a system dynamic model of socio-technical and techno-organizational factors developed in this PhD research study to develop a system dynamics model of techno-economic factors once some more detailed data has been established.

ACKNOWLEDGEMENTS

All glory to the Lord who is my strength and my shield. My heart trusts in Him and I am helped. So I greatly rejoice and praise Him with my song (Ps 28:7).

I am grateful to my supervisor, Prof. Leon Pretorius, for his continuous guidance, support and encouragement. I am also thankful to my co-supervisor, Dr Louwrence Erasmus, for all great insights and supports during those breakfast meetings. My gratitude also goes to all GSTM staffs for being a great family and support all the time.

My dearest wife, Tsega, my lovely son, Daniel, and a little joy, Hasset, I love you all and thank you for your patience and support.

This research project would not have been possible without a valuable contribution from HITD teams of the MOH in Ethiopia and other informants. Thank you for your time and the important documents you shared with me.

Lastly, but not least, thank you all friends and family members who supported me morally, spiritually and materially in my long journey.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

List of Acronyms

AIDS	Acquired Immune Deficiency Syndrome
CBA	Cost-benefit analysis
CEA	Cost-effectiveness analysis
CEO	Chief Executive Officer
CLD	Causal Loop Diagram
CBA	Cost-benefit Analysis
CEA	Cost-effectiveness Analysis
CMA	Cost-minimization analysis
CUA	Cost-utility analysis
DHIS	District Health Information Software system
DSR	Design Science Research
eCHIS	Electronic Community Health Information System
ECS	Emergency Care Summary
eHealth	Electronic Health
eHAMM	eHealth Architectural Maturity Model
eHMIS	Electronic Health Management Information System
EHR	Electronic Health Records
eHRIS	Electronic Human Resource Information System
eIFMIS	Electronic Integrated Financial Management Information System
eLIS	Electronic Laboratory Information System
eLMIS	Electronic Logistic Management Information System
EMR	Electronic Medical Records
EPHI	Ethiopian Public Health Institute
FMOH	Federal Ministry of Health
GIS	Geographic Information System
GSMA	Groupe Spéciale Mobile Association
HIC	High-Income Countries
HIS	Health Information Systems
HIT	Health Information Technology
HITD	Health Information Technology Directorate
HIV	Human Immunodeficiency Virus
ICER	Incremental Cost-Effectiveness Ratio
ICT	Information and Communication Technology
IEA	International Energy Agency
IMF	International Monetary Fund
IS	Information Systems
IT	Information Technology
ITU	International Telecommunications Unit
LAN	Local Area Network
LIC	Low-Income Countries
LIS	Laboratory Information System
LMIC	Low- and middle-income countries
MDGs	Millennium Development Goals
mHealth	Mobile Health
MOH	Ministry of Health
MRU	Medical Record Unit

NGO	Non-Governmental Organization
NMT	Neuromuscular Training
NRI	Networked Readiness Index
P-TAM	Pharmaceutical Technology Acceptance Model
PHR	Patient Health Records
PPD	Policy and Planning Directorate
PRISM	Performance of Routine Information System Management
QALY	Quality-Adjusted Life Years
RHB	Regional Health Bureau
RCT	Randomized Control Trial
SFD	Stocks and Flows Diagram
SNNP	South Nations, Nationalities and People
SNNPR	South Nations, Nationalities and People Region
SMS	Short Messaging Service
TAM	Technology Acceptance Model
TOT	Training of Trainers
TPB	Theory of Planed Behaviour
TRA	Theory of Reasoned Action
TWG	Technical Working Group
UN	United Nations
UNDP	United Nations Development Programme
UTAUT	Unified Theory of Acceptance and Use of Technology
WCED	World Commission on Environment and Development
WEF	World Economic Forum
WHO	World Health Organization
WTO	World Trade Organization
WTP	Willingness-to-pay
ZHB	Zonal Health Bureau

1. INTRODUCTION

"Many eHealth technologies are not successful in realizing sustainable innovations in health care practices." (van Gemert-Pijnen *et al.*, 2011).

1.1. Background

The burden of disease, the shortage of skilled healthcare professionals, and inequity in healthcare service delivery between rural and urban, are some of the major challenges of healthcare services in developing regions (WHO, 2011a). The eight Millennium Development Goals (MDGs) are derived from the United Nations Millennium Declaration, signed in September 2000, to combat poverty, hunger, disease, illiteracy, environmental degradation and discrimination against women (Islam, 2004). Although all eight MDGs directly or indirectly influence health, three of them are specifically related to health: to reduce child mortality; to improve maternal health; and to combat HIV/AIDS, malaria and other diseases (UN, 2013).

In 2012, the average under-five mortality rate in low-income countries (82 deaths per 1 000 live births) was 13 times more than the average rate in high-income countries (WHO, 2014). According to the UN (2013) report, in sub-Saharan Africa countries in 2011, one in nine children died before age five. Similarly, in 2013, the lack of access to quality maternal care by pregnant women before, during and after childbirth was the reason for the death of nearly 800 women every day; and almost all these deaths (99%) occurred in developing countries (WHO, 2014). Although the coverage of women who gave birth with the assistance of skilled birth attendants increased in the developing world, the UN (2013) report indicated that the urban-rural gap remains high. In developing countries in 2011, 53% of women in rural areas were assisted by skilled personnel at delivery, compared to 84% in urban areas (UN, 2013).

Globally, an estimated 2.3 million people were newly infected with HIV in 2012 and sub-Saharan Africa accounted for 70% of this incidence (WHO, 2014). "The Africa region also bears the highest burden of malaria, with 80% of the estimated 207 million cases and 90% of the estimated 627 000 malaria deaths worldwide occurring in this region in 2012" (WHO 2014:17).

In summary, although significant progress has been made towards health related MDGs in the past years, developing countries still lag behind in achieving these targets. It seems to indicate that with the limited resources available in developing countries, it is difficult to improve healthcare outcomes. Hence to alleviate the healthcare burden of the resource-constrained world, it is important to bring innovative ways of using technology to improve challenges of healthcare services, specifically in developing countries.

It is believed that Information Communication Technology (ICT) has a great potential to address some of the challenges of healthcare service by improving accessibility and quality of healthcare services at a reduced cost. However, the desired outcomes have not been achieved in developing countries because of issues such as high costs, underdeveloped infrastructure, and lack of technical expertise. In developed countries issues surrounding patient privacy and confidentiality, competing for health system priorities and a perceived lack of demand are some of the barriers of eHealth systems success (WHO 2010b:6-7).

In resource-constrained settings where both ICT and enabling environments are at the early stage, eHealth projects are rarely sustainable because of a lack of infrastructure, skills and ownership (WHO & ITU 2012:4). In both developing and developed countries, only a few eHealth projects managed to sustain themselves once the initial seed fund has ended. Some of the reported challenges for the lack of longevity in many eHealth projects are associated with patients and healthcare workers resistance to change, lack of ICT skills, cultural differences and language barriers (WHO 2010b:11). In this research study, some of these challenges may be addressed by increasing the collaboration between engineering and medicine. The safety, effectiveness, patient-centeredness, timeliness, efficiency, and equitability of healthcare services can be improved by engineering and medicine collaboration (Reid et al. 2005:15).

The multidimensional problems of healthcare service in resource-constrained settings such as the shortage of resources and skilled manpower to deliver quality healthcare services can be improved through the successful implementation of eHealth technologies. However, the implementation success of eHealth is not only the issue of technology alone but also end-users, technical team, leadership and organizational (Rippen *et al.*, 2013). This research study explores the drivers that influence eHealth implementation success and discover the dynamic relationship among each factor to ensure a sustainable eHealth system that improves the outcomes of healthcare services.

The implementation of healthcare technology requires a multidisciplinary approach that addresses a wide range of stakeholders with different needs and requirements. These requirements are often conflicting yet need to be addressed to ensure implementation success of eHealth technology. The patient needs fast, quality and cheaper healthcare services, the clinicians require easy to use technology that can save time and effort. On the other hand, healthcare organizations want cheaper technologies that can fit into their organizational settings to make a profit. The isolated view of a system makes one stakeholder happy while leaving the others disappointed which will result in failure. Hence a holistic approach of eHealth ecosystem should be used to address the dynamic complexity of eHealth technology implementation. This is one focus area of the research addressed in this thesis.

1.2. Technology in Healthcare

In the broader sense, the term technology refers to the tools, techniques, processes used for transforming organizational inputs into outputs (Geisler & Heller, 1996:13). Technology integrates people, knowledge, tools and systems with the objective to improve people’s lives (Pretorius, 2000). Technology plays a significant role in improving the quality of healthcare service delivery (Kern and Jaron, 2003; Weeks, 2012).

According to Geisler & Heller (1996), the technology in the healthcare delivery system is composed of five major categories:

- Medical Devices
- Drug/Pharmaceuticals
- Disposables
- Medical/Surgical Procedures and Services
- Information Technology

The healthcare technology focus of this study falls within the information technology category.

1.2.1. eHealth Systems

World Health Organization (WHO) defines Electronic Health (eHealth) as the use of Information and Communication Technology (ICT) for health (WHO, 2011a). Several eHealth applciations were introduced in both developed and developing worlds to alleviate some of the healthcare challenges (Al-Aswad and Brownsell, 2013). Since healthcare is an information intensive environment, eHealth systems are believed to be conducive to improve the quality of healthcare services delivery by providing up to date information about patients (Reid *et al.*, 2005; WHO, 2012b).

The review of the 51 published definitions of eHealth systems resulted in a positive connotation to eHealth systems, without any adverse, negative, harmful or disadvantageous effect (Oh et al., 2005). This is an indication of the level of benefits expected from the use eHealth systems in healthcare service deliveries, which includes (Khoumbati, Themistocleous and Irani, 2006; WHO and ITU, 2012; Adebesin *et al.*, 2013):

- Improved access to healthcare services, especially in rural and remote communities that do not have access to healthcare specialists.
- Enhanced efficiency in healthcare delivery.
- Increased quality of healthcare services.
- Improved safety in healthcare services delivery for relevant health information is available.
- Improved health monitoring and reporting.
- Improved access to health knowledge and education.
- Reduced medication errors and adverse drug reactions.
- Eliminates unnecessary duplication of efforts.
- Access to accurate and reliable information to make informed decisions (policy makers).
- Eliminate missing patient records (e.g. missing films, prescriptions)

Despite a number of efforts to deliver efficient, effective and sustainable eHealth systems, eHealth systems could not always demonstrate sustainability beyond the pilot phase (van Dyk, 2014). In resource-constrained settings, where both ICT and enabling environments are at the early stage, eHealth projects are rarely sustainable, because of inadequate ICT infrastructure, skills and ownership (WHO & ITUT, 2012). In both developing and developed countries, only a few eHealth projects managed to sustain themselves once the initial seed funding ended (WHO, 2010b). The reported challenges for the lack of longevity of eHealth projects in resource-constrained environments are associated with (Khoumbati, Themistocleous and Irani, 2006; Molefi, 2010; WHO, 2010b, 2010a; WHO and ITU, 2012; Adebesin *et al.*, 2013):

- High cost of technology acquisition.
- Patients and healthcare workers resistance to change.
- Lack of ownership.
- Lack of ICT skills or inadequate human capacity.
- Cultural differences and language barriers.
- Lack of enabling policy environments.
- Weak leadership and coordination.
- Weak ICT infrastructure and services.
- Inadequate financial resources.
- Weak monitoring and evaluation systems.
- Legal issues.

- Political will and support.

There are a number of eHealth applications that are implemented in healthcare sectors globally. Examples of popular eHealth applications include:

- *Electronic Medical Record (EMR)* is a real-time patient health related information that can be created, gathered, managed and used to aid decision-making of authorized clinicians and staff within one healthcare organization (ALLIANCE, 2008; WHO, 2012b).

- *Electronic Health Record (EHR)* is “a longitudinal electronic record of patient health information generated by one or more encounters in any care delivery setting”(WHO 2012b:11).

- *Personal Health Record (PHR)* is “an electronic record of health-related information on an individual that conforms to nationally recognised interoperability standards and that can be drawn from multiple sources while being managed, shared, and controlled by the individual” (ALLIANCE 2008:19).

- *Telemedicine:* the WHO adopted definition of telemedicine is “the delivery of health care services, where distance is a critical factor, by all health care professionals using information and communication technologies for the exchange of valid information for diagnosis, treatment and prevention of disease and injuries, research and evaluation, and for the continuing education of health care providers, all in the interests of advancing the health of individuals and their communities”(WHO 2010b:9).

- *Mobile Health (mHealth):* the Global Observatory of WHO defines mHealth as “medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices”(WHO 2011b:6).

1.3. Sustainable technology

Sustainability is the term often associated with improving ecological efficiency to enable human beings to live on Planet Earth for the indefinite future (Dodds and Venables, 2005; Fiksel, 2003; Gmelin and Seuring, 2014). However, Hay et al (2014) define sustainability as the ability to sustain, continue or maintain the operation of a system. A system cannot be sustained indefinitely as it has an operational lifetime. Therefore, in this research project, sustainability is associated with a long-term future of a technology (Musango and Brent, 2010). The sustainability of technology is determined by the economic, social and organizational sub-systems in which the technology is embedded (Dodds and Venables, 2005; Musango and Brent, 2010). Therefore, understanding the dynamic relationship between sustainability factors is a key to ensuring the implementation success of a technology.

The responsibility of donor or partner organizations at the early phases of eHealth implementation is significantly high in the context of developing countries. This responsibility believed to weaken through time as partner or donor organizations transfer the ownership of the eHealth projects to the local organizations, the Ministry of Health (MOH). The long-term sustainability of eHealth projects depends on the capacity and commitment of the local organization, MOH. The smooth transition of ownership from partner organizations to the local institutions (i.e., MOH) and the capacity building commitment of partner organizations through training and mentoring facilitates the sustainability of eHealth systems in developing countries (See Figure 1.1). The partner or donor organizations have limited project span, therefore the ownership of eHealth projects by the local health organization (i.e., MOH) plays a key role in the long-term sustainability of eHealth systems in the developing countries.

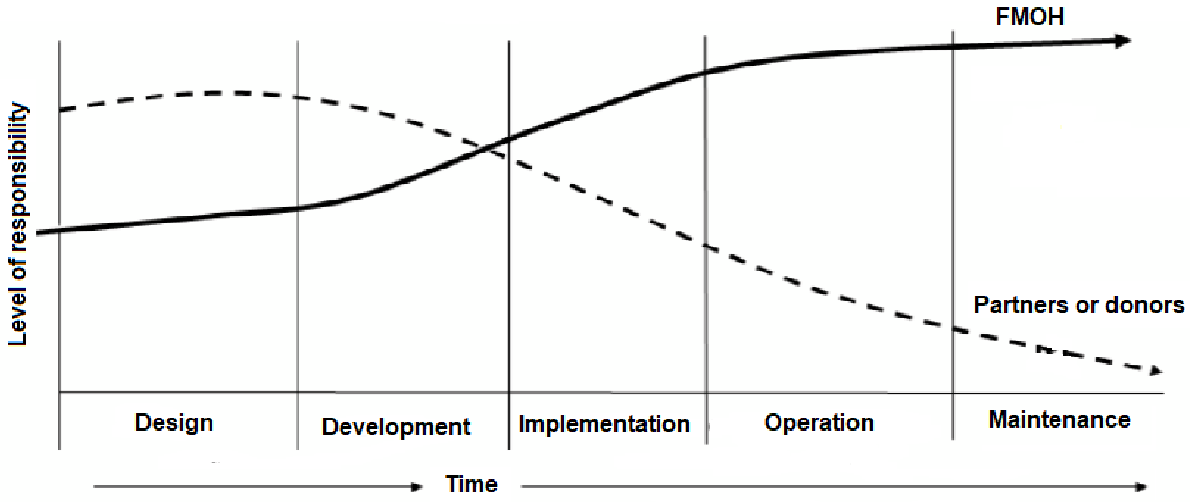


Figure 1.1 Shared responsibility of MOH and Partner organizations for the long-term suitable eHealth implementation (FMOH and MEASURE Evaluation, 2012).

The implementation of donor-funded eHealth systems are regarded as sustainable when

- The system owner (such as MOH) and users value the eHealth and desire to integrate it with the existing health system management.
- The system owners strive to maintain the quality of information product to meet the current information need.

- The system owner uses the information product from the eHealth system for decision making at all tiers of the health system.
- The system owner is willing to take responsibility for the success or failure of the system.
- The system owner is capable of managing resource allocation, maintaining and financial decision of the technology implementation.

1.4. Rationale of the research

The healthcare system of developing countries is confronted with a high burden of disease, shortage of skilled healthcare workforce, medical errors, inequity and inefficient healthcare service delivery (WHO, 2011c). The ICT has revolutionised the performance of most major manufacturing and services industries such as transportation, financial services, communications and manufacturing (Reid et al. 2005). Despite highly anticipated benefits of eHealth system to improve the efficiency of healthcare delivery, advance patient record keeping and reduce healthcare costs; the healthcare has barely begun to take advantage of ICT mainly in a resource constrained environment (van Gemert-Pijnen *et al.*, 2011). Although there is evidence of a sharp increase in the implementation of eHealth systems globally, most of the implementations could not proceed beyond the pilot phase to demonstrate sustainability on a large scale rollout (Djorlolo and Ellingsen, 2013).

The challenges associated with sustainability and uptake of eHealth systems are still unresolved issues that require further analysis and intervention (Bergmo, 2015). The working paper published based on the Vital Wave Consulting Report (2009) and the Royal Tropical Institute’s mobile health projects online database (www.mhealthinfo.org) revealed that only 7 of 94 (7.5%) mHealth projects were managed to be successfully scaled up in developing countries (Marshall, Lewis and Whittaker, 2013). The healthcare organizations are excited about using electronic technologies to deliver quality healthcare services; however, eHealth systems that are successful in the developed world could not replicate the same result in the resource-constrained environments.

There is evidence of increasing research efforts to improve the implementation success of eHealth systems, but a little attention has been paid to understand the complex relationship among each element of the ecosystem to ensure sustainable eHealth implementations (Lipsitz, 2013). As a result, most eHealth implementation frameworks are linearly modeled that do not clearly reflect the feedback elements and dynamic complexity in real life. The dynamic and nonlinearity of eHealth implementation need to be reflected in the eHealth implementation frameworks to realize success. The ecosystem of sustainable eHealth implementation covers wider ranges of factors in technological, social, organizational and economic dimensions to promote the meaningful and sustained use of information in healthcare settings. The sustained use of eHealth is influenced by the dynamic nonlinear interaction among several factors that creates complexity in the implementation of eHealth systems in healthcare settings.

The successful implementation of eHealth technology is believed to bridge the shortage of skilled healthcare workforce, and inequity in healthcare service delivery between rural and urban in resource-constrained settings (WHO, 2011a; Luna *et al.*, 2014). Hence it is important to address the implementation challenges through the scientific approach in order to capitalize on the anticipated benefits from the technology. This research study focuses on addressing sustainability challenges of eHealth systems implementation in a resource-constrained environment through systems thinking and system dynamics modelling approaches. The successful implementation of an eHealth system is influenced by the dynamic interaction between the new technology and individual users, social elements within an organization, organizational readiness and economic factors. The implementation of sustainable eHealth systems in resource-constrained settings will significantly contribute to the improvement of healthcare services delivery in the developing world.

The study aims at contributing to the existing body of knowledge in terms of illustrating the dynamic and nonlinear interaction of eHealth acceptance factors within healthcare institutions. Moreover, the result of the research will benefit eHealth implementation decision makers by recommending relevant management and policy interventions to ensure sustained use of technology and information product. It provides insight concerning the complex interaction of socio-technical, techno-organizational, and techno-economic elements of eHealth implementation in healthcare organizations.

The study assists stakeholders to identify key factors of sustainable eHealth implementation and their dynamic interaction in complex healthcare settings to facilitate acceptance by the end-users. The result of the study will serve as a practical input in each phase of eHealth implementation process to increase technology acceptance by the end-users. It will also help to foresee key areas of eHealth implementation and the possible intervention to facilitate technology and information use in healthcare institutions.

1.5. Research problem statements and research objectives

The promises of eHealth systems to alleviate some of the healthcare challenges have encouraged many governments and international organizations to invest heavily in eHealth solutions (Brown 2011; Holmdahl 2014; Reid et al. 2005). Nevertheless, there is very limited evidence on the success of eHealth systems and their impact on healthcare outcomes. The reported successful eHealth projects were either at a pilot phase of implementation or they did not have concrete evidence of sustainability on a large scale of implementation. The challenges associated with sustainability and uptake of eHealth systems are still unresolved issues that require further analysis and intervention (Bergmo, 2015).

The study on mHealth projects in the context of developing country indicated that only 7 of 94 (7.5%) projects managed to be successfully scaled up (Marshall, Lewis and Whittaker, 2013). Moreover, the linear models of eHealth implementation reported in the literature, could not describe the dynamic and complex relationship between the elements of sustainable eHealth implementation. The complexity of healthcare systems require appropriate techniques that could handle the dynamic complexity of a system. System thinking and system dynamics can be used to address the nonlinear relationship of eHealth implementation in the complex healthcare settings (Adam and De Savigny, 2012). Hence the overall target of this study is to identify factors that influence sustainable eHealth implementation and illustrate their nonlinear dynamic relationship to ensure sustained use of technology and information product. The system dynamics modelling and simulation approach is an appropriate tool to understand the behaviour of complex systems (Forrester, 1994; Sterman, 2000)

1.5.1. Problem statements

The introductory investigation suggests there exists evidence of several eHealth pilot projects in the resource-constrained settings that could not progress beyond the pilot phase to demonstrate sustainability; sometimes referred to as “pilotitis” of the eHealth system. The term “pilotitis” refers to the inability of eHealth projects to break out of pilot stage (Samarthya-Howard, 2016). “Pilotitis” is frequently used by the donors and governments to express dissatisfaction in taking the implementation of eHealth projects beyond the pilot stage in the low- and middle-income countries (LMICs) (Franz-Vasdeki *et al.*, 2015; Samarthya-Howard, 2016). The pilot phase of eHealth projects mainly focuses on the technical feasibility of a system but it fails to consider other success elements such as the organizational and social factors. Furthermore, eHealth technologies that showed some level of success in the developed world may not replicate the same result in developing countries. The long-term sustainability of eHealth implementation is crucial to ensure the quality of healthcare service delivery and reduce the healthcare cost.

The interrelated factors such as end-users skill, ICT infrastructure and financial resources are capable of influencing the level of eHealth usability to ensure long-term sustained use of the technology by end-users. However, these factors differ between the developing and developed worlds. This study plans to address the challenges of sustainable eHealth implementation in the resource-constrained settings by using sustainability theory and applying systems techniques and methods. The annual net benefit of Emergency Care Summary (ECS) in Scotland exceeded the annual cost for the first time after seven years (Jones *et al.*, 2009). This indicated that the sustained utilization of the system was a key factor to generate economic benefit from the ECS (Jones *et al.*, 2009). The general research problem in this thesis focuses on how factors of eHealth implementation interplay to influence technology and information use to ensure the long-term sustainability of eHealth in resource-constrained settings. The associated research questions are:

- How do socio-technical factors influence the sustainable use of eHealth systems?
- How do the operating environments (organizational factors) of resource-constrained settings affect the long-term sustainability of eHealth use?
- What is the implication of techno-economic factors on the sustainable use of eHealth systems by end-users in resource-constrained settings?

1.5.2. Research objectives

By answering the above research questions, the general objective of the study is to apply a systems thinking approach and system dynamics modelling method together with the sustainability theory in order to develop a system dynamics model of sustainable eHealth implementation. The study aims to simulate, verify, validate and test the system dynamics model of sustainable eHealth implementation in the resource-constrained environments by considering key elements of the ecosystem. The study aims at describing the dynamic complexity of sustainable eHealth implementation under three important sub-categories, i.e., socio-technical, techno-organizational and techno-economic. The study targets at understanding the dynamic interaction between technical, social, economic and organizational factors of sustainable eHealth implementation. The related research objectives are:

- To assess the influence of socio-technical factors on the sustainable use eHealth systems.

- To determine the effect of techno-organizational factors on the successful implementation and sustainable use of eHealth technology.
- To evaluate the techno-economic features of sustainable eHealth use in a resource-constrained environment.

1.6. Importance of the research problem

The study considers the ecosystems of eHealth implementation factors and promotes the sustainable use of eHealth systems in resource-constrained environments to minimize wastage of the limited resources made available for the implementation of eHealth systems. The implementation fund of most eHealth projects in developing country come from international organizations and donors from the developed country (Jahangirian and Taylor, 2015; Quaglio *et al.*, 2016). The majority of these eHealth systems either do not meet the objective of the local organizations or the projects phase-out before a successful transfer of ownership to the local organizations (MOH) (Schweitzer and Synowiec, 2012). There is a limited coordination between the donor or partner organizations and the local organization (MOH) that owns the eHealth projects . As a result, most eHealth projects in the developing countries could not progress beyond a pilot stage to ensure the long-term sustainability of eHealth systems (Franz-Vasdeki *et al.*, 2015; Samarthya-Howard, 2016). The implementation of eHealth in the healthcare settings is a complex process. Addressing a complex system partly is not an adequate solution to ensure the sustainability implementation of eHealth.

The lack of the holistic understanding and evaluation of dynamic and nonlinear factors of eHealth implementation process is a threat to a successful implementation of eHealth technology. The research study intends to engage key stakeholders involved in the development, implementation, operation and use of eHealth to understand and evaluate the key factors of sustainable eHealth implementation. Moreover, the study attempts to describe the dynamic and nonlinear relationship between each element of the ecosystem to ensure sustainable eHealth implementation. The study plans to reduce the ultimate rejection of the eHealth technology by the end-users and to maximize the use of information for decision making to advance the long-term sustainability of eHealth. The holistic view of a systems thinking approach is applied and system dynamics modelling method is used to describe the relationship between factors of sustainable eHealth implementation and technology use.

Most of the published frameworks of eHealth technologies fail to address the entire elements of the ecosystem and also present eHealth implementation as a linear process (Adam and De Savigny, 2012; Leon, Schneider and Daviaud, 2012; Khoja *et al.*, 2013). A healthcare organization is a complex system and the implementation of eHealth technologies in a healthcare institution is a complex process (Adam and De Savigny, 2012). This research addresses the eHealth implementation process as a complex, dynamic and nonlinear process. The incorporation of feedback loops in the process of learning the relationship among factors of eHealth ecosystem can create a deeper awareness of a dynamic and nonlinear interplay of sustainable eHealth implementation factors. The study will enhance the understanding of complex relationships of eHealth implementation factors and contributes to the knowledge base in terms of applying systems thinking approach and complexity studies into eHealth implementation in the healthcare settings. The final study result aims to guide decision makers to foresee the possible consequence of new policies intervention towards the sustainable use of eHealth technology and information for decision making.

1.7. Limitations and assumptions of the study

This research assumes that the healthcare institutions of resource-constrained environments have different eHealth operational settings from that of resource-abundant environments. The operational environments of healthcare organizations differ significantly between the developing and developed world, as well as rural and urban areas. Moreover, this study proposes successful eHealth systems need to demonstrate sustainability. The technological, social, organizational and economic factors impact the implementation of sustainable eHealth systems. Healthcare is a complex environment, hence the implementation of eHealth in the healthcare sector may not be addressed properly by the traditional linear approach. System dynamics modelling is a coherent approach to address complex systems through the incorporation of feedback loops. In this study, a system approach is assumed to be a logical process to address the complex factors in the ecosystem of sustainable eHealth systems implementation.

Sustainability theory is usually associated with ecological studies, yet the three pillars of sustainability are assumed to be a valuable input to the study of sustainable eHealth implementation. The three pillars of sustainability, i.e., social, economic and environmental (i.e., organizational in this study) are considered as important factors in the process of implementing successful eHealth system (Dodds and Venables, 2005; Musango and Brent, 2010; Hay, Duffy and Whitfield, 2014).

The five-stages of innovation-decision process can broadly be explained as the decisions process of technology adoption and acceptance. This study assumes that the eHealth technology has been adopted at a healthcare institution level, i.e., the adoption process is already completed at a firm level. Hence the focus is on the final two stages of the innovation diffusion processes (implementation and confirmation) that usually happens within the organizational settings of the adopting institution (Rogers, 2003). Therefore the organizational or environmental factors addressed in this research study are internal to the healthcare organization; i.e., factors under the organization's sphere of control. All other environmental factors external to the healthcare organization are outside the scope of the study.

The availability of infrastructure, resources and skilled healthcare workforces vary across healthcare institutions based on the geographic location of the healthcare institution, rural or urban. Often healthcare organizations in the urban area have access to a better infrastructure, resources and skills to implement eHealth systems compared to healthcare institutions in the rural area. Therefore, the boundary of the study is set at healthcare institution level instead of a national level. This does not eliminate the importance of considering the broad picture of eHealth implementations at a national level, but it helps to facilitate the system dynamics modelling process followed in this study. The successful implementation of eHealth at a firm level is a foundation to implement sustainable national eHealth systems.

The result-based intervention process of the sustainable project comprises the delivery processes (input, activities and outputs) and the results (outcome and impacts). In the process of eHealth implementations, the results have the feedback effect on the delivery process of eHealth implementation, in contrary to the linear approach of result-based intervention. The outcome and impact of eHealth affect the input, process and output of eHealth implementation. This study aims at addressing only the delivery process section of the results chain in the implementation of eHealth. The study acknowledges the influence of output and impact on the delivery process, yet it does not address the results section of the framework to reduce the complexity of the model. Moreover, the outcome and impact studies require study for a prolonged period which is not the purpose of this research study.

The tight ethical and patient privacy policies in the healthcare sector limits access to certain types of research data. Furthermore, most eHealth technologies in developing countries are at a pilot phase of implementation, therefore the data availability of a large-scale eHealth implementation is limited. This poses a limitation to the study of sustainable eHealth implementation as a small number of eHealth systems progresses from pilot to large-scale implementation stage.

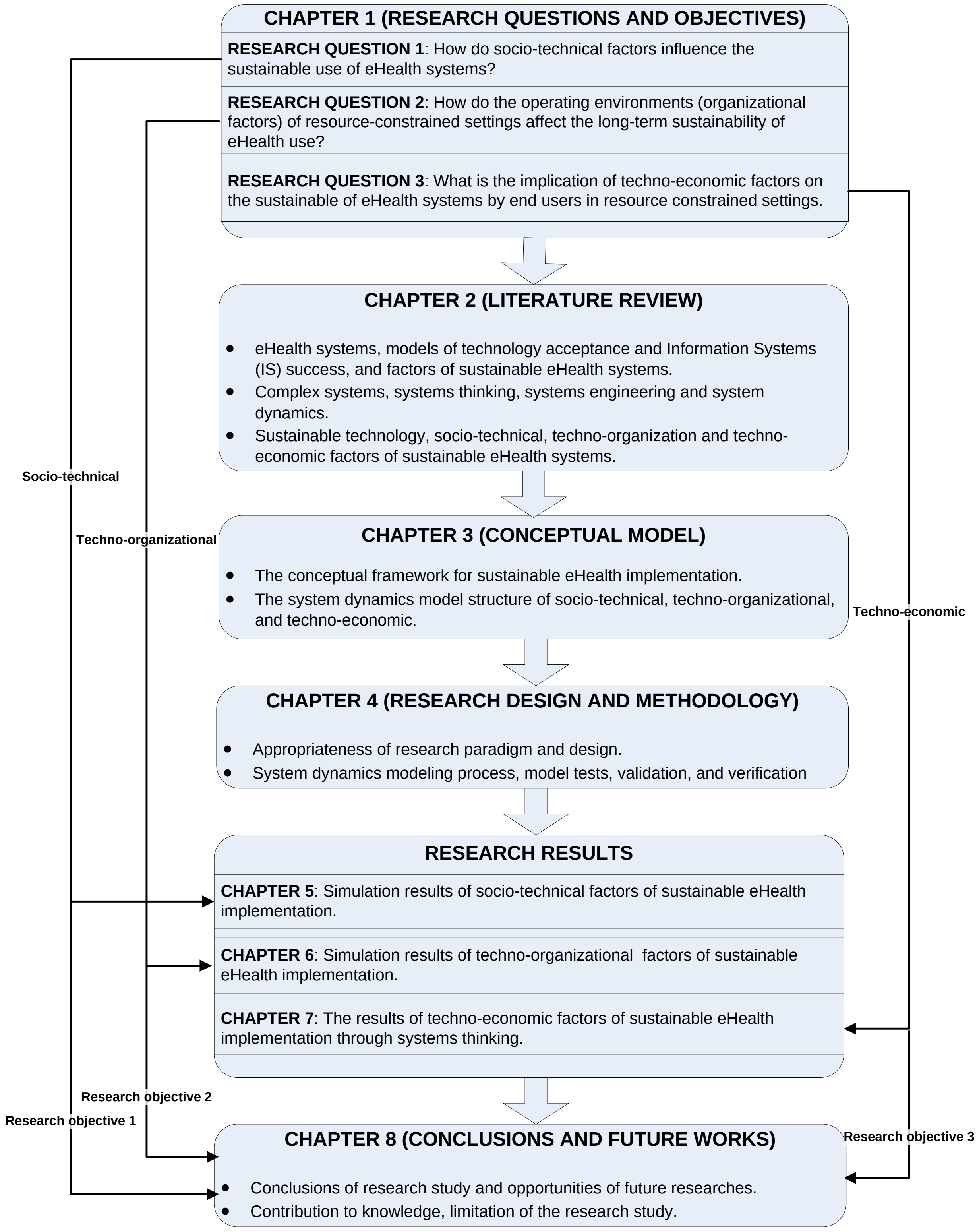
1.8. Type of research and chapter summary

This is an applied research study that focusses at addressing the problems of sustainable eHealth systems implementation in resource-constrained environments (Cooper and Schindler, 2001). In this model-based theory building research study, the aim is to enhance the understanding of sustainable eHealth implementation in a resource-constrained environment and recommend policy interventions to maximize the acceptance of eHealth by the end-users. A system dynamics modelling approach is used to learn the complexity associated with the implementation of eHealth systems within healthcare organizations (Forrester, 1994; Sterman, 2000; Adam and De Savigny, 2012). The mixed-method design or methodological triangulation is applied to enhance the research study (Thurmond, 2001). Triangulation is the combination of two or more theoretical perspectives, methodological approaches, data sources, investigators or data analysis methods within the same study with the intent to decrease, negate, or counterbalance the deficiency of a single strategy, thereby increasing the ability to interpret the findings (Thurmond, 2001). A qualitative case study, descriptive quantitative research design and computer simulation models are used to answer the research questions.

The case study method allows investigators to retain the holistic and meaningful characteristics of real-life events (Yin, 2009). The investigator has little control over actual behavioural events but has access to the contemporary events. A case study research is a preferred approach when a researcher has access to full variety evidence – documents, artefacts, interviews, and observations- without full control over the contemporary event (Yin, 2009). An interview with a structured questionnaire and a focus group discussions using a semi-structured research instrument were conducted to collect evidence from respondents in this research. As recommended by Reid et al. (2005), the end-users, technology providers and system owners were part of informants. A total of three focus group discussions were conducted with teams of project members from the Federal Ministry of Health (FMOH), the FMOH partner organizations and experts from academia and business. Further research data were collected through face-to-face interview sessions with end-users of eHMIS and SmartCare systems in Ethiopia. The full details of the research approach will be discussed and motivated in a later Chapter of this thesis.

This explanatory case study research uses the cases of Electronic Health Management Information System (eHMIS) and SmartCare (an Electronic Medical Record system) implementation in Ethiopia to understand the dynamic interaction between the elements of technological, social, organizational and economic factors during the implementation of sustainable eHealth. A focus group discussion with members of the project team from the FMOH and partner organizations, as well as end-users of the two eHealth systems from purposefully selected health facilities were interviewed to collect research data. The details of informants' selection and data collection will be presented in Chapter 4 of this report. Healthcare is recognised as a complex system. To capture the dynamic complexity of eHealth implementation, the system dynamics simulation method is used. The empirical evidence and findings from the literature review to build a system dynamics model of sustainable eHealth systems.

This thesis report is presented in eight chapters. The organization of each chapter is summarised in Figure 1.2 below. The research report is structured as follows. The succeeding section provides details of a literature review about the sustainable implementation of the eHealth system. Chapter 3 describes the conceptual design of sustainable eHealth implementation followed by the research design and methodology in Chapter 4. The simulation results of this research study are discussed under three chapters (Chapter 5, 6 and 7) to answer the three research questions posed in this chapter. The simulation results of the dynamics of socio-technical factors of eHealth implementation is presented in Chapter 5. Chapter 6 discusses the simulation results of dynamic and complex relationships in the techno-organization factors of eHealth implementation. The discussion of the preliminary results of the techno-economic factors of sustainable eHealth implementation follow in Chapter 7. Finally, Chapter 8 discusses the concluding remarks according to the research objectives and results discussed in the previous three chapters. Future research opportunities for further studies are also presented in this chapter.



CHAPTER 1 (RESEARCH QUESTIONS AND OBJECTIVES)

RESEARCH QUESTION 1: How do socio-technical factors influence the sustainable use of eHealth systems?

RESEARCH QUESTION 2: How do the operating environments (organizational factors) of resource-constrained settings affect the long-term sustainability of eHealth use?

RESEARCH QUESTION 3: What is the implication of techno-economic factors on the sustainable of eHealth systems by end users in resource constrained settings.

CHAPTER 2 (LITERATURE REVIEW)

- eHealth systems, models of technology acceptance and Information Systems (IS) success, and factors of sustainable eHealth systems.
- Complex systems, systems thinking, systems engineering and system dynamics.
- Sustainable technology, socio-technical, techno-organization and techno-economic factors of sustainable eHealth systems.

CHAPTER 3 (CONCEPTUAL MODEL)

- The conceptual framework for sustainable eHealth implementation.
- The system dynamics model structure of socio-technical, techno-organizational, and techno-economic.

CHAPTER 4 (RESEARCH DESIGN AND METHODOLOGY)

- Appropriateness of research paradigm and design.
- System dynamics modeling process, model tests, validation, and verification

RESEARCH RESULTS

CHAPTER 5: Simulation results of socio-technical factors of sustainable eHealth implementation.

CHAPTER 6: Simulation results of techno-organizational factors of sustainable eHealth implementation.

CHAPTER 7: The results of techno-economic factors of sustainable eHealth implementation through systems thinking.

CHAPTER 8 (CONCLUSIONS AND FUTURE WORKS)

- Conclusions of research study and opportunities of future researches.
- Contribution to knowledge, limitation of the research study.

Figure 1.2 The structure of the research thesis.

2. LITERATURE REVIEW: SUSTAINABLE EHEALTH SYSTEMS

“Literature allows us to be open, to listen, and to be curious.”
Tracy K. Smith

2.1. Introduction

The goal of this chapter is to explore an existing knowledge base to address the results of prior research studies associated with the sustainability of eHealth systems implementation in a resource-constrained environment. This research study aims at addressing the sustainability of eHealth systems under three dimensions, namely socio-technical, techno-organizational and techno-economic, as discussed in Chapter 1. The detailed literature review in this chapter is aligned with the research objectives of this study, i.e. to assess the influence of socio-technical, techno-organizational and techno-economic factors on the sustainable eHealth implementation in a resource-constrained environment.

A wide range of journal databases was searched that includes PUBMED, Google Scholar, ScienceDirect, ELSEVIER, Scopus and Mendeley. The keywords such as sustainability, eHealth, system engineering, system dynamics, systems thinking, mHealth, Electronic Medical Record (EMR), Electronic Health Record (EHR), telemedicine, socio-technical, organizational, economic and developing countries are used to search the journal databases. The relevant literature articles are reviewed critically and the bibliographies of the selected papers are visited to search for related articles. The three broad relevant topics covered in the literature study are related to eHealth applications, sustainability theory and systems thinking approach as depicted in Figure 2.1. The resource-constrained environment describes the specific context of the research study.

This study focuses on the sustainable implementation of eHealth technology. Therefore, a study of existing researches regarding eHealth applications gives an overall understanding of the systems. Furthermore, it supports the effort of identifying technological factors that influence the long-term sustainable use of technology. eHealth technology is the system of interest in this study which interacts with the operating environment. The inner environment refers to the coordination of a set of components that make up the IS artefact, the system of interest (Kuechler and Petter, 2017:3). Hence the study of eHealth technology will support the process of answering the questions to achieve the first three objectives of this research study. It is necessary to identify the eHealth technological factors before studying the interaction of technology with the operating environment. Technology is always embedded in the subsystems of the economy, society (and its institutions), and the natural environment (Musango and Brent, 2010).

A healthcare institution where eHealth technology is deployed is a natural operating environment of eHealth technology. In the design of IS artefacts, the inner environment, the outer environment and the interface between the two need to work in coordination to achieve the desired goal (Kuechler and Petter, 2017). The system environment is an outer environment that significantly influences the long-term sustainability of the technology. “The outer environment refers to the total set of external forces and effects that act on the artefact” (Kuechler and Petter, 2017:3). The three pillars of sustainability addressed in the theory of sustainability can be used to organise factors of the system environment in the implementation of sustainable eHealth systems. Sustainability aims at achieving the economic success, social benefit and environmental quality of a system simultaneously. The process of achieving the first three research objectives of this study can be supported by the sustainability theory. Therefore, the sustainability theory and its connection to the implementation of sustainable eHealth technology is covered in the literature study. The long-term sustainability of eHealth technology is associated with the fit between the technological, economic, social and organizational factors (Musango and Brent, 2010; Hay, Duffy and Whitfield, 2014).

The implementation of eHealth in the healthcare systems is recognised as a complex system in this research study. Hence a systems approach that aids the learning process of a complex system is addressed in this detailed literature survey. A system dynamics modelling that captures a dynamic and nonlinear feedback system are explored in detail in the literature study.

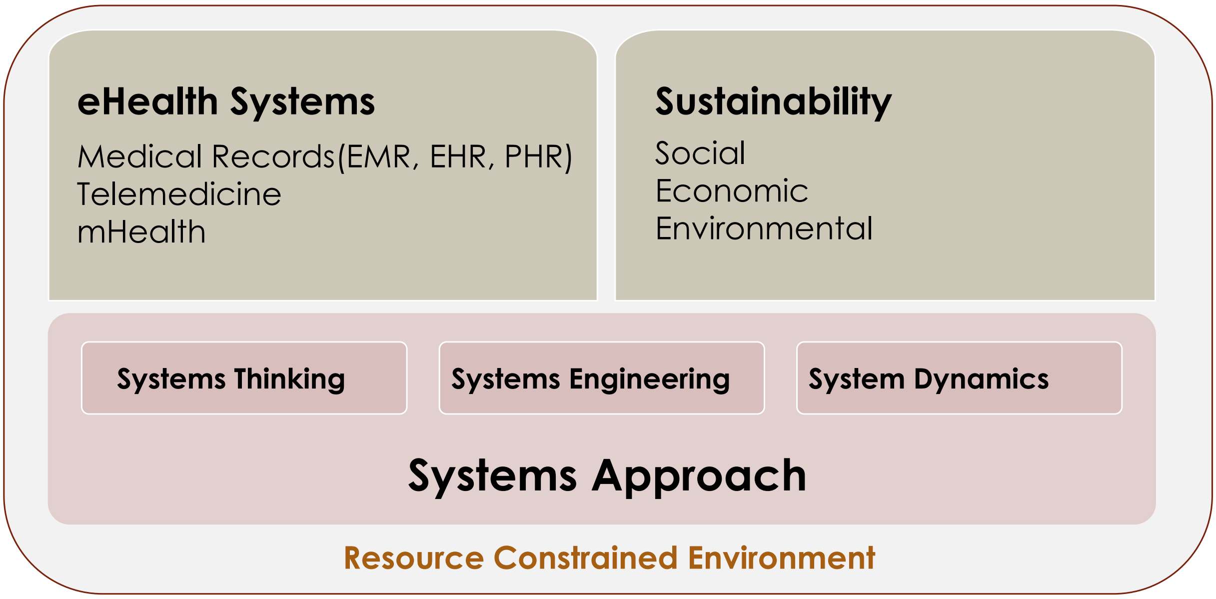


Figure 2.1 Framework for literature review (Own research).

The first section of this chapter discusses definitions and categories of eHealth systems such as Electronic Medical Records (EMR), Electronic Health Records (EHR), Patient Health Records (PHR) as well as Mobile Health (mHealth). Although there are far more eHealth lists implemented globally, only eHealth systems that are popular in developing countries are addressed in this literature study. The benefits and problems of eHealth applications, as well as frameworks of successful eHealth implementation, are explained in more depth. These frameworks explain and evaluate factors that influence the eHealth implementation outcomes to create awareness and better understanding of sustainable eHealth implementation.

The next section focuses on sustainability theory and the implementation of sustainable technologies. The three pillars of sustainability (namely: social, economic and environmental) and their implication to the implementation of sustainable eHealth systems are explored based on previous research studies.

The systems approach is used as an underlying principle in this research study to address and evaluate the dynamic complexity of healthcare technology implementation. Hence three core areas of systems approach namely, systems thinking, systems engineering and system dynamics are discussed. The systems approach is applied to learn the holistic view of sustainable implementation as well as to gain a deeper understanding of eHealth ecosystems and the nonlinear relationship among elements of sustainable eHealth implementation. In this study, the system dynamics modelling approach is used to develop, simulate, test and validate the model of sustainable eHealth implementation. A system dynamics modelling approach is further discussed in systems approach section.

In addition to the eHealth technology under investigation, the environment in which the technology operates plays a significant role in the successful implementation of eHealth. Therefore aspects of the operating environment are linked with resource-constrained settings and factors associated with the operating environment are covered in the literature survey. The findings of this literature review section have been presented and published in the proceedings of International Association for Management of Technology (IAMOT), Cape Town, South Africa in 2015 and Birmingham, UK in 2018.

Fanta, G. B., Pretorius, L. and Erasmus, L. (2015) ‘An Evaluation of EHealth Systems Implementation Frameworks for Sustainability in Resource Constrained Environments: a Literature Review’, in *International Association for Management of Technology (IAMOT)*. Cape Town.

2.2. Electronic health (eHealth) technology

Following the explosion of the internet in the 1990s and the emergence of words such as e-Business, e-Solutions and e-Commerce, the term eHealth or e-Health was introduced to represent the promise of ICT to improve healthcare services (Eysenbach, 2001; Oh, Rizo, Enkin and Jadad, 2005). Despite the lack of consensus on a clear definition of eHealth, there is a tacit understanding of its meaning and the term is widely used by industries, academic institutions, funding agencies, professional bodies and many individuals (Oh et al., 2005). Among others, the technical capability of eHealth technology is one of the important factors that influence the successful implementation technical systems. Clearly defined functional and non-functional requirements, interoperability and user interface designs are some of the key success factors of eHealth implementation in the technology category (Rippen *et al.*, 2013). In the course of this research study, eHealth technology remains the system of interest and aims at achieving the sustainable use of eHealth technology and information product for decision making (Franz-Vasdeki *et al.*, 2015; Huang, Blaschke and Lucas, 2017).

2.2.1. eHealth definitions

In the systematic review of eHealth definitions, Oh et al. (2005) observed that ’health’ and ’technology’ were the dominant terminologies linked to eHealth in almost all the 51 analysed definitions of eHealth. According to Eysenbach (2001), the association of the term ’technology’ with eHealth makes it difficult to precisely define eHealth, because of the dynamic and evolving nature of technology at a fast pace. Currently, there are a number of terminologies that link technology with healthcare, such as health technology; health information system; electronic medical device; electronic medical equipment; medical informatics; health informatics; telemedicine; telehealth; telecare; eCare; teleconsultation; electronic medical records; health medical records; electronic patient records; mobile health (mHealth), etcetera (Jahangirian and Taylor, 2015). Hence ‘technology’ and ‘health’ are important but inadequate terminologies to define eHealth system in full.

In addition to the explosion of vast numbers of terminologies that represent various forms of technology, the increasing convergence of technology in digital world blurs the boundaries among technologies. This adds to the challenge of clearly defining technologies (Dutta and Mia, 2010). The integration of mobile phones, music players, digital cameras, Global Positioning Systems (GPS), alarm clocks, flashlights, calculators, handheld gaming devices, e-book readers, voice recorders, electronic dictionaries, computers and internet browsing makes it difficult to draw clear boundaries among these technologies.

Healthcare technologies are networked and linked to the central databases in the healthcare organizations for easier access by a different group of users. Moreover, different eHealth applications are integrated to talk to each other that further eliminates the boundaries between eHealth applications and complicates the effort of defining eHealth applications. As a result of frequently emerging technical terminologies and the fast pace of technological convergence, several terms have evolved in the healthcare environment that are related to the words ’technology’ and ’health’. Some of these terminologies are used interchangeably in different reports, e.g. Electronic Medical Records and Electronic Health Records (Boonstra and Broekhuis, 2010; WHO, 2011a:Vi); Electronic Medical Records and Patient Health Records (Vital Wave Consulting, 2009:14); Telehealth and eHealth (van Dyk, 2014:1285).

The WHO definition of eHealth adopted for the purpose of this study is “the cost-effective and secure use of information and communications technologies (ICT) in support of health and health-related fields, including health-care services, health surveillance, health literature, and health education, knowledge and research” (WHO, 2005). Even though several categories of eHealth systems exist globally, the subsequent sections focus on eHealth technologies widely piloted and implemented in resource-constrained environments.

2.2.2. Types of eHealth system

There are several types of eHealth systems available in the marketplace with different names and functionalities. All ICT applications that support the healthcare services delivery are eHealth systems (WHO, 2012b). Jahangirian & Taylor (2015) categorized eHealth applications into four groups, i.e., telemedicine, health information system, health education and health-related research. Although the boundaries between different eHealth types are not always clear, some commonly used eHealth applications include mHealth, Health information systems and telemedicine. The eHealth projects in Africa focus on mHealth, telemedicine, health education and health-related researchers (Jahangirian and Taylor, 2015). These eHealth projects are growing in number over time especially in African countries with larger Gross National Incomes (Jahangirian and Taylor, 2015). These eHealth types are the focus of this research study and discussed in the following section.

Mobile Health (mHealth) is a type of eHealth system that uses a mobile device to support medical and public health practices (WHO, 2011b). The number of m-Health projects has been rising sharply in Africa (Jahangirian and Taylor, 2015). However, the number of mHealth projects within African countries with high mobile phone penetration rates of over 90%, such as Seychelles, Gabon, Botswana, Mauritius, and Libya is still very low (Jahangirian and Taylor, 2015). There are different types of mHealth applications and some of these applications are summarised in Table 2.1.

Table 2.1 Types of mHealth application - developed from (Leon, Schneider and Daviaud, 2012; Marshall, Lewis and Whittaker, 2013).

mHealth Applications	**Examples**
Text messaging	Appointment reminders, treatment reminders, medication reminder, health promotion, emergency notifications, surveillance, community mobilisation, patient diagnostics.
Voice and video services	Automated health information lines, health call centres, emergency toll-free lines, patient monitoring, mobile telemedicine
Internet connection	Health promotion, population surveys, patient records, surveillance, decision-support systems, patient monitoring.
Data collection	Access to data for research and disease surveillance.
Management	Planning, monitoring, evaluation and supervision of workers; data collection and rapid reporting; improving administrative systems; facilitating communication.
Clinical service delivery	Diagnosis and treatment at point care; electronic prescribing system.
Health promotion activities	Increase patients' health awareness via messaging, promote access to health services.
Education and training	Training personnel, evaluating impact of training, access to reference materials

The rapid penetration of mobile networks in developing countries has increased the potential of mobile technology to support the healthcare service delivery in disadvantaged areas. The use of mobile services for development has increased almost five times between 2007 and 2011 (Cargo, 2013). The use of mobile communication for health (mHealth) dominates the mobile development activities in developing countries as shown in Figure 2.2. Figure 2.2 is based on mobile-enabled products and services in developing world reported by Groupe Spéciale Mobile Association (GSMA) as of September 2012.

mHealth has been used for education and awareness, remote data collection, remote monitoring, communication and training to health care workers, disease and epidemic outbreak tracking, diagnosis and treatment support (Marshall, Lewis and Whittaker, 2013). Although there is a rapid increase in the number of mobile subscribers in Africa, its use is limited because of high tariff (Dutta and Mia, 2010).

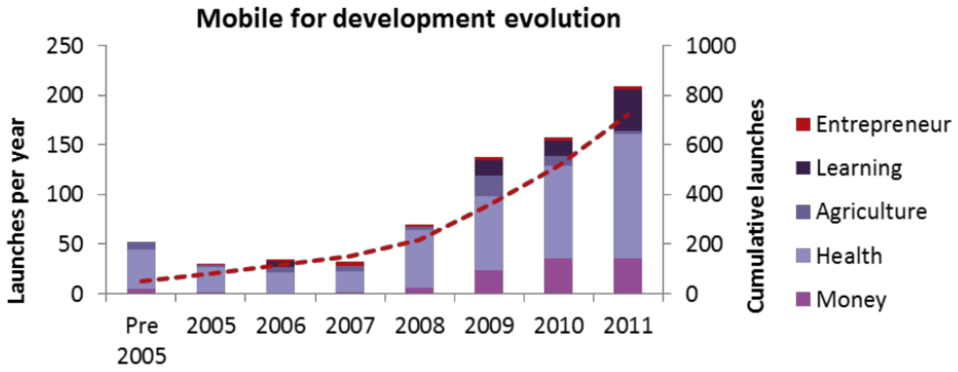


Figure 2.2 The evolution of mobile for development in developing countries (Cargo, 2013).

Healthcare Information Systems (HIS) is an ICT system concerned with the storing, processing, and transferring patient medical records and other health-related data electronically (Jahangirian and Taylor, 2015). The compilation of individual and aggregated health-related data to make them accessible to other healthcare professionals in a digital format is referred as Electronic Records Systems (WHO, 2012b). The three common electronic record systems in health are:

Electronic Medical Record (EMR) is a real-time patient health-related information that can be created, gathered, managed and used to aid the decision of authorized clinicians and staff within one healthcare organization (ALLIANCE, 2008; WHO, 2012b).

Electronic Health Record (EHR) is “a longitudinal electronic record of patient health information generated by one or more encounters in any care delivery setting” (WHO 2012b:11).

Personal Health Record (PHR) is “an electronic record of health-related information on an individual that conforms to nationally recognised interoperability standards and that can be drawn from multiple sources while being managed, shared, and controlled by the individual” (ALLIANCE 2008:19).

Telemedicine is the use of electronic communication or ICT to exchange medical information from one site to another for the purpose of patient care, and education to the patient and healthcare providers (ATA, 2012). Jahangirian & Taylor (2015) defined telemedicine as the use of ICT to support some form of remote consultation between medical staff and patients. Sood et al. (2007) studied 104 peer-reviewed articles from four different perspectives to understand the definitions of telemedicine.

- Medical Perspective: provision of healthcare services through the exchange of valid information for diagnosis, treatment and prevention of disease and injuries, research and evaluation, and for the education of healthcare providers (WHO, 2010b).
- Technological Perspective: It uses ICT.
- Spatial Perspective: there is a geographic separation between the patient and healthcare provider.
- Benefits Perspective: brings medical care to people whenever it is not feasible to get people to the medical care.

Telemedicine service is either delivered asynchronously or synchronously (Mars, 2013). In asynchronous or store and forward telemedicine, medical information is gathered and sent to another health care provider electronically; whereas synchronous telemedicine is real-time consultation and distance examination through video conferencing (Mars, 2013). Telemedicine has been used in several domains of healthcare in several African countries, including cardiology (telecardiology), radiology (teleradiology), pathology (telepathology), dermatology (teledermatology), obstetrics (teleultrasonography), psychiatry (telepsychiatry) and ophthalmology (teleophthalmology) (Mars, 2013). There are reports of telemedicine activities in all African countries except South Sudan, but countries like South Africa, Kenya, Uganda, Botswana, Ghana, and Ethiopia reported more than five papers on telemedicine activity (Mars, 2013; Scott and Mars, 2013). The first telemedicine implementation has failed in Ethiopia and South Africa for similar reasons; this includes lack of change management plan, poor project management, connectivity problem and staff turnover (Shiferaw and Zolfo, 2012; Mars, 2013).

The electronic health education program also referred to health-related eLearning program is the use of ICT for the activities of health and medical education (Jahangirian and Taylor, 2015). The electronic health-related research denotes the use of ICT to support health-related research studies (Jahangirian and Taylor, 2015). Telemedicine systems supported telehealth programs in South Africa through tele-education services (Mars, 2014).

2.2.3. eHealth stakeholders

A stakeholder is anyone (group or individual) who can directly or indirectly affect or is affected by the implementation of a system (Mengesha *et al.*, 2013). The stakeholders are involved in the development, implementation, support, operation, funding, decision making, policy or utilisation of the system (WHO and ITU, 2012). The four group of stakeholders in the development of national eHealth vision are clustered into four categories: broader stakeholders and the general public, engaged stakeholder, key influencers and decision makers (WHO and ITU, 2012).

- Broader stakeholder and general public indicate individuals, carers, families, community groups and employers.
- Engaged stakeholder refers to advocacy groups, health executives, insurers, patient associations.
- Key Influencers include advisors, academics and senior executives in health, funding and investment organizations.
- Decision-makers represent national eHealth steering committee.

Recognising the key stakeholders will help to identify the different interests of the concerned groups who will have a significant influence on the successful implementation of eHealth technology. The ongoing involvement of key stakeholders from conception stage until implementation and operation can help to meet the stakeholder requirement and ensure the long-term sustainability of the system (Cresswell and Sheikh, 2012). A four-level model of the healthcare system represents stakeholders under four bigger groups, i.e., patient, care team, organization and environment (Reid *et al.*, 2005).

- *Patient* represents patients and family members receiving the service.
- *Care team* refers to the frontline care providers such as health care workforce, family members and others.
- *Organization* indicates infrastructure and resources within hospitals, clinics, nursing homes, etc.
- *Environment* implies regulatory, market, policy environment such as public and private regulators, insurers, health care purchasers, research funders, et al.

The patients and care teams in a four-level model of the healthcare system correspond to the broader stakeholder and general public group categories of WHO & ITU eHealth stakeholders' framework. The environment comprises a group of people outside the control of the organization. All stakeholder groups influence the success of eHealth implementation directly or indirectly.

2.2.4. The benefits of eHealth

The eHealth systems are anticipated to benefit the healthcare system by improving the efficiency and effectiveness of healthcare service delivery. The benefit of eHealth systems varies across the different interests of stakeholder groups and the type of eHealth systems. This section discusses the various features and benefits of eHealth technologies to different stakeholders groups. For example, patients can use electronic health system to communicate with caregivers about their health. Moreover, the healthcare professional can also use eHealth systems to maintain records, to make clinical decisions or inform patients about their health (Michel-Verkerke et al. 2015). eHealth technology can facilitate the provision of healthcare services, the collaboration of healthcare team, and the evaluation and research (Michel-Verkerke et al. 2015). The health statistics, billing information and quality assurance are some of the advantages of eHealth to the public users (Michel-Verkerke et al. 2015).

The computerized patient record system captures and reports allergies or adverse reactions, problem lists, medications, test results, discharge summaries, physicians notes, notifications or patient record flags (Byrne et al., 2010:631). The digital recording of this information helps to reduce costs associated with preventable adverse drug events, unnecessary redundant laboratory and radiology tests and also reduce the time spent at reception by file clerks (Byrne et al., 2010:631). In general, electronic patient record, picture archive, pharmaceutical and laboratory systems benefit patients and caregivers to decrease expenses, eliminate redundancy, reduce workload and avoid utilization (Byrne et al., 2010:631).

According to Peek et al. (2014), the four pre-implementation acceptance factors associated with the expected benefits of eHealth technology for ageing communities include:

- *Increased safety:* the technology helps an early detection of diseases and enables to get medical attention before it is too late.
- *Perceived usefulness:* the older adults are willing to use the technology when the potential benefits are recognised.
- *Increased independence:* using the technology for ageing people will increase their independence.
- *Reduced burden on family caregivers*: the increased independence of older adults reduce the burden on family caregivers.

The potential benefits of mHealth systems to patients, providers, and other stakeholders are summarised in Table 2.2 (Schweitzer and Synowiec, 2012). Maffei, Burciago and Dunn, (2009:274) indicated that the Regional health information organizations (RHIOs) helps:

- To support safe clinical decision making by sharing current and complete patient record with caregivers within the region.
- To improve operating efficiency by reducing the cost of the patient data management process.
- To improved clinical efficiency by reducing medical errors, shortening hospital lengths of stay, avoiding duplicate tests and reducing readmissions.

Table 2.2 The potential benefits and outcomes of mHealth to different stakeholder groups (Schweitzer & Synowiec 2012:77-79).

Outcome Group	Outcome Measures
Clients/Patients	
Medical effectiveness	Reduce morbidity
	Avoid Mortality
Healthcare services and others	Increased access to healthcare
	Increased knowledge/ ability for self-care
	Reduced waiting and/or consultation time
	Increased adherence to medical regimen
Occupation	Continuity of income
	Increase employment/ leisure/ classroom time
Travel	Reduce money spent on travel (transportation, accommodation and other expenses)
Providers	
Healthcare services and others	Reduced the length of stay at a medical facility
	Avoided medical readmissions
	Avoided inpatient visits
	Avoided laboratory tests
	Avoided patient's transportation to healthcare facilities
Other outcomes	Reduced the length of consultations
	Increased medication adherence
	Increased knowledge transfer among practitioners
	Increased accuracy and faster diagnosis and treatment
	Increased patient satisfaction
Decreased travel and/or home visits for staff	Increased employment time (productivity)
	Money spent on travel: transportation and accommodation
Other stakeholders	
Healthcare services and others	Increase productivity of workers (less travel, less illness)
	More efficient access to health for special groups or informal sectors: transportation costs, staff costs
	Avoided cases of communicable diseases

The benefits of eHealth technology discussed above mainly link to the two key stakeholder groups, i.e., patients and caregivers. This could possibly comes from a patient-centric healthcare services delivery approach advocated by the healthcare organizations. However, it is important to remember that healthcare providers bear two third of the overall costs of eHealth, but estimated to share only 6% of the benefits through improved efficiency (Parv *et al.*, 2012). Hence the benefit to the healthcare organiations need to be explained vividly to facilitate the implementation of sustinable eHealth systems in the healtcare facilities. Some of the benefits of eHealth to the healthcare organization includes improved healthcare quality outcomes, better performance, time savings, resource liberation and cost avoidance (Stroetmann et al. 2006: 13-14).

Stroetmann *et al.*, (2006) indicated that quality, access and efficiency are the three main types of benefits arising from the eHealth investment for all stakeholder groups. The benefit for citizens includes better quality of care and better access to healthcare service (Stroetmann et al. 2006:10). A survey result of eHealth experts suggested that the three top benefits of eHealth in low and middle-income countries (LMIC) are to facilitate health information, to increase access to healthcare services and to provide health-related training to staffs (Quaglio *et al.*, 2016).

2.3. Challenges and successes of eHealth implementation

2.3.1. Challenges of eHealth implementation

The realization of eHealth promises is deterred by several challenges, especially in developing countries. The potential barriers to the wide-scale adoption and use of eHealth systems include lack of access to capital (financial), systems complexity (technological), privacy concerns (social) and legal barriers (environmental) (Anderson, 2007:482). In a systematic review of twenty-two articles, Boonstra & Broekhuis (2010) categorised the barriers of eHealth implementation into eight major groups as perceived by physicians. These categories are financial, technical, time, psychological, social, legal, organizational, and change process (Boonstra and Broekhuis, 2010).

Financial issues refer to the cost of purchasing the system, ongoing maintenance costs, and uncertainty over return on investment (ROI) and lack of financial resources (Boonstra and Broekhuis, 2010; Stroetmann, 2015). The lack of computer skill by physicians and staffs, lack of technical training and support, the complexity of the system, limitations of the system, lack of customizability, unreliability, lack of interoperability and shortage of equipment were mentioned as the technical barriers in the implementation of eHealth (Boonstra and Broekhuis, 2010).

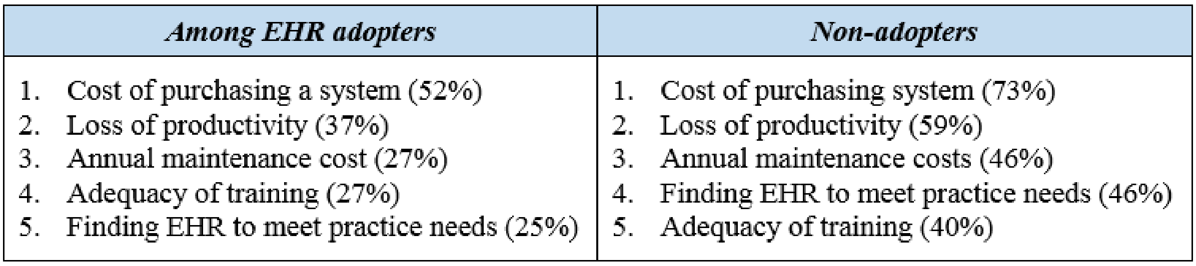
The implementation obstacles in the time category include the time required to select, purchase and implement the system, time to learn the system, the time required to enter data, additional time spent per patient, and time to digitalize patient records (Boonstra and Broekhuis, 2010). The psychological barriers to eHealth implementation were reported to be the lack of trust in electronic systems and fear of losing control (Boonstra and Broekhuis, 2010).

The literature studies on the social obstacles of eHealth implementation include lack of confidence on the vendor, lack of external support such as government, problems on the doctor-patient relationship, lack of support from other colleagues and management (Boonstra and Broekhuis, 2010).

Privacy and security concerns are the key legal issues that had a negative impact on the implementation of eHealth (Boonstra and Broekhuis, 2010). The size and type of the organization were reported to influence the implementation of eHealth in the organizational category (Boonstra and Broekhuis, 2010). Larger organizations and private healthcare institutions showed higher adoption rate of eHealth than small organizations and public healthcare institutes (Boonstra and Broekhuis, 2010). The barriers to eHealth implementation in the change process category include lack of support from the organizational culture, lack of incentives, lack of participation and lack of leadership (Boonstra and Broekhuis, 2010).

A survey that investigated the benefits and limits of eHealth indicated that poor infrastructure, lack of political support and human capital, and low financial affordability were the main impediments of eHealth success (Quaglio *et al.*, 2016). The physicians' concern on the issues that could prevent the adoption of the electronic system are listed in Table 2.3. The lack of stable electricity supply and connectivity, poor infrastructure, financial affordability, lack of political support and human capital reduced the potential benefits of eHealth in LMICs (Quaglio *et al.*, 2016).

Table 2.3 Top five barriers to EHR adoption by office-based physicians (ONC, 2014).



Among EHR adopters	*Non-adopters*
1. Cost of purchasing a system (52%)	1. Cost of purchasing system (73%)
2. Loss of productivity (37%)	2. Loss of productivity (59%)
3. Annual maintenance cost (27%)	3. Annual maintenance costs (46%)
4. Adequacy of training (27%)	4. Finding EHR to meet practice needs (46%)
5. Finding EHR to meet practice needs (25%)	5. Adequacy of training (40%)

The top two barriers of eHealth are associated with the availability of financial resources to purchase the system and cover the maintenance costs according both adopters and non-adopters of EHR. The significance of financial barrier is high in the implementation of sustainable eHealth systems in the developing countries where the financial resources are limited.

Despite their greatest needs of healthcare services, elderly people are often less familiar with eHealth technology. The barriers to the adoption eHealth technology in the elderly people include (Fischer *et al.*, 2014):

- Lack of familiarity and access.
- Lack of technical support.
- Lack of trust.
- Privacy concerns.
- Design issues associated with weak sight and hearing ability.

As indicated by a systematic review of mixed studies, the pre-implementation concerns of eHealth technology within community-dwelling older adults are (Peek *et al.*, 2014):

- High cost of implementation.
- Privacy implications.
- Forgetting or losing technology.
- False alarms.
- Obstructiveness.
- Burdening children.
- Ineffectiveness.
- Impracticality.
- Low ease of use.
- Negative effect on health.
- Lack of control over technology.

On the other hand, key challenges to the use of eHealth by the elderly people is associated with technology use, i.e., low ease of use, lack of technical support, poor sight and hearing, forgetting the technology, false alarms as a result of technology miss uses. Likewise, legal issues connected to lack of control over technology, trust and privacy concern indicated as barriers of eHealth use by older adults.

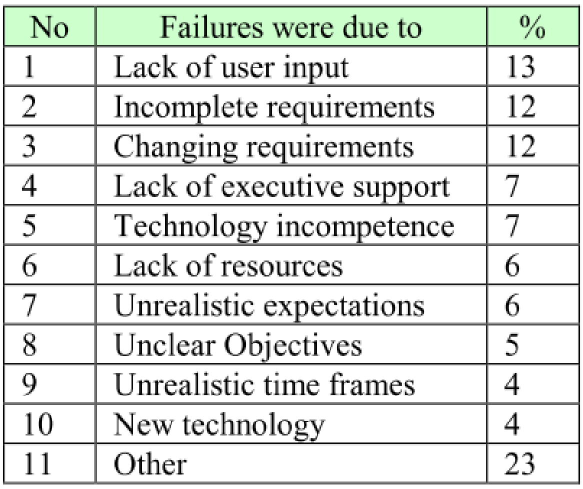
The major weaknesses of donor-funded programs were found to be the lack of long-term support after the pilot phase, duplication and fragmentation of electronic applications, absence of technical support and maintenance, insufficient capacity building and rare long-term sustainability (Quaglio *et al.*, 2016). The six factors that hinder eHealth systems from going beyond pilot phase to achieve sustainability in developing world as explained in the non-systematic review of the literature study include (Luna *et al.*, 2014):

- *Resources and infrastructure limitations:* the infrastructure limitations include non-reliable electricity, low-quality and expensive Internet access. Moreover, the scarcity and irregular distribution of infrastructure between rural and urban, private and public healthcare institutions pose addition infrastructure problem in the implementation of eHealth systems. As a result, information is fragmented and projects are difficult to scale-up.
- *Lack of comprehensive Health IT Agendas*: include lack of eHealth IT agendas for health data standards, and priority setting to facilitate the implementation and acceptance of eHealth through economic incentives and professional training programs.
- *Uncertainties, ethical and legal factors*: overcoming new eHealth implementation challenges, as well as addressing explicit and broad legal regulations is required. Furthermore, managing ethical issues and safeguarding patient data through training and other technical approaches are necessary to assist sustainable eHealth implementation.
- *Lack of use of common interoperability standards*: the fragmented, incomplete, inaccurate, and isolated health information system without a common standard to exchange and use information between different systems (interoperability) is huge obstacle to accomplish healthcare goals.
- *Lack of a trained workforce*: an appropriately trained workforce is a critical component of sustainable eHealth implementation. The implementation of educational programs and short-term health informatics training in partnership with trusted institutions; and use of ICT to share resources within healthcare team supports the effort of training workforce to ensure sustainability of eHealth systems.
- *Lack of regional integration:* the transition from a pilot project to a sustainable implementation requires sharing experiences of eHealth implementation programs and teaching resources.

The implementation challenges of sustainable eHealth systems in the developing countries are linked to the limitations of infrastructure and resources (Luna *et al.*, 2014). The shortage of financial resources is also described as a major eHealth adoption challenge by the EHR adopter and non-adopter groups (ONC, 2014). Moreover the lack of trained workforce is indicated as one of the barriers of eHealth implementation in the developing country that affects technology use. Similarly, elderly people mentioned technology usability factors as challenges of eHealth technology use. The resources limitations and eHealth technology usability factors are two of the major barriers of sustainable eHealth implementation in the developing worlds.

The reliability, speed, and cost of information technology (IT) systems have increased through time, yet the complexity and risks of IT projects continue to rise (Marchewka, 2003). In the United States, one-third of IT projects were cancelled before completion, and half of the projects were completed with over budget, over schedule, or/and missed original specification (Marchewka, 2003). Table 2.4 below shows 10 major reasons for the failure of IT projects.

Table 2.4 Reasons for failure of IT projects (Marchewka, 2003).



No	Failures were due to	%
1	Lack of user input	13
2	Incomplete requirements	12
3	Changing requirements	12
4	Lack of executive support	7
5	Technology incompetence	7
6	Lack of resources	6
7	Unrealistic expectations	6
8	Unclear Objectives	5
9	Unrealistic time frames	4
10	New technology	4
11	Other	23

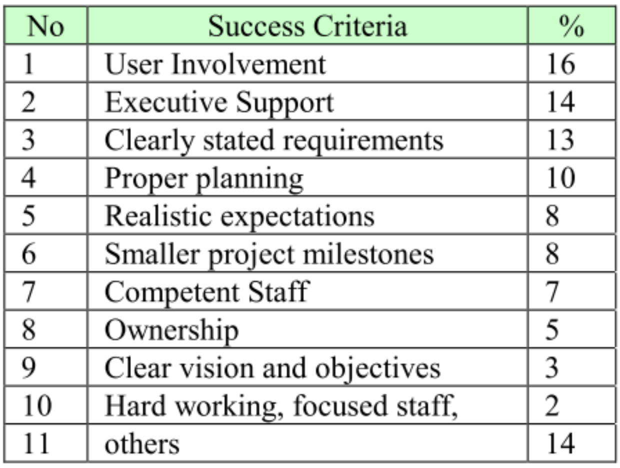
The failure factors of IT projects listed above are also indicated as challenges of eHealth technology implementation. The lack of resources and technology incompetence are the two popular barriers of eHealth implementation in the developing countries. The lack of users input and incomplete requirements are discussed as design issues in the implementation of eHealth systems. In general, the IT project challenges are also noticed as barriers to the implementation of sustainable eHealth systems.

2.3.2. Successful Implementation of eHealth

The participation of several stakeholders in the implementation of eHealth with different levels of expectation makes it difficult to explicitly indicate the success determinants of eHealth systems without associating it with stakeholders. As a result, the success of eHealth implementation is aligned with the stakeholder requirements (van der Meijden *et al.*, 2003). Moreover, technological changes may also force success determinants to change over time. The short technological innovation life cycle can easily make successful systems to become obsolete as determinants of success factors evolve. As indicated by Hadji et al. (2016), the success determinants of early and late post-adoption may also vary over time. Success factors depend on the settings, the objectives, and the interests of stakeholders (van der Meijden *et al.*, 2003).

Marchewka (2003) ranked the key factors for successful implementation of IT projects as shown in Table 2.5.

Table 2.5 Key factors for the IT projects (Marchewka, 2003).



No	Success Criteria	%
1	User Involvement	16
2	Executive Support	14
3	Clearly stated requirements	13
4	Proper planning	10
5	Realistic expectations	8
6	Smaller project milestones	8
7	Competent Staff	7
8	Ownership	5
9	Clear vision and objectives	3
10	Hard working, focused staff,	2
11	others	14

The effectiveness of eHealth implementation is associated with ease of accessibility, low implementation and operations cost, and user-friendliness of the technology (Jahangirian and Taylor, 2015). The successful implementation of eHealth systems was also linked to the acceptance or use of the technology by the end-users (Michel-Verkerke et al. 2015; Tilahun & Fritz 2015b), the sustainability of the technology (Isabalija, Mbarika and Kituyi, 2013), managing stakeholders expectations (Mettler, 2015), and meaningful use and end-users satisfaction (Hadji *et al.*, 2016). In this research study, eHealth success is mainly associated with the sustainability of the technology aiming at associating sustainable implementation of eHealth system to the acceptance of technology by end-users and the use of information for evidence-based decision making in healthcare institutions.

2.3.3. eHealth Success Factors

The analysis of 47 publications resulted in 381 success criteria for health IT implementation and 229 corresponding measurements (Fritz, Tilahun and Dugas, 2015). These success factors of health IT implementation were categorised into seven core groups (Fritz, Tilahun and Dugas, 2015):

- Ethical: includes regulatory and cultural issues.
- Financial: contains resources and funding.
- Functionality: refers to the system architecture and functions.
- Organizational: denotes managerial circumstances within the organization.
- Political: includes legal health policies and country-wide circumstances.
- Technical: comprises infrastructure.

- Training: includes educational background and knowledge.

Fritz et al. (2015) recommended that functional (data handling, usability and local adaptability), organizational (skill, project management, executives commitment, stakeholder involvement and attitude towards the system) and infrastructure (system architecture to address security and privacy) aspects should be given special focus in the low-resource settings.

The users of electronic patient record system identified five requirements for successful implementation of the technology (Michel-Verkerke et al. 2015:139).

- Relevance to the end-users.
- Complete and integrated patient data.
- Availability and accessibility anywhere at any time.
- Active functionality, like alerts, decision support and workflow management.
- Inclusion of data necessary for quality and finance.

The complete lists of eHealth success factors are addressed in more detail (Appendix 2.1).

2.3.4. eHealth implementation frameworks

Several research studies published eHealth implementation frameworks that support the sustainable implementation of eHealth. The common eHealth implementation frameworks and factors that influence eHealth success are presented in this section. The frameworks address the social, organizational, economic and technological factors of sustainable eHealth implementations.

Framework 1

After reviewing eHealth frameworks in nine published articles, van Dyk (2014) confirmed the importance of a holistic approach for the implementation of a telehealth service that considers the following themes: technology, organizational structures, change management, economic feasibility, societal impacts, perceptions, user-friendliness, evaluation and evidence, legislation, policy and governance. The themes mentioned above address both the system of interest and its operating environment to ensure sustainability of eHealth. However, the article did not discuss the themes in an adequate depth and also the categories were not compact enough to understand and apply the model.

Framework 2

The study combined 19 key informant interviews, site visits to three mobile health (mHealth) projects and document reviews, to propose a health systems framework that addresses the four major health system dimensions required for scaling up mHealth systems and the associated capacity requirements for each dimension (Leon, Schneider and Daviaud, 2012). The framework illustrates the four health system dimensions that should be considered when making mHealth scale up decision (Figure 2.3).

- *Government stewardship*: policy environment supportive of mHealth.
- *Organizational*: culture and capacity to use information technology for management.
- *Technological*: usability, integration, and sustainability of the chosen technology.
- *Financial*: adequacy of finance for the medium to long-term use of mHealth.

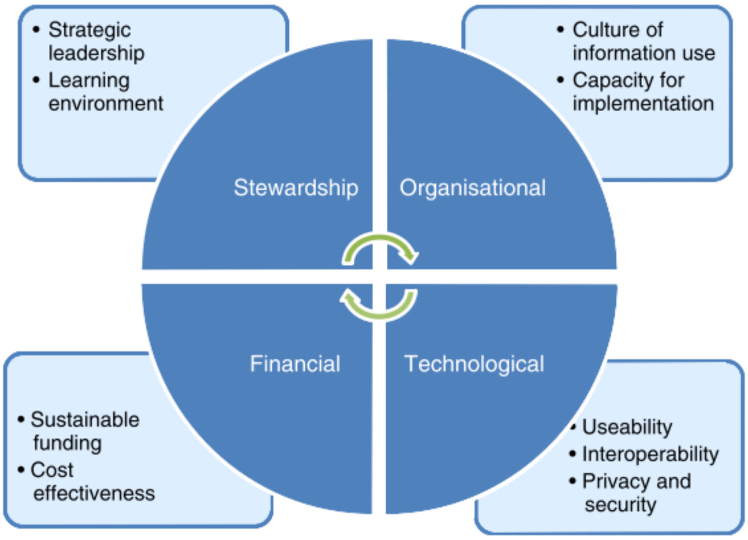


Figure 2.3 Health Systems framework for decision-making about mHealth for community-based health services (Leon, Schneider and Daviaud, 2012:5).

The strength of the framework is its ability to address key eHealth sustainability factors, covering both the eHealth system and its operating environment. The economic and technological factors appear to be addressed in more depth compared to the social and organizational factors. The ethical, behavioural and stakeholders' related issues are missing from the social factors. Moreover, legal and change management are also not considered under the environmental factors.

Framework 3

The four components of the eHealth Architectural Maturity Model (eHAMM), which can be used for systems analysis and development of strategy, as described in ISO/TR 14639-1 are (ISO, 2012):

- *Governance and National Ownership:* consists of executive sponsorship; national leadership of the eHealth program; adoption and implementation of eHealth standards; development of eHealth capacity and capability; eHealth financing and performance management; eHealth planning; and architectural maintenance.

- *Foundation – eHealth Infostructure:* includes EHR and health information repositories; identification registries and directories; clinical terminology and classifications; data interchange interoperability and accessibility; consent/access control and workflow management; privacy; security and safety regimes; census and population information; and data warehouse.
- *Foundation – ICT Infrastructure:* comprises local access to ICT equipment and facilities; electronic communication infrastructure; ICT processing and storage services; ICT professional and technical support; standards, methods, guidelines and frameworks.
- *Health Process Domain Components:* cover community based; primary care; hospital/institutional; public health and disease surveillance; diagnostic; emergency response; pharmacy; healthcare supply chain services; human resources in health; health finance and insurance; vital records collection and management; environmental monitoring; and knowledge management and eLearning.

The health process domain of the model deals with different components of healthcare services that can be supported by eHealth systems. The eHealth infostructure relates to the technological aspect of eHealth sustainability factors; whereas on the other hand, the ICT infrastructure, governance and national ownership components of the ISO model mainly link to the organizational factors. The model of eHealth architecture covers the environmental and technological factors of eHealth sustainability in detail; however, the model does not seem to address the social dimension of eHealth system’s implementation.

Framework 4

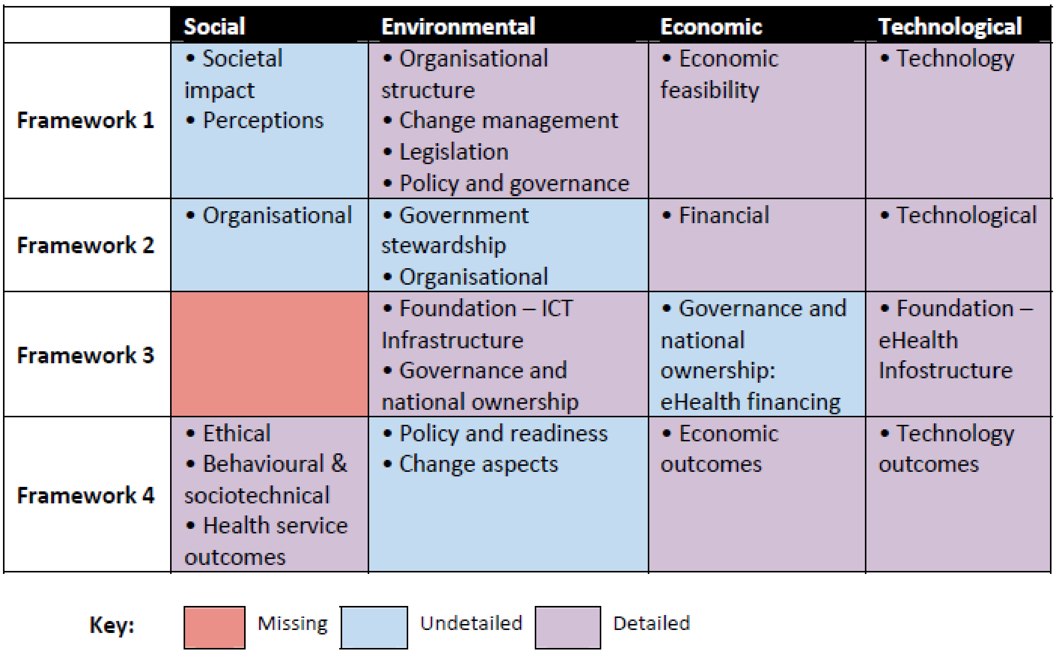
The Khoja-Durrani-Scott (KDS) framework covers a wide range of areas influenced by eHealth interventions, including (Khoja *et al.,* 2013):

- Health services outcomes.
- Behavioural and socio-technical outcomes.
- Technological outcomes.
- Economic outcomes.
- Ethical outcomes.
- Policy outcomes.
- Readiness and change outcomes.

The KDS framework aims at evaluating eHealth programs at the development, implementation, integration and sustained operation stages of the eHealth implementation life cycle (Khoja et al., 2013). The KDS framework is comprehensive in covering the social, organizational, economic and technological factors of sustainable eHealth implementation. The economic factors are covered under economic outcomes of the KDS framework; whereas the technology outcomes of the KDS framework addresses the technological factors of sustainable eHealth implementation. The KDS framework addressed the social factors under ethical, behavioural, socio-technical and health service outcomes. The organizational factors are also discussed in the policy, readiness and change aspects of eHealth programs in the framework. The weakness of KDS framework is its failure to cover the legal factors and aspects of management and political supports in-depth under the organizational dimension.

The four eHealth implementation frameworks discussed in this section are summarised in Table 2.6. The frameworks are evaluated under the social, organizational, economic and technological factors of sustainable eHealth implementation.

Table 2.6 Summary of eHealth frameworks evaluation



	Social	Environmental	Economic	Technological
Framework 1	🟦 • Societal impact • Perceptions	🟪 • Organisational structure • Change management • Legislation • Policy and governance	🟪 • Economic feasibility	🟪 • Technology
Framework 2	🟦 • Organisational	🟦 • Government stewardship • Organisational	🟪 • Financial	🟪 • Technological
Framework 3	🟥	🟪 • Foundation – ICT Infrastructure • Governance and national ownership	🟦 • Governance and national ownership: eHealth financing	🟪 • Foundation – eHealth Infostructure
Framework 4	🟪 • Ethical • Behavioural & sociotechnical • Health service outcomes	🟦 • Policy and readiness • Change aspects	🟪 • Economic outcomes	🟪 • Technology outcomes

Key: 🟥 Missing 🟦 Undetailed 🟪 Detailed

2.3.5. eHealth evaluation frameworks

The Health Information Systems (HIS) implementation effort in a developing country is fragmented because of the pressure from donors, economic and political factors (WHO, 2012). Most donor-funded electronic health systems are modelled by disease categories such as TB, HIV/AIDS and Malaria as per the information needs of donors (Aqil, Lippeveld and Hozumi, 2009; WHO, 2012a). As a result, multiple information systems run within a healthcare facility without talking to each other electronically. This puts data collection burden on healthcare workers and causes dichotomy between healthcare data team and health systems managers (Aqil, Lippeveld and Hozumi, 2009).

The PRISM (Performance of Routine Information System Management) framework is composed of inputs, processes and outputs or performance (Figure 2.4). The framework describes the causal pathways of organizational, technical and behavioural determinants to improve the performance of routine information system management (Aqil, Lippeveld and Hozumi, 2009). The PRISM framework aims at improving the quality of data and ensure continuous use of information within a healthcare organization setting (Aqil, Lippeveld and Hozumi, 2009).

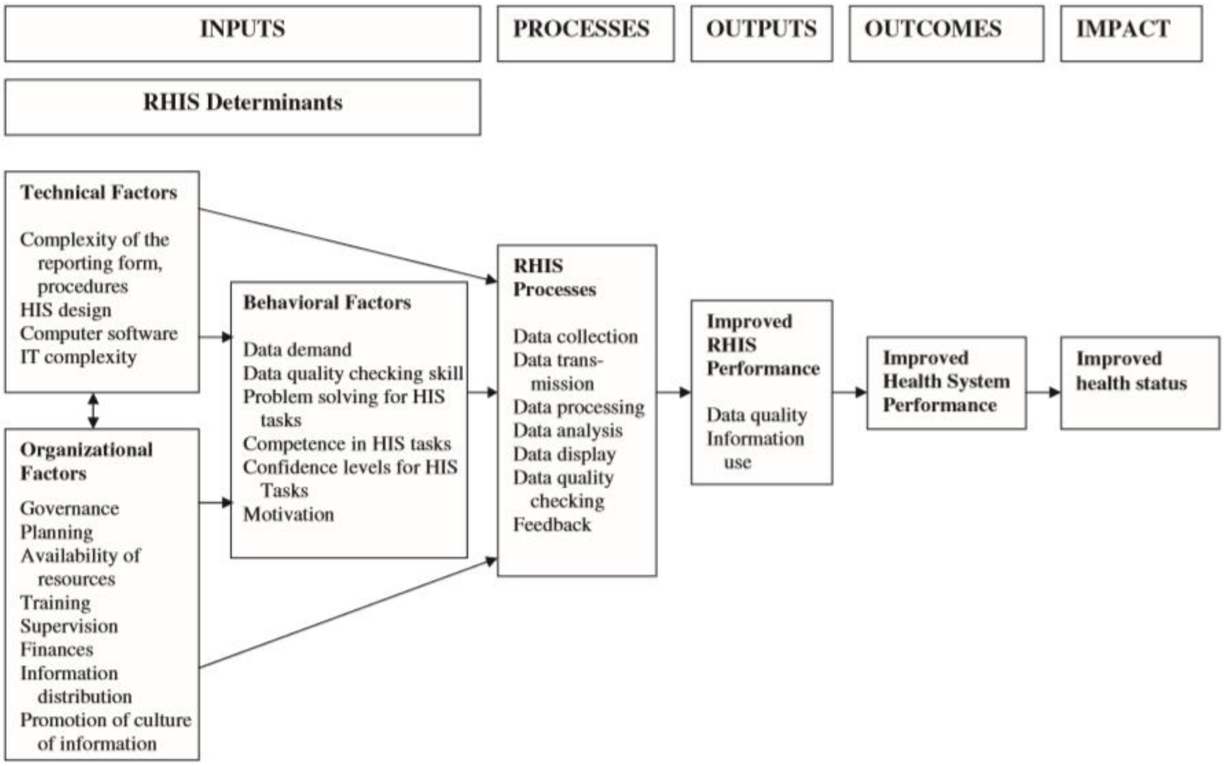


Figure 2.4 PRISM (Performance of Routine Information System Management) framework (Aqil, Lippeveld and Hozumi, 2009:220).

The inputs or HIS determinants are captured not only under technical categories but also as a set of interrelated elements that are specific to the contextual issues of the organization and behavioural categories of the healthcare team (Aqil, Lippeveld and Hozumi, 2009).

Behavioural determinants: the individuals' feelings about the usefulness of the system, their motivation, the user's problem-solving skills, competence and confidence to use the system are factors that have a direct influence on the process and performance of HIS (Aqil, Lippeveld and Hozumi, 2009).

Organizational determinants: HIS is implemented and used within an organizational context which is influenced by organizational factors such as organizational structure, procedures, culture, rules, values and practices, resources, management support, supervision and leadership. Organizational determinants affect the performance of HIS directly or indirectly through behavioural factors (Aqil, Lippeveld and Hozumi, 2009).

Technical determinants: factors associated with the design complexity of information technology affects HIS performance directly or indirectly through behavioural factors (Aqil, Lippeveld and Hozumi, 2009).

The HIS processes category measures the existence of procedures for data collection, transmission, processing, analysis as well as data quality checks and feedbacks to improve individual and system performance (Aqil, Lippeveld and Hozumi, 2009:218). The outputs or RHIS performance category captures the data quality issues such as relevance, completeness, timeliness and accuracy (Aqil, Lippeveld and Hozumi, 2009). Moreover, this dimension addresses information use for problems identification, decisions making and advocacy (Aqil, Lippeveld and Hozumi, 2009).

Developing indicators based on information needs, data collection, transmission, processing and analysis are described as the core components of an information system. Aqil, Lippeveld and Hozumi (2009) indicated senior management plays a key role in developing organizational rules and providing resources such as training, finances, material, computer equipment, etc. to ensure sustainable use of electronic health systems. In order to achieve a quality data for decision making, the eHealth needs to be accepted by the users. The next section discusses the technology acceptance models which is a necessary condition to the production of quality information for decision makings.

2.4. Models of Information Technology Acceptance, Diffusion and Success

Technology diffusion is a process that covers a wide range of stages from knowledge inception to technology acceptance by the end-users. On the other hand, technology acceptance is part of technology diffusion process that focuses on the ultimate acceptance of a technology by the end-users. The acceptance of technology by end-users is a key to ensure the long-term sustainability of eHealth system implementation. The technology that is not accepted by the end-users cannot be sustainable, even after a successful adoption of technology by the organization.

2.4.1. Technology diffusion model

The five stage innovation-decision process model incorporates the decision as well as the process stages of technology adoption and technology acceptance (Rogers, 2003). Technology adoption and acceptance play a key role in the process of effective technology diffusion. The adoption of technology can happen at the institutional level or at an individual level; whereas, the acceptance of technology typically takes place at an individual level (Oliveira and Martins, 2011). The term user adoption refers to the individual’s willingness towards using particular technologies (Sezgin, Alaşehir and Yıldırım, 2014). Despite several eHealth implementation efforts, only a few studies link the socio-technical factors such as individual and organizational characteristics to the acceptance or rejection of new technologies (Ward, 2013).

Technology adoption process precedes technology acceptance in the process of an innovation-decision process model. Venkatesh & Bala (2008) discussed two interventions in the process of technology adoption: pre-implementation that refers to the adoption process and post-implementation that indicates the acceptance process. Rogers (2003) described the innovation-decision process in five phases (Figure 2.5):

- *Knowledge*: learning about the existence, use and function of the innovation.
- *Persuasion*: forming a favourable or unfavourable attitude towards the innovation.
- *Decision*: individual chooses to adopt or reject the innovation.
- *Implementation*: putting an innovation to use.
- *Confirmation*: “the ultimate acceptance or rejection of the innovation”(Ward 2013:225).

The first three stages of the innovation-decision process model are linked to the process and decision of technology adoption. The adoption decision is a strategic decision to acquire an innovation or technology at a firm or individual level. The last two stages of the model describe the acceptance process and the ultimate decision of individuals to accept or reject the technology (See Figure 2.5). Technology acceptance refers to the actual use of the acquired technology or innovation by the end-users. Thus, the adoption of a technology does not necessarily indicate the ultimate acceptance.

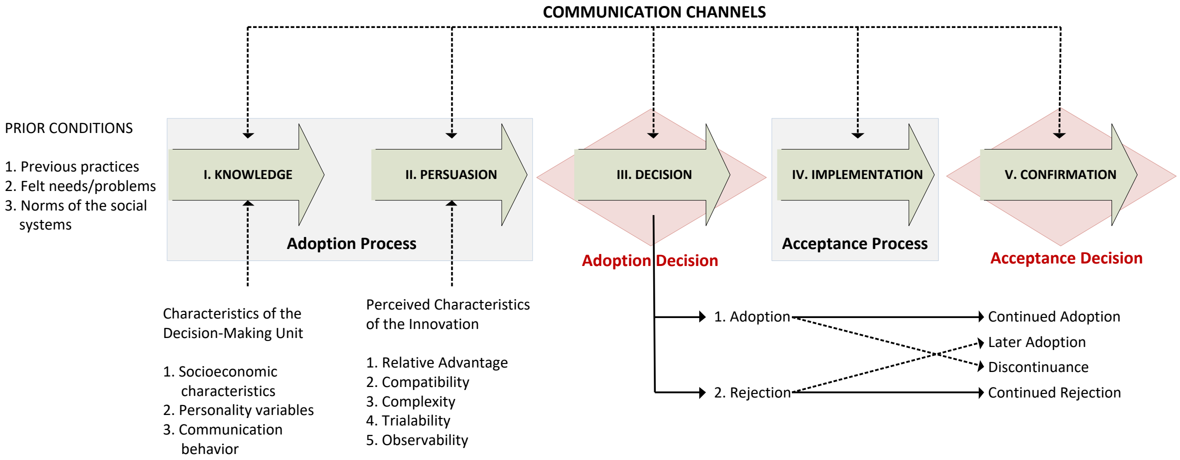


Figure 2.5 The five stage innovation-decision process (Rogers, 2003).

The usability of a system is summarised as the appropriateness of the system to the intended purpose, which is influenced by the behaviour of end-users and the characteristic of the physical, organizational and social environments in which it will be used (Jordan *et al.*, 1996). Ward (2013) analysed the technology acceptance and innovation diffusion models and highlighted the weakness of the models in predicting the behaviour of individuals and organization within a complex healthcare domain. The usability of a system is dependent on the context in which it is used, yet it is suggested that usability measures should cover (Jordan *et al.*, 1996):

- *Effectiveness:* the ability of users to complete tasks using the system, and the quality of the output of those tasks.
- *Efficiency:* the level of resources consumed in performing tasks.
- *Satisfaction:* Users' objective reaction to using the system.

2.4.2. Technology acceptance models (TAM)

Technology acceptance model is introduced to improve understanding of user acceptance processes and provide a theoretical basis for the user acceptance testing methodology (Davis, 1989). The two determinants that mediate between the system characteristics and actual use of information system were hypothesised to be *perceived usefulness* and *perceived ease of use* (Davis, 1989).

- *Perceived usefulness* is defined as “the degree to which a person believes that using a particular system would enhance his or her job performance” (Davis, 1989:320).
- *Perceived ease of use* refers to “the degree to which a person believes that using a particular system would be free of effort” (Davis, 1989:320).

Davis (1989) argued *usefulness* had a greater correlation with user behaviour than *ease of use* according to the two studies involving 152 users and four applications programs. The regression analyses further indicated that perceived ease of use may actually be a causal antecedent to perceived usefulness, instead of a direct determinant of system usage (Davis, 1989). In subsequent study, Venkatesh & Davis (2000) used the Technology Acceptance Model (TAM) as the starting point and incorporated additional theoretical constructs to capture social influence processes (subjective norm, voluntariness, and image) and cognitive instrumental processes (job relevance, output quality, result demonstrability, and perceived ease of use) to propose the second version of TAM (TAM-2) as shown in Figure 2.6.

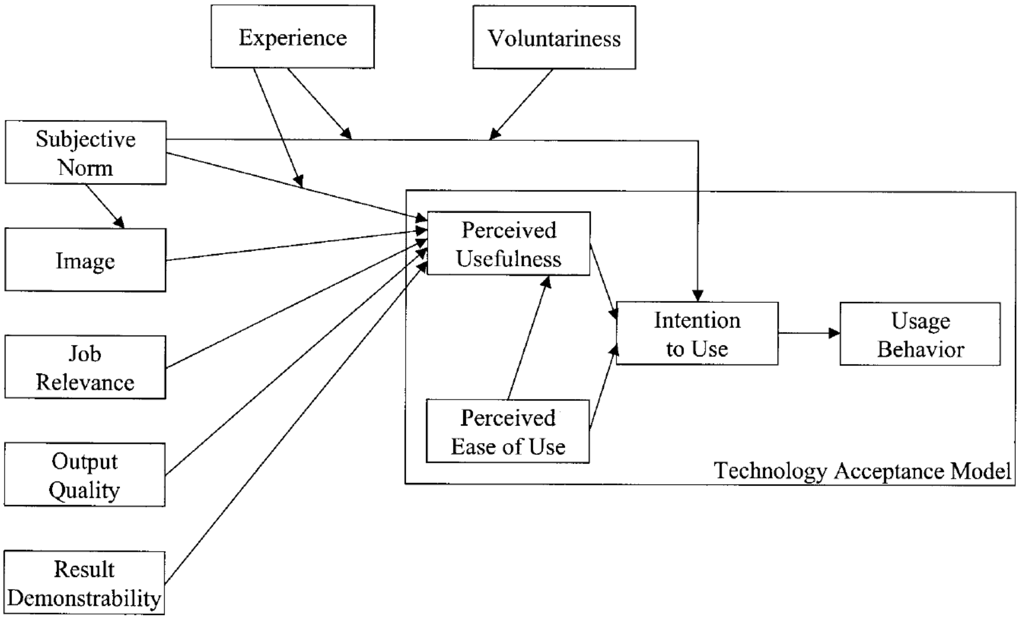


Figure 2.6 Extension of Technology Acceptance Model (Venkatesh & Davis, 2000:188).

The data polled from four studies across the three time periods yielded samples of 468, with 156 samples each period. The result indicated that “unlike the social influence processes, the effect of cognitive instrumental processes remained significant over time” (Venkatesh & Davis, 2000:199). The study further concluded that "subjective norm" may significantly affect the "intention to use" directly only when the usage is mandatory and the experience is in the early stages (Venkatesh & Davis, 2000:198). The additional constructs in TAM-2 are defined as follows:

- *Subjective Norm* is the degree to which “an individual perceives that most people who are important to him think he should or should not use the system” (Venkatesh & Davis, 2000:187).
- *Voluntariness* is defined as “the extent to which potential adopters perceive the adoption decision to be non-mandatory” (Venkatesh & Davis, 2000:187).

- *Image* refers to “the degree to which an individual perceives that use of an innovation will enhance his or her status in his or her social system (Venkatesh & Bala, 2008:277).
- *Job Relevance* is defined as “the degree to which an individual believes that the target system is applicable to his or her job” (Venkatesh & Davis, 2000:191).
- *Output Quality* indicates the degree to which an individual perceives that the system helps to perform his job tasks well (Venkatesh & Davis, 2000:191).
- *Result Demonstrability* is defined as “the degree to which an individual believes that the results of using a system are tangible, observable, and communicable” (Venkatesh and Bala, 2008).

In another study of Venkatesh & Bala (2008), TAM-2 was combined with the model of the determinants of perceived ease of use to propose an integrated model of technology acceptance – the third generation of TAM (TAM-3). The model incorporated a number of determinants that influence technology acceptance. The "behavioural Intention" refers to “an individual's performing a conscious act, such as deciding to accept (or use) a technology" (Sezgin et al., 2014:1330). The additional determinants of perceived ease of use in the TAM-3 are described as follows (Venkatesh & Bala, 2008:279):

- *Computer self-efficacy:* the degree to which an individual believes that he or she has the ability to perform a specific task/job using a computer.
- *Perception of external control:* the degree to which an individual believes that organizational and technical resources exist to support the use of the system.
- *Computer anxiety:* the degree of an individual’s apprehension, or even fear, when she/he is faced with the possibility of using computers.
- *Computer playfulness:* the degree of cognitive spontaneity in microcomputer interactions.
- *Perceived enjoyment:* the extent to which the activity of using a specific system is perceived to be enjoyable in its own right, aside from any performance consequences resulting from system use.
- *Objective usability:* a comparison of systems based on the actual level (rather than perceptions) of effort requires to completing specific tasks.

The perceived ease of use, subjective norm, image, and result demonstrability were identified as a significant predictor of perceived usefulness in the study (Venkatesh & Bala, 2008). The study further indicated that perceived usefulness was the strongest predictor of behavioural intention during pre- and post-implementation (Venkatesh & Bala, 2008).

Venkatesh, Morris, Davis, & Davis (2003) reviewed eight user acceptance models and formulated the Unified Theory of Acceptance and Use of Technology (UTAUT) that integrates elements across the eight models. The UTAUT identified three direct determinants of intention to use (performance expectancy, *effort* expectancy*, and social influence) and two direct determinants of usage behaviour (intention and facilitating conditions).* Furthermore, the model confirmed four moderators of key relationship (*gender, age, experience and voluntariness of use)* as integral features of UTAUT (Venkatesh et al., 2003). The elements of UTAUT are defined as follows.

- *Performance expectancy* is defined as the degree to which an individual believes that using the system will help him or her to attain gain in job performance" (Venkatesh et al., 2003:447).
- *Effort Expectancy refers to "the degree of ease associated with the use of the system" (Venkatesh et al., 2003:450).*
- *Social influence* is defined as "the degree to which an individual perceives that important others believe he or she should use the system" *(Venkatesh et al., 2003:451).*
- *Facilitating conditions* refers to "the degree to which an individual believes that an organizational and technical infrastructure exists to support the use of the system"(Venkatesh et al., 2003:453).

The four core determinants and root constructs of UTAUT together with their definitions are summarised in Table 2.7.

Table 2.7 Core determinants and root constructs of UTAUT (Venkatesh et al., 2003:453).

Determinants	Constructs	Definition
Performance Expectancy	Perceived Usefulness	The degree to which a person believes that using a particular system would enhance his or her job performance. (fulfils the needs of users, organizations and/or patients Cresswell & Sheikh, 2012)
	Extrinsic Motivation	The perception that users will want to perform an activity because it is perceived to be instrumental in achieving valued outcomes that are distinct from the activity itself, such as improved job performance, pay, or promotions
	Job-fit	How the capabilities of a system enhance an individual's job performance
	Relative Advantage	The degree to which using an innovation is perceived as being better than using its precursor.
	Outcome Expectations	Outcome expectations relate to the consequences
Effort Expectancy	Perceived ease of use	The degree to which a person believes that using the system would be free of effort.

	Complexity	The degree to which a system is perceived as relatively difficult to understand and use.
	Ease of use	The degree to which an innovation is perceived as being difficult to use
Social Influence	Subjective norm	The person's perception that most people who are important to him think he should or should not use the system.
	Social factors	The individual internalization of the reference group's subjective culture, and specific interpersonal agreements that the individual has made with others, in specific social situations.
	Image	The degree to which use of an innovation is perceived to enhance one's image or status in one's social system
Facilitating Conditions	Perceived behavioural control	Reflects perception of internal and external constraints on behaviour and encompasses self-efficacy, resource facilitating conditions, and technology facilitating conditions.
	Facilitating conditions	Objective factors in the environment that observers agree to make an act easy to do, including the provision of computer support.
	Compatibility	The degree to which an innovation is perceived as being consistent with existing values, needs, and experiences of the potential adopters.

Generally, the TAM assumes that people are rational when making technology acceptance decisions. However, humans are not always logical and rational in their technology acceptance decisions.

2.4.3. Information system success model (IS success model)

The IS success model is one of widely used and empirically validated models that aimed to contribute to the success of information technology implementations. The model shows the interdependency of the six distinct dimensions necessary for the success of IS within three process components (DeLone and McLean, 1992). The processes are namely, the creation of a system, the use of the system, and the consequences of this system use (DeLone and McLean, 1992). The 'System Quality' and 'Information Quality' belong to the 'creation of system' process dimension and believed to affect both 'Use' and 'User Satisfaction'. In a process sense, the 'Use' precedes 'User Satisfaction', however, both can positively or negatively affect each other. The model also indicates that 'Information Use' and 'User Satisfactions' are direct antecedents of 'Individual Impact'; which eventually have some effect on 'Organizational Impact' (DeLone and McLean, 1992).

The six distinct aspects of Information System (IS) success described in Figure 2.7 are (DeLone and McLean, 1992):

- System quality: measures the desired characteristics of the IS itself (technical success).
- Information quality: measures the IS output.
- Use: recipient consumption of the output of an information system.
- User satisfaction: recipient response to the use of the output of an IS.
- Individual impact: the effect of information on the behaviour of the recipient.
- Organizational impact: the effect of information on organizational performance.

After ten years, DeLone and McLean (2003) visited the contributions of researches toward D&M IS success model, specifically the research efforts that applied, validated, challenged, and proposed enhancements to the original IS success model, and came up with updated DeLone and McLean IS Success Model. Service quality, i.e., the measure of overall support delivered, was one of the inclusions in the updated model as the third quality dimension. To address the process versus causal concerns of the model as well as to resolve the difficulties of several interpretation of “use”, such as mandatory versus voluntary, informed versus uninformed, effective versus ineffective, the “intention to use” was introduced in the updated model (DeLone and McLean, 2003). “‘Intention to use’ is an attitude, whereas ‘use’ is a behaviour.” (DeLone & McLean, 2003:23).

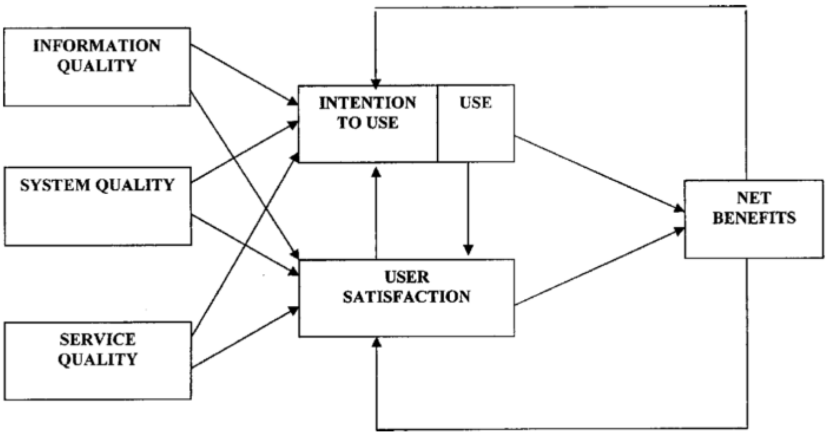


Figure 2.7 Updated IS Success Model (DeLone and McLean, 2003).

Furthermore, all the IS impact measures, such as work group impact, organizational impact, consumers impact, societal impacts, were grouped into a single category called “net benefit”, i.e., the consequence of system use (DeLone and McLean, 2003). Figure 6 depicts the influence of net benefits on the intention to use, use and user satisfaction with the feedback loops.

Wang & Liu (2005) combined the TAM and IS Success Model to propose the Integrated IS Success Model as shown in Figure 2.8. In their effort to develop a system dynamics model of

IS success, Wang & Liu (2005) suggested three exogenous variables, namely: “Training efforts”, “User involvement in system development”, and “perceived sufficiency of organizational resources”.

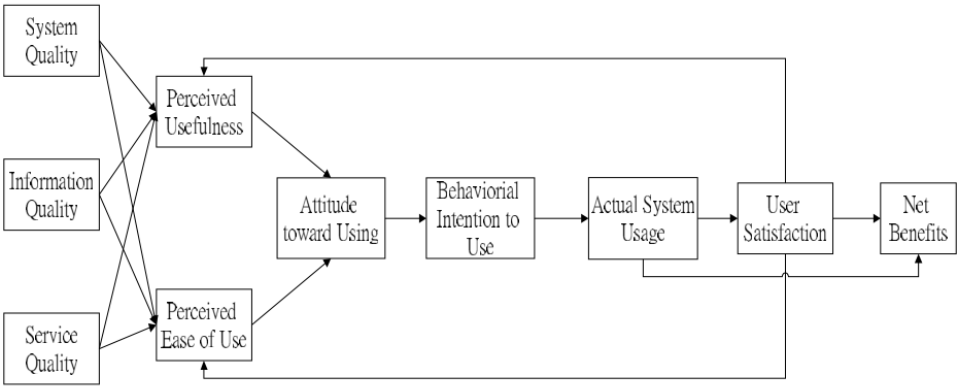


Figure 2.8 The Integrated IS Success Model (Wang & Liu, 2005).

2.4.4. Technology acceptance models in health information system

The use of IS Success Model to assess the success of EMR in the developing countries was conducted in 384 health professionals working in five governmental hospitals in Ethiopia (Tilahun and Fritz, 2015b). Computer literacy, i.e., “the knowledge and skill that enable individuals to use computers effectively for a specific task”, was used as a mediating factor (Tilahun and Fritz, 2015b:3). The findings of the study indicated that the influence of services quality on the use and user satisfaction was substantially stronger than the system quality and information quality. Additionally, the study observed that computer literacy had a strong mediating effect on the relationship between services quality and EMR use than services quality and user satisfaction (Tilahun and Fritz, 2015b).

In low resource settings, Tilahun & Fritz (2015b) indicated that service qualities such as technical support, infrastructure and computer training, were the strongest influencers of EMR use and user satisfaction. This finding confirms the significant influence of technical, political and management support to the successful implementation of eHealth systems. Ward (2013:277) used TAM in the healthcare domain to indicate that “’perceived usefulness’ is more likely to influence clinicians than ‘ease of use’, and ‘individual and organizational attitude and culture’ is likely to be significant in both ‘initial acceptance and subsequent diffusion’ of the innovation”.

The Pharmaceutical Technology Acceptance Model (P-TAM) was used to investigate the Pharmaceutical Service System called Medula, by conducting a survey with 2169 pharmacists from a different region of Turkey (Sezgin, Alaşehir and Yıldırım, 2014). The Theory of Planned Behaviour (TPB) and TAM were the major resource of inputs to the development of P-TAM with five sets of behavioural constructs: Perceived Behavioural Control, System Factors, Perceived Usefulness, Perceived Ease of Use and Behavioural Intention (Sezgin, Alaşehir and Yıldırım, 2014). Three of the five constructs of P-TAM were similar to those defined in TAM-2, whereas the other two were defined as follows:

- *Perceived Behavioural Control* is defined as "the perceived ease or difficulty of performing the behaviour". It asks questions such as the ability of the users to use the system and to operate the functions of the system needed for their job (Sezgin et al., 2014:1330).
- *System Factors* refers to "objective factors in the environment that observers agree to make an act easy to accomplish" (Sezgin et al., 2014:1330).

The P-TAM model showed significant reliability but the hypothesis that tests the relationship between the constructs is yet to be conducted. The study concluded that P-TAM has potential to be used for Health Information Systems adoption studies on pharmacists (Sezgin, Alaşehir and Yıldırım, 2014).

The technology diffusion model, TAM and IS success models have different focus areas in the implementation of successful technology, yet they overlap each other. The TAM focuses on the processes and decision of acceptance, namely the implementation and confirmation stages of innovation diffusion model. The individual perception and the social factors are the focus areas of the TAM. Likewise, the IS success model shares various factors such as intention to use, technology use and satisfaction with TAM. Moreover, the IS success addresses the technological factors under three quality groups and the influences of benefits from the technology on the acceptance and success of technology implementation. The literature studies show that elements of these three models are widely used to assess the success level of different healthcare technologies.

2.5. Systems theory

A system is defined as a set of interrelated elements working together towards some common objective to produce a result that is not obtainable by the elements alone (Blanchard, 2008; Kossiakoff *et al.*, 2011). "The elements can include people, hardware, software, facilities, policies, and documents; that is, all things required to produce system-level results. The results include systems-level qualities, properties, characteristics, functions, behaviour and performance" (Blanchard, 2008:3). Systems theory is multidisciplinary in both its theoretical foundations and applications (Adams *et al.*, 2014).

The system environment, i.e., the environment in which a new system operates, may broadly be defined as everything outside of the system that interacts with the system (Kossiakoff et al., 2011:51). Understanding a system's operational environment and its interaction with the system of interest is important to characterize a system of interest. This is necessary so that the full range of operational environment dynamics required for the successful implementation of a system can be considered throughout the entire life cycle of the system (Kossiakoff et al., 2011). The successful execution of systems engineering principles and concepts depends on the good understanding of the environment and some of the challenges ahead (Blanchard, 2008). In order to define the system boundaries, one should consider the following important conditions (Kossiakoff et al., 2011).

- *Developmental control:* If the system developer does not have control over an entity's development, the entity does not belong to the system of interest.
- *Operational control:* If the entity is beyond the operational control of the organization that owns the system, it is not part of the system.
- *Unity of purpose:* If the entity cannot be removed without objection by another entity, it does not belong to the system of interest.
- *Functional allocation:* If it is not possible to allocate a function to the entity in the process of defining functional requirements of the system, it is not part of the system.

2.5.1. Complex systems

The nature of cause-and-effect relationship within the contexts of an organization is grouped into four domains, i.e. *simple*, *complicated*, *complex* and *chaotic*, to assist leaders in making decisions (Snowden and Boone, 2007). The first two represent the ordered domain, whereas the latter two are the unordered domain (Van Beurden *et al.*, 2013). The business world operated more dominantly in complex domain requiring different counterintuitive responses in a particular context (Snowden and Boone, 2007). The Cynefin Framework describes the different domains of complexity as shown in Figure 2.9.

Simple context is a "known knowns" realm which is characterized by a linear cause-and-effect relationship with a predictable outcome (Snowden and Boone, 2007). The appropriate decision-making approach follows sense, categorize, and respond (Van Beurden *et al.*, 2013).

Complicated context is a realm of “known unknowns” that the cause-and-effect relationship cannot be fully understood with a possibility of multiple correct approaches (Snowden and Boone, 2007). The complicated domain requires leaders to sense, analyse, and respond in making decisions (Van Beurden *et al.*, 2013).

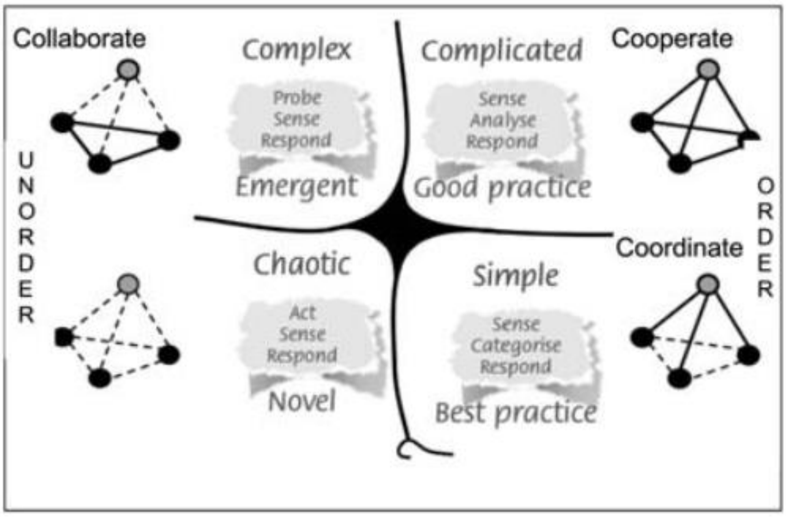


Figure 2.9 The Cynefin Framework (Van Beurden et al., 2013).

Complex context is a realm of “unknown unknowns” which is characterized by a nonlinear cause-and-effect relationship that unpredictable patterns emerge as elements of a system interact each other (Snowden and Boone, 2007). To make decisions, leaders develop probes to understand emergent patterns, sense useful alternatives and respond (Van Beurden *et al.*, 2013).

Chaotic contexts: is a realm of “unknowables” which is impossible to predict the cause-and-effect relationship; therefore, a leader must act to establish order, then sense stability, and then respond to bring the condition from chaos to complex domain (Snowden and Boone, 2007; Van Beurden *et al.*, 2013).

A complex system is characterised by (Snowden & Boone, 2007:3):

- A large number of nonlinear interacting elements.
- Minor changes can trigger major consequences.
- The system is dynamic and exhibits emerging characteristics.
- The elements of the system evolve one another and with the environment.
- The external conditions and systems change constantly, so difficult to predict.
- The agents and the system constrain one another; hence one cannot predict or forecast the future.

The unpredictability and intellect nature of humans create complexity and make a human modelling process very difficult (Snowden and Boone, 2007). “Humans have multiple identities and can fluidly switch between them without conscious thought” (Snowden & Boone, 2007:3). Moreover, humans make a decision based on the experience of past failure and success, rather than on logical and definable rules (Snowden & Boone, 2007:3). These distinct characteristics make organizational systems involving humans a complex system.

The healthcare service delivery is complex as it involves the coordination and management of large numbers of highly specialized and distributed personnel, multiple streams of information, and material and financial resources across multiple care settings (Geisler and Heller, 1996; Reid *et al.*, 2005). One of the complexities of a healthcare system is associated with the large problem spaces that address about 500,000 illnesses (Carayon, 2006). The social system of healthcare is composed of many people who must work together to deliver healthcare services, that includes healthcare providers, patients and their families (Carayon, 2006).

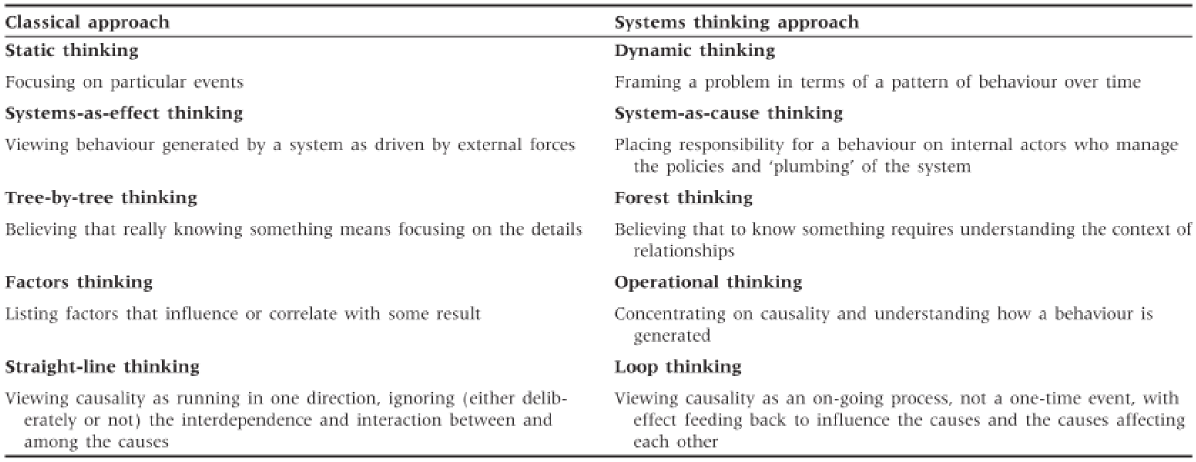
Sterman (2000) indicated that dynamic complexity arises because systems are dynamic, tightly coupled, nonlinear, history-dependent, self-organising, adaptive, counterintuitive, policy resistance and characterized by trade-offs.

2.5.2. Systems thinking

System thinking seeks to recognise patterns and interrelationships to understand the whole and effectively structure the interrelationships (Chuang, Howley and Undercurrent, 2012). On the contrary to the traditional analytical or linear thinking approach, system thinking appreciates the dynamic complexity of systems, the changing nature of systems, the influence of history and feedback effects, the critical role of stakeholders, and the influence of context on a system (Adam and De Savigny, 2012). System thinking is a way of thinking that focuses on the holistic nature of a system instead of focusing on specific element alone in designing solutions to problems (Chuang, Howley and Undercurrent, 2012). Systems thinking can be applied to any field of study and offers a holistic approach to solving complex problems in complex systems (Adam and De Savigny, 2012).

The classical linear approach to healthcare systems is hindering efforts of achieving improved health outcomes (Adam and De Savigny, 2012). In a complex system, everything is interconnected so that a change in one element will gradually impact other elements (Sterman, 2000). The holistic worldview of systems thinking approach helps to ensure the long-term best interests of the system as a whole (Sterman, 2000). The complex and dynamic nature of healthcare system requires a system thinking approach that can address the complexity of the interconnected components of health systems and their stakeholders (Adam and De Savigny, 2012). Table 2.8 depicts the difference between the classical and system thinking approaches in solving system problems.

Table 2.8 Classical and system thinking approach (Adam and De Savigny, 2012).



Classical approach	Systems thinking approach
Static thinking	**Dynamic thinking**
Focusing on particular events	Framing a problem in terms of a pattern of behaviour over time
Systems-as-effect thinking	**System-as-cause thinking**
Viewing behaviour generated by a system as driven by external forces	Placing responsibility for a behaviour on internal actors who manage the policies and 'plumbing' of the system
Tree-by-tree thinking	**Forest thinking**
Believing that really knowing something means focusing on the details	Believing that to know something requires understanding the context of relationships
Factors thinking	**Operational thinking**
Listing factors that influence or correlate with some result	Concentrating on causality and understanding how a behaviour is generated
Straight-line thinking	**Loop thinking**
Viewing causality as running in one direction, ignoring (either deliberately or not) the interdependence and interaction between and among the causes	Viewing causality as an on-going process, not a one-time event, with effect feeding back to influence the causes and the causes affecting each other

System thinking replaces the classical reductionist, narrow and static view of the world with a holistic, broad and dynamic view (Sterman, 2000). Feedback determines the dynamics of the system and they are the core concepts of system dynamics. Causal loop diagrams (CLDs) and stocks and flows diagrams (SFDs) are important tools to represent the feedback structure of systems (Sterman, 2000). A causal loop diagram connects variables of a system to explain the relationships in the systems thinking process (Forrester, 1994). The engineering of complex systems is facilitated by the functions of system engineering (Kossiakoff *et al.*, 2011). The use of system engineering to explore complex problem domains require the use of system thinking approach (Reid *et al.*, 2005; Kossiakoff *et al.*, 2011). System thinking is required to understand the environment, process, and policies of systems problem (Kossiakoff *et al.*, 2011).

2.5.3. Systems engineering

Systems engineering is “an interdisciplinary approach and means to enable the realisation of successful systems. It focuses on defining customer needs and required functionality early in a development cycle, documenting requirements, and then preceding with design synthesis and system validation while considering the complete problem. System engineering considers both the business and technical needs of all customers with the goal of providing a quality product that meets the user needs” (Blanchard, 2008:17). Its function is to guide the engineering of complex systems (Kossiakoff *et al.*, 2011).

Major manufacturing and services industries applied systems engineering concepts and tools to meet quality, cost, safety, and other objectives, of complex production/distribution systems (Reid *et al.*, 2005). As shown in Figure 2.10, system engineering encompasses or overlaps with many related fields such as engineering, technical, management, architectures, modelling and simulation, social, human, operations analysis, political and legal domains (Kossiakoff *et al.*, 2011). Systems engineering focuses on the life cycle of a system to produce an affordable product that meets requirements and development objectives (Kossiakoff *et al.*, 2011).

The life cycle covers the entire spectrum of interrelated activities commencing from the stage of identifying stakeholders need to the system retirement stage of a given system (Blanchard, 2008). A systems engineering life cycle model consists of three broad phases that correspond to the system's active life. These are concept development, engineering development and post-development phases (Kossiakoff *et al.*, 2011). The design and development of a system should assume a total life-cycle approach to consider the construction, maintenance, support and retirement phases of a system (Blanchard, 2008).

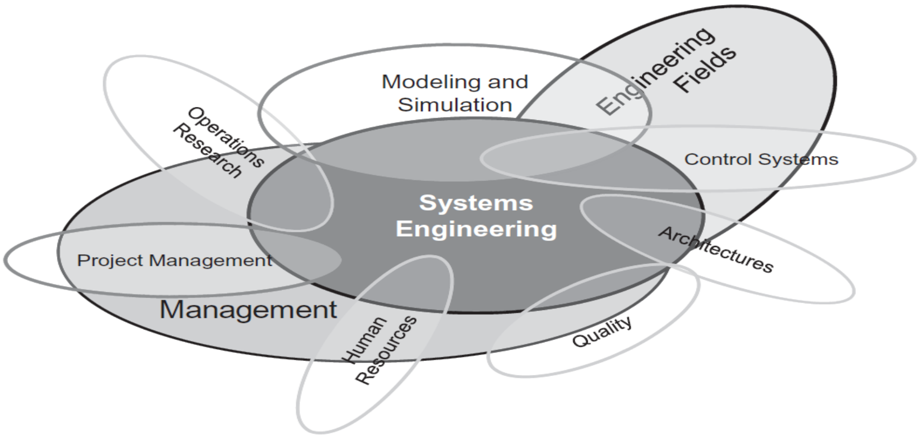
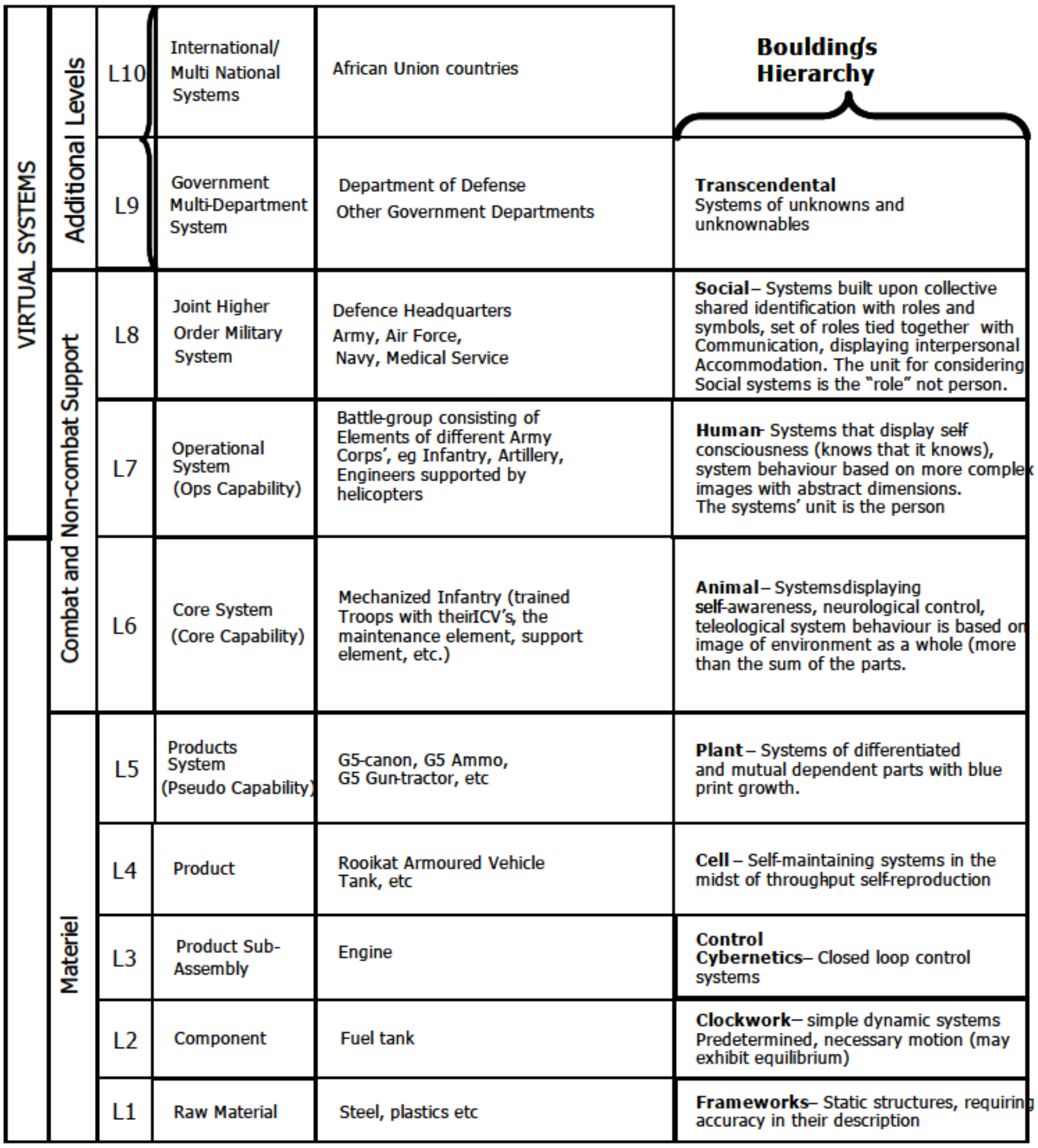


Figure 2.10 Examples of systems engineering fields (Kossiakoff et al., 2011:35).

The systems engineering approach focuses on building a system by addressing problems associated with products. The approach follows the sequence of processes and methodologies to execute the design, development, integration, and testing of a system (Kossiakoff *et al.*, 2011). This systems engineering approach seems technical that seeks to understand stakeholder needs to set requirements and concepts of operations before designing, developing, manufacturing, and testing a system solution for the problem (Kossiakoff *et al.*, 2011). The systems engineering approach can be applied to different degrees of complexity to develop successful and operational products (Kossiakoff *et al.*, 2011). As a viable solution to complex systems, the design, analysis, and control of the system engineering approach have not been better used in the healthcare (Reid *et al.*, 2005; Kossiakoff *et al.*, 2011).

Systems can be broken down into different levels of components also known as system hierarchy. Complex systems have a hierarchical structure that consists of the number of subsystems composed of components, the components are further divided into subcomponents that contain many parts (Kossiakoff *et al.*, 2011). The nonlinear interaction between these elements increases the complexity of a system (Kossiakoff *et al.*, 2011). De-Wall & Buys (2007) adopted the Boulding's systems hierarchy to extend the systems hierarchy used by the South African Department of Defence to promote holistic approach through interfaces with external organizations (See Figure 2.11). Humans are absent in the first five levels (1 to 5) of the system hierarchy; hence the development of identical products or services is possible (De-Wall and Buys, 2007). The introduction of the human beyond level 5 brings complexity into a system and the complexity growths as the hierarchal level increases.

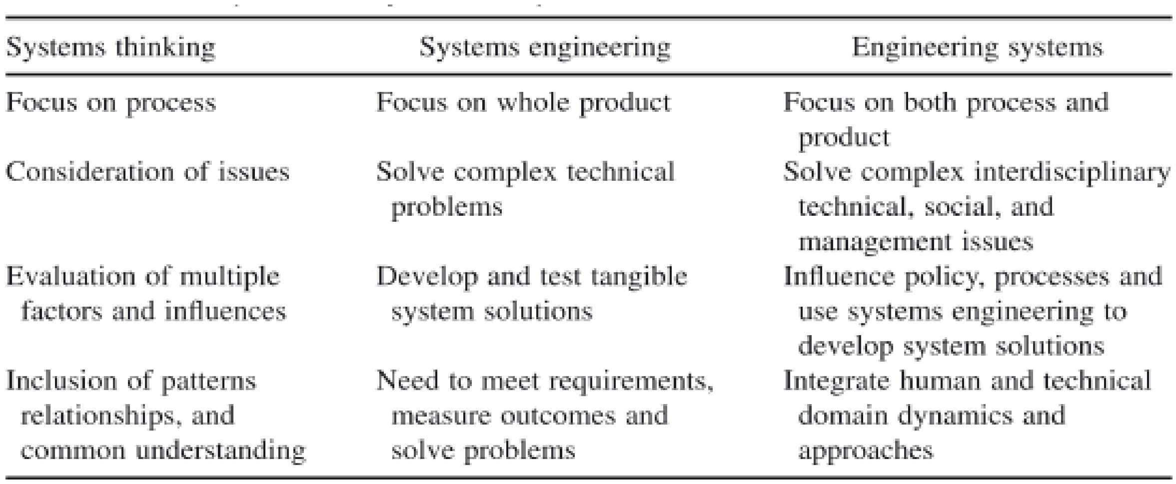


					Bouldings Hierarchy
VIRTUAL SYSTEMS	Additional Levels	L10	International/ Multi National Systems	African Union countries	
		L9	Government Multi-Department System	Department of Defense Other Government Departments	**Transcendental** Systems of unknowns and unknownables
	Combat and Non-combat Support	L8	Joint Higher Order Military System	Defence Headquarters Army, Air Force, Navy, Medical Service	**Social** – Systems built upon collective shared identification with roles and symbols, set of roles tied together with Communication, displaying interpersonal Accommodation. The unit for considering Social systems is the "role" not person.
		L7	Operational System (Ops Capability)	Battle-group consisting of Elements of different Army Corps', eg Infantry, Artillery, Engineers supported by helicopters	**Human**- Systems that display self consciousness (knows that it knows), system behaviour based on more complex images with abstract dimensions. The systems' unit is the person
		L6	Core System (Core Capability)	Mechanized Infantry (trained Troops with theirICV's, the maintenance element, support element, etc.)	**Animal** – Systemsdisplaying self-awareness, neurological control, teleological system behaviour is based on image of environment as a whole (more than the sum of the parts.
	Materiel	L5	Products System (Pseudo Capability)	G5-canon, G5 Ammo, G5 Gun-tractor, etc	**Plant** – Systems of differentiated and mutual dependent parts with blue print growth.
		L4	Product	Rooikat Armoured Vehicle Tank, etc	**Cell** – Self-maintaining systems in the midst of throughput self-reproduction
		L3	Product Sub-Assembly	Engine	**Control Cybernetics**– Closed loop control systems
		L2	Component	Fuel tank	**Clockwork**– simple dynamic systems Predetermined, necessary motion (may exhibit equilibrium)
		L1	Raw Material	Steel, plastics etc	**Frameworks**– Static structures, requiring accuracy in their description

Figure 2.11 The Systems Hierarchy (De-Wall and Buys, 2007:182).

The system thinking approach can help to examine the environment, process and policies of a system problem to define the domain and scope of a problem (Kossiakoff *et al.*, 2011). System analysis refers to the analytical process of evaluating various system design alternatives (Blanchard, 2008). A robust systems approach integrates engineering, management and social science methods to solve complex engineering problems also known as “engineering systems” (Kossiakoff *et al.*, 2011). The system engineering approaches may be applied with some level of flexibility to address the engineering, management and social factors of the infrastructure, healthcare, energy, environment, information security and other problems (Kossiakoff *et al.*, 2011). Table 2.9 compares the systems thinking, systems engineering and engineering systems perspectives of system approach. Systems thinking may be used to describe a system at the conceptualization stage of a system dynamics modelling process leading to a deeper understanding of a system (Forrester, 1994). System analysis refers to the analytical process of evaluating various system design alternatives (Blanchard, 2008).

Table 2.9 Comparison of systems perspectives (Kossiakoff et al., 2011)



Systems thinking	Systems engineering	Engineering systems
Focus on process	Focus on whole product	Focus on both process and product
Consideration of issues	Solve complex technical problems	Solve complex interdisciplinary technical, social, and management issues
Evaluation of multiple factors and influences	Develop and test tangible system solutions	Influence policy, processes and use systems engineering to develop system solutions
Inclusion of patterns relationships, and common understanding	Need to meet requirements, measure outcomes and solve problems	Integrate human and technical domain dynamics and approaches

2.5.4. System dynamics

The system dynamics process is motivated by undesirable system behaviour, but the goal is to bring improvement to the system (Forrester, 1994). Forrester (1994) discusses the six steps of the system dynamics process. The first step is to describe the relevant system followed by the translation of system description into the level and rate equations of a system dynamics model. The third stage of the processes is a model simulation to understand the dynamic behaviour of a system by satisfying the logical criteria of the operable model. The fourth step evaluates alternative policies. A consensus for the implementation of a better policy with the greatest promise is accomplished at the fifth step. The final step is the implementation of new policy to achieve improvements. There are several iterations of each step to improve the model and simulation in the system dynamics process. System dynamics is a method to deal with the dynamic complexity of systems and enhance the learning process of nonlinear systems (Sterman, 2000).

Modelling

The models and techniques developed through elicitation and mapping process are an initial hypothesis about the structure of a system that must be tested (Sterman, 2000:37). Identifying the real problem and the real client is the first step of the modelling process. The five-step iterative modelling processes are (Sterman, 2000:87):

- Step 1 - Problem articulation (Boundary selection): includes theme selection, key variables, time horizon, and dynamic problem definition.
- Step 2 - Formulation of dynamic hypothesis: addresses initial hypothesis generation, endogenous focus, mapping.
- Step 3 - Formulation of simulation model: includes specification, estimation and tests.
- Step 4 - Testing: includes a comparison to reference modes, robustness under extreme conditions, sensitivity and other tests.
- Step 5 - Policy design and evaluation: scenario specification, policy design, “what if” analysis, sensitivity analysis, the interaction of policies.

Simulation

The mental models are dynamically deficient, omit feedbacks, time delays, accumulations, and nonlinearities (Sterman, 2000:37). Simulation is a cost-effective practical way to test the models (Sterman, 2000:37). Simulation speeds and strengthens the learning feedback by improving discrepancies between the formal and mental models, as well as assumptions such as model boundaries, time horizon, and dynamic hypothesis (Sterman, 2000:37).

Causal loop diagram

Causal loop diagrams (CLDs) are used to represent the feedback structure of systems (Sterman, 2000). CLDs are important tools to capture hypotheses about the causes of dynamics; to elicit and capture the mental models of individuals or teams; and to communicate feedbacks responsible for a problem (Sterman, 2000). The causal influence between variables is denoted by variables connected by arrows, causal links (Sterman, 2000). The polarity, positive (+) or negative (-), assigned to each causal links indicate the change in the dependent variable when the independent variable changes A positive link indicates that an increase in cause increases a dependent variable. Similarly, if the cause decrease, the effect decreases below what it would otherwise have been (Sterman, 2000). On the other hand, a negative link depicts that an increase in the cause makes the effect decrease; and the decrease in the cause will result in an increase of the dependent variable above what it would otherwise have been (Sterman, 2000). A loop identifier highlights positive feedback loops (reinforcing loops) or negative feedback loops (balancing loops) (Sterman, 2000). The causal loop diagram notations such as variables, causal links, polarities, reinforcing loop and balancing loop are described in the Figure 2.12.

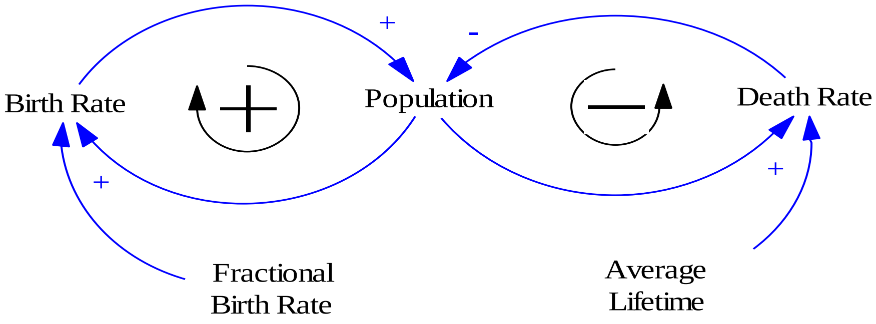
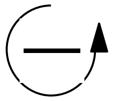


Figure 2.12 Casual loop diagram notations – adapted from (Sterman, 2000).

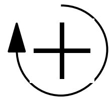
Variables: Birth rate, Population, Death Rate, Fractional Birth Rate and Average Lifetime.

Casual links: all arrows that connect the variables.

Link polarities: the positive and negative signs at the tip of the causal links.



Loop Identifier: Negative (Blancing) Loop



Loop Identifier: Positive (Reinforcing) Loop

Stocks and flows

Stocks are accumulations that arise from the difference between inflows and outflows of the process (Sterman, 2000:192). They create delays, give systems inertia and provide them with memory (Sterman, 2000). The stocks and flows diagram notation uses a rectangle to represent stock, a pipe with an arrow pointing into the stock to represent inflow, an arrow out of the stock to represent outflow, valves to show flow control and clouds to represent the sources and sinks of a model as shown in Figure 2.13 (Sterman, 2000). Sources and sinks represent stocks outside the model boundary that originate the flow and drain of flows that leave the model

(Sterman, 2000). The clouds represent never starving source and never filling sink (Sterman, 2000).

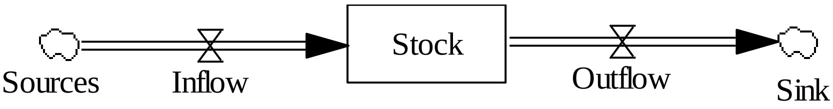


Figure 2.13 Stock and flow diagramming notion – adapted from (Sterman, 2000).

Stocks are an integration of net flow into the stock (See Equation 2.1). Stock(s) represents the value of a stock at time (s) between initial time (t_0) and the current time (t).

$$Stocks\ (t) = \int_{t_0}^{t} [Inflow(s) - Outflow(s)]ds + Stocks\ (t_0) \qquad 2.1$$

Inflows (s) is the value of inflow at any time (s) between time t_0 and the current time t, and Stock (t_0) represents the initial stock level at time t_0 (See Equation 2.1).

The net rate of change of flow is mathematically represented by the differential equation (See Equation 2.2), the difference between inflow and outflow (Sterman, 2000). Stocks are accumulations (the states of the system) and flows are the rate of change of the states of the system (Wolstenholme, 1983; Sterman, 2000).

$$\frac{d(Stock)}{dt} = Inflow\ (t) - Outflow\ (t) \qquad 2.2$$

The contribution of stocks to the dynamics of systems include (Sterman, 2000: 195-196):

- To characterize the state of the system and provide the basis for action.
- To provide systems with inertia and memory.
- To serve as a source of delays.
- To decouple rates of flow and create disequilibrium dynamics.

“Linear systems are systems in which the rate equations are linear combinations of the state variables and any exogenous inputs” (Sterman, 2000:264). The linear growth of interest rate will accelerate the net interest income exponentially because of a positive feedback from the stock (principal) as shown in Figure 2.15 (Sterman, 2000). A positive feedback is a self-reinforcing loop (See Figure 2.14).

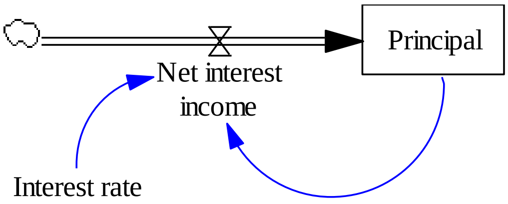


Figure 2.14 Positive feedback loop (Sterman, 2000:266).

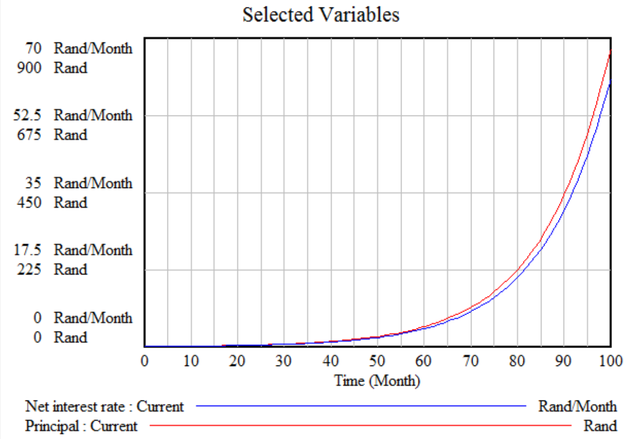


Figure 2.15 Exponential growth (Sterman, 2000:268).

Conversely, the first-order negative feedback system exhibits exponentially decaying behaviour (See Figure 2.16 & 2.17). A negative loop is a self-correcting loop. Complex systems consist of networks of positive and negative feedbacks, and the dynamics arise from the interaction of these loops with one another (Sterman, 2000).

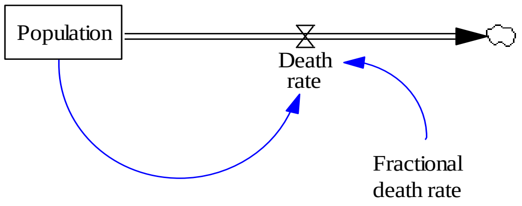


Figure 2.16 Negative feedback loop (Sterman 2000:275).

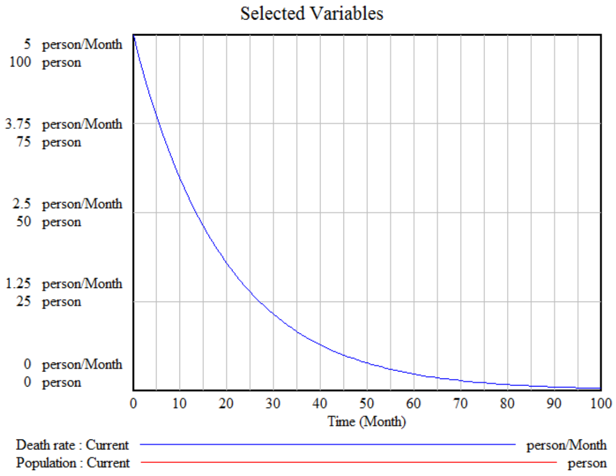


Figure 2.17 Exponentially decaying (Sterman, 2000:276).

A linear feedback systems addresses positive and negative feedback systems in isolation (Sterman, 2000). However in real life, the quantity cannot grow or decline forever as there is always a limit. The exponential growth of birth rate and the exponential decay of death rate exist simultaneously in real life. In the case of population growth, the relative strength shifts from a positive feedback loop (birth rate) to a negative feedback loop (death rate) as the environment reach to its carrying capacity (Sterman, 2000).

The S-shaped growth is an indication of smooth nonlinear transition from exponential growth to equilibrium (Sterman, 2000). It is a commonly observed mode of behaviour in system dynamics (See Figure 2.18). There are important nonlinearity in real life that can be represented by the nonlinear first-order system. Nonlinear first-order system generates more complex dynamics than the linear first-order system that generates only exponential growth, decay or equilibrium (Sterman, 2000). Yet no matter the form of nonlinearity, first-order systems never oscillate (Sterman, 2000).

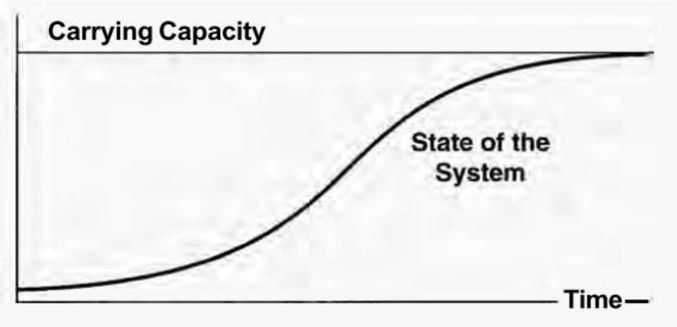


Figure 2.18 S-shaped growth behaviour (Sterman, 2000:118).

<u>Delays</u>

“A delay is a process whose outputs lags behind its input in some fashion” (Sterman, 2000:411). Material delays capture the physical flow of materials through a delay process (Sterman, 2000:411). Information delays represent the gradual adjustment of perceptions or beliefs to the information received (Sterman, 2000:411). People develop beliefs, expectations, forecasts and projections through time to make current judgments (decision) based on the information available from the past (Sterman, 2000). Changing perceptions comes through reflection and deliberation often takes considerable time to adjust emotionally to a new situation before changing beliefs or behaviours (Sterman, 2000). Information delay is not observed, so it needs a different structure to capture information delay (Sterman, 2000).

Adaptive expectations are the gradual adjustment of perceptions or beliefs to the actual value of the variable (Sterman, 2000). The belief or perceived value of an input is a stock and adjusts to the actual input (reported value of variables) to reduce the size of the error in belief. The adjustment time represents a delay that determines the speed at which belief responds to the error (See Figure 2.19). Perception is a state of mind, and the current belief tends to remain at its current value unless it is different from the actual states of affairs. The larger the error, i.e., the difference between the actual state of affairs and the perceived state of affairs, is the greater the rate of adjustment of belief (Sterman, 2000). First order information delay describes the adjustment in the state of the system in response to the gap between the current belief and actual value of the variable (see Equation 2.3) (Sterman, 2000).

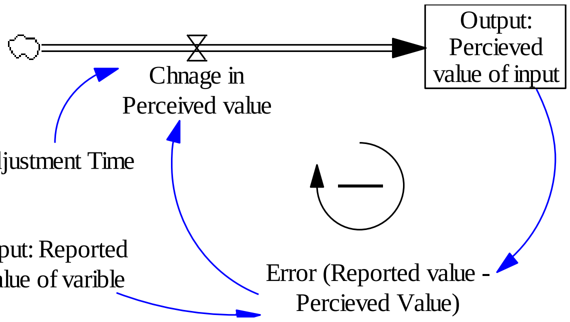


Figure 2.19 Feedback structure of adaptive expectation (Sterman, 2000:428).

$$\text{Change in perceived value} = \frac{\text{Error}}{\text{Adjustment Time}} = \frac{\text{Input} - \text{Output}}{\text{Adjustment Time}} \qquad 2.3$$

The CLD and SFD are important diagrammatic tools to capture the dynamic interactions between system elements to understand the causal relationships and feedbacks. The nonlinear behaviour of sustainable eHealth implementation can be captured with the system dynamics approach. The complex dynamics of sustainable technology development and implementation presented in the next section can be represented by the stocks, flows, delays and feedback loops in a system dynamics modelling method.

A systems thinking can be used to recognise patterns and interrelationships to understand the whole and effectively structure the interrelationships between elements of eHealth systems and system environment. System dynamics simulation model captures the dynamic complexity of eHealth system implementation through modelling the CLDs and SFDs. The next section discusses the theory of sustainability of technology and processes to assess sustainability.

2.6. Sustainable technology development and implementation

The sustainability of technology is not about ensuring indefinite operation of technology as indicated in the ecological sustainability definition (Dodds and Venables, 2005); rather, sustainable technology meets the current need of stakeholders and manages the emerging technological changes to ensure the long-term operation of a system (Hay, Duffy and Whitfield, 2014). Understanding the dynamic and nonlinear relationships between the elements of a complex system is a key to a successful implementation and sustainable operation of a technology.

2.6.1. Theory of sustainability

The evolution of the sustainability and sustainable development were categorised into three historical periods (Mebratu, 1998).

- Pre-Stockholm (-1972): covers the period until the Stockholm United Nations (UN) Conference on Environment and Development. In this period, the concept of sustainability was predominantly based on religious beliefs and traditions wisdom, “living in harmony with nature and in society” (Mebratu, 1998:498).
- From Stockholm to World Commission on Environment and Development (WCED) (1972-1987): The 1972 Stockholm conference recognised the importance of environmental management in the process of development. On 1987, the WCED report (also known as the Brundtland Commission) defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987). This definition of sustainability has received a broad acceptance with very diverse interpretations (Mebratu, 1998).
- Post-WCED (1987-1997): In this period, several definitions and interpretations of sustainability shared the core concept of the WCED definition of sustainable development. The practical implementation of sustainable development to clarify the vague concepts of the definition was also the focus of many studies in this period (Mebratu, 1998).

Sustainability is the term often associated with improving ecological efficiency to enable human beings to live on Planet Earth for the indefinite future (Dodds and Venables, 2005; Fiksel, 2003; Gmelin and Seuring, 2014). In another definition, sustainability is described as the goal of sustainable development (Diesendorf 2000; Dodds and Venables, 2005); However, Fiksel (2003) and Hay et al. (2014) argue that it is rather an emergent property manifested as a behaviour that is conducive to the continued operation of the particular system of interest within its environment.

Mebratu (1998) described the two important concepts within the definitions of sustainable development, *the needs* and *limitations.* In the context of eHealth systems implementation, the needs are to achieve the anticipated benefits through continued operation of the system. The limitations are challenges associated with social, organizational, technical and economic factors during the implementation, operation and support of the technology. Hay et al. (2014:236) described sustainability as "an ability that is, a property of an entity, and manifested to human as behaviour that produces the effect of maintenance/continuation, either of the entity in question or some other target".

The three essential dimensions of sustainability – environmental, social and economic factors – are adopted by a wide range of literature (Mebratu, 1998; Diesendorf, 2000; Fiksel, 2003; Harris, 2003; Musango and Brent, 2010). Sustainability simultaneously evaluates achievements against economic success, social benefit and high environmental quality by satisfying the constraints in all three pillars of sustainability (Dodds and Venables, 2005).

Mbratu (1998) discussed the two basic misconceptions associated with word "environment". First, the word environment and ecology has become increasingly synonymous limiting the focus to the natural environment only. Second, "there is a danger of abstraction due to the distended notion of the word environment" (Mebratu, 1998:514). According to Mebratu (1998), the environment associated with economic, social, political and cultural issues within the human universe that extends from the street corner to the stratosphere.

To ensure sustainability of a technology, it is necessary to understand its social, environmental and economic implications before implementation (Dodds and Venables, 2005). For the purpose of this study, sustainability is defined as the ability to sustain, continue or maintain the operation of a system by addressing the three dimensions of sustainability and other important factors of the intended system (Hay et al., 2014). A system cannot be sustainable in an absolute sense (Fiksel, 2003), however, sustaibility is naturally associated with a long-term future orientation (Musango and Brent, 2010).

Hay et al. (2014) explain the Sustainability Loop (S-Loop) at three different levels: the systems, activities and knowledge levels. People focus on the sustainability of different systems that interest them, such as agricultural systems, transport systems, healthcare systems, political systems and so on. Therefore, defining a system's boundaries and the environment in which the system operates helps to understand activities that transform inputs into outputs in the context of the defined system.

A system is defined as “a set of interrelated components working together toward some common objective” according to Kossiakoff et al. (2011:3-4). Systems exist in the “real” world, but an observer defines the boundary between a system and its environment (Hay et al., 2014). However, Fiksel (2003) and Kossiakoff et al. (2011) appreciate the challenges associated with defining system boundaries. From the perspective of an activity, sustainability can be viewed as the ability of an activity to continue operating within a system. From a systems perspective, it is the ability of a system to continue operating within its environment in a socially acceptable manner (Hay et al., 2014). Through an iterative process, “humans interpret the behaviour of activities in a system to produce knowledge, and on the basis of the knowledge, then take action to alter the behaviour of the activities” (Hay et al., 2014:249).

To better understand sustainability in a system context, Fiksel (2003) discussed three ’nested’ systems:

- Sustainable society: to satisfy the needs of the present without compromising the needs of future generations.
- Sustainable enterprise: a component of the socio-economic system that continues to grow and adapt to meet the expectations of stakeholders and shareholders.
- Sustainable product or service: a component of the overall enterprise system that continues to meet the needs of its stakeholders (producers, distributors and consumers).

It is necessary to highlight the importance of the environmental context of sustainability under the three nested systems. Dodds and Venables (2005) indicate that social and economic dimensions of sustainability fit within the environmental dimension as a system progress towards sustainability.

2.6.2. Sustainable technology

The three pillars of sustainability, i.e. economic, social and organizational, are important sub-systems in which a technology is embedded (Musango and Brent, 2010). These factors play a key role in the success of eHealth implementation (Dodds and Venables, 2005). The long-term future of eHealth technology is associated with the fit between the technology, economic, social and organizational factors (Musango and Brent, 2010; Hay, Duffy and Whitfield, 2014). The dynamic relationship between the sustainability factors influences the implementation success of eHealth technology. Moreover, the sustainability of a project is affected by the ability of the project to ensure long-term results (outcomes and impact).

eHealth systems are implemented to support the long-term development objectives of an organization, therefore sustainability of eHealth projects is crucial to achieving benefits.

Gmelin and Seuring (2014) discuss the triple bottom-line of sustainability in a new product development environment to ensure the consideration of sustainability factors in product life-cycle management.

- The life-cycle assessment (environmental) evaluates the impact of the product or service throughout its entire lifespan on the environment.
- The social life-cycle assessment (social) focuses on the level of social benefit for stakeholders of the product or service across its life-cycle.
- Life-cycle costing (economic) analyses assesses the cost-effectiveness of the development, use and disposal of the product or service.

The implementation of eHealth in developing countries is driven by the non-governmental organizations (NGOs) and private players (Jahangirian and Taylor, 2015; Quaglio *et al.*, 2016). The limited amount of budget and the short project span of donor organizations present a threat to the large-scale and long-term sustainable implementation of eHealth (Quaglio *et al.*, 2016). Technology needs to operate in the balance between the economic, social, organizational and technology factors of sustainable technology implementation to ensure the long-term outcomes and impact results.

Technology is always embedded in the sub-systems of the economy, society (and its institutions), and the natural environment (Musango and Brent, 2010). In the case of eHealth implementation, the natural environment is a healthcare institution where the technology is deployed. In this study, the boundary is scaled down from the planet earth to organizational level. Hence, the boundary for eHealth implementation environment is set around the healthcare organization where the technology is implemented. Similar, instead of representing the entire population on the planet earth, in this study, the society refers to employees within the organization who are either users of eHealth or consumers of the information product of the system. The success of eHealth technology is influenced by the economic affordability of the healthcare institution. The economic and social factors are a sub-system of the healthcare institution.

The society (patients and caregivers) and economy (finance) depend on the environment (healthcare organization) that provide all the resources for successful implementation of the technology (Musango and Brent, 2010). Figure 2.20 depicts the key factors of sustainable technology development and the possible interaction of the technology with the three pillars of sustainability. The implementation of sustainable eHealth technology may bring economic benefits to patients, caregivers, and healthcare organization. The benefits to patients and caregivers include decreased expense, reduce workload, eliminate redundant laboratory and radiology tests (Byrne *et al.*, 2010). The healthcare origination bears two third of the overall costs of eHealth intervention, hence the financial gain to the organization contributes to the sustainability of the technology (Parv *et al.*, 2012). The technology may streamline the service delivery process and reduce the problem of missing patient medical files, medical errors, and patient waiting time to improve the branding of the organization and attract patients (Byrne *et al.*, 2010). The healthcare organization can minimize the legal fines associated with missing patient medical files and medical errors by implementing eHealth systems.

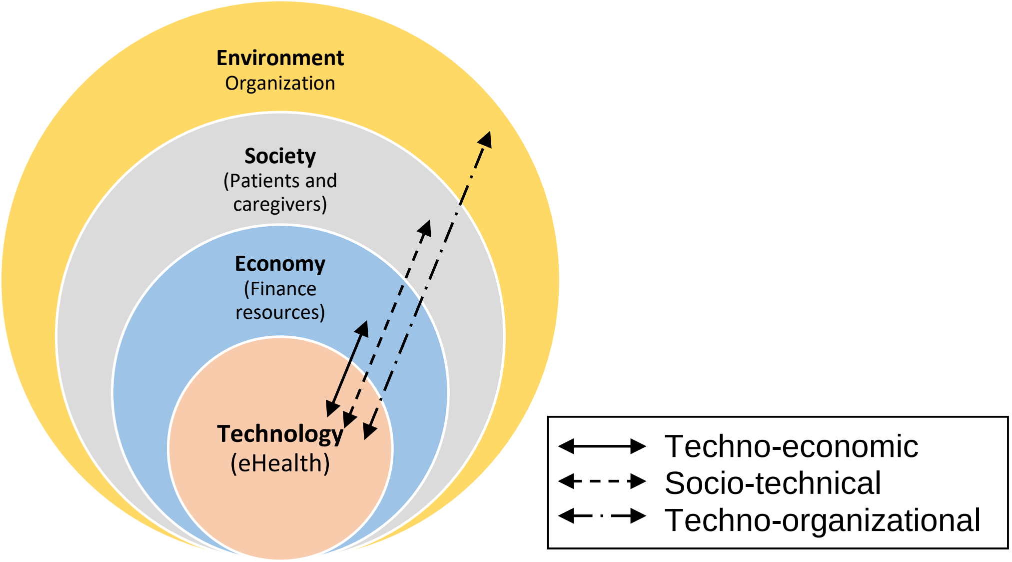


Figure 2.20 Development of sustainable technology (Musango and Brent, 2010).

The challenges associated with sustainability and uptake of eHealth systems are still unresolved issues that require further analysis and intervention (Bergmo, 2015). The technological capability of eHealth systems is one of the key factors that influence the successful implementation of a technology. The functional and non-functional requirements, interoperability and user interface designs are some of the key success factors of eHealth implementation in the technology category (Rippen *et al.*, 2013). The long-term sustainability of eHealth technology depends on the economic, social and organizational sustainability in which the technology is embedded.

2.6.3. Measuring sustainability

Sustainability is often a long-term goal and it is necessary to monitor the progress of activities to fulfil sustainability goals, i.e. whether the behaviour of an activity in a system is moving in the desired direction (Hay, Duffy and Whitfield, 2014). Sustainability assessment is the term used to describe the effort of producing knowledge on how activities within a system behave in relation to the goal (Hay, Duffy and Whitfield, 2014). “Measures employed to evaluate behaviour in sustainability assessment may generally be referred to as sustainability indicators” (Hay et al., 2014:244).

The three dimensions of sustainability: economic, social and environmental are used to measure corporate sustainability. However, researchers used different indicators for each dimension of sustainability, showing the lack of a standardised method to measure corporate sustainability (Montiel and Delgado-Ceballos, 2014). These three pillars of sustainability are also used to measure the sustainability of the dairy industry (Buys *et al.*, 2014), the sustainability of system design (Fiksel, 2003) and the sustainability of financial institutions’ lending policy (Zeidan, Boechat and Fleury, 2015). Although the three dimensions of sustainability are commonly used in assessing the sustainability of various systems, the focus of the indicators in each dimension varies based the system of interest.

Hay et al. (2014) emphasised the importance of engaging multiple stakeholders in discussions during the process of defining and selecting the sustainability indicators of the intended system. Moreover, it is necessary to note that “the choice of sustainability indicators may have an unintended and undesired impact on the behaviour of activities within a system” (Hay et al., 2014:245). As depicted in Figure 2.21, the sustainability assessment may be conducted over a range of spatial scales, from local to global, by extending the boundaries of the system of interest within which the behaviour of activities is interpreted (Hay, Duffy and Whitfield, 2014). The local boundary can further extend to country, organization, or department levels.

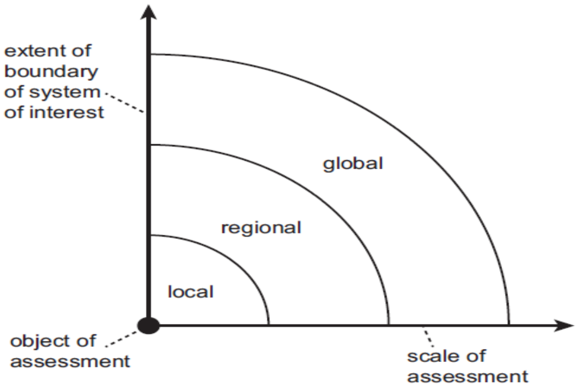


Figure 2.21 Boundaries of sustainability assessment (Hay, Duffy and Whitfield, 2014:246).

The results-based management chain (Figure 2.22) focuses on the monitoring and evaluation of the outputs, outcomes and impact of a project to ensure sustainable benefits (Spreckley, 2009). Products or services are immediate results achieved (or outputs) from project inputs and activities. The utilization of the outputs results in benefits (outcomes) to stakeholders (Spreckley, 2009). The outcomes together with other development interventions will lead to higher development goals or impacts (Spreckley, 2009).

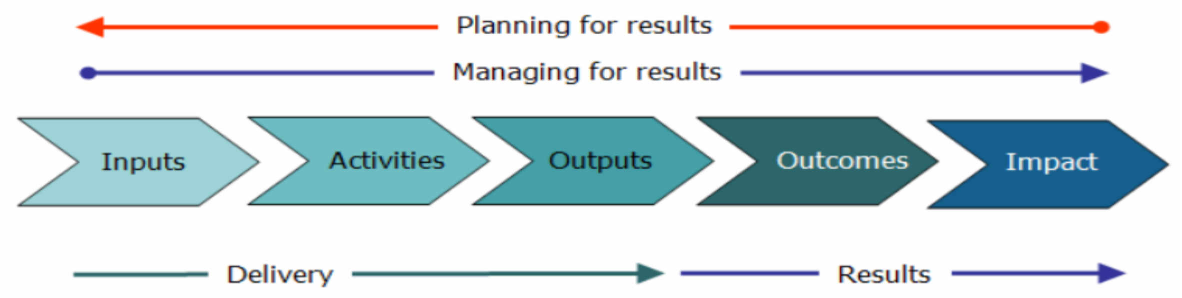


Figure 2.22 Results chain (Spreckley, 2009:3).

Projects fail to ensure sustainability when they fail to demonstrate long-term results (outcomes and impact). The effectiveness and relevance of a project is an important driver of sustainability to ensuring long-term benefit. The social, economic and environmental factors are key pillars of sustainability that aid the development of indicators to assess the sustainability of technology.

2.7. The socio-technical factors of eHealth acceptance

The introduction of eHealth technology in healthcare facility results in the emergent and recursive interactions among new technology and existing social systems, technologies, and physical environments (Harrison et al., 2007). The success of HIT implementation is not only hindered by technical flaws, but also by the undesirable outcomes of social and behavioural factors (Harrison, Koppel, & Bar-Lev, 2007; Sauer 1994). The socio-technical systems design (STSD) should consider - people, machines, and context - when developing complex socio-technical systems (Baxter and Sommerville, 2011:5). In general, the socio-technical perspective of eHealth implementation considers the interaction between the technical features of an eHealth system with the social features of a healthcare work environment (Ludwick and Doucette, 2009).

The socio-technical factors of eHealth implementation within the boundary of healthcare organization will be discussed in this section based on evidence from literature. The brief discussion of technological and social factors of sustainable eHealth implementation are addressed from the perspective of technology acceptance by end-users. The technological and social parameters of TAM and IS models are discussed independently in section 2.4. The relationships among the elements TAM and IS models as well as the socio-technical models are reviewed in detail. This section provides additional insight into socio-technical factors and their interaction during implementation and use of eHealth technology within a healthcare facility to maximize the users' acceptance.

2.7.1. Technological factors

The IS success model presented the quality of information systems as important factors to measure the technological aspect of ICT implementation (DeLone and McLean, 2003; Gorla, Somers and Wong, 2010). The technological factors of ICT acceptance (see Chapter 2.4.3) are subcategorized into three quality groups namely system quality, information quality, and services quality (DeLone and McLean, 2003; Gorla, Somers and Wong, 2010).

System quality denotes the technical soundness of the IS itself (Gorla, Somers and Wong, 2010). It is linked to the quality of software, data components, user interface, and performance of a system which is measured by the ease of use, functionality, reliability, flexibility, portability, integration and importance (DeLone and McLean, 2003; Maryati Mohd. Yusof *et al.*, 2008; Gorla, Somers and Wong, 2010).

Information quality refers to the quality of outputs of IT system (DeLone and McLean, 1992; Gorla, Somers and Wong, 2010). It comprises information content (relevance of information to the user) and information format (style of information presentation) (Gorla, Somers and Wong, 2010). The measures of information quality consist of accuracy, timeliness, completeness, relevance, and consistency of information produced by IT system (DeLone and McLean, 2003; Maryati Mohd. Yusof *et al.*, 2008; Aqil, Lippeveld and Hozumi, 2009; Gorla, Somers and Wong, 2010).

Services quality is concerned with the level of overall support delivered to the end-users to meet their expectations (Gorla, Somers and Wong, 2010). The services quality measures include up-to-date hardware and software, reliability, responsiveness, assurance, and empathy of technical support (DeLone and McLean, 2003; Maryati Mohd. Yusof *et al.*, 2008).

2.7.2. Social factors of technology acceptance

The social factors represent the individuals' perception to use technology and the influence of people in the surroundings of technology users (co-workers and managers). The acceptance and use of technology by the intended end-users is one of the key success factors of information systems (IS) implementation (DeLone and McLean, 1992, 2003; Michel-Verkerke, Robert A Stegwee and Spil, 2015). However, Seddon (1997) argued that IS success should be measured by its net benefit instead of the system use. Studies indicated a strong association between system use and net benefit (DeLone and McLean, 2003); hence, technology acceptance or system use is a necessary but not sufficient condition to the success of eHealth systems. Technologies not used by the users cannot produce any benefit. Yet technologies that are accepted and used by users do not necessarily yield benefits.

The individuals' perception to use.

The two determinants, perceived usefulness and perceived ease of use, were hypothesized to be fundamental determinants of user acceptance of Information Technology in the technology acceptance model (TAM) as discussed in Chapter 2.4.2.

- Perceived usefulness is defined as "the degree to which a person believes that using a particular system would enhance his or her job performance" (Davis, 1989:320).
- Perceived ease of use refers to "the degree to which a person believes that using a particular system would be free of effort" (Davis, 1989:320).

In two studies involving 152 users and four applications programs, Davis (1989) argued usefulness had a greater correlation with usage behaviour than ease of use. The regression analyses further indicated that perceived ease of use may actually be a causal antecedent to perceived usefulness, rather than a direct determinant of system usage (Davis, 1989).

The social influence on technology acceptance.

The 'social influences' category represents the support from supervisor and senior management, the influence of co-workers, the prestige of users as well as the representation of users in the system decision (Venkatesh and Davis, 2000; Venkatesh *et al.*, 2003; Venkatesh and Bala, 2008; Garcia-Smith and Effken, 2013). The list of social influences that impact acceptance of technology are described in Appendix 3.3.

Socio-technical outcome factors.

The successful implementation of eHealth technology has a potential to bring positive impact on the healthcare services delivery. Based on the finding of literature study, Rippen et al. (2013) indicated four categories associated with the outcomes of eHealth technologies. These are clinical, business/ financial, adoption and methodology outcome categories. The business or financial outcomes are related to indicators associated with cost savings or profit-making; whereas the adoption outcomes assess the number of users and the depth of their use (Rippen *et al.*, 2013). The net benefit associated system use incorporates all the IS impact measures, such as workgroup impact, organizational impact, consumers impact, societal impacts (DeLone and McLean, 2003).

2.7.3. The socio-technical models

“The socio-technical systems design (STSD) methods are an approach to design that consider human, social and organizational, as well as technical factors in the design of organizational systems” (Baxter & Sommerville 2011:4). The 8-dimensional socio-technical model aimed to address challenges in the design, development, implementation, use, and evaluation of Health Information Technology (HIT) within complex healthcare environment (Sittig and Singh, 2010). The model categorises “technology” dimension into sub-components to dissect out the causes of particular HIT implementation problems (Sittig & Singh 2010:3). The technology aspect of the model includes dimensions such as *hardware and software computing, infrastructure*, *clinical content,* and *human-computer interface*. The *people* dimension includes human involved in all aspects of the design, development, implementation, use and evaluation of HIT (Sittig and Singh, 2010). The interaction between the key players is addressed in the *workflow and communication dimension* of the model. The *internal factors* such as organizational policies, procedures and cultures; as well as the *external rules, regulations and pressures* are also addressed in the model. Eventually, the *system measurement and monitoring* dimension aimed to assess the impact of the system on the quality of healthcare service delivery and support the continuous improvement effort (Sittig and Singh, 2010).

The socio-technical factors directly influence the eHealth implementation success (Ludwick and Doucette, 2009). The five key characteristics of socio-technical systems are (Baxter and Sommerville, 2011:5):

- Systems have interdependent parts.
- System adapts to and pursues goals in external environments.
- Internal environment of a system comprises separate but interdependent technical and social subsystems.
- There are more than one system of choices to achieve the system goals.
- System performance depends on the joint optimisation of the technical and social aspects of the system.

Figure 2.23 describes the emergence of four different socio-technical system levels, namely hardware, software, human-computer interaction and socio-technical (Whitworth and Sylla, 2012).

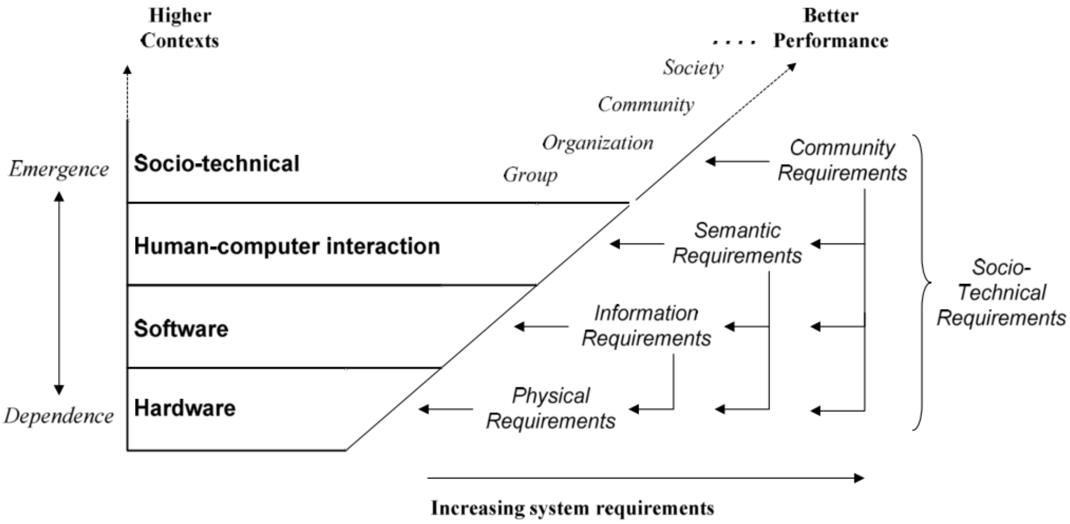


Figure 2.23 Socio-technical systems levels (Whitworth & Sylla 2012: 2).

The relationship between the four levels of socio-technical systems and the 8-dimensions of socio-technical systems are shown in Table 2.10.

Table 2.10 Interrelationships between technological and socio-technical factors.

	Socio-technical system levels (Whitworth & Sylla 2012)			
Socio-technical dimensions of HIT (Sittig & Singh, 2010)	Hardware	Software	Human Computer Interaction	Socio-technical
Hardware and software computing infrastructure.	X	X		
Clinical content		X		
Human computer interface			X	
People.				X
Workflow and communication.				X
Internal Organizational policies, procedures, and cultures				X
External rules, regulations, and pressures.				X
System measurement and monitoring.				X

Sources: Sittig & Singh 2010; Whitworth & Sylla 2012.

Harrison et al. (2007) described the socio-technical interaction as an interplay between a new HIT and the adopting organization’s existing socio-technical conditions such as technologies, workflows, culture, and social interaction. In addition to the contribution of technical flaws to the failure of a HIT, the undesirables outcomes of socio-technical interactions during HIT implementation significantly hinder its success (Harrison, Koppel and Bar-Lev, 2007). Sauer (1994) also indicated that the social and behavioural factors are the main reasons for information systems failures may be more than the technical factors. The Interactive Socio-technical Analysis (ISTA) framework recognises the conditions characterizing complex adaptive systems – the socio-technical interactions are dynamic, emergent, hard to understand and often surprising (Harrison, Koppel and Bar-Lev, 2007).

The ISTA framework shows interactions among subcomponents of the socio-technical system that act as major sources of unintended consequences during new HIT introduction and use that can sometimes undermine quality and safety and can lead to implementation failure (Harrison, Koppel and Bar-Lev, 2007). “It also emphasizes the emergent and recursive interactions among HIT and existing social systems, technologies, and physical environments” (Harrison et al., 2007:547). The framework addresses the following five interaction types:

- New HIT changes existing social system.
- Technical & physical infrastructures mediate HIT use.
- Social system mediates HIT use.
- HIT-in-use changes social system.
- HIT-social system interactions engender HIT redesign.

The better design of technology, especially the *human computer interface* is described as one of the four strategies to reduce the risks of HIT implementation failure (Beuscart-Zéphir, Aarts and Elkin, 2010). The design of HIT in the controlled environment cannot fully replicate the intrinsic properties of a naturalistic context of use in a healthcare organization resulting in the problem of usability (Beuscart-Zéphir, Aarts and Elkin, 2010). Petrakaki, Cornford, & Klecun (2010) argued that the “socio-technical changing” is a continuous process, therefore, it should not be treated as a static or discrete post and pre-implementation notions. The processes of “socio-technical changing” incorporates ensuring stakeholders engagement, understanding the interaction of people with technology, and manifesting changing as a process (Petrakaki, Cornford and Klecun, 2010).

The dynamic complexity arises from socio-technical interaction during the design, development, implementation, and operation of eHealth technology within a complex healthcare environment. The complex interactions and feedbacks occurring within a dynamic environment influence the acceptance of eHealth technology by the end-users. The usability problem of eHealth technology could result from the technological factors like the graphic user interface for human-computer interaction, or the social factors such as the users’ perception towards the usefulness of technology to achieve their operational goal. Moreover, organizational policies, procedure, and cultures are also believed to affect the use of eHealth technology within an adopting organization (Sittig and Singh, 2010).

The acceptance of technology by users is one of the key success factors during the implementation of eHealth systems. Ward (2013) analysed the potential of technology acceptance and innovation diffusion models and highlighted the models' weakness to differentiate between the technological and human factors for the acceptance of health-related IT projects. This was considered as the limitation of the models' applicability in practice. The system quality, information quality, and services quality affect the success of eHealth implementation in the technological dimension. The individual perception (usefulness and ease of use) and social influence are the two important factors that determine the social dimension of IS success (Petter, DeLone and McLean, 2013). The Individual perception relates to the attitude, behaviour and personal demography of individuals towards using the IS (Petter, DeLone and McLean, 2013). The social influence refers to the impact of peer groups or social networks influence on individuals towards using technology (Petter, DeLone and McLean, 2013).

2.7.4. The socio-technical factors of eHealth acceptance

The TAM has been widely used and empirically tested to predict the user acceptance and use of Information Systems (Davis, 1989); besides the IS success model has been applied in a wide range of research studies to empirically validate the success of Information Systems (DeLone and McLean, 1992). The implementation of new eHealth technology is believed to bring changes into an existing social system (Harrison, Koppel and Bar-Lev, 2007). Moreover, Harrison et al. (2007) indicated that the social and technological features play a key role in mediating technology use. The technology end-users and their social network are the key IS success determinants with in the social dimension (Petter, DeLone and McLean, 2013). The elements of the social factors, individual perception (usefulness and ease of use) as well as social influence, are widely addressed and emperically tested by the studies that used the TAM.

The relationships among the elements of the socio-technical factors of eHealth acceptance are determined from the literature findings that have empirically tested the TAM and IS success model. The summary of evidence from the literature survey is presented in the Tables 2.11 – 2.14. The information in the tables present the relationship between technological and socio-technical factors, social and socio-technical factors, outcome and intention to use factors, technology use and socio-technical factors.

Table 2.11 Interrelationships between technological and socio-technical factors.

Relationships	Significance	Sources
System Quality - User Satisfaction	7/7 Supported	Tilahun & Fritz 2015; Iivari 2005; Hadji et al. 2016; Aggelidis & Chatzoglou 2012; Garcia-Smith & Effken 2013; Chang et al. 2011; Petter & Mclean 2009
System Quality - Information Quality	2/2 Supported	Aggelidis & Chatzoglou 2012; Gorla et al. 2010
System Quality - Ease of use	2/2 Supported	Pai & Huang 2011; Aggelidis & Chatzoglou 2012
Information Quality - Actual Use	2/3 Supported	Tilahun & Fritz 2015; Petter & Mclean 2009
	1/3 Not Supported	Iivari 2005
Information Quality - Usefulness	2/2 Supported	Pai & Huang 2011; Moores 2012
Information Quality - Intention to Use	2/2 Supported	Chang et al. 2011; Petter & Mclean 2009
Information Quality - User Satisfaction	7/7 Supported	Tilahun & Fritz 2015; Iivari 2005; Aggelidis & Chatzoglou 2012; Garcia-Smith & Effken 2013; Chang et al. 2011; Petter & Mclean 2009; Hou 2012
Services Quality - Social Influence	2/2 Supported	Aggelidis & Chatzoglou 2009; Garcia-Smith & Effken 2013
Services Quality - Intention to Use	4/6 Supported	Aggelidis & Chatzoglou 2009; Holden & Karsh 2010; Gagnon et al. 2012; Chang & Hsu 2012
	2/6 Not Supported	Venkatesh et al. 2003; Chang et al. 2011
Services Quality - Net Benefit	2/2 Supported	Chang et al. 2011; Gorla et al. 2010
Services Quality - Actual Use	2/3 Supported	Tilahun & Fritz 2015; Venkatesh et al. 2003
	1/3 Not Supported	Petter & Mclean 2009
Services Quality - User Satisfaction	2/4 Supported	Tilahun & Fritz 2015; Garcia-Smith & Effken 2013
	2/4 Not Supported	Aggelidis & Chatzoglou 2012; Petter & Mclean 2009

Table 2.12 Relationship between social factors and socio-technical elements.

Relationships	Significance	Sources
Ease of Use - Usefulness	10/10 Supported	Pai & Huang 2011; Chen et al. 2008; Tung et al. 2008; Aggelidis & Chatzoglou 2009; Dünnebeil et al. 2012; Holden & Karsh 2010; Melas et al. 2011; Moores 2012; Cheung & Vogel 2013; Kim & Chang 2007.
Ease of Use - Intention to Use	7/7 Supported	Pai & Huang 2011; Tung et al. 2008; Aggelidis & Chatzoglou 2009; Dünnebeil et al. 2012; Holden & Karsh 2010; Aldosari 2012; Melas et al. 2011.
Usefulness - Intention to Use	9/9 Supported	Pai & Huang 2011; Chen et al. 2008; Tung et al. 2008; Aggelidis & Chatzoglou 2009; Dünnebeil et al. 2012; Holden & Karsh 2010; Melas et al. 2011; Aldosari 2012; Gagnon et al. 2012.
Social Influence - Intention to Use	3/3 Supported	Venkatesh et al. 2003; Aggelidis & Chatzoglou 2009; Holden & Karsh 2010

Table 2.13 Relationship between outcome factors and intention to use.

Relationships	Significance	Sources
Net Benefit - Intention to Use	1/1 Strongly Supported	Petter & Mclean 2009

Table 2.14 Relationship between technology use and socio-technical factors.

Relationships	Significance	Sources
User Satisfaction - Net Benefit	6/6 Supported	Tilahun & Fritz 2015; Iivari 2005; Garcia-Smith & Effken 2013; Chang et al. 2011; Petter & Mclean 2009; Hou 2012
User Satisfaction - Actual Use	3/3 Supported	Tilahun & Fritz 2015; Iivari 2005; Hou 2012
User Satisfaction -Intention to Use	2/2 Support	Chang et al. 2011; Petter & Mclean 2009
Intention to Use - Actual use	4/4 Supported	Venkatesh et al. 2003; Iivari 2005; Holden & Karsh 2010; Venkatesh & Bala 2008
Actual use - User Satisfaction	3/4 Supported	Iivari 2005; Hou 2012; Petter & Mclean 2009
	1/3 Not supported	Tilahun & Fritz 2015

The sustained use of technology to ensure the long-term sustainability of eHealth is not only influenced by the socio-technical factors but also the techno-organizational factors. The following section will cover the evidence of techno-organizational factors of eHealth acceptance as reported in literature.

2.8. The techno-organizational factors of eHealth acceptance

The elements of an organizational factor that influence eHealth implementation and their dynamic interactions with technological dimensions are the focus in this section of the thesis. Healthcare organization is a complex system that involves nonlinear interaction among organizational elements that keep changing overtime. The subsequent section of this chapter presents the organizational factors of eHealth implementation, techno-organizational processes of eHealth implementation, organizational frameworks of eHealth implmentation.

2.8.1. Organizational factors of eHealth acceptance

The categories associated with the environment facet includes organizational culture, leadership, resources, settings, support and business drivers (Rippen *et al.*, 2013). Similarly, organizational structure, resources, procedures, support services, and culture to develop, manage and improve eHealth process and performance are considered as critical factors under organizational determinants (Aqil, Lippeveld and Hozumi, 2009). On another study, top management support and end-users training were recommended as variables that affect MIS adoption in organizational dimensions (Al-Mamary, Shamsuddin and Aziati, 2014). In a systematic literature review of 79 papers, organizational management barriers for eHealth adoptions were grouped into five categories, namely organizational structure, tasks, people, incentives and information and decision processes (Lluch, 2011). The key elements of organizational dimension of eHealth implementation are discussed below.

Organizational culture/climate comprises organizational rule, values and practices of end-users towards information and technology use such as culture of data collection, analysis and use (Aqil, Lippeveld and Hozumi, 2009). Researches showed that organizations that have developed a decision-making culture based on clear data insight rather than on intuition have managed to be more productive and profitable than their competitors (Bilbao-Osorio, Dutta and Bruno Lanvin, 2014). Organizations that promote culture of information perform better in the implementation eHealth technology and use of information (Aqil, Lippeveld and Hozumi, 2009).

Organizational structure refers to the coordination of different healthcare team members to work together to achieve the organizational goal (Lluch, 2011). Organizational structure that includes hierarchy, teamwork and cooperation, and autonomy, has been identified as the potential barriers to eHealth adoption (Lluch, 2011). The traditions of healthcare structures are strongly hierarchical which does not support teamwork, moreover, healthcare professionals have autonomy (Lluch, 2011).

Organizational leadership is the way of ensuring strategic consistency when utilizing technology; i.e. ensuring individuals are working together toward the common goal (Cresswell and Sheikh, 2012). An ICT-friendly policies of an organization could possibly increases the uptake of eHealth technologies within healthcare organizations (Bilbao-Osorio, Dutta and Bruno Lanvin, 2014).

Resources cover availability financial, physical and human resource (Aqil, Lippeveld and Hozumi, 2009). This includes skill human resources to use and give technical support, as well as electric power and ICT infrastructures, namely computers, local area networks (LANs), internet connections, printer, and scanner to support implementation of the health IT (Rippen *et al.*, 2013).

Workflow process refers to the way in which activities and working processes are organised and executed by users (Tsiknakis and Kouroubali, 2009; Lluch, 2011). The patient centred care process is highlighted as preferred approach than task focused care process. Virtual patient-care giver interaction is replacing face-to-face interaction to become a new reality in healthcare to influence the workflow process (Lluch, 2011).

Management support refers to the level of general support offered by top management which includes encouraging the use of a system, allocating resources, understanding the benefits of the system, intent to see the users are happy in using the system (Al-Mamary, Shamsuddin and Aziati, 2014).

2.8.2. Techno-organization processes of eHealth implementation

The organizational elements listed above not only influence each other but also interact with the technology to influence the use. The anticipated outcomes of technology implementation can only be realized with meaningful use of technology. Environmental or organizational context directly influence the successful implementation and use of technology (Aqil, Lippeveld and Hozumi, 2009; Gorla, Somers and Wong, 2010). The level of influence may vary as the project progress from pre-implementation to implementation and post-implementation phases of implementation (Rippen *et al.*, 2013). The model for organizational issues in health informatics indicated the cyclic and dynamic nature of organizational changes and the implementation of health IT (Aarts, Peel and Wright, 1998).

The implementation process of eHealth system within a healthcare organization transforms the given inputs (determinants) into an output, use of technology and information (WHO, 2012a). Organizational processes are key factors in transforming the organizational determinants to facilitate the use of technology and information. The techno-organizational process of eHealth implementation includes:

User training refers to the amount of training provided to the organization by internal or external entities(Al-Mamary, Shamsuddin and Aziati, 2014). Lluch (2011) described that lack of training and competency of end-users as a potential barrier of HIT adoption under the category of people policies of an organization.

Change management is one of a key component of task to ensure a patient oriented process (Lluch, 2011). Aarts et al. (1998) described eight steps of organizational change to manage the complexity of organizational issues in health informatics implementation. The stages begin with assessing and understanding the nature and content of clinical work; followed by identifying its consequences; prioritization; recognising appropriate requirements; creating strategic plans; informing and persuading changes; introducing new technologies; and finally continuous evaluation of the impact (Aarts, Peel and Wright, 1998).

Data management addresses aspects of data handling including collection, storage, quality control and flow, to processing, compilation, analysis and presentation of data (WHO, 2012a). Data quality can be improved by setting a “minimum dataset” to reduce the burden of data collection (WHO, 2012a). The data quality can be influenced by timeliness, periodicity, consistency, confidentiality, data security and accessibility of information (WHO, 2012a).

Stakeholders’ engagement refers to an involvement of key stakeholders starting from planning phase to reduce resistance, increase acceptance, and meet system requirements (Cresswell and Sheikh, 2012; van Dyk *et al.*, 2012).

Project Management is an application of knowledge, skills, tools, and techniques to project activities in order to meet the stakeholder needs and to balance schedule, quality and budget expectations from a project (Project Management Institute, 2013)

Organizational communications is an effective exchange of timely and accurate information with all relevant stakeholders to improve informed decision-making (Project Management Institute, 2013).

The two variables of organizational factors (top management support and end-users training) are hypothesized to influence perceived usefulness and users satisfaction (Al-Mamary, Shamsuddin and Aziati, 2014). The study that examined the influence of system, information and services quality on organizational impact showed that services quality has the highest impact on the organization than the system and information quality (Gorla, Somers and Wong, 2010). The same study indicated that the system quality has an indirect effect on organizational impact through information quality (Gorla, Somers and Wong, 2010).

Information culture of a healthcare organization influences the workflow process and affects the output of technology performance, i.e. the quality of data and continuous information use (Aqil et al. 2009:222). The use of information leads to improved evidence-based decision-making (Aqil, Lippeveld and Hozumi, 2009). Data quality describes relevance, completeness, timeliness, and accuracy of information used in decision-making process (Aqil, Lippeveld and Hozumi, 2009).

2.8.3. Organizational framework of eHealth Implementation

The systematic reviews of 13 articles related to the implementation of eHealth systems in organizational settings indicated the importance of technical, social and organizational factors in ensuring the success of eHealth implementations (Cresswell and Sheikh, 2012). The different organizational frameworks of eHealth implementations combine the technological factors and techno-organizational processes discussed in the previous sections. The organizational frameworks associated with technology implementation are addressed in the following sections. The models share some common factors

The business world operated more dominantly in complex domain requiring different, counterintuitive, responses in a particular context (Snowden and Boone, 2007). Complexity is a realm of “unknown unknowns” which is characterized by emerging unpredictable patterns of nonlinear cause-and-effect relationship (Snowden and Boone, 2007). To make decisions in a complex domain, leaders develop probes to understand emergent patterns, sense useful alternatives and respond (Van Beurden *et al.*, 2013). The nonlinear characteristics of feedback systems are addressed in system dynamics through the learning process of a complex system (Sterman, 2000).

The Fit between Individuals, Task and Technology (FITT) framework

The FITT framework (Figure 2.24) explains the adoption and diffusion of ICT in healthcare organizations (Tsiknakis and Kouroubali, 2009). The level of adoption and success of health IT implementation depends on the quality of the optimal interaction between the individuals, task and technology (Tsiknakis and Kouroubali, 2009). Tasks in the FITT framework refer to activities and workflow processes that are supported by the implemented technology (Tsiknakis and Kouroubali, 2009).

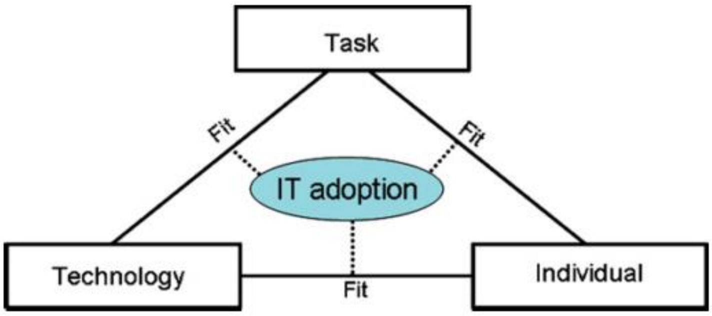


Figure 2.24 The FITT framework (Tsiknakis & Kouroubali 2009).

The lack of properly trained local technical support resulted a low fit in the task-technology dimension (Tsiknakis and Kouroubali, 2009). Poor technical support resulted in weak ICT infrastructure (Tsiknakis and Kouroubali, 2009). At the time of technology introduction, the use of both paper and electronic systems, as well as slow data entry skill of users doubled the average patient consultation time, leading to the absence of individual-task fit (Tsiknakis and Kouroubali, 2009). The introduction of technology in organizations with high patient volume put burden on healthcare professionals and forced them to work extended hours (Tsiknakis and Kouroubali, 2009).

Organizational framework for health IT

The five constructs discussed under organizational framework for health IT includes *technology, use, environment, temporal,* and *outcomes;* are essential for comprehensive understanding of eHealth implementation and use (Rippen *et al.*, 2013). The study showed that technology was not the key elements in the improved use of health IT, but environmental condition played a significant part in the success or failure of a technology (Rippen *et al.*, 2013). Organizational culture, business drivers, leadership, setting, resources and support are categories associated with environmental dimensions (Rippen *et al.*, 2013). The study of two health IT applications indicated that technology fit into the clinician's workflow, resource availability and leadership support in the domain of use and environment were the reasons for success of an application over another application that was pushed without meeting the requirements (Rippen *et al.*, 2013). The study concluded that technology use and environment conditions of the organizational framework often influence each other either positively or negatively (Rippen *et al.*, 2013).

Technological, organizational, and environmental (TOE) framework

The innovation decision making process of an organization is influenced by TOE factors (Vest, 2010). The technological context deals with existing technology portfolio and an organization readiness to facilitate the adoption and implementation of health IT (Vest, 2010). The organizational context refers to the control (focus of health IT policy), integration (information exchange within and between organizations) and information needs of the organization that can be best achieved through health IT systems (Vest, 2010). The environmental context discusses the competitive pressure of the surrounding environment to adopt and implement health IT (Vest, 2010). The TOE framework (Figure 2.25) has been used to organise health IT adoption and implementation evidences, and the analysis demonstrated the significant influence of organizational and inter-organizational issues on the success of health IT projects in addition to technological factors (Vest, 2010). The organizational factors covers issues within the organization's reach, whereas the environmental factors are pressures from the surrounding environment which may not necessary be within the organization's control (Vest, 2010).

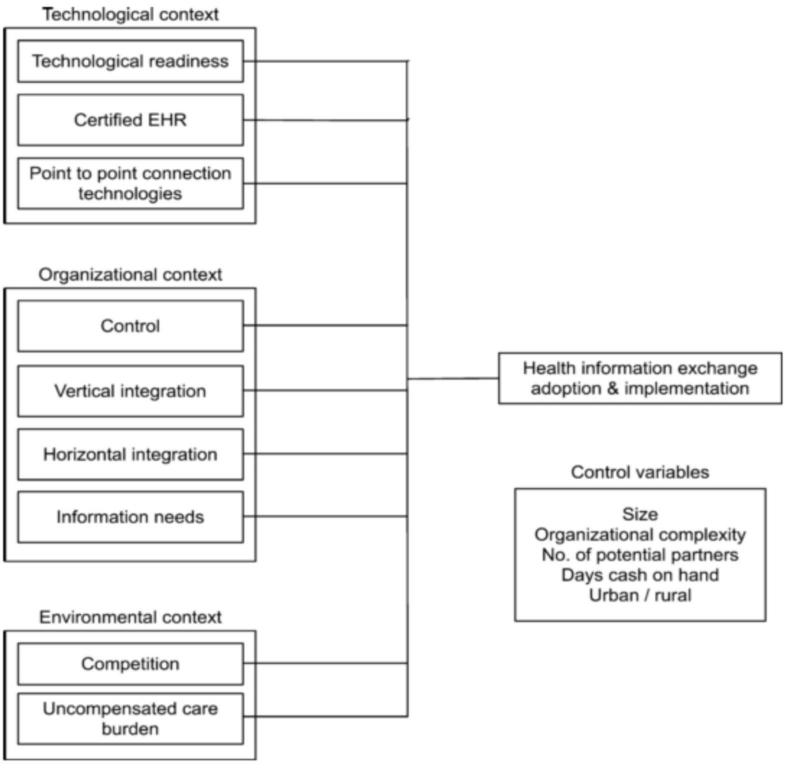


Figure 2.25 TOE Framework (Vest 2010).

The ‘effective’ fit framework

The ‘effective’ fit framework (Figure 2.26) explains the importance of a fit between clinical work, organizational system and technology domains for effective implementation of ICT in a healthcare organization (Aarts, Peel and Wright, 1998). Clinical work refers to activities of healthcare delivery services as a result of patient and clinician interaction (Aarts, Peel and Wright, 1998). Clinician are physicians, nurses and allied health professionals (Aarts, Peel and Wright, 1998). Organizational system denotes the setting in which clinical works are performed; these include resources, rules, regulations, law, and cultures in an organization (Aarts, Peel and Wright, 1998). Technology considers all kind of ICT systems that support clinical work practices (Aarts, Peel and Wright, 1998).

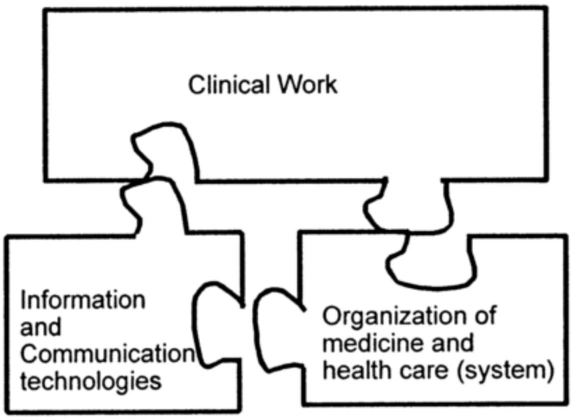


*Figure 2.26 Three domains needing an ‘effective’ fit (Aarts, Peel and Wright, 1998)***.**

The clinical work (Aarts, 2012) and tasks (Tsiknakis and Kouroubali, 2009) refer to workflow process but presented distinctively from organizational dimensions in the ‘effective’ fit and FITT frameworks. However other frameworks addressed the workflow process under organizational (Cresswell and Sheikh, 2012) and envirornment (Rippen et al., 2013) dimensions of eHealth implmentation. The ‘effective’ fit and PRISM frameworks incorporated behavioural (Aqil, Lippeveld and Hozumi, 2009) and individual (Tsiknakis and Kouroubali, 2009) elements but these social dimensions are absent from other organizational frameworks.

In summary, all five organizational frameworks commonly address technological and organizational determinants in their frameworks. Moreover, additional determinants of organizational dynamics such as task, behavioural, individual, environmental are also presented in some of the frameworks. Most of the frameworks acknowledge the dynamic complex nature of health IT implementation in healthcare organizations but fail to address these dyamcities in their frameworks through feedback processes. The techno-econcomic factors of sustainable eHealth implementation are discussed in the next section.

2.9. The techno-economic factors of eHealth acceptance

The economic strategies are described as one of the key factors for a long-term sustainability of eHealth implementation (De Rosis and Nuti, 2018). The financial model of eHealth implementations in the developing countries differs from the developed world in terms of the amount, source and period of funding. The implementation of eHealth in developing countries is typically driven by the non-governmental organizations (NGOs) and private players (Jahangirian and Taylor, 2015; Quaglio *et al.*, 2016). However, donor-funded projects pose a strong hindrance to interoperability and standardization of eHealth system pushing high the overall cost of eHealth implementation (Schweitzer and Synowiec, 2012). The limited amount of budget and the short project duration of donor organizations presented a threat to the long-term sustainability and large-scale implementation of eHealth (Quaglio *et al.*, 2016).

The implementation of eHealth is anticipated to reduce the healthcare cost; however, evidence shows that technological innovations have tended to drive the healthcare unit cost upwards in the developed world (Da´valos *et al.*, 2009; Schweitzer and Synowiec, 2012). The 25.9 billion dollars of financial incentives launched in the USA to support the “meaningful use” of electronic health systems accelerated the broad use of Electronic Health Records (EHRs) by the hospitals (Stroetmann, Motti and Kalra, 2015). Similarly, incentives such as reimbursement schemes, free computers and software, grants and ultimately pay-for-performance played a key role in the diffusion of eHealth systems in the UK (Stroetmann, Motti and Kalra, 2015).

Stroetmann et al. (2015) concluded that financial incentives can facilitate the use of EHR but it does not ensure sustainable use of EHRs. The high investment and incentive costs are hardly affordable by the developing countries to facilitate the adoption of eHealth.

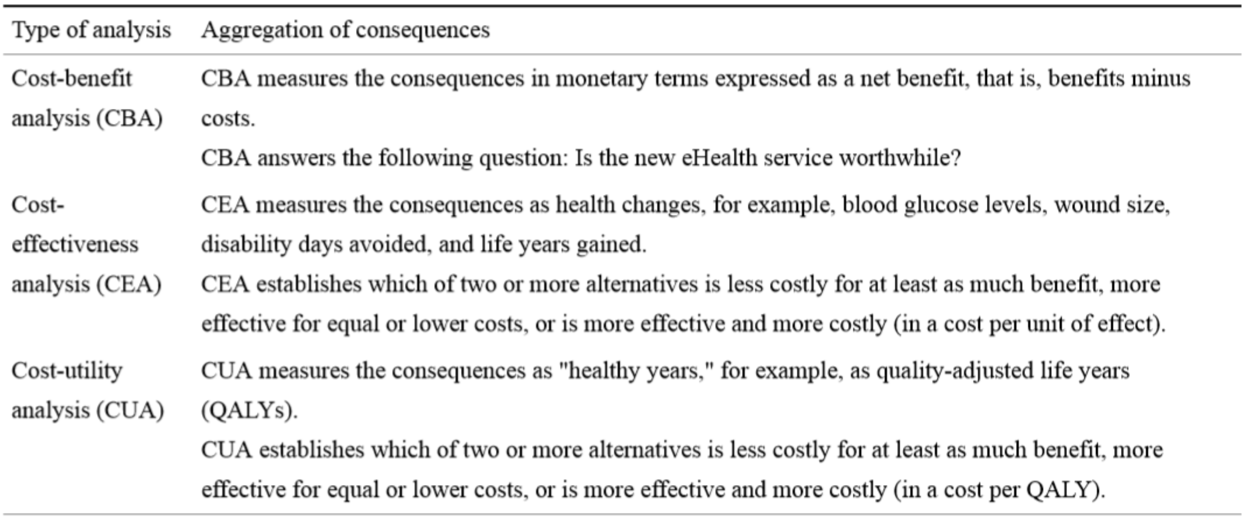
The eHealth implementation success significantly differs between the high-income countries (HIC) and low-income countries (LIC) as a result of resource availability which is linked to economic factors and efficiency of existing paper-based workflows (Driessen *et al.*, 2013). For the 2018 fiscal year, the World Bank classified developing countries or LIC as countries with GNI per capita $1,005 USD or less in 2016 (the World Bank, 2017). The economic affordability of the countries is one of the major differences between developed and developing countries in terms of implementing sustainable eHealth (Hebert, 2011). The total health expenditure of LIC in 2014 was only 5.8% of GDP compared to the health expenditure of the HIC (12.3% of GDP) (The World Bank, 2017). The per capita total expenditure on health at average exchange rate was $37 USD for LIC which was significantly less than HIC ($5,266 USD) in 2014 (The World Bank, 2017).

The financial category was one of the eight major barriers of eHealth implementations as discussed in the systematic review study of electronic medical records acceptance by physicians (Boonstra & Broekhuis 2010). Financial issues of eHealth implementation refer to initial investment costs, ongoing maintenance costs, uncertainty over return on investment (ROI), cost-effectiveness, cost-minimization, and availability of financial resources (Boonstra & Broekhuis 2010; Stroetmann et al. 2015). The shortage of funding and health professionals' willingness to use eHealth is often referred as the main challenge to sustaining and increasing the uptake of eHealth services (Bergmo, 2015). In order to ensure the cost-effectiveness of eHealth interventions, Naversnik & Mrhar (2014) proposed a cost-sharing scheme between the payer and provider that helps to avoid a potential loss to the provider and high treatment cost to the payer. Despite the financial constraints in LIC, the role of economic factors in the long-term sustainability of eHealth systems did not get enough research attention in developing countries.

2.9.1. Health economic evaluation techniques

The economic evaluation in healthcare aims at comparing the costs and outcomes of two or more health interventions (McCabe, 2009). In the economic evaluation of eHealth, measuring costs appear more direct than valuing health outcomes (Bergmo, 2015). The economic evaluation in health care differs in their approach to measuring outcomes (McCabe, 2009). The two popular economic evaluation techniques in healthcare are cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA) (McCabe, 2009; Bergmo, 2015). The need for economic evaluation of eHealth is high, because of insufficient scientific evidence to reach a generalizable conclusion for eHealth investment decisions (Schweitzer and Synowiec, 2012; Bergmo, 2015). The economic evaluation techniques in health care are summarised in Table 2.15.

Table 2.15 Summary of economic evaluations in health care (Bergmo, 2015).



Type of analysis	Aggregation of consequences
Cost-benefit analysis (CBA)	CBA measures the consequences in monetary terms expressed as a net benefit, that is, benefits minus costs. CBA answers the following question: Is the new eHealth service worthwhile?
Cost-effectiveness analysis (CEA)	CEA measures the consequences as health changes, for example, blood glucose levels, wound size, disability days avoided, and life years gained. CEA establishes which of two or more alternatives is less costly for at least as much benefit, more effective for equal or lower costs, or is more effective and more costly (in a cost per unit of effect).
Cost-utility analysis (CUA)	CUA measures the consequences as "healthy years," for example, as quality-adjusted life years (QALYs). CUA establishes which of two or more alternatives is less costly for at least as much benefit, more effective for equal or lower costs, or is more effective and more costly (in a cost per QALY).

Cost-benefit analysis (CBA)

CBA compares the total expected costs of an intervention against the total expected benefits to verify if the benefits surpass the costs of intervention (McCabe, 2009). In CBA, a monitory value is attached to benefits and costs and adjusted for the time value of money (McCabe, 2009; Bergmo, 2015). The effort of assigning monitory values to health outcomes and non-resource benefits is often difficult; hence CBA is rarely used in healthcare evaluation (Bergmo, 2015).

Cost-effectiveness analysis (CEA)

CEA is a method for determining the gains in health using a natural unidirectional index of outcomes, for example, blood glucose level and wound size, relative to the costs of different health interventions (McCabe, 2009). The aim in CEA is to achieve better benefit which is measured as health changes at a lower cost (Parsi, Chambers and Armstrong, 2012). It involves determining costs and assigning values to the outcomes. The CEA is necessary to evaluate the sustainability of eHealth technology (Parsi, Chambers and Armstrong, 2012). The two types of CEA are standard CEA and cost-utility analysis (CUA) (Bergmo, 2015). In standard CEA, the costs per unit of health (i.e., quality-adjusted life years [QALY]) is calculated for a given intervention and compared to current practice (Naversnik and Mrhar, 2014; Bergmo, 2015). QALY represents the combination of the duration of life and the health-related quality of life (McCabe, 2009). The conditions of cost-effectiveness treatment are (Parsi et al. 2012:565):

- Added health benefit at an equal or lower cost than the alternative treatment;
- Added health benefit is worth an additional cost
- Saving cost that is more valuable than the health benefit lost.

Cost-utility analysis (CUA)

CUA measures the difference in the expected health outcomes of two interventions in terms of QALY and compares with the difference between the expected costs of achieving a health benefit to calculate the incremental cost-effectiveness ratio (ICER), money/QALY gained (McCabe, 2009; Bergmo, 2015). A cost-effective intervention has ICER value below a predetermined threshold (Naversnik and Mrhar, 2014). CUA allows decision makers to compare the value of interventions for different health issues which cannot be addressed by CEA (McCabe, 2009). The failure of QALY to capture the differences in the process characteristics of interventions is one of the limitations of CUA (McCabe, 2009).

Cost-minimization analysis (CMA)

Another economic evaluation technique that compares the cost of alternative interventions that have equal health outcomes is CMA (Bergmo, 2015). It is usually difficult to establish a similar level of health outcomes from two or more health interventions which make CMA less practical method of economic evaluation (Bergmo, 2015). CMA focuses on the cost side of eHealth intervention and can be useful if the goal of the economic evaluation is to select the least costly system to deliver health service (Bergmo, 2015).

2.9.2. Measuring Costs and Benefits of eHealth

Measuring costs

In 2015, the eHealth expenditure in the Italian healthcare sector was 1.34 billion Euros, which was 1.2% of the national GDP (De Rosis and Nuti, 2018). The eHealth investment is growing globally. The direct health technology costs and non-health technology costs are the two cost categories of eHealth interventions (Schweitzer and Synowiec, 2012; Bergmo, 2015). The direct health technology costs include initial investment, change management, human resources, training and maintenance of technology (Parv *et al.*, 2012; Schweitzer and Synowiec, 2012). The implementation of eHealth incurs fixed costs such as equipment costs and variable costs such as a monthly or yearly leasing cost of connectivity (Bergmo, 2015).

The cost analysis of several studies failed to address the costs of essential infrastructure, personnel, maintenance and network connectivity costs associated with the implementation and operation of electronic discharge communication tool (Sevick *et al.*, 2017). The healthy time lost due to illness is assumed to be relevant non-health care costs in eHealth interventions (Bergmo, 2015). The non-healthcare costs associated with eating disorder includes costs related to transportation, social service and absence due to illness and loss of productivity at work or premature death (Aardoom *et al.*, 2016). The increasing variable costs associated with scale-up should be considered in the cost analysis of eHealth interventions (Paganini *et al.*, 2017). Hebert (2011) recommended eHealth implementation budget of a country including one-time investment costs and ongoing maintenance and support expenses should not exceed 1% of the annual health budget of the country.

Measuring benefits

The benefits of EHR are categorized into direct, indirect and intangible benefits (Parv *et al.*, 2012). Some of the potential benefits of eHealth intervention in terms of reducing costs and increasing efficiency of healthcare service include facilitating patient information record, remote diagnostics, disseminating health information, training staff, disease surveillance, appointments and scheduling follow-ups (Schweitzer and Synowiec, 2012). The benefits of eHealth interventions can be discussed from the perspective of three key stakeholders groups, i.e., patient, provider, and other stakeholder or society (Parv *et al.*, 2012; Schweitzer and Synowiec, 2012). The eHealth benefit to a patient includes improved medical effectiveness, better quality of healthcare services, continuity of employment or income generation, reduced travel and better-informed patient (Parv *et al.*, 2012; Schweitzer and Synowiec, 2012). The providers' benefit from eHealth intervention may include the reduced burden of healthcare services, better-informed professionals, accurate and fast diagnosis, and improved productivity of healthcare professionals (Parv *et al.*, 2012; Schweitzer and Synowiec, 2012). Other stakeholder groups such as patient relatives may benefit from eHealth interventions by avoiding communicable diseases, reducing transportation cost and lowering absenteeism from work (Schweitzer and Synowiec, 2012).

In summary, measuring the costs benefits of eHealth intervention requires a comprehensive approach to include the initial and ongoing investment costs. Although it may not be always simple, valuing the direct and indirect health benefits of eHealth intervention from the perceptive of key stakeholder groups is necessary to evaluate the cost-effectiveness of eHealth interventions. The next section discusses the ICT readiness and implementation of eHealth systems in resource-constrained settings.

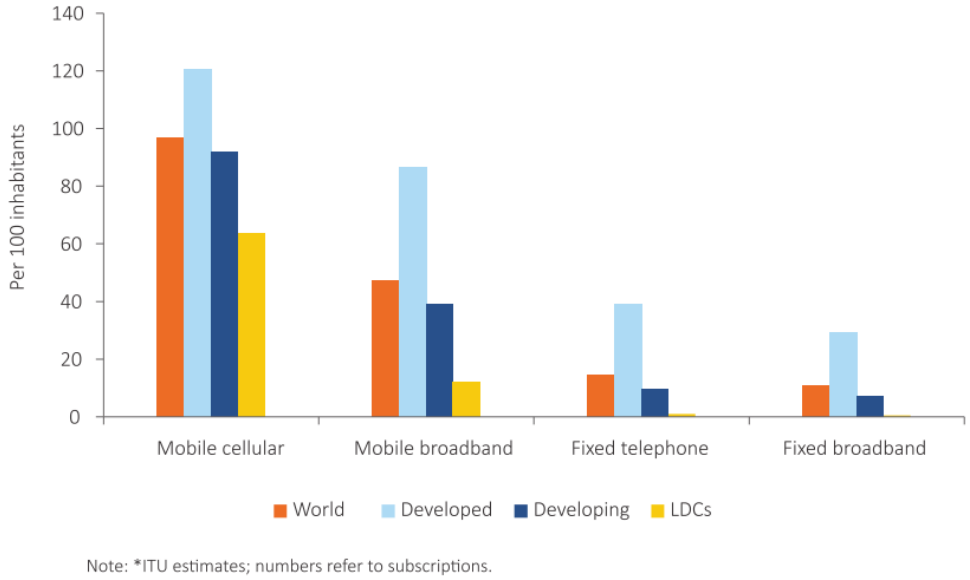
2.10. Resource-constrained environment

The international organizations such as the United Nations Development Programme (UNDP), the World Bank, the International Monetary Fund (IMF) and the World Trade Organization (WTO) classify countries based on their development as developed (advance or high-income) countries and developing (Low- and middle-income or emerging market) countries (Nielsen, 2013). The networked readiness, which is also described as a new economy, is used by the World Economic Forum (WEF) to measure the readiness of countries to exploit the opportunities offered by ICT to manage and organise economic activities (Bilbao-Osorio, Dutta and Bruno Lanvin, 2014). The Networked Readiness Index (NRI) framework comprises four sub-indexes: the environment for ICTs; the readiness of a society to use ICTs; the actual usage by all main stakeholders; ICT impact on the economy and society (Bilbao-Osorio et al., 2014). The WEF report of NRI is a more convenient way of categorizing countries to learn their capacity to meet the resources necessary for eHealth implementation.

2.10.1. ICT readiness in developing countries

The coverage of the mobile network, the number of mobile-cellular (voice and short messaging service (SMS)) and mobile-broadband subscriptions, and individual use of the internet showed rapid growth globally (ITU, 2015). However, there is a substantial digital divide between developing and developed countries as shown in Figure 2.27. The Internet and mobile phone were considered as the key technologies to influence eHealth diffusion and the economic growth in LMICs (Quaglio *et al.*, 2016). The economic development policies of health and education in LMIC can be supported by the use of ICTs (Quaglio *et al.*, 2016). However, limited Internet access and costly mobile services in LMICs limit the implementation eHealth systems to advance the development efforts (Quaglio *et al.*, 2016).

The regional breakdown of ICT access indicates that Africa has lower ICT density level (mobile phone, broadband subscriptions, and internet users) than other regions (ITU, 2015). The digital divides between the rural and urban, men and women, is significantly high within the developing countries (ITU, 2015). Furthermore, there is a widespread digital divide associated with ICT affordability, the capability required to use the internet, the capacity of broadband networks in remote areas in the developed world (ITU, 2015). The fixed telephone and mobile cellular services are 5 times less affordable in the developing countries than the developed countries; similarly the fixed broadband price is 14 times less affordable in developing country (ITU, 2015). The fast growth of ICT in developing world has a potential to improve the service delivery of several sectors; however, the wide digital divide could slow down the adoption and use of ICT in the developing country (ITU, 2015).



Note: *ITU estimates; numbers refer to subscriptions.

Figure 2.27 ICT access by development status, 2015(ITU 2015).*

2.10.2. eHealth Implementation in resource-constrained settings

The NRI measures the ICT readiness of countries to fully benefit from the advancement of ICT (Dutta and Mia, 2010). The NRI report indicated that Sub-Saharan Africa region suffers from a relatively poor ICT infrastructure resulting in costly access and slow economic and social impacts (Bilbao-Osorio, Dutta and Bruno Lanvin, 2014). The implementation of eHealth technologies is directly linked with the level of connectivity which is dependent on ICT infrastructure and the supporting frameworks. The low NRI rank of Sub-Saharan Africa region indicates weaknesses of the region to incubate innovation such as ICT for health (Bilbao-Osorio, Dutta and Bruno Lanvin, 2014).

In the landscape analysis of health information systems (HIS) in developing countries, the Vital Wave Consulting report used the five-stage representations to describe the progress of HIS in improving informed management decision making (VWC, 2009). The first stage is characterised by the use of a paper-based system for data collection; the second stage focuses on the optimisation of a paper-based system to simplify indicators for effective data collection process. The migration to the electronic system begins at the third stage, followed by the introduction of HIS as a source of data at stage four. The full comprehensive and integrated HIS is represented at the five-stage (VWC, 2009). The assessment showed that the economic development was not the only factor for the improvement of HIS implementation. As indicated in the report, Zambia (low-income country) was at an advanced stage more so than Mexico (upper middle-income country) in the implementation of eHealth systems (VWC, 2009).

The case study of HIS in India, Brazil, and Zambia showed the existence of several HIS due to a rise of donor-driven programs (VWC, 2009). The benefits from HIS system could not be capitalised fully in developing countries because of rare system interoperability and lack of appropriate environment and user capability for electronic system (VWC, 2009). The data harmonisation effort to reduce the amount and frequency of data collection might be challenging but it increased the quality of care and healthcare services delivery enabling to focus on the manageable number of indicators in Zambia and India (VWC, 2009).

The level of involvement of African countries in the implementation of eHealth projects is shown in the colour coded map of Figure 2.28. Kenya and Uganda participated in the SHARE (Satellites for Health and Rural Education) project in 1985 to implement arguably the first eHealth in African countries (Jahangirian & Taylor 2015). Perhaps South Africa became the first developing country to initiate the development of 'national' telemedicine system in 1998 (Jahangirian & Taylor 2015). The systematic literature review of Jahangirian & Taylor (2015) showed that Kenya, Uganda and South Africa are the most involved African countries in eHealth projects followed by countries like Kenya and Ethiopia.

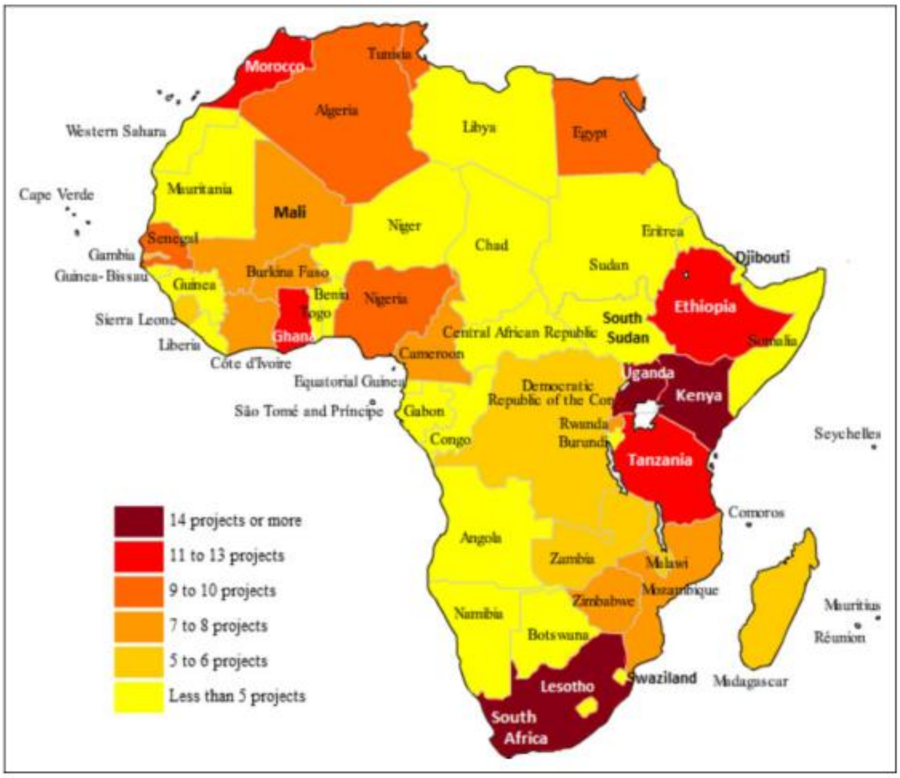


Figure 2.28 An e-Health map of Africa, showing frequency of e-Health projects in African countries (Jahangirian & Taylor 2015:211).

The implementation of eHealth follows a different financial model in the developing and developed countries. Most eHealth implementation efforts in the developing countries are economically supported by the developed countries (Sheikh and Braa, 2011). However, a large number of donor-funded programs failed to achieve sustainable outcomes of eHealth implementation in many developing countries. The misplaced measures, targets and timelines, as well as miss judging the local context of the developing countries, are some of the reasons for the failure of donor-funded eHealth projects (Spreckley, 2009; Sheikh and Braa, 2011).

Donor-funded health IT projects are established through highly skilled commercial consultants and researchers from developed world; however as the project sponsorship ends, the client organizations are left to handle the project with their limited resource and little knowledge (Sheikh and Braa, 2011). Furthermore, technological solutions designed and developed in the developed countries context are imported and implemented in developing countries resulting in failure because of mismatching context (Sheikh and Braa, 2011). It has been recommended to address the issues of ownership, alignment, harmonisation, results and mutual accountability to minimize the failure rate of donor-funded projects (Spreckley, 2009).

Although eHealth projects require longer duration to be institutionalized and accepted by end-users, most donor-funded eHealth projects have short project span resulting in low performances and outcomes (Kimaro and Nhampossa, 2004). The donor-funded programs are only present for short-term sponsorship usually not long enough to transfer skills and empower the client organization to own, maintain and support the technological solution (Sheikh and Braa, 2011). The client organizations in developing countries usually have limited resources. These local contexts in developing country affect the sustainability or long-term development programs of donor-funded health IT projects in the resource-constrained environments (Sheikh and Braa, 2011). Kimaro & Nhampossa (2004) indicated that the number of donor-funded health IT projects in Mozambique resulted in an improper distribution of resources and manpower. Another challenge of donor-funded programs in developing country is balancing the struggle between the long-term organizational needs and the short term donor needs (Kanjo, 2011). These factors add difficulty to existing complex healthcare organization's effort of implementing sustainable eHealth systems in the resource-constrained environments.

2.11. Conclusions

The successful implementation of eHealth system is associated with the long-term sustainability of the eHealth system. This study aims at associating sustainable implementation of eHealth system to the end-users acceptance of technology and the use of information for evidence-based decision making to improve healthcare services. The acceptance of technology by the end-users is a key to the long-term sustainability of eHealth systems. The technology diffusion model covers a wide range of stages from knowledge inception to technology acceptance. The five-stage innovation-decision process model address both technology adoption and acceptance processes. The adoption decision is a strategic decision to acquire an innovation or technology at a firm or individual level; whereas acceptance refers to the actual use of the acquired technology or innovation by the end-users. Thus, the adoption of a technology does not necessarily indicate the ultimate acceptance. TAM and IS success factors are popular and widely tested models to evaluate the successful implementation of information systems. These two models have been used to assess the implementation success and acceptance of eHealth systems in healthcare settings.

The eHealth implementation frameworks are discussed under social, organizational, economic and technological factors of sustainable eHealth implementation. The literature study covers the elements of successful eHealth implementation and challenges to the long-term sustainability of eHealth technology. The most common barriers to realize the sustainable implementation of eHealth are the high cost of implementation, lack of adequate training, infrastructure limitations, lack of trained workforce and technical quality of the system.

The review of existing eHealth implementation frameworks discovered that frameworks lack comprehensiveness in addressing the ecosystems of eHealth success factors. Besides, the frameworks use a classic linear approach despite the dynamic and complex nature of the healthcare systems. Systems thinking, systems engineering and system dynamics methods addressed in the literature review are reported to be a natural fit to address the dynamic complexity of healthcare systems. Understanding the dynamic interaction between the system of interest and elements of the operating environment is important to ensure the sustainability of the eHealth systems.

The ICT readiness of the developing country is challenged by poor network infrastructure, capability gap, and digital divide between urban and rural areas. The low NRI rank of developing country is an indication of low-level ICT supporting environment for eHealth implementation. There are a large number of donor-funded eHealth projects in developing countries. These projects are established through skilled consultants and researchers from the developed world. The eHealth solutions designed in the context of developed countries result in a contextual mismatch when implemented in developing countries. The struggle between the long-term organizational needs and the short term donor needs is another challenge in the implementation of sustainable eHealth systems in developing countries. In general, the economic model, organizational context, workforce skill, ICT infrastructure and resources availability vary significantly between developing and developed countries. The topics addressed and the gaps identified in this literature study are summarised in Table 2.16.

The next chapter discusses the conceptual design for sustainable eHealth implementation based on the findings of the literature study. The systems approach is used to analyse and holistically address the system of interest and the operating environment. The eHealth implementation factors related to the system environment are organised in three dimensions of sustainability, i.e., social, economic and organizational. The dynamic complexity of eHealth systems is recognised in the process of designing the conceptual framework for sustainable eHealth implementation by incorporating feedbacks.

Table 2.16 Summary of literature study.

	Literature categories	References	Dates	Topics addressed	Gaps identified
Electronic Health (eHealth) technology	eHealth definition	Eysenbach, 2001; Oh et al. 2005; Jahangirian & Taylor 2015; Rippen et al. 2013; Huang et al. 2017, Franz-Vasdeki et al., 2015; Dutta and Mia, 2010; Boonstra & Broekhuis 2010; WHO, 2011; van Dyk 2014; WHO, 2005; Vital Wave Consulting, 2009	2001-2017	eHealth definitions link technology and health. Vast number of terminologies are used to represent eHealth technology.	Lack of consensus on a clear definition of eHealth.
	Types of eHealth	Jahangirian & Taylor 2015; WHO 2012b; Leon et al. 2012; Marshall et al. 2013; WHO 2011b; WHO 2012b; ALLIANCE 2008; Sood et al 2007; Mars 2013; Shiferaw & Zolfo 2012; Mars 2014. Cargo 2013; Scott & Mars 2013; WHO 2010b; ATA 2012.	2007 - 2014	mHealth; Health information systems; telemedicine;	The boundaries between different eHealth types are not always clear.
	eHealth Stakeholders	Mengesha et al. 2013; WHO & ITU 2012; Cresswell & Sheikh 2012; Reid et al. 2005	2005-2013	Patient and their relatives; Care team; healthcare organization and government are the key stakeholders of eHealth projects.	eHealth stakeholders might have conflicting interests.
	Benefits of eHealth	Michel-Verkerke et al. 2015; Byrne et al., 2010; Maffei et al. 2009; Peek et al. 2014; Schweitzer & Synowiec 2012; Parv et al. 2012; Stroetmann et al. 2006; Quaglio et al. 2016	2006-2016	The benefits of eHealth to patients and caregivers are addressed widely.	The benefit of eHealth to the healthcare organizations is not well reported in literature.
	Challenges of eHealth Implementation	Anderson, 2007; Boonstra & Broekhuis 2010; Stroetmann 2015; Quaglio et al. 2016; Fischer et al. 2014; Peek et al. 2014; Luna et al. 2014; ONC 2014; Marchewka 2003;	2003-2016	The lack of resources and technology usability are the two popular barriers of eHealth implementation in the developing countries	Lack of stakeholders' engagement (top reason for IT failure) is not indicated as major challenge in eHealth implementation.

	eHealth success factors	van der Meijden et al. 2003; Hadji et al. 2016; Jahangirian & Taylor 2015; Michel-Verkerke et al. 2015; Tilahun & Fritz 2015b; Isabalija et al. 2013; Mettler 2015;Marchewka 2003 ;Fritz et al. 2015; Tung, et al., 2008; Venkatesh & Davis, 2000; Davis, 1989; Venkatesh & Bala, 2008; Ventkatesh et al 2003; Chang & Hsu, 2012; Petter et al, 2013; Garcia-Smith & Effken, 2013; Chang et al. 2011; DeLone & McLean, 2003; Al-Mamary et al., 2015; Venkatesh & Bala, 2008; Cresswell & Sheikh, 2012; Al-Mamary et al., 2015; Belay et al. 2014; Gorla et al. 2010; ou, 2012; Bossen et al. 2013	1989 - 2016	Over 126 anticipated benefits of eHealth are reported in literature (Appendix 2.1).	Only few of these anticipated benefits are confirmed with empirical evidence.
	eHealth Frameworks	Khoja et al., 2013; ISO, 2012; Leon et al., 2012; van Dyk 2014	2012-2014	In general, the eHealth frameworks address the social, organizational, economic and technological factors.	Some of the frameworks lack depth or fail to address the social, organizational, economic or technological factors of sustainable eHealth implementation.
Models of Information Technology Acceptance, Innovation Diffusion and IS Success	Technology Diffusion Model	Rogers 2003; Oliveira & Martins 2011; Sezgin et al. 2014; Ward 2013; Venkatesh & Bala 2008;	2003-2014	The technology diffusion model addresses the processes and decisions of technology adoption and acceptance stages.	The technology diffusion model addresses the process and decision of technology adoption in detail; but it lacks depth in addressing the acceptance stages.
	Technology Acceptance Models (TAM)	Davis, 1989; Venkatesh & Davis 2000; Venkatesh & Bala, 2008; Sezgin et al., 2014; Venkatesh et al. 2003; Cresswell & Sheikh, 2012	1989-2014	The TAM focuses on the individual perception and social influences towards technology acceptance. The TAM factors has been used to investigate the acceptance level of eHealth systems.	Generally, the TAM assumes that people are rational when making technology acceptance decisions. However, humans are not always logical and rational in their technology acceptance decisions.

	Information System(IS) Success Model	DeLone & McLean 1992; DeLone & McLean 2003; Wang & Liu 2005;	1992-2005	The IS success model is a widely used and empirically validated model. It has overlapping elements of with TAM such as intention to use, actual use and satisfaction. The IS success model has been used to assess the success level of eHealth systems.	The IS success model focuses on the influence of technological factors on the use of technology by end-users. However the model does not address the individual and social factors of technology use.
Systems Theory	Complex Systems	Snowden & Boone 2007; Van Beurden et al. 2013; Reid et al. 2005; Geisler & Heller 1996; Kossiakoff et al. 2011; Reid et al. 2005; Sterman 2000	1996-2013	The complexity of healthcare system is well recognised.	The proposed solutions follow the traditional linear approach.
	Systems Thinking	Chuang et al. 2012; Adam & De Savigny 2012; Sterman 2000; Reid et al. 2005; Kossiakoff et al. 2011	2000-2012	System thinking looks the world with a holistic, broad and dynamic view. It uses to explore complex problem domains such as eHealth systems implementation.	The use of systems thinking approach to healthcare systems is limited. The use of the classical linear to complex health technology problems is hindering efforts of achieving improved health outcomes.
	Systems Engineering	Blanchard, 2008; Kossiakoff et al. 2011; Reid et al. 2005; De-Wall & Buys 2007; Forrester 1994	1994-2011	The engineering of complex systems is facilitated by the functions of system engineering.	As a viable solution to complex systems, the design, analysis, and control of the system engineering approach have not been better used in the healthcare.
	System Dynamics	Forrester 1994; Sterman 2000;	1994-2000	System dynamics is a modelling and simulation method to deal with the dynamic complexity of systems and enhance the learning process of nonlinear systems.	The use of system dynamics modelling in healthcare systems is limited.

Sustainability	Theory of sustainability	Dodds and Venables, 2005; Fiksel, 2003; Gmelin and Seuring, 2014; Hay et al. 2014; Mebratu 1998; Diesendorf, 2000; Musango & Brent 2010; Kossiakoff et al. 2011;	2000-2014	Sustainability aims at achieving the economic success, social benefit and environmental quality of a system simultaneously	The discussion of sustainability is usually associated with ecological efficiency and the three pillars are not often applied to the sustainability of technology.
	Sustainable Technology	Musango & Brent 2010; Dodds & Venables 2005; Hay et al. 2014; Gmelin and Seuring 2014; Quaglio et al. 2016; Jahangirian & Taylor 2015	2005-2015	The economic, social and organizational pillars of sustainability are important sub-systems in which a technology is embedded. Sustainability is the ability of the project to ensure long-term results.	Donor driven eHealth projects in the developing country present a threat to the large-scale and long-term sustainable implementation of eHealth.
Resource-constrained environment	ICT Readiness in the developing countries	Nielsen, 2013; ITU 2015; Quaglio et al. 2016; Bilbao-Osorio et al., 2014; Sheikh & Braa 2011	2011-2015	The networked readiness, which is also described as a new economy shows the capacity of operating environment to incubate eHealth implementation.	The Networked Readiness Index (NRI) shows that developing countries are lagging but catching with developed country in terms of ICT access and affordability.
	eHealth in resource-constrained settings	Dutta & Mia 2010; Bilbao-Osorio et al. 2014; VWC 2009; Jahangirian & Taylor 2015; Sheikh & Braa 2011; Spreckley 2009; Kimaro & Nhampossa 2004; Kimaro & Nhampossa 2004; Kanjo 2011	2004-2015	Most eHealth implementation efforts in the developing countries are economically supported by the developed countries. Yet a large number of donor-funded programs failed to achieve sustainability in many developing countries.	The financial sustainability of donor-funded eHealth projects in the developing regions is one of the main challenges of eHealth implementation. The ICT infrastructure, cultural gaps and skill issues are also other barriers of eHealth success in the developing countries.

3. CONCEPTUAL DESIGN FOR SUSTAINABLE EHEALTH IMPLEMENTATION

“The hard stuff is the soft stuff”
D. Protti

3.1. Introduction

Healthcare institutions are confronted with the unsuccessful implementations of eHealth in developing countries (Aqil, Lippeveld and Hozumi, 2009). Though the healthcare organizations are excited about using electronic technologies to deliver quality healthcare services; little attention has been paid to understand the dynamic relationship between each element of the ecosystem to ensure sustainable eHealth implementation. Sustainability is often discussed in a wide range of literature under three essential dimensions namely, environmental, social and economic dimensions (Mebratu, 1998; Diesendorf, 2000; Fiksel, 2003; Harris, 2003; Musango and Brent, 2010). The three key pillars of sustainability are necessary to understand the social, organizational and economic implications of technology implementation to ensure long-term sustainability (Dodds and Venables, 2005). Hay et al. (2014:244) described the sustainability of a system as the ability of a particular system of interest to continue operating within its environment.

A design science research (DSR) has gained popularity in performing the IS research activities to know and understand the design problems to propose a solution acquired in the building and application of an artefact (Hevner and Chatterjee, 2010; Kuechler and Petter, 2017). DSR targets at solving important problems through innovative IT artefacts by evaluating and predicting the benefits and risks of the artefacts (Hevner et al., 2004). According to Kuechler and Petter (2017), the two primary activities of the DSR are:

- The creation of new knowledge through design of novel or innovative artifacts or processes.
- The analysis of the artifact’s use and/or performance with reflection and abstraction.

An in-depth literature study in the previous chapter showed that social, organizational, economic and technological dimensions are key factors to ensure the long-term sustainability of eHealth systems. The system of interest, i.e., eHealth system, is grouped in the technological dimension of sustainable eHealth framework. The conceptual framework for sustainable eHealth implementation applies the social, environmental and economic pillars of sustainability theory to the system environment. A system environment refers to the setting in which the system of interest operates. The sustainability pillars are adopted to ensure the sustainability of eHealth system, whereas the systems thinking approach is applied to holistically and logically structure the sustainability factors of the eHealth system and later to develop and simulate the system dynamics model. The descriptive model for sustainable eHealth systems implementation (Figure 3.1) aims at illustrating the system of interest and the key elements of the system environment. It also describes the interplay among these elements to ensure sustainable eHealth technology implementation.

The DSR process (refer to Chapter 4 for more detail) is followed to analyse the use of eHealth technology and the use of information for decision making in the healthcare institutions. The descriptive model for sustainable eHealth implementation depicts the system of interest and the operating environment. The descriptive model presented in this chapter is the result of an in-depth literature review and a DSR efforts. The literature study covered topics about eHealth, model of technology acceptance, innovation diffusions and IS success. Furthermore, the literature review addressed the theory of sustainability, sustainability of technology, ICT readiness and eHealth implementation in the resource-constrained settings.

The outputs of this chapter supports the modelling and simulation stages of the research to facilitate the acceptance of eHealth technology and the use of information for decision making. Technology development is regarded as an interaction of the technology with the system in which the technology is embedded (Musango & Brent 2010). The boundary between the system of interest (eHealth technology) and the system environment is depicted with the broken circle to indicate the fuzziness of the boundary (Figure 3.1).

The three key factors within the system environment (social, economic and environmental factors) dynamically interact among themselves as well as with the system of interest (eHealth technology). Not only the system of interest and the system environment or the two side by side but also the phenomenon that emerges from the interaction need be examined in the IS research (Hevner and Chatterjee, 2010). The interaction among the three categories in the system environment creates emergent properties such as socio-economic, socio-environmental and economic-environmental factors. Furthermore, the economic, social and environmental factors interplay with the system of interest (technology) to bring emergent properties known as the socio-technical, techno-economic, techno-environmental elements of eHealth implementation (Figure

3.1). In the design of IS artefacts, the inner environment interfaces with the outer environment that need to work in harmony to achieve the desired goal (Kuechler and Petter, 2017).

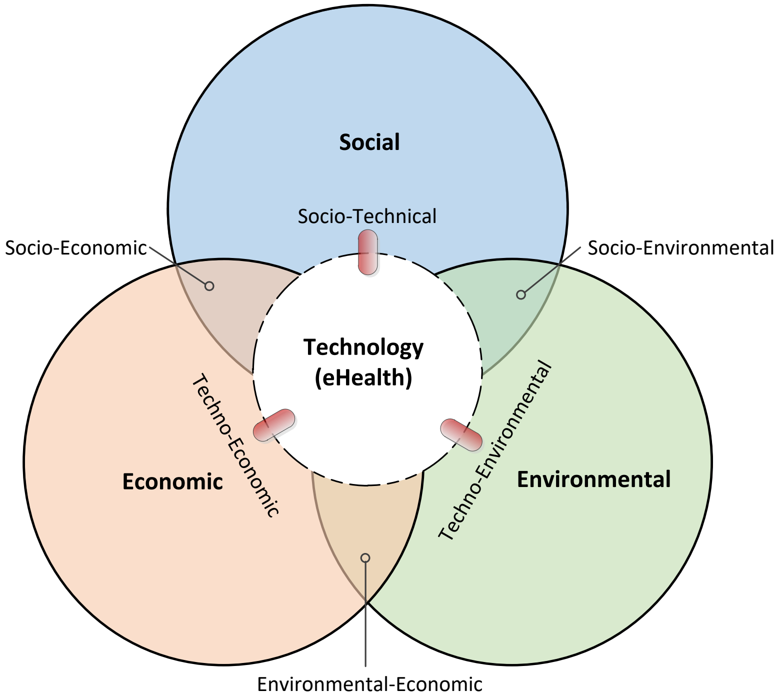


Figure 3.1 Descriptive model of sustainable eHealth implementation

This research study focuses on identifying the factors influencing the interplay between the social and technical categories (socio-technical factors), economic and technical categories (techno-economic factors) and also organizational and technical categories (techno-organizational factors). The conceptual framework shows the nonlinear interaction of social, organizational, economic and technological factors to understand the socio-technical, techno-economic, techno-environmental factors of sustainable eHealth implementation. The study further aims at using system dynamics modelling as part of the research process to develop, simulate, test and validate the dynamic behaviour of socio-technical, techno-economic and techno-organizational factors towards the acceptance of technology by end-users.

The conceptual framework of sustainable eHealth implementation discussed in this section is published in the South African Journal of Industrial Engineering.

Fanta, G. B. and Pretorius, L. (2018) ‘A conceptual framework for sustainable eHealth implementation in resource-constrained settings’, South African Journal of Industrial Engineering, 29(3), pp. 132–147.

3.2. Conceptual Framework for Sustainable eHealth Implementation

The evidence from Cresswell & Sheikh (2012) systematic reviews of published articles indicated that technical, social and organizational considerations influence the usefulness and usability of technological innovations. Based on the sustainability theory and reviews of eHealth literature, four major factors, namely social, economic, environmental (organizational) and technological, are identified as key elements of sustainable eHealth implementation. These factors are later confirmed with qualitative empirical data collected from the focus group discussions that was analysed in ATLAS.ti. The conceptual framework for the sustainability of eHealth aims to realise the fit among the social, economic, environmental and technological factors.

The social, economic and organizational factors focus on the system environment, i.e., the environment in which the system of interest operates. The technological factor focuses on the quality of the system of interest (eHealth system) to meet stakeholders' needs. The framework uses the sustainability theory and applies the systems approach to analyse and categorise the success factors of eHealth implementation into a system of interest and system environment. The sustainability pillars are adapted to analyse the sustainability of a system; simultaneously, the systems thinking approach is applied to logically structure elements of sustainable eHealth implementation.

A systems thinking approach encourages a holistic view of a system instead of focusing only on specific elements (Adam and De Savigny, 2012; Chuang, Howley and Undercurrent, 2012). A sustainable implementation of eHealth system in a healthcare settings is a complex problem that requires a systems approach to handle the complexity. A systems approach is a proper method to understanding a system holistically instead of thinking elements in isolation (Adam & De Savigny 2012). Figure 3.2 describes factors of sustainable eHealth implementation and their nonlinear interactions. The conceptual framework for sustainable eHealth implementation adopts the traditional linear input, process, output, outcome and impact approach of sustainable program implementation (Spreckley, 2009), but incorporates sustainability pillars and feedback loops in the proposed framework to enhance understanding and assessment of the nonlinear dynamics of eHealth system implementation behaviour (Mebratu, 1998; Diesendorf, 2000; Fiksel, 2003; Harris, 2003; Musango and Brent, 2010). The key input factors of the framework are discussed as follows.

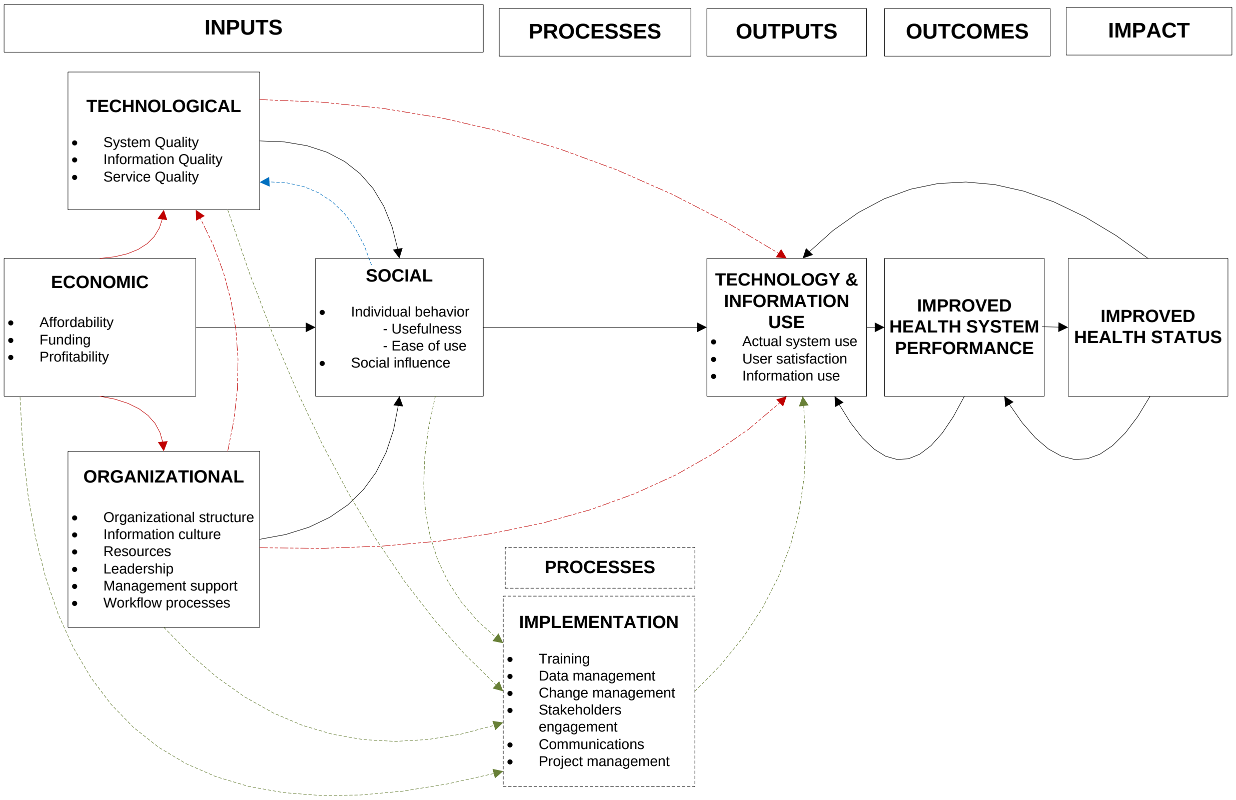


Figure 3.2 A Conceptual framework for sustainable eHealth implementation.

3.2.1. Inputs dimensions

Social factors

The social subsystem refers to the relationship between people within and across organizations (Baxter and Sommerville, 2011). It represents people and cultural factors, tasks and structure of an organization (Baxter and Sommerville, 2011). In the context of eHealth systems, the social factors represent the eHealth framework's ability to address stakeholder's related issues such as ethical, behavioural, cultural, and stakeholder requirements in the process of eHealth systems development, implementation, operation and improvement (Khoja *et al.*, 2007, 2013; Bilbao-Osorio, Dutta and Bruno Lanvin, 2014). It aims at improving clinical safety, quality of care, equity of healthcare services, decision making, and speed of service delivery to all stakeholders (WHO, 2011a; Leon, Schneider and Daviaud, 2012).

The social factors take account of an individual behaviour, i.e., the individual perception of a system's usefulness and ease of use (Davis, 1989). The perceived usefulness and perceived ease of use are the two popular end-users perception that influences the success of eHealth technologies in the social dimension of sustainable eHealth implementation (Venkatesh and Davis, 2000; Venkatesh *et al.*, 2003; Venkatesh and Bala, 2008). The comprehensive list of social factors associated with the perceived usefulness are compiled in Appendix 3.1; and perceived ease of use are presented in Appendix 3.2.

The social influence which is associated with the support from supervisor and senior management, the influence of co-workers, the prestige of users and the representation of users in the system decision is another category in the social dimension of sustainable eHealth systems (Venkatesh and Davis, 2000; Venkatesh *et al.*, 2003; Venkatesh and Bala, 2008; Garcia-Smith and Effken, 2013). Appendix 3.3 represents factors of social influence under the social dimensions.

Organizational factors

The successful implementation of an eHealth system is influenced by the settings of the operating environment and its dynamic interaction with the technology. The operating environment refers to organizational settings that influence the implementation and use of eHealth technology in healthcare facilities (Rippen *et al.*, 2013). The healthcare team operates in the context of health institution which is influenced by the resources as well as values and practices of the organization (Aqil, Lippeveld and Hozumi, 2009). The organizational culture, material, financial and human resources available through the organization play key role in the successful implementation of eHealth (Aarts, Peel and Wright, 1998). The environmental dimension addressed in this study is linked to factors internal to the organization, i.e., factors under the organization's control (Aqil, Lippeveld and Hozumi, 2009; Gorla, Somers and Wong, 2010). Other environmental factors that influence eHealth implementation but external to the organization, i.e., beyond the control of the organization, are not within the scope of this study.

From the perspective of sustainable eHealth systems, the environment gauges the friendliness of the regulatory framework, ICT infrastructure, and digital content at national and organizational levels in supporting high eHealth uptake (Bilbao-Osorio, Dutta and Bruno Lanvin, 2014). The environmental factors address issues such as legal, organizational and individual readiness; management and political supports; policy and capacity building aspects of the system operational environment (Khoja *et al.*, 2007, 2013; WHO, 2011a; Leon, Schneider and Daviaud, 2012; Bilbao-Osorio, Dutta and Bruno Lanvin, 2014). The availability of training to the technology users, the capability of the technical support team and the capacity building aspects are organizational factors (WHO, 2011a; Bilbao-Osorio, Dutta and Bruno Lanvin, 2014).

The management support refers to the organization's learning environment, the efficiency of leadership and coordination, level of collaboration and partnership and effectiveness of change management to ensure the successful implementation of eHealth system (Khoja *et al.*, 2007). The organizational readiness in terms of human resource, ICT infrastructure and digital content play key role in the success of eHealth implementation (Bilbao-Osorio, Dutta and Bruno Lanvin, 2014). The lack of proper fit of technology to the operating environment results in failure to eHealth implementation.

The environmental factors associated with legal, political and competitive pressure are factors that are external and not within the organization control (Bilbao-Osorio, Dutta and Bruno Lanvin, 2014); hence they are not addressed in this study. The legal issues refers to the ICT and eHealth related laws, intellectual property protection, procedures to enforce contracts, software piracy and efficiency of legal systems in settling disputes (Khoja *et al.*, 2007, 2013; WHO, 2011a; Leon, Schneider and Daviaud, 2012; Bilbao-Osorio, Dutta and Bruno Lanvin, 2014). The political support addresses awareness and support of eHealth among politicians and policymakers, as well as ownership and commitments also influence the implementation of eHealth (Bilbao-Osorio, Dutta and Bruno Lanvin, 2014). The crucial impact of legal, political and other external pressures to the long-term sustainability of eHealth is recognised in this research. However the aim of this study is to help healthcare organizations properly address eHealth implementation factors that are within their control. Therefore, the boundary of the study is set around a healthcare organization and factors under the organization's control.

Economic factors

The long-term sustainability of eHealth implementation is influenced by the economic factors. The economic factors of eHealth refer to financial issues such as the availability of sustainable funding, affordability of technology, cost-effectiveness, cost-minimization and return on investment (ROI) (Bilbao-Osorio et al., 2014; Leon et al., 2012). The economic factors aim at improving profits and reducing healthcare expenses (Bilbao-Osorio et al., 2014). The economic outcomes are directly affected by the affordability of connectivity such as mobile cellular tariffs, broadband internet tariffs, eHealth system procurement prices (Bilbao-Osorio et al., 2014; Leon et al., 2012).

Technological factors

The focus of technological factors is the technical capability of the eHealth system to meet the users' expectation where it is deployed. It also addresses technical indicators such as user-friendliness, flexibility, reliability, availability, accuracy, efficiency, data quality, scalability and adaptability (Khoja et al., 2013; Leon et al., 2012). The elements of technological factors that influence acceptance of technology are subcategorized into three quality groups namely system quality, information quality and services quality (Lluch, 2011).

- *System quality* measures the desired characteristics of the IS itself, i.e., technical success (DeLone and McLean, 1992). It is linked to ease of use, functionality, reliability, flexibility, portability, integration and importance (DeLone and McLean, 2003). Appendix 2.1 presents the comprehensive lists of system quality.
- *Information quality* measures the IS outputs (DeLone and McLean, 2003; Aqil, Lippeveld and Hozumi, 2009). It refers to accuracy, timeline, completeness, relevance, and consistency of information (DeLone and McLean, 1992). The full list of information quality factors are presented in Appendix 2.2. Accuracy is the level of agreement between the information stored in IS database and a real-world entity (Gorla, Somers and Wong, 2010).
- *Services quality* measures the level of overall support delivered to users (Gorla, Somers and Wong, 2010). The reliability, responsiveness, assurance, and empathy of technical support, as well as up-to-date hardware and software factors, belong to the services quality in the technological dimension (DeLone and McLean, 2003). The complete services quality factors are compiled in Appendix 2.3.

The context diagram for the eHealth system (Figure 3.3) summarises the system environment in the social, environmental and economic categories, and shows their interaction with the technology, i.e., eHealth system. The dynamic interaction of the system environment with the eHealth system results in the socio-technical, techno-organizational and techno-economic factors of sustainable eHealth implementation. In summary, factors of sustainable eHealth system analyse the system and its operating environment's ability to ensure the successful implementation and operation of eHealth in resource-constrained settings.

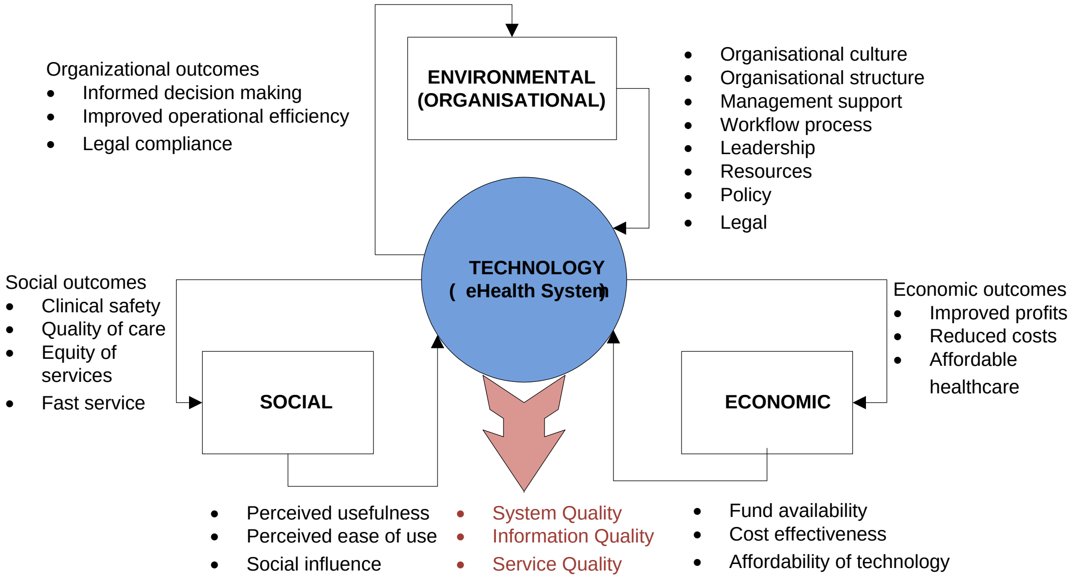


Figure 3.3 Context diagram for eHealth system.

3.2.2. Processes dimension

The processes dimension of the concept framework (Figure 3.2) focuses on the implementation processes of eHealth technology. The implementation process facilitates the conversion of input factors to outputs as indicated in Figure 3.2.

Training refers to the amount of training provided to the eHealth users in the healthcare institutions by internal or external entities to facilitate technology use (Al-Mamary, Shamsuddin and Aziati, 2014). The intensity, timing and availability of training influenced end-users participation in eHealth success, and the post-implementation training improved the users' experience (Belay, Azim and Kassahun, 2013).

Data management addresses the collection, storage, quality control and flow, processing, compilation, analysis and presentation of data (WHO, 2012a). The timeliness, periodicity, consistency, confidentiality, data security and accessibility of information impact the quality of data (WHO, 2012a).

Change management begins with assessing and understanding of the nature and content of clinical work to support the operation of eHealth system. The change management process continues by identifying its consequences; prioritization; recognising appropriate requirements; creating strategic plans; informing and persuading changes; introducing new technologies, and continuous evaluation of the impact (Aarts, Peel and Wright, 1998).

Communications is an effective exchange of timely and accurate information with all relevant stakeholders to improve informed decision-making (Project Management Institute, 2013). The communication gap between the IT staffs and clinicians was one of the organizational problems in staff-clinical communication category as indicated in the case study of Fundus Imaging System (Maryati Mohd Yusof *et al.*, 2008).

Project management is an application of knowledge, skills, tools, and techniques to project activities in order to fulfil stakeholder needs and to balance schedule, quality and budget expectations (Project Management Institute, 2013). The use of project management processes gives control over finance, schedule, tasks, resources and quality of the project which in turn can minimize failure rate of eHealth systems implementation (Ludwick and Doucette, 2009).

Stakeholder engagement refers to the involvement of key stakeholders in the process of eHealth implementation starting from the planning phase to reduce resistance, increase acceptance, and meet the needs of users (Cresswell and Sheikh, 2012; van Dyk *et al.*, 2012).

3.2.3. Outputs dimension

The actual technology use, the level of users' satisfaction and the use of information product for decision making are the expected immediate outputs of eHealth implementation (Davis, 1989; DeLone and McLean, 2003; Venkatesh and Bala, 2008; Aqil, Lippeveld and Hozumi, 2009). The acceptance of technology by the end-users is the basis for the long-term sustainability of eHealth (Davis, 1989; Venkatesh and Bala, 2008). The factors in the outputs dimension that are selected for the framework of sustainable eHealth implementation mainly come from the Technology Acceptance Model (Davis, 1989; Venkatesh and Bala, 2008) and Information System Success Model (IS Model) (DeLone and McLean, 2003). The variables in the outputs dimension are discussed in Table 3.1.

Table 3.1 The outputs dimension of sustainable eHealth implementation.

Output factors	***Descriptions***
Actual system use	The use of eHealth technology or to have the first-hand experience of the technology (Chen, 2011; Mutingi and Matope, 2013).
Users satisfaction	The use of eHealth system recognising its ease of use and the usefulness of the technology to perform day-to-day tasks.
Information use	The use of reports generated from the eHealth system for discussions, advocacy, decisions, and referrals for action at a higher level (Aqil, Lippeveld and Hozumi, 2009).

Not only the actual system use but also the satisfaction of users is important to the long-term sustainability of eHealth system. Dissatisfied users have a higher possibility to provide low-quality data or fail to capture critical information that affects the overall quality of information generated from the eHealth system. Poor data quality affects the accuracy of the decisions made by the information users. Moreover, dissatisfied users might terminate to use eHealth anytime affecting the sustainability of the technology. Hence, the outputs dimension are a necessary condition for the success of eHealth implementations.

3.2.4. Outcomes dimensions

The improved health system performance represents the outcomes dimension of sustainable eHealth implementation (Aqil, Lippeveld and Hozumi, 2009). It aims at reducing the healthcare costs to achieve the health system economic outcomes, and targets to deliver efficient clinical services to ensure patient satisfaction (Elbert *et al.*, 2014). Table 3.2 shows some of the key outcomes dimension that can be achieved through the successful implementation of eHealth systems.

Table 3.2 The outputs dimension of sustainable eHealth implementation.

Outcome factors	***Descriptions***
Decision making	The availability of quality data for research and evidence-based decision making to improve healthcare services delivery (FMOH, 2015).
Supply chain system	The availability of essential drugs and to avoid stock-outs through improved supply chain system (FMOH, 2015).
Emergency management	The capacity to control disease outbreaks, handle accidents and natural disasters through emergency care services (FMOH, 2015).
Clinical service	Reduced waiting time, shorter hospital stay and quick healthcare services delivery to patients (FMOH, 2015).
Healthcare cost	Reduced healthcare cost by avoiding costs associated with travels and redundant laboratory and radiology tests (Byrne *et al.*, 2010).

3.2.5. Impact dimension

The impact dimension focuses on achieving improved health status in terms of reducing morbidity, avoiding mortality, minimizing hospitalization, increasing life expectancy and achieving a high quality of life through the implementation of eHealth systems (Aqil, Lippeveld and Hozumi, 2009; Elbert *et al.*, 2014). The improved health status for everyone is the ultimate objective or the final goal of implementing eHealth systems (Aqil, Lippeveld and Hozumi, 2009).

Table 3.3 The impact dimension of sustainable eHealth implementation.

Impact factors	***Descriptions***
Life expectancy	The average time (years) a person is expected to survive.
Morbidity	The state of having a disease or a symptom of a disease.
Mortality	The state or condition of being subject to death.
Hospitalization	The state of admission to hospital for treatment.
Quality of life	The average period of life without illness.

Table 3.3 shows the impact factors that can be achieved through the implementation of eHealth systems towards improved health status. eHealth technology is relatively in the early phase of implementation in the developing countries. As a result, measuring its long-term impact is a difficult task. Besides, eHealth is an integral part of a bigger health care system hence the improved health status may be as a result of other healthcare processes optimization.

The use of eHealth technology in the healthcare organizations is relatively new stage in the developing countries to measure the outcome and impact of the technology. Besides, most of eHealth projects are in the pilot phase of implementation making difficult to measure the outcomes and impacts of the technology in the healthcare services delivery. Therefore, the outcome and impact dimensions of the framework (Figure 3.2) are not the focus of this research, but the importance of outcomes and impact is well recognised in this study.

The focus of the conceptual framework for sustainable eHealth implementation (Figure 3.2) is important interactions between the system of interest, i.e., technology, and the three pillars of operating environment, i.e., social, organizational and economic factors. The socio-technical, techno-organizational and techno-economic factors evolve from the dynamic interplay between the system of interest and system environment which is the target of this study instead of individual elements of sustainable eHealth implementation factors.

The technological, social, organizational and economic factors of eHealth implementation are well covered in many research studies which are usually linear. However, this study recognises the complexity of eHealth implementation in healthcare settings that arises from the interplay among technological factor with social, organizational and economic elements. The nonlinear nature of eHealth implementation can be understood through the study of technology interaction with social, organizational and economic elements of the healthcare institutions. Therefore, the concept of socio-technical, techno-organizational and techno-economic concept models are studied in this research.

In the following sections, a system dynamics modelling process followed to convert the conceptual framework of sustainable eHealth technology (Figure 3.2) to a system dynamics model will be presented.

3.3. The System Dynamics Bass Diffusion Model

The Bass diffusion model describes how potential adopters of innovation become adopters through external sources of awareness and the word of mouth from social exposure and imitation (Sterman, 2000). The model shows that the total adoption rate is the sum of adoption from word of mouth and adoption from advertising (Sterman, 2000). The stock and flow diagram of the Bass diffusion model is shown in Figure 3.4.

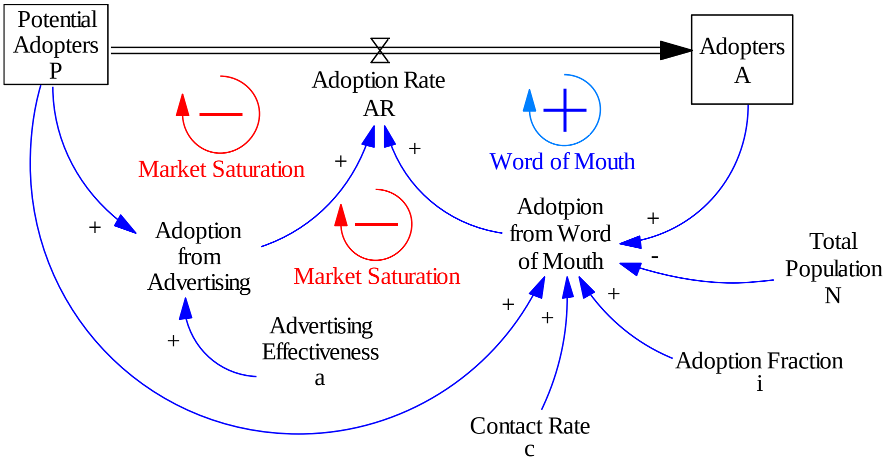


Figure 3.4 The Base diffusion model (Sterman, 2000:333).

$$Adoption\ from\ Advertising = Advertising\ Effectivness\ (a) *\ Potential\ Adopters\ (P) \tag{3.1}$$

$$Adoption\ from\ Word\ of\ Mouth = \frac{Contact\ Rate(c) * Adoption\ Fraction\ (i) *\ Potential\ Adopters\ (P) * Adopters\ (A)}{Total\ Population\ (N)} \tag{3.2}$$

From Equation (3.1) and (3.2),

$$Adoption\ Rate\ (AR) = Adoption\ from\ Advertising + Adoption\ from\ Word\ of\ Mouth$$

$$AR = aP + ciPA/N \tag{3.3}$$

$$Total\ Population\ (N) = Potential\ Adopters\ (P) + Adopters\ (A)$$

$$N = P + A \tag{3.4}$$

The concept of Bass diffusion model is used as a basic model and extended to develop a system dynamics model of eHealth acceptance for long-term sustainable operations. The TAM and IS Success Model are incorporated to expand on the model variables. The Theory of Reasoned Action (TRA) states that the individual's intention to perform a given behaviour is an immediate causal determinant of the performance of the behaviour (Hale, Householder and Greene, 2003). According to TRA, the individuals' intention to use technology is jointly determined by the individual attitude (A) and the perceived social influence or subjective norm (SN) of those people important to the individual (Hale, Householder and Greene, 2003). In summary, an individual performs an action based on their personal belief of the action's positive influence or/and a positive influence of people who are important to them. Although the original TAM focuses on an individual behavioural intention to use as a core factor that influences technology acceptance (Davis, 1989), further studies incorporated social influences as key contributors to technology acceptance (Venkatesh & Bala, 2008; Venkatesh, Morris, Davis, & Davis 2003).

In this study, it is assumed that the technology adoption by the healthcare firm is completed; hence the focus is on the acceptance of technology by end-users, i.e., the ultimate end-users decision to use or reject the technology (Rogers, 2003). The social influence of technology acceptance is similar to technology acceptance through the word of mouth as indicated in the Bass model (Venkatesh et al. 2003). However, there are not only positive social influences but also negative influences of the social group on individual's intention of technology use (Mutingi & Matope 2013). The social influences are grouped in two categories in the proposed sustainable eHealth implementation framework. The influence of social groups on individual users to promote technology use and inhibit technology use. The acceptance of technology by end-users is the total effect of an individuals' intention to use, influence from social promoters (positive word of mouth) and influence from social inhibitors (negative word of mouth) as shown in Equation 3.5.

$$\begin{aligned} Acceptance\ Rate\ (AR) = {} & Individuals\ Intention\ to\ Use\ (I) \\ & +Influence\ from\ Social\ Promoters\ (SP) \\ & -Influence\ from\ Social\ Inhibitors\ \ (SI) \end{aligned} \tag{3.5}$$

Snowden & Boone (2007:3) indicated that humans have multiple identities and can fluidly switch between them without conscious thought". However, in this PhD research project the individuals' intention to use technology refers to a conscious act of accepting a technology which develops from the individual's perception of usefulness and ease of use of technology according to TAM. On the other hand, the influence of social promoters comes from a positive word of mouth of satisfied individuals in using the system. Conversely, the influence of social inhibitors results from the negative word of mouth from users who terminated using the system because of dissatisfaction. Potential users become actual users at a rate of acceptance which is influenced by individuals' intention and social influence (promoters or inhibitors). The actual users become satisfied users or dissatisfied users based on the hands-on experience of using the technology. The concerns of dissatisfied users require attention and need to be addressed quickly through a management intervention such as staffing, training, incentive or improving technical quality to avoid the termination of use by the dissatisfied users.

3.4. System dynamics model structure of eHealth acceptance: socio-technical factors

The successful adoption of a Computerized Patient Record System (CPRS) in one paediatric office and failure in another paediatric office is an indication of the social structure influence to the successful implementation of technology (Reddy, Pratt, Dourish, & Shabot, 2003). Besides the contribution of technical flaws to the failure of a HIT, the undesirable outcomes of socio-technical interactions during HIT implementation significantly hinder its success (Harrison, Koppel, & Bar-Lev, 2007). The introduction of eHealth technology in healthcare facility results in the emergent and recursive interactions among new technology and existing social systems, technologies and physical environments. Understanding the individual components of a socio-technical system and the interplay between them helps to expose the causes of particular eHealth implementation or use problems. The socio-technical factors directly influence the eHealth implementation success (Ludwick and Doucette, 2009).

The term socio-technical system originally emerged to describe systems that involve complex interactions between humans, technologies, and the environmental aspects of a system (Baxter & Sommerville, 2011:5). Harrison et al. (2007) indicated that a socio-technical system addresses dynamic and mutual influences among the social subsystems (people, tasks, and relationships), technical subsystems (technologies, techniques, task performance methods, and work settings) and the social and organizational environments. A socio-technical system is widely used to describe many complex systems; hence the interaction among people, technologies, and context needed to be considered during the development process (Baxter & Sommerville, 2011:5; Badham et al., 2000).

There are five key characteristics of open socio-technical systems (Baxter & Sommerville, 2011:5):

- Systems should have interdependent parts.
- Systems should adapt to and pursue goals in external environments.
- Systems have an internal environment comprising separate but interdependent technical and social subsystems.
- Systems have equifinality; i.e., systems goals can be achieved by more than one design choices during system development.
- System performance relies on the joint optimisation of the technical and social subsystems.

The Information System (IS) success, technology acceptance model (TAM) and socio-technical models are used to develop the concept model for the socio-technical framework of sustainable eHealth implementation. Moreover, literature that validates the models with empirical evidence is used to determine different elements of the concept model and the relationship among them. The study identified the technological, social, technology use and outcome category as key socio-technical factors of eHealth acceptance. The proposed socio-technical framework for eHealth acceptance supports the effort of successful eHealth technology design, development, implementation, and operation by providing additional insight into the socio-technical factors and their interaction during the implementation and use of eHealth technology within a healthcare facility to maximize the users' acceptance.

The socio-technical framework of eHealth acceptance is developed based on the literature review findings summarised in Tables 2.11 – 2.14 (see Chapter 2.7.4). The framework adapts the system, information, and services quality factors from IS success model in the technological dimension; and the constructs of TAM in the social dimension. Moreover, the TAM and IS success models are combined to develop the technology use dimension of the theoretical framework. Eventually, the net benefit element of IS success model is adapted to address the outcome section of the theoretical socio-technical framework (Figure 3.5). The socio-technical framework of eHealth acceptance addresses the important dimensions of socio-technical systems, the interplay between its elements and the feedback processes.

The immediate outputs of eHealth implementation are technology acceptance and information use. The technology must be used to generate information product that supports informed decision making. The socio-technical framework for eHealth acceptance is used as a basis to develop a system dynamics model. The purpose of socio-technical system dynamics model is to learn the dynamics of key socio-technical factors in the implementation of eHealth that influence technology acceptance and information use.

The interaction between technology and social factors influences the ultimate acceptance of technology by end-users. The final output of eHealth implementation is to ensure the use of information which is the product of eHealth technology use by the end-users. It is hypothesised that without the sustained use of technology and the information product, it is not possible to ensure the sustainability of eHealth system. Hence the socio-technical concept model of technology acceptance focuses on maximizing eHealth acceptance and the use of information and minimizing the rejection of technology by end-users to support the long-term sustainability of eHealth systems. Sustainability of technology is manifested through the continued operation of the technology within its environment (Fiksel, 2003; Hay, Duffy and Whitfield, 2014)

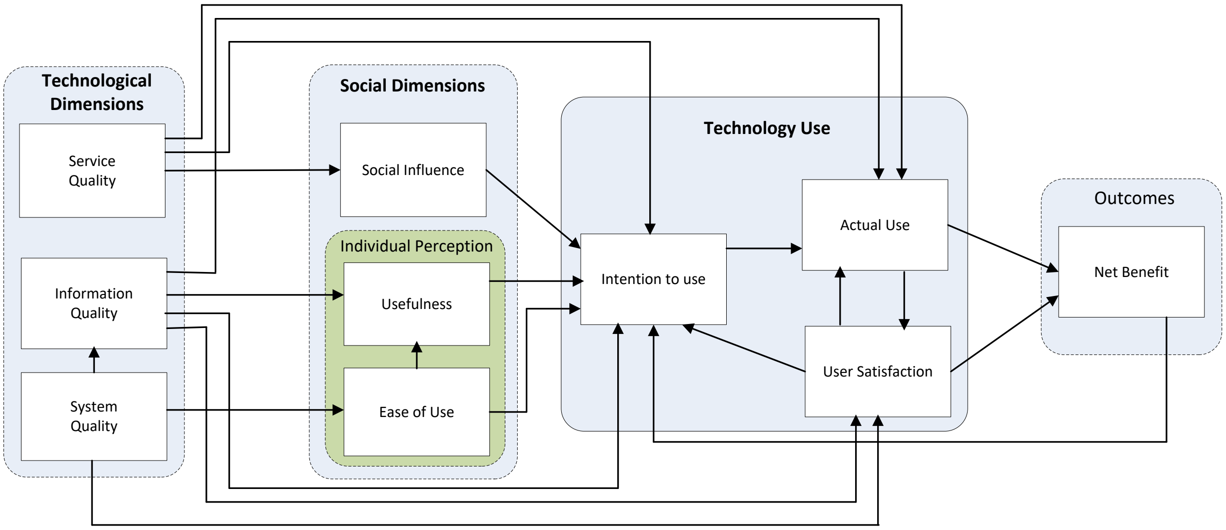


Figure 3.5 The Socio-technical Framework for Sustainable eHealth Acceptance.

The system dynamics model of eHealth acceptance is developed in the research for this thesis based on the socio-technical factors around the stocks of ‘potential users’, ‘actual users’, ‘satisfied users’, ‘dissatisfied users’, ‘terminated users’ and ‘individual perception on use’ as shown in Figure 3.6. The socio-technical factors address stakeholders and technical quality related issues. The endogenous variables describe elements of technical factors and social factors. The boundary of the model is set around these factors to learn the dynamic interaction between technology and social factors of eHealth implementation. In developing the system dynamics model of technology acceptance model, Wang & Liu (2005) included ‘training efforts’, ‘user involvement in system development’, and ‘sufficiency of organizational resources’ as exogenous variables. However, the sufficiency of organizational resources is more associated with techno-organization factors of technology acceptance; therefore, the variable is not considered in the study of socio-technical factors of technology acceptance. Four key variables selected to study the behaviour of socio-technical factors of eHealth acceptance are “Services quality, "system quality”, “Training and communication efforts” and “User involvement”.

The model structure (Figure 3.6) highlights the importance of not only increasing the rate of acceptance but also keeping users satisfied by meeting their expectations. The feedback loops predict that the dissatisfied users may increase the number of terminated users who later can have a negative impact on the acceptance rate through negative words of mouth. The dissatisfied users might become terminated users unless their concerns are addressed through management and policy intervention to make them satisfied users. It is important to address users concern as early as possible to avoid dissatisfaction and termination at last that may require costly intervention processes to motivate former users to use the technology (Mutingi and Matope, 2013).

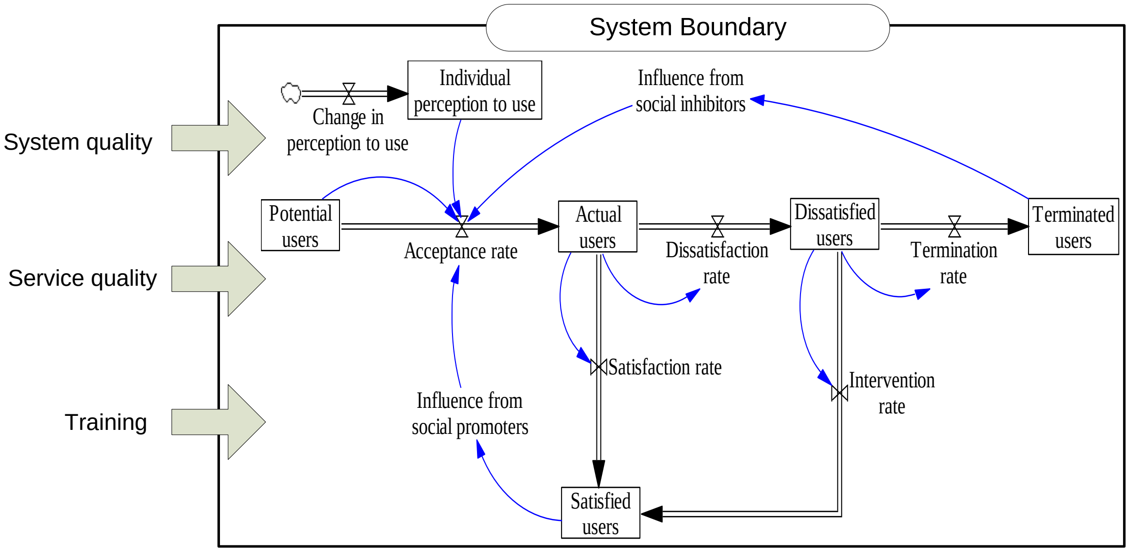


Figure 3.6 The socio-technical model structure of technology acceptance.

The system dynamics model shows that the promoting or inhibiting social influence on acceptance rate grows as more individuals become actual users. The acceptance rate was mainly influenced by the individual's perception of the system usefulness and ease of use at the beginning of the technology acceptance process. The individuals' perception to use technology develops from the ability of technology use to reduce work burden in the system development process and the effectiveness of training efforts (Wang and Liu, 2005). The socio-technical model of eHealth acceptance is discussed in detail in Chapter 5.

3.5. The system dynamics concept model of techno-organizational factors

Similar eHealth system can exhibit different success levels in healthcare institutions because of the difference in the organizational factors (Tsiknakis and Kouroubali, 2009; Rippen *et al.*, 2013). Organizational factors like culture, structure, resources, workflow process, leadership and management support could result in a different level of technology success within a healthcare institution (Aarts, Peel and Wright, 1998; Rippen *et al.*, 2013). The techno-organizational factors deal with the dynamic interactions between the technological and organizational elements of sustainable eHealth implementation. Most businesses operate dominantly in the complex domain that requires an understanding of the context of the operating environment and the nonlinear dynamic interaction among organizational elements (Snowden and Boone, 2007). Although the complexity of healthcare organizations is recognised by several research studies, the proposed solutions fail to address the dynamic and nonlinear interaction between organizational and technological factors (Cresswell and Sheikh, 2012).

The techno-organizational factors of sustainable eHealth implementation deals with subjects of user training to increase competency (Al-Mamary, Shamsuddin and Aziati, 2014); change management to ensure users oriented processes (Lluch, 2011); data management to improve data quality (WHO, 2012a); stakeholders' engagement to increase technology acceptance (Cresswell and Sheikh, 2012; van Dyk *et al.*, 2012); project management to effectively balance schedule, quality and budget (Project Management Institute, 2013); and organizational communications for effective exchange of timely and accurate information (Project Management Institute, 2013). The techno-organizational factors of sustainable eHealth implementation seeks to understand the elements of organizational factors and the dynamic interactions with technological factors. The detailed explanations and the techno-organizational model of sustainable eHealth implementation are presented in Chapter 6.

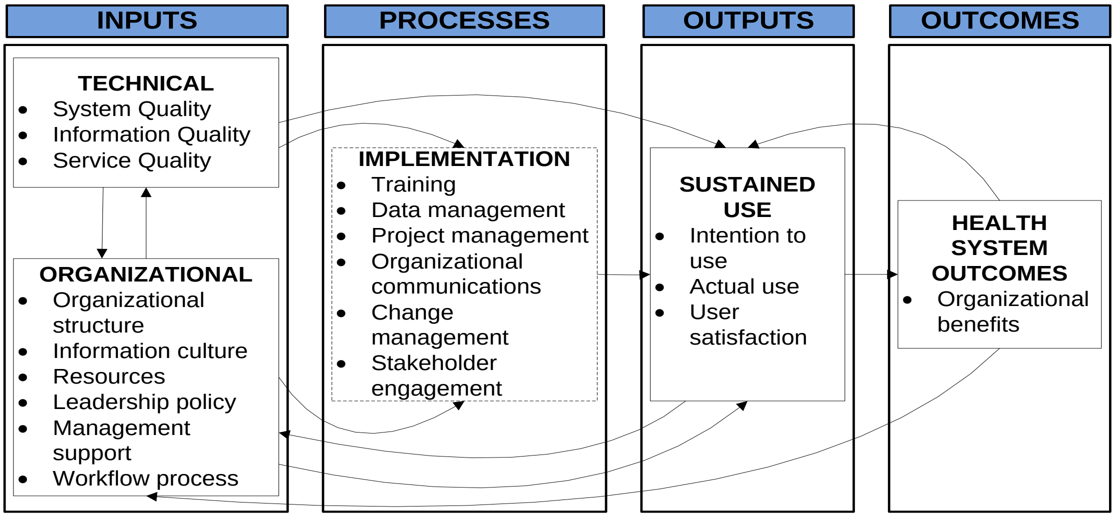


Figure 3.7 Conceptual framework for organizational dynamics of eHealth acceptance.

A conceptual framework for the organizational dynamic of eHealth acceptance (Figure 3.7) is developed based on the literature review (refer Chapter 2.8) of existing organizational frameworks of health IT implementation. A conceptual framework for the organizational dynamics (Figure 3.7) represents the techno-organizational dimension of the conceptual framework for sustainable eHealth implementation (Figure 3.2). Figure 3.7 shows the interaction between the technological and organizational factors, as well as the feedbacks of outputs and outcomes factors on organizational inputs and processes factors. The techno-organizational study in this research intentionally excluded the outcome and impact sections of the conceptual framework because of the longer duration required to study the impact of eHealth.

Factors that influence the implementation of eHealth goes beyond the immediate boundaries of organizational environment. Nevertheless, the model only considers factors within the organization’s control. Hence variables outside the organization’s sphere of influence such as political, legal, and competitive pressures of the environment are not discussed in this framework as they are outside the scope of this study. Snowden & Boone (2007) pointed that setting boundaries and interactive discussions are among the recommended approaches to manage in a complexity domain.

The technological and organizational factors of sustainable eHealth implementation are addressed in the inputs section of the model. The technological factors are concerned with the system, information and services quality. Organizational structure, culture, resources, policy, workflow and management support are part of the organizational factors of the framework. The processes section deal with implementation activities necessary to achieve the desired outputs. The proper execution of key processes of eHealth implementation such as stakeholders engagement, change management, project management, data management, training and communications are important to the success of sustainable eHealth implementation (Ludwick and Doucette, 2009; Gorla, Somers and Wong, 2010). Stakeholders involvement and the process of users feedback incorporation was weak in the process of defining requirements of an eHealth system in Western Cape, South Africa; as a result, there was a high level of user resistance (Fanta and Erasmus, 2014).

The socio-technical model structure of eHealth acceptance (Figure 3.6) is expanded to capture techno-organizational factors of sustainable eHealth implementation (Figure 3.8). The full simulation model of SFD of techno-organizational model of technology acceptance is discussed in Chapter 6. In addition to other organizational variables, the stocks of workforce and ICT infrastructure resources are incorporated into the socio-technical framework to capture techno-organizational factors as endogenous factors to model structure. Infrastructure, workforces, management support, ICT culture, policy, organizational structure and workflow alignment are highlighted in the techno-organizational model structure. These variables are selected to study the dynamics of techno-organizational factors in the process of implementing a sustainable eHealth system. Infrastructure refers to the internal capability of a healthcare organization to support the implementation of sustainable eHealth systems (Bilbao-Osorio, Dutta and Bruno Lanvin, 2014). These capabilities include electric power, computers, local area networks (LANs), internet connection, printer, and scanner that support the implementation of the eHealth (Rippen *et al.*, 2013). Labour force addresses readiness of skilled human resources that are able to use technology and provide technical support (Rippen *et al.*, 2013; Bilbao-Osorio, Dutta and Bruno Lanvin, 2014).

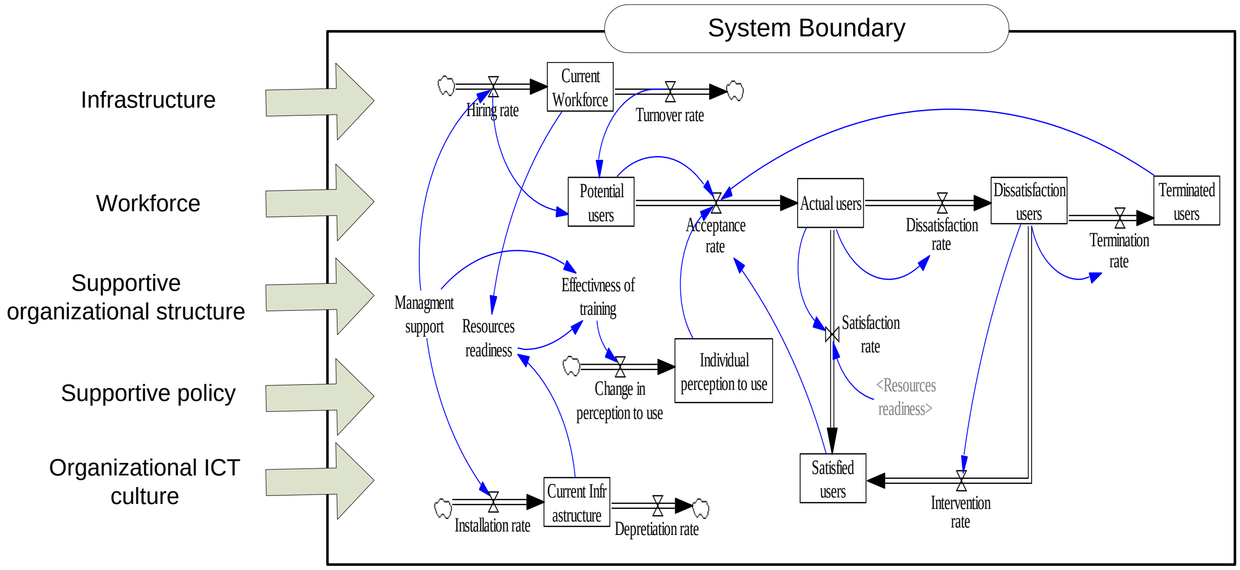


Figure 3.8 Techno-organizational model structure of technology acceptance.

The use of information for decision-making is an immediate output of eHealth implementation in healthcare organizations (Aqil, Lippeveld and Hozumi, 2009). The main benefits of using eHealth system are enhancing the internal organizational efficiencies such as improving the decision-making process and internal communications in the organization (Gorla, Somers and Wong, 2010). The next section address the third techno-economic factors of sustainable eHealth implementation as depicted in Figure 3.2.

3.6. Techno-economic factors

The techno-economic factors are indicated in the conceptual framework as one of the key factors of sustainable eHealth implementation. The financial model of eHealth implementation in the developing countries is different from the developed world in terms of the amount, source and period of funding. The implementation of eHealth in developing countries is driven by the non-governmental organizations (NGOs) and private players (Jahangirian and Taylor, 2015; Quaglio *et al.*, 2016). The limited amount of budget and the short project span of donor organizations present a threat to the large-scale and sustainable eHealth implementation (Quaglio *et al.*, 2016).

The absence of coherent approach in donor-funded eHealth projects caused fragmented and program- or disease-specific eHealth systems (Quaglio *et al.*, 2016). Moreover, “parallel systems” produced a duplication of effort and wastage of resources in donor-funded eHealth interventions in the developing countries (Quaglio *et al.*, 2016). The implementation of eHealth in the developing countries relies on the fund from international donors that usually covers the pilot phase of the implementation (Luna *et al.*, 2014). The alternative resources to maintain, support and scale-up eHealth system are scarce; hence the eHealth projects struggle to continue operating after the end of donors’ fund (Luna *et al.*, 2014). The economic factors of eHealth refer to financial resources such as the availability of sustainable funding, affordability of technology, cost-effectiveness and return on investment (Bilbao-Osorio et al., 2014; Leon et al., 2012). The limited financial resources within the Ministries of Health in developing countries were one of the major problems that hindered the scale-up and sustainability of eHealth projects (Quaglio *et al.*, 2016).

The economic evaluation in healthcare aims at comparing the costs and outcomes of two or more health interventions (McCabe, 2009). In the economic evaluation of eHealth, measuring costs appear more direct than associating financial value to the health outcomes (Bergmo, 2015). The need for economic evaluation of eHealth is high, because of insufficient scientific evidence to reach a generalizable conclusion for eHealth investment decisions (Schweitzer and Synowiec, 2012; Bergmo, 2015). The two popular economic evaluation techniques in healthcare are cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA) (McCabe, 2009; Bergmo, 2015). These healthcare economic evaluation methods differ in their approach to measuring outcomes (McCabe, 2009).

The PhD research project did not include techno-economic factors in the system dynamics model of sustainable eHealth implementation. This was mainly due to lack of financial data associated with eHMIS and SmartCare implementation in Ethiopia. However, a systematic literature study was conducted to address the third research objective, i.e., to evaluate the techno-economic features of sustainable eHealth use in a resource-constrained environment.

3.7. Conclusions

The ecosystem of sustainable eHealth implementation is grouped into social, organizational, economic and technological factors based on findings from literature study (Chapter 2). The DSR process (refer Chapter 4 for detail discussion) and the literature findings are used as basis to develop the conceptual framework of sustainable eHealth implementation. The technological factors describe the technical capability of the system of interest, eHealth system. It is further sub grouped into system quality, information quality, and services quality. On the other hand, the social, organizational and economic factors describe the system environment, i.e., the environment in which the system of interest operates.

A systems thinking approach is applied in the design of the conceptual framework to group an ecosystem of sustainable eHealth implementation into a system of interest and the system environment. The three pillars of sustainability theory are adapted to structure the system environment factors of sustainable eHealth implementation. The system environment interaction with the system of interest results in the socio-technical, techno-organizational and techno-economic factors of sustainable eHealth implementation. The conceptual framework for sustainable eHealth implementation focuses on these three important interactions in this research study. The system dynamics modelling approach is used to learn the interplay between the eHealth systems and the operating environment.

System dynamics Bass diffusion model is adapted and expanded to develop a socio-technical system dynamics model of eHealth acceptance by incorporating the elements of TAM and IS success models. The endogenous variables describe elements of technical factors and social factors. Services quality, "system quality”, “Training and communication efforts” and “User involvement” are selected to study the behaviour of socio-technical factors of eHealth acceptance. A social system is a subset of an organizational system. Therefore, a techno-organizational system dynamics model of eHealth acceptance is developed by adding organizational factors to the socio-technical system dynamics model of eHealth acceptance. The importance of techno-economic factors in terms of implementing sustainable eHealth systems is recognised but the system dynamics simulation model is not covered in this research study.

The philosophical assumptions of the research methodology and the research design processes followed in this research study are addressed in detail in the following section. A model-based theory building research approach and a system dynamics modelling processes are discussed. The details of case study research and the description of selected cases, the process of case selection, and the method of case study research followed in this research study is addressed. Finally, the research instruments used, the process of informants' selection, data collection and analysis are reported in the next section of the thesis.

4. RESEARCH DESIGN AND METHODOLOGY

"I think you can have a ridiculously enormous and complex data set, but if you have the right tools and methodology then it's not a problem."
Aaron Koblin

4.1. Introduction

The focus of this research thesis is to enhance the understanding and assess the dynamic relationship among factors of sustainable eHealth implementation in developing countries. This chapter discusses the research philosophy, methodology and testing approaches applied in this research thesis. The research study is an applied research aiming at solving practical problems associated with sustainable eHealth implementation in developing countries. Applied research has a practical problem-solving emphasis, and conducted to reveal answers to specific questions related to action, performance, or policy needs (Cooper and Schindler, 2001). In this model-based theory building research study, the real-world problems associated with the sustainable implementation of eHealth system in resource-constrained settings are addressed.

The DSR followed in this research study aims at contributing new knowledge to the body of science knowledge from the experience of eHealth implementation in resource constrained settings. "DSR is a research paradigm in which a designer answers questions relevant to human problems via the creation of innovative artefacts, thereby contributing new knowledge to the body of science evidence." (Hevner and Chatterjee, 2010:5).

To gain in-depth insight, an extensive review of relevant literature on system dynamics, technological, social, organizational, and economic factors of sustainable eHealth implementation was undertaken to build a basis for parameters selected for the system dynamics modelling and data gathering process. The systems thinking approach was applied to the knowledge acquired from previous research studies to learn the dynamic interaction between elements of sustainable eHealth systems. Furthermore a socio-technical, techno-organizational, techno-economic factors of sustainable eHealth implementations are studied from the literature. The system dynamics modelling and simulation technique was used to understand the interplay between factors of sustainable eHealth implementations.

The research questions are addressed in the literature survey presented in Chapter 2. Later in Chapter 3, the conceptual design of sustainable eHealth implementation is developed based on the knowledge from the literature survey. The system dynamics modelling and simulation effort aims at meeting the research objectives discussed in Chapter 1. This chapter explains the suitable research design and methodology used in this research study. An appropriate research methodology to confirm the conceptual framework of sustainable eHealth implementation discussed in Chapter 3 is presented in this section of the thesis.

The strengths and weaknesses of the methodology, as well as its appropriateness to this study, is explored further. A system dynamics model building method, a case study research and model testing approaches are described as part of research design approach followed in this thesis. The sections of this chapter are organised as follows: the research design for model-based theory building is described as part of the research design followed. A system dynamics modelling and simulation approach applied in this study is also addressed in the following section. Thereafter, the case of eHMIS and SmartCare, the data collection process and data analysis methods used in this research study are discussed.

4.2. Research paradigms

Research is a systematic investigation based on reasoning (theory) and observations (data or information) (Blumberg et al. 2008:19). The relationship between observations and reasoning is a hotly debated philosophical matter on the development of knowledge (Easterby-Smith, Thorpe and Jackson, 2012). Eastearby-Smith et al. (2012) discussed three benefits of understanding the philosophical issues of a research.

- To clarify the research design.
- To recognise working research design.
- To adopt proper research design.

“A research paradigm is a way of describing a worldview that is informed by philosophical assumptions about the nature of social reality (ontology), ways of knowing (epistemology), and ethics and value systems (axiology)” (Chilisa 2012:20). A paradigm also has theoretical assumptions about the research methodology (Chilisa 2012). The research paradigm can be characterized through ontology (what do we believe about the nature of reality?), epistemology (how do we know what we know?), methodology (how should we study the world?), and methods (what are individual techniques for data collection and analysis?) (Chilisa and Kawulich, 2012; Easterby-Smith, Thorpe and Jackson, 2012; Scotland, 2012).

- *Ontology* focusses on the nature of reality and deals with the essential characteristics of what it means to exist (Guba, 1990; Chilisa, 2012).
- *Epistemology* seeks to understand the nature of the relationship between the inquirer, and the knowledge and truth (Guba, 1990; Chilisa, 2012). It asks questions about the source of knowledge, the reliability of these sources, what to know and how to know if it is true (Chilisa 2012).
- *Axiology* refers to the analysis of values to better understand their meanings, characteristics, origins, purpose, acceptance as true knowledge, and influence on people’s daily experience (Chilisa 2012).
- *Methodology* is the research process and approach to a systematic inquiry to find out knowledge (Guba, 1990; Chilisa, 2012).

Chilisa (2012) discussed the classification of research methodology based on the ontological, epistemological and methodological assumptions into three research paradigms: positivism, constructivism or interpretive, and transformative. The beliefs and assumptions of positivism and constructivism are discussed below.

Positivism is rooted in the position that a scientific method is the only way to establish truth and objective reality (Chilisa 2012). It holds realist ontology, objective epistemology and follows empirical experimentation methodology. Positivism is based on a view that assumes true knowledge is founded on a natural science which time- and context-free (Guba, 1990; Chilisa, 2012). The current position of positivism has been built based on the contributions of many philosophers such as Aristotle, Francis Bacon, and John Locke (Chilisa 2012). The ontological, epistemological and methodological assumptions of positivism are as follows (Guba, 1990; Chilisa, 2012):

- Ontology: there is a single, tangible and measurable objective reality which is independent of the researcher’s interest. The positivism assumes that this reality is relatively constant across time and settings.
- Epistemology: positivism recognises knowledge is objective and constitutes hard data independent of the researchers.

- Methodology: positivism supports quantitative research aiming at predicting, testing a theory and finding the cause-effect relationships.

Constructivism or Interpretive argues that the "reality" exists only in the context of a mental framework or construct, and many constructions are possible (Guba 1990:25). A phenomenological philosopher Edmund Husserl and philosopher of hermeneutics Wilhelm Dilthey were among the contributors to the interpretive approach (Chilisa 2012). The constructivism paradigm takes a position of relativism ontologically, chooses subjectivist position epistemologically and follows hermeneutic methodologically (Guba 1990). The interpretive assumptions about the nature of reality, knowledge and methodology include (Guba, 1990; Chilisa, 2012):

- Ontology: interpretivists believe that reality is socially constructed and its form and content depend on the people constructing it. Interpretivists assume that reality is limited to the context, space, time and individuals in a given situation.
- Epistemology: knowledge is subjective according to interpretivists' belief. It is socially constructed and mind-dependent based on individual's experience.
- Methodology: interpretive research aims to understand human experience within a natural setting to reconstruct the "world". Qualitative research is the common methodology in the interpretive approach.

The characteristics of positivist and constructivist paradigms are summarised in the Table 4.1. It shows the frameworks of assumptions used in both types of paradigms.

The implementation of eHealth depends on the context and settings of the implementing healthcare organization and the end-users of the technology. As a result, similar eHealth technologies exhibit different results in different healthcare institutions. The financial factors, the skill of end-users, ICT infrastructure, and organizational readiness are some of the realities that differ between resource-abundant and resource-constrained settings. The constructivist paradigm argues that there can be multiple socially constructed realities, therefore truth is context dependent. The nature of reality in this research study is embedded in the context and settings of healthcare organization that has implemented eHealth technology. Hence, the context and setting dependency of sustainable eHealth implementation in this study supports the ontological assumption of the constructivist paradigm. The type of eHealth applications, the type of users and the environment in which the system implemented determines the research outcome.

Table 4.1 Comparison of positivist and constructivist paradigms (Chilisa 2012:41).

	POSITIVIST/ POSTPOSITIVIST PARADIGM	**CONSTRUCTIVIST/ INTERPRETATIVE PARADIGM**
Reason for doing the research	To discover laws that are generalizable and govern the universe	To understand and describe human nature
Philosophical underpinnings	Informed mainly by realism, idealism and critical realism	Informed by hermeneutics and phenomenology
Ontological assumptions	One reality, knowable within probability	Multiple socially constructed realties
Place of values in the research process	Science is value free, and values have no place except when choosing a topic	Values are an integral part of social life; no group's values are wrong, only different
Nature of knowledge	Objective	Subjective; idiographic
What counts as truth	Based on precise observation and measurement that is verifiable	Truth is context dependent
Methodology	Quantitative; correlational; quasi-experimental; experimental; causal comparative; survey	Qualitative; phenomenology; ethnographic; symbolic interaction; naturalistic
Techniques of gathering data	Mainly questionnaires, observations, tests and experiments	Mainly interviews, participant observation, pictures, photographs, diaries and documents

The epistemological assumption of the research agrees with the subjectivity of knowledge and social constructionism. Knowledge is socially constructed and dependent on the content, context and individuals' experience (Chilisa 2012). There could be multiple realities about the sustainability of eHealth based on the stakeholders' group. An eHealth application can be technological reliable and sustainable from the technology suppliers perspective, however, end-users might have a different position in terms of the sustainability of similar eHealth technology. Similarly, an efficient eHealth technology for end-users may not be economically feasible for the healthcare organization. Therefore, the epistemological assumption of this research study supports the position of the constructivist research paradigm.

Methodologically, this study mainly applies qualitative research methodology. It requires detailed observations, thick description, in-depth inquiry, interviews to capture people's personal experiences and perspectives, documents review and case studies (Patton, 2002). Qualitative studies consider programs as dynamic and developing; and aim at describing the dynamic process and the holistic effects of the system elements (Patton, 2002). The qualitative research is a preferred methodological approach in this research and it is the common methodology in the interpretive approach.

This research study falls dominantly in the constructivist paradigm. It assumes that reality is limited to the context, space, time and individuals in a given situation which supports the ontological assumption of the constructivist paradigm. Besides the epistemological assumption of this research study agrees with the possibility of multiple socially constructed realities from different stakeholder groups about the sustainability of eHealth implementation that supports the constructivist paradigm. Finally, the qualitative research methodology followed in this research study is in agreement with the philosophy of the constructivist research paradigm.

4.3. Research design

Research designs are types of inquiry within qualitative, quantitative, and mixed methods approach that provides specific direction for procedures to find answers to research questions (Creswell, 2014). Ritchie & Lewis (2003) discussed research design aspects from the perspective of research questions development, research settings and population decision, the choice of data collection methods and research relationships (such as access and ethics). The set of methods and procedures followed to validate and test the conceptual framework of sustainable eHealth implementation presented in Chapter 3 is discussed in details. The research design processes need to have a clearly defined purpose which is coherent with the research questions and the proposed methods. The appropriate research method to assess the socio-technical, techno-organizational and techno-economic factors of sustainable eHealth implementation described in Chapter 3 is discussed in the following section.

4.3.1. Design description

Patton (2002) argued that a systems perspective is important in dealing with complexities in real-world. It facilitates the holistic view of entities embedded within a context (Patton, 2002).

Understanding the physical and geographical settings or contexts is critical in qualitative studies to document human experience and organizational culture (Patton 2002). A systems approach is heavily dependent on qualitative inquiry (Patton 2002). A broad, holistic and long-term view of a system is central to a systems perspective (Patton 2002). A holistic perspective strives to understand the relationships between parts and wholes of a phenomenon or program (Patton 2002).The holistic approach assumes that the whole is understood as a complex system that is greater than the sum of its parts (Patton 2002:59). The parts within a system are interconnected and interdependent that any small change in one part can lead to changes in all parts and the system (Patton 2002).

Healthcare is recognised as a complex system, and Lipsitz (2013) highlighted the importance of using complexity science to address the problems of healthcare systems. Complexity is often accompanied by dynamic and nonlinear interactions of system components, emergent and self-organising behaviours (Lipsitz, 2013). System dynamics is an interdisciplinary modelling approach that helps to understand the structure and dynamics of the complex system (Sterman, 2000). It aids the design of effective policies and organizations through computer simulation of the complex systems (Sterman, 2000). The learning process of dynamic interactions among sustainable eHealth implementation factors in complex healthcare settings can be enhanced by using system dynamics modelling approach. It is an appropriate method for understanding the nonlinear behaviour of complex systems. System dynamics research method has been used to understand the complexity of different real-world systems (Sterman, 2000). Complex systems follow simple rules that can lead towards a common goal (Lipsitz, 2013). General direction pointing (aims), prohibitions (limits) and resources or permissions (incentives) are the three simple rules that can lead to self-organising innovation in healthcare systems (Lipsitz, 2013).

This study is explanatory in its nature trying to describe and attempting to explain the reason or cause for certain phenomena by answering the why and how research questions (Cooper and Schindler, 2001). The research approach in this study combines both the system dynamics modelling and the case study research approach to strengthening the learning process of the dynamic interaction among factors of sustainable eHealth implementation. A system dynamics could be used in different categories of the research paradigm based on the assumptions defined in the process of research approaches (Pruyt, 2006). The basic assumptions behind the system dynamics modelling process define the philosophy of the research paradigm (Pruyt, 2006).

The system dynamics model of sustainable eHealth technology is described through the acceptance of technology from the end-users perspective in this thesis. There could be other ways of representing the reality of sustainable eHealth implementation from the perspective of different stakeholder groups. Multiple system dynamics representations might be used to represent the reality of sustainable eHealth implementation from different stakeholders' perspective (patients, caregivers, policymakers, donors). Therefore, the ontological assumption of the system dynamics in this study supports the view of constructivists' research paradigm. Similarly, the subjectivity of knowledge with respect to the context and settings of the system dynamics model of a sustainable eHealth system in this research study agrees with the epistemological position of the constructivist paradigm. The actors involved (stakeholders) in the design, implementation and operations of the eHealth system make sense of the system under study to make their own interpretation of the reality (Schwaninger, 2006). Methodologically, this study uses a system dynamic modelling together with qualitative research approach which is the preferred methodology of a constructivist paradigm.

There are indeed various system dynamics practices with ontological, epistemological, causal, logical and methodological assumptions spanning the range all the way from positivism to constructivism (Pruyt, 2006). Constructivist causal models are models of perceptions or interpretations of the causal theories to give meaning to complex relationships (Pruyt, 2006). Possible uses of constructivist system dynamics are modelling for learning and understanding about other points of view, modelling for assumptions and concepts hypotheses surfacing, modelling to gain insight in possible evolutions, modelling to build shared interpretation, modelling to find compromises between fundamentally different views, which lead to better-informed decisions and actions in specific domains, commitment to structural changes, etcetera (Pruyt, 2006).

The causal theories can be models of perceptions or interpretation of the jumble in the case of the constructivist paradigm (Pruyt, 2006). The system dynamic modelling and validation process is positioned in the relative philosophy of science (Barlas and Carpenter, 1990). Constructivist system dynamics practice focuses on only induction (qualitative modelling) and no deduction (purely quantitative simulation) (Pruyt, 2006). System dynamics modellers argue that the nature and context of the problem, the purpose of the model, the background of the user and analysis affect the validity of a model (Barlas and Carpenter, 1990). Barlas & Carpenter (1990) discussed the existence of objectivity within every model in terms of carrying the world view of the modeller.

Williams (2002) integrated system dynamics modelling and case study research methods in a model-based theory building research for requirements engineering process modelling and improvements. The mixed-method design or methodological triangulation is used to enhance the research study by combining two or more approaches (Thurmond, 2001).

Case studies of two eHealth systems (eHMIS and SmartCare) together with system dynamics modelling approach are used to illustrate an evolutionary concept of theory development objective of this research study. The combination of system dynamics methodology and a case study to illustrate the process of model-based theory building approach applied by Schwaninger & Grösser (2008) is adopted for this research study. As recommended by Reid et al. (2005), the end-users, technology providers and owners of electronic health system were involved in the data gathering processes in this thesis. To increase the flexibility and response rate of data collection process, a structured questionnaire was used to conduct interview with end-users of the eHealth systems. Three focus group discussion sessions were conducted to get further insight from a different group of stakeholders. Focus group sessions with technology owners, technology providers and academia were conducted to collect evidence using semi-structured instruments in this research study.

A national level scale-up and a sustainable implementation of eHealth begins with a successful and sustainable implementation of eHealth systems at health facility level. As a result, the system boundary of a system dynamics modelling study in this thesis is set at healthcare institution level. The boundary for the modelling, data collection and analysis processes in this thesis is bounded at organizational level. Therefore, only eHealth sustainability factors internal to the organization are considered in the modelling process. All other eHealth sustainability actors outside organizational control are not addressed in this study. Sterman (2000) indicated that simplifying the reality to represent the complexity in real-world enhances the usefulness of models. The long-term sustainable implementation of eHealth at healthcare institution level is the foundation for nationwide scale-up effort. Yet, the study acknowledges the significant influence of broader legal frameworks, interoperability standards, and ICT infrastructure at a national and regional level to the large-scale and sustainable implementation of eHealth systems. But this study focuses on the long-term sustainable use of eHealth technology, quality of data and health information product for decision making at healthcare institutions level.

4.3.2. Design science research

The design science research is highly relevant to information systems (IS) research focusing on the IT artefacts with a high priority on relevance in the application domain (Hevner and Chatterjee, 2010). The DSR is discussed under three closely related cycles of activities – relevance cycle, rigor cycle and design cycle (Hevner, 2007). The relevance cycle initiates DSR not only with identifying the requirements of the research but also setting evaluation criteria of the research outputs (Hevner, 2007). The rigor cycle “provides past knowledge to the PhD research project to ensure its innovation” (Hevner, 2007). In general, the requirements and evaluation criteria are inputs from the relevance cycle, whereas the design and evaluation theories and methods are drawn from the rigor cycle (Hevner, 2007). “The design cycle iterates between the core activities of building and evaluating the design artefacts and processes of the research” (Hevner, 2007).

The DSR contributes to the study of socio-technical artefacts of information systems such as decision support systems, modelling tools, IS change interventions, and governance strategies (Gregor and Hevner, 2013:337). “DSR is a research paradigm in which a designer answers questions relevant to human problems via the creation of innovative artefacts, thereby contributing ne knowledge to the body of science evidence.” (Hevner and Chatterjee, 2010:5). In this DSR, the models and theories are mapped to the implementation of a sustainable eHealth system in the socio-technical, techno-organizational and techno-economic groups to create the type of missing knowledge using system dynamic modelling approach (Kuechler and Petter, 2017).

Information technology is used to acquire and process information in support of human purpose (Hevner and Chatterjee, 2010:5). The focus in this thesis is eHMIS which of an IT to support healthcare services delivery through improved information quality for decision making. In general, “IT systems represent complex coordination of hardware, software, procedures, data and people developed to address tasks faced by individuals and groups typically within some organizational settings” (Hevner and Chatterjee, 2010:5). Design science identifies the building and evaluation processes (build and evaluate) to build an artefact that can address unsolved problems (Hevner et al., 2004).

The general process followed by DSR is described in Figure 4.1 below. Different activities are carried out within the different phases of a DSR processes. The contribution of new (and true) knowledge needs to be a key focus of DSR (Kuechler and Petter, 2017).

Awareness of problem phase may come from multiple sources (Kuechler and Petter, 2017). The problems in this PhD research project were derived from the researcher's experience in the field of health IT, literature findings and feedback from end-users and projects staffs of eHealth systems. The output of this phase is a formal or informal proposal for a new research effort (Kuechler and Petter, 2017).

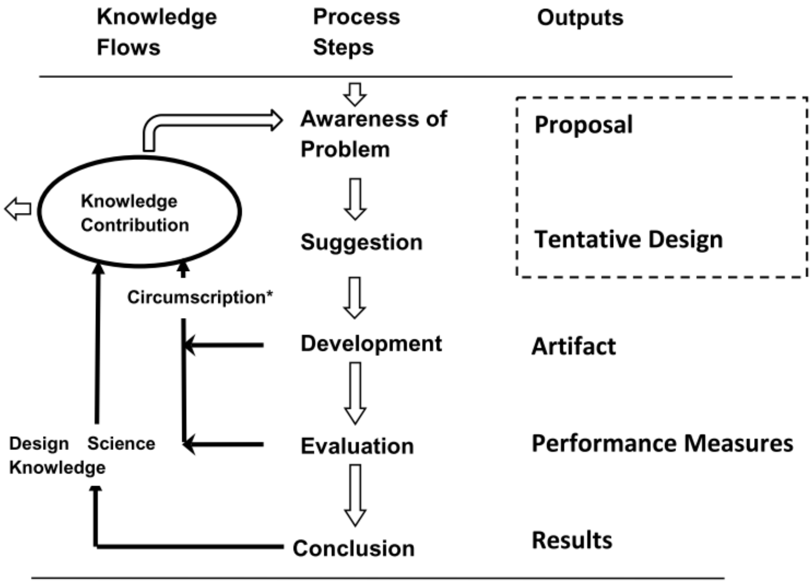


Figure 4.1 Design science research process model (Kuechler and Petter, 2017).

Suggestion phase follows the proposal and is intimately connected with the proposal developed based on the Awareness of a Problem. The intimacy is shown with the dotted line surrounding the outputs of the Awareness of a Problem and Suggestion phase (Kuechler and Petter, 2017). The conceptual framework discussed in Chapter 3 suggests a possible approach to address the research problems described in Chapter 1.

Development phase focuses on further development and implementation of the Tentative Design which is done through system dynamics modelling approaches in this research study (Kuechler and Petter, 2017).

Evaluation phase aims at evaluating the constructed artefacts according to criteria in the Proposal (Kuechler and Petter, 2017). The model validation and verification process evaluate the capability of the model to meet the research objectives set in Chapter 1.

Conclusion phase could be just the end of a research cycle or is the finale of a specific research effort (Kuechler and Petter, 2017).

The DSR generates knowledge in the form of constructs, models, methods, and instantiations to define, communicate, understand and solve the problems and demonstrate the feasibility of an artefact to its intended purpose in order to produce better design theory (Hevner et al., 2004; Hevner and Chatterjee, 2010; Kuechler and Petter, 2017). The possible types of knowledge contribution in the DSR presented in Figure 4.2 based on the maturity of the problem and solution domains (Gregor and Hevner, 2013).

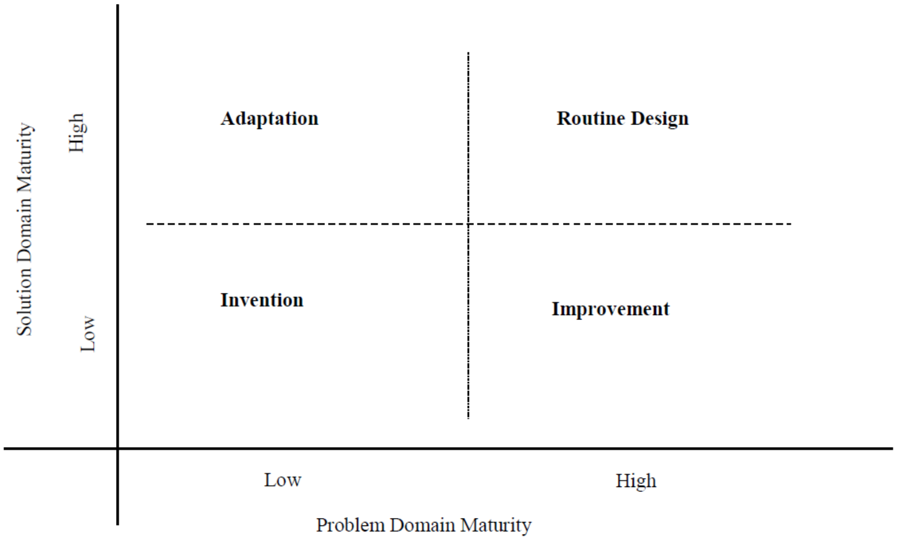


Figure 4.2 DSR knowledge contribution framework(Gregor and Hevner, 2013).

Invention (new solutions for new problems) refers to a breakthrough into a new solution or knowledge space from a little-recognised problem domain (Gregor and Hevner, 2013).

Improvements (new solutions for known problems) represents the creation of better solution in the form of more efficient and effective products, processes, services, technologies or ideas for known problems (Gregor and Hevner, 2013). The knowledge contributions in the improvement quadrant could be (Gregor and Hevner, 2013).

- Level 1: situated instantiation of a software product or implementation process;
- Level 2: nascent design theory in the form of constructs, methods, model, design principles and technological rules;
- Level 3: Improved understanding of problems and solutions to formulate well-developed mid-range design theory.

The goal of this research study is to improve the sustainability of eHealth systems through technology acceptance by end-users. The problem of sustainable eHealth implementation in the developing countries is well recognised, however, the proposed solutions are not holistic that recognises the complex and nonlinear nature of the problem. Hence the contribution of the design science research in this study dominantly fall in the improvements quadrant, a well-known problem but seeking a new solution to ensure sustainable eHealth implementation in a resource-constrained setting (Gregor and Hevner, 2013).

Adaptation or exaptation (known solutions extended to new problems) refers to the expropriation of artefacts or design knowledge in one field to solve the problem in another field (Gregor and Hevner, 2013).The DSR in this study also contributes to generating new knowledge in the exaptation quadrant by using the theory of sustainability from the ecological domain to the context of eHealth implementations. The economic, social and environmental factors are the key pillars in the evaluation of the ecological sustainability of planate Earth. However, these factors are adopted to assess the sustainability of eHealth systems in the context of a resource-constrained environment. The exaptation research extends known design knowledge into a new field (Gregor and Hevner, 2013).

Routine design (known solutions for known problems) occurs when a solution is applied to a well-understood problem (Gregor and Hevner, 2013). It seldom contributes to the knowledge base research as existing knowledge is applied in familiar problem areas in a routine way (Gregor and Hevner, 2013).

4.3.3. Model-based theory building

A theory is a structured, explanatory, abstract and coherent set of interconnected statements about a reality (Schwaninger and Grösser, 2008). The building blocks of a theory as explained by Cooper & Schindler (2001) are:

Concepts create common ground to understand and communicate information by providing generally accepted meanings or characteristics associated with certain events, objects, conditions, situations, and behaviours (Cooper & Schindler 2001:39).

A *construct* is an image or an idea specifically invented for the purpose of theory-building or/and other research types (Cooper & Schindler 2001:41).

Definitions provide an understanding and measurements of concepts. Definitions can be either dictionary definition or operational definition. A dictionary definition is a synonym concept. An operational definition is a definition in terms of specific testing or measurement criteria (Cooper & Schindler 2001:42).

Variables are symbols to which the numbers or values assigned (Cooper & Schindler 2001:44). Researchers are interested in understanding the relationship between variables, mainly dependent and independent variables. Independent variable is a predictor, antecedent, stimulus or presumed cause; whereas dependent variable is criterion, consequence, response or presumed effect (Cooper & Schindler 2001:45). In system dynamics, variables are categorised as endogenous and exogenous. Endogenous variables have an internal cause or origin, whereas, exogenous variables have an external cause or origin (Sterman, 2000).

A *proposition* is a statement about concepts that may be judged as true or false if it refers to observable phenomena. A *hypothesis* is a proposition formed for empirical testing (Cooper & Schindler 2001:47). Hypothesis guides the direction of the study, define relevant factors of the study, suggests appropriate research design, provides a framework for organising the conclusions (Cooper & Schindler 2001:49). A good hypothesis is adequate for its purpose, testable and better than its rivals (Cooper & Schindler 2001:50).

A *theory* is a set of systematically interrelated concepts, definitions and propositions that are advanced to explain and predict phenomena or facts (Cooper & Schindler 2001:51). Schwaninger & Grösser (2008:450-451) presented the different ranges of theory as follows:

- General theories are a highly generic, often overall explanation of a whole range of phenomena.
- Middle-range theories consolidate different hypotheses or findings, address connections of specific hypothesis to explain all the observed uniformities of a system.
- Local theories apply to a particular context and explain behaviour encounters in the specific instances.

Theory building generates and formalises a theory in order to orientate action (Schwaninger & Grösser 2008:448). Based on the difference in the source of knowledge, theory building is categorized as (Schwaninger & Grösser 2008):

- Inductive (data-to-theory): data is collected, analysed and then tested to formulate a theory.
- Deductive (theory-to-data): a theory is derived from the logical steps and assumptions to be tested later through data.

The different phases of the system dynamics research cycle are based on different types of logic (Pruyt, 2006). Inductive logic is used when the first micro-theory is induced which later on used to simulate (deductive logic) (Pruyt, 2006). In this inductive reasoning study, specific observations were made on the two cases of eHealth systems in Ethiopia (eHMIS and SmartCare) to make a broad generalization. The inductive reason is followed in this study to form a theory regarding the sustainable implementation of eHealth.

In a model-supported theory building, the theory emerges in the iterative process of the construction and validation of a model (Schwaninger & Grösser 2008). The source of the knowledge in the system dynamics model is a reservoir of mental models. The mental models can be of an inductive or a deductive origin; usually they are both (Schwaninger & Grösser 2008).

In conclusion, Schwaninger & Grösser (2008:461-462) put forward eight points recommendation to be followed in the process of model-based theory building.

- Issue orientation. Theory building effort with system dynamics should be issue-oriented to achieve a substantive, operational, local theory than aim to achieve “grand theories”.
- Formalization. It aims at building theories on the basis of the formal model. However, formalization is disputed for its costly, cumbersome and complicated processes.
- Generalization. Theory-building principles promote generalization to enhance external validity.
- Validation. The ability of the model to represent what supposed to represent.
- Explanation. It requires not only the ability of the model to reproduce the behaviour under study but also its ability to explain why the model produces a certain behaviour.
- Falsification. The proper theory-building approach should undertake serious attempts to falsify a theory, not try to justify it.
- Process design. The quality of the theory is impacted by the theory-building process. System dynamics model building process using a group of a multi-disciplinary team is a key to process design.
- Concept of learning. A system dynamics supported theory building process is a vehicle for a learning process.

The following set of criteria can evaluate the quality of model-based theory building Schwaninger & Grösser (2008:451).

- Refutability: the ability of a theory to be falsified (refuted) or supported.
- Importance: a quality or aspect of having great worth or significance; acceptance by competent professionals may be indicative of importance;
- Precision and clarity: a state of being clear; hypotheses can easily be developed from the theory;
- Parsimony and simplicity: uncomplicated; limitation of complexity and assumptions to essentials;
- Comprehensiveness: covering completely or broadly the substantive areas of interest;
- Operationality: specific enough to be testable and measurable;
- Validity: valid, accurate representation of the real system under study;
- Reliability: free of measurement errors;
- Fruitfulness: statements are made that are insightful, leading to the development of new knowledge;
- Practicality: provides a conceptual framework for practice.

4.3.4. Systematic literature review

A systematic review attempts to collate all empirical evidence that fits pre-specified eligibility criteria to answer a specific research question (Liberati et al., 2009). The systematic methods minimise bias, thus providing reliable findings from which conclusions can be drawn and decisions made (Liberati et al., 2009). A meta-analysis is also used in some systematic reviews as a statistical methods to summarise and combine the results of independent studies. (Liberati et al., 2009). A Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) approach were followed in this research study. PRISMA focuses on ways in which authors can ensure the transparent and complete reporting of systematic reviews and meta-analyses (Liberati et al., 2009).

The abstract, title and keyword of ScienceDirect, title and abstract of PubMed, and abstract of SAGE journal databases were searched to identify eligible studies that meet the search criteria. The last search for all databases was performed in October 2017. A systematic review was carried out on the topic of eHealth economics to identify the gaps in the techno-economic dimension of sustainable eHealth implementation in the resource constrained settings and to recommend for future research works on sustainable eHealth implementation. The systematic literature review of three databases (ScienceDirect, PubMed, SAGE journal) conducted with the search terms e-Health, eHealth, econom*, finance* and fund* on studies published between 2007 and 2017.

Both “eHealth” and “e-Health” were used interchangeably in the academic literature to represent electronic health systems; hence eHealth and e-Health were used as search terms to address electronic health systems. The Boolean operator “OR” was used to include all studies that used either of the terms. The economic factors were represented by search terms such as econom*, finance* and fund*. The advanced search option on all three databases. The final search phrase was [eHealth OR “e-Health”] AND [econom* OR finance* OR fund*]. The search term “econom*” was used to include phrases such as economic or economy; “financ*” was included to address financial or finance related studies; “fund*” was used to incorporate terms such as fund, funding, funder and funded. The advanced search option were used on all three databases. Table 4.2 shows the detail search algorithm used for the three databases. The identified articles were imported into Mendeley reference database and the duplications were removed.

Table 4.2 Details of search algorithm

Database	Search phrase	Searched in	Publication dates	Access type
SAGE journals	[[Abstract eHealth] OR [Abstract "e-Health"]] AND [[Abstract econom*] OR [Abstract financ*] OR [Abstract fund*]]	Abstract	2007 - 2017	All content
ScienceDirect	TITLE-ABSTR-KEY(eHealth OR "e-Health") and TITLE-ABSTR-KEY(econom* OR financ* OR fund*)	Abstract, Title, Keywords	2007 -Present	All Journals in All sciences
PubMed	((eHealth[Title/Abstract] OR "e-Health"[Title/Abstract]) AND (econom*[Title/Abstract] OR financ*[Title/Abstract] OR fund*[Title/Abstract]))	Abstract/Title	10 years	Full text

Eligibility criteria are necessary to the evaluation of the review’s validity, applicability and comprehensiveness (Liberati et al., 2009). The economic studies of eHealth systems in developing countries published from 2007 to 2017 and reported in the English language were included in this research. Moreover, only studies available in full text were selected. The type of articles included in this study addressed issues of sustainable funding, affordability, cost-effectiveness, cost-utilization, cost-benefit analysis, return on investment (ROI), cost-saving, and cost-minimization of eHealth technology. The selection decisions were made based on the title and abstract of the papers. The full-paper review was performed on studies that met the inclusion criteria and studies that were not conclusive from their titles and abstracts.

The information extracted from each of the included studies comprises

- The perspective of the study such as patient, health care professionals, societal or providers.
- The health economic evaluation techniques used, like CBA, CEA, CUA, and CUA.
- The type of eHealth application such as EMR, EHR, mHealth, telemedicine, and web-application.
- The area of intervention addressed by the eHealth like dermatology, depression disorder, diabetes, health record digitalization, or others.
- The place or country of study.
- The number of participants.
- Period of study.
- Research methodology.
- The outcomes of economic evaluation studies.

4.3.5. System dynamics and qualitative research

Qualitative and quantitative research methodologies are the two broad categories of scientific research (Leedy and Ormrod, 2010). The underpinning philosophy of qualitative research is empiricism. It follows an unstructured, flexible and open approach to enquiry, and aims to describe the phenomenon than measure (Kumar, 2011). On the contrary, the quantitative research philosophy is rooted in rationalism. It follows a structured, rigid, predetermined methodology, and aims to quantify the variation in a phenomenon, and tries to make generalisations to the total population (Kumar, 2011). A qualitative research uses few cases to describe variations in a phenomenon whereas quantitative research stresses on greater sample size to quantify the extent of variation in a phenomenon (Kumar, 2011). The qualitative and quantitative research are compared in Table 4.3 to aid selection of research approach.

Qualitative and quantitative research methodologies are the two broad categories of scientific research (Leedy and Ormrod, 2010). The underpinning philosophy of qualitative research is empiricism. It follows an unstructured, flexible and open approach to enquiry, and aims to describe the phenomenon than measure (Kumar, 2011). On the contrary, the quantitative research philosophy is rooted in rationalism. It follows a structured, rigid, predetermined methodology, and aims to quantify the variation in a phenomenon, and tries to make generalisations to the total population (Kumar, 2011). Qualitative research uses few cases to describe variations in a phenomenon whereas quantitative research stresses greater sample size to quantify the extent of variation in a phenomenon (Kumar, 2011). The qualitative and quantitative research are compared in Table 4.3 to aid selection of a research approach.

Table 4.3 Comparisons of qualitative and quantitative research approaches (Leedy & Ormrod 2010:96).

Questions	**Quantitative**	**Qualitative**
What is the purpose of the research?	To explain and predict	To describe and explain
	To confirm and validate	To explore and interpreted
	To test theory	To build theory
What is the nature of the research process?	Focused	Holistic
	Known Variables	Unknown variables
	Established guidelines	Flexible guidelines
	Predetermined methods	Emergent methods
	Somewhat context-free	Context bounded
	Detached view	Personal view
What is the data like, and how is it collected?	Numerical data	Textual and/or image based data
	Representative, large sample	Informative, small sample
	Standardized instruments	Loosely structured or non-standardized observations and interviews
How are data analysed to determine their meaning?	Statistical analysis	Search for themes and categories
	Stress on objectivity	Acknowledgment that analysis is subjective and potentially biased
	Deductive reasoning	Inductive reasoning
How are the findings communicated?	Numbers	Words
	Statistics, aggregated data	Narratives, individual quotes
	Formal voice, scientific style	Personal voice, literary style

The research in this thesis focuses on acquiring the experience of end-users and project members of eHMIS and SmartCare systems in terms of sustainable use of technology and information. Moreover, it follows an unstructured, flexible and open methodology to describe the eHealth implementation phenomenon in resource-constrained settings. The study explores the users' experience, feelings, and perceptions regarding the two eHealth systems through interviews, focus group discussions, document review and specific observations to describe the characteristics of the larger population. The details of the evidence collected from the two cases and the model simulation outputs are used to drive general principles through inductive reasoning approach. The research findings are communicated in more descriptive and interpretive narratives. Therefore, the study follows a dominantly qualitative research approach for data analysis and findings reporting.

The use of qualitative research method guides the system dynamics modelling process and builds confidence in the process of model building and formulation (Luna-Reyes and Andersen, 2003). The data and variables created in the process of observing the world are mostly qualitative in nature at the beginning. The researcher's decision to record a variable in a qualitative or quantitative way is influenced by the theoretical and mental model of the research (Luna-Reyes and Andersen, 2003). In social system studies, there are variables difficult to be directly observed or multidimensional in nature (Luna-Reyes and Andersen, 2003). Systems thinking is used as a qualitative modelling technique to formalize and analyse feedback loops (Luna-Reyes and Andersen, 2003). Further simulation of a mathematical system dynamics model is applied to build a model (Luna-Reyes and Andersen, 2003).

The use of qualitative research in a system dynamics modelling approach adds richness and details to understand the complexity of real-world systems (Luna-Reyes and Andersen, 2003). However, the benefits of qualitative approach come with time and labour costs associated with data collection, transcribing interviews, coding documents and lengthy transcript (Luna-Reyes and Andersen, 2003). The system dynamic simulation method followed in this PhD research project is discussed in the next section.

4.4. System dynamics modelling and simulation method

A model is a representation of a system or phenomena through the use of analogy that is constructed to study some aspect of those systems or a system as a whole (Cooper & Schindler 2001:52). Theories explain whereas models represent phenomena (Cooper & Schindler 2001:52). The three functions of modelling include a description (descriptive models), explications (explicative models) and simulation (simulation models) (Cooper & Schindler 2001:52). Models can represent either *static* phenomena at one point in time, or *dynamic* system that evolves over time (Cooper & Schindler 2001:52). Modelling is conceived as a process of building a model (Schwaninger & Grösser 2008).

A system dynamics modelling process supports a dynamic system modelling effort. A system dynamics model is constructed as continuous feedback systems that evolve over time

(Schwaninger & Grösser 2008). The complexity, nonlinearity, and feedback loop structures of social and physical systems in the real world can be represented adequately using system dynamics modelling method (Forrester, 1994). The system dynamics process begins with understanding the system problem, but the process continues seeking to improve the system performance (Forrester, 1994).

The complex and dynamic nature of the healthcare system requires a system thinking approach that can address the complexity of the interconnected components of health systems and their stakeholders (Adam and De Savigny, 2012). System dynamics is a method to deal with the dynamic complexity of systems and enhance the learning process of nonlinear systems (Sterman, 2000). A system dynamics modelling approach is used to learn the complexity associated with the implementation of eHealth systems within healthcare organizations to learn the changing nature of systems, the influence of history and feedback effects, the critical role of stakeholders, and the influence of context on a system (Forrester, 1994; Sterman, 2000; Adam and De Savigny, 2012). The system dynamic modelling process followed in this PhD research project is discussed in the following section.

4.5. System dynamics modelling process

Modelling is an iterative nonlinear process with feedback processes as shown in Figure 4.3 (Sterman, 2000). The iteration can occur many times from any step of the modelling process to other steps (Sterman, 2000). The models and techniques developed through elicitation and mapping process are an initial hypothesis about the structure of a system, which must be tested (Sterman, 2000).

Identifying the real problem and client is the first step of the System Dynamic modelling process. Forrester (1994) discussed six steps of system dynamics modelling processes to achieve the goal of system improvement. The first step of system dynamics modelling process aims at identifying relevant elements of a system (Forrester, 1994). Case study, soft operations research, systems thinking and system dynamics are some of the soft methodological approaches used in conceptualisation phase (first step) of system dynamics (Forrester, 1994). The first step focuses on understanding undesirable system behaviour that needs to be corrected (Forrester, 1994). This stage is known as problem definition, system conceptualization, diagram construction and analysis phase (Wolstenholme, 1990). In the first phase of the system dynamics modelling process, this study applied system thinking to the elements of sustainable eHealth implementation established from the findings of a literature review. Furthermore, the researcher's experience and understanding of eHealth implementation in Ethiopia are considered.

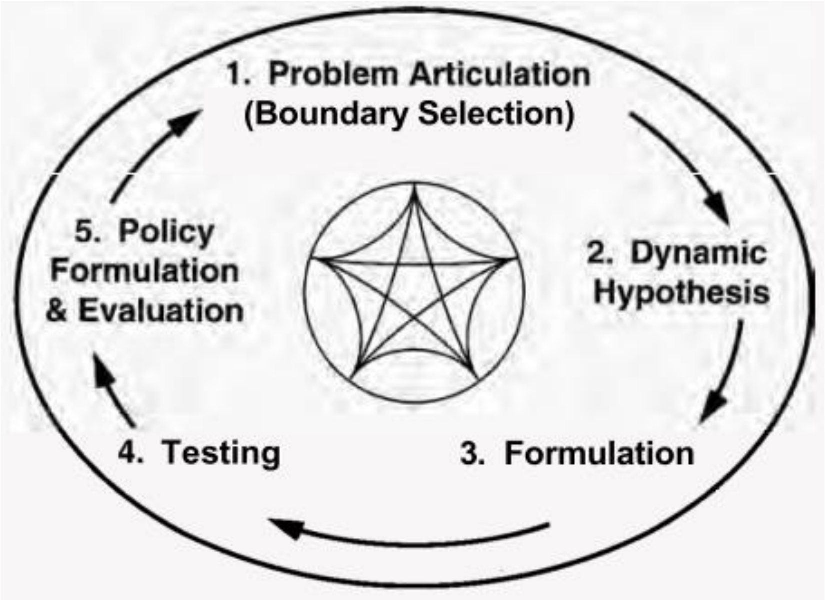


Figure 4.3 Iterative modelling process (Sterman, 2000:87).

The first step is followed by translation of system description into the level and rate equations to formulate simulation model (Forrester, 1994), also referred to as model formulation (Wolstenholme, 1990; Sterman, 2000). The simulation of the model can be done at the third step if the simulation model passes logical criteria of an operable model (Wolstenholme, 1990; Forrester, 1994). Sterman (2000) denotes it as formulation, whereas other authors address the simulation of the model as the analysis of model behaviour. Simulation models clarify the structural relations of concepts and attempt to reveal the process relations among them (Cooper & Schindler 2001:52). If the simulation outputs exhibit unrealistic behaviour, it is necessary to return to Steps one and two to refine the equations until adequate confidence is achieved (Forrester, 1994).

Step four focuses on simulation tests to determine alternative policies that show the greatest promise for improvements (Wolstenholme, 1990; Forrester, 1994; Sterman, 2000). The fifth step works toward a consensus for implementation of alternative promising policies which require leadership and coordination skills. The final step of the system dynamics modelling process is about the implementation of new policies. The effectiveness of step 6 depends on the sufficiency of education in Step 5 (Forrester, 1994). The evaluation of new policies implementation impact in addressing system problem is a long process that can take several years (Forrester, 1994). The last two steps are combined and presented as stages of implementation or policy analysis and model use (Forrester, 1994).

Although the ways of the system dynamics modelling process activities grouped and described vary across studies, the comparison across stages remain fairly constant. Luna-Reyes & Andersen (2003) summarised the system dynamics modelling process across the classic literature in Table 4.4.

Table 4.4 The system dynamics modelling processes (Luna-Reyes & Andersen 2003:275).

Randers (1980)	Richardson and Pugh (1981)	Roberts et al. (1983)	Wolstenholme (1990)	Sterman (2000)
Conceptualization	Problem definition	Problem definition	Diagram construction and analysis	Problem articulation
	System conceptualization	System conceptualization		Dynamic hypothesis
Formulation	Model formulation	Model representation	Simulation phase (stage 1)	Formulation
Testing	Analysis of model behavior	Model behavior		Testing
	Model evaluation	Model evaluation		
Implementation	Policy analysis	Policy analysis and model use	Simulation phase (stage 2)	Policy formulation and evaluation
	Model use			

Luna-Reyes & Andersen (2003) argued that the use of qualitative data in the four-stage modelling process is appealing, and further answers when and how to use qualitative data appropriately in system dynamics models. The four stages of the modelling process are (Luna-Reyes & Andersen 2003):

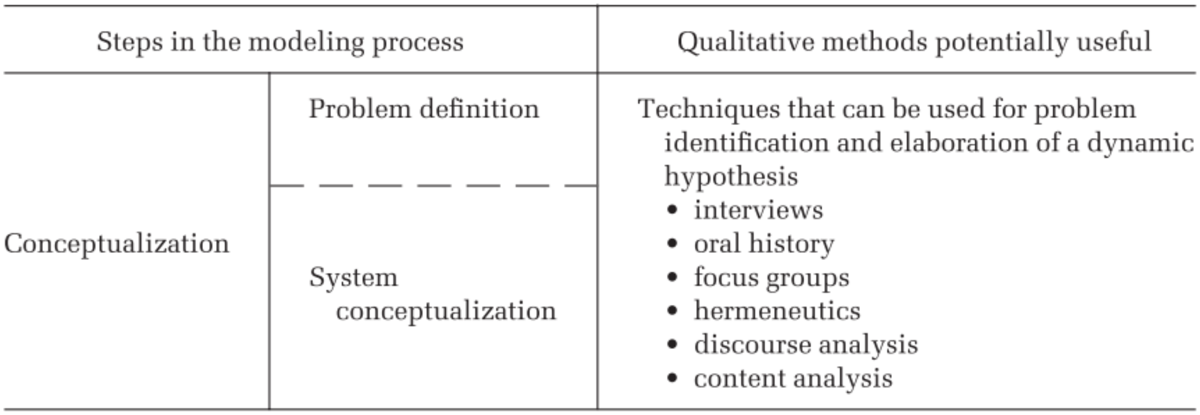
Conceptualization

This is the first stage of a system dynamics modelling process. It includes theme selection, key variables identification, time horizon fixation, dynamic problem definition, boundary selection and system conceptualization (Sterman, 2000; Luna-Reyes and Andersen, 2003). The process of problem definition focuses on the development of a part of the real world, a “mental model”, a description of feedback loops (Luna-Reyes & Andersen 2003). The time horizon influences the perception of the problem description, hence it should be chosen appropriately to capture the emerging problem and to describe its symptoms (Sterman, 2000).

A dynamic hypothesis follows the identification and characterization of problems (Sterman, 2000). A dynamic hypothesis is a working theory describing the problematic behaviour of the system (Sterman, 2000). A hypothesis is dynamic because it provides an explanation to the dynamics characterizing the problems through the underlying feedback and stock and flow structure (Sterman, 2000). It is a hypothesis because it is always provisional and subject to revision through modelling process and lesson from the real world (Sterman, 2000).

The qualitative data gathering techniques such as interview and focus groups have great potential to get an initial understanding of the problem in the early stage of system dynamic modelling (Luna-Reyes & Andersen 2003). The interviews range from informal conversation to structured and closed interview discussions (Table 4.5).

Table 4.5 Conceptualization and potential qualitative methods (Luna-Reyes & Andersen 2003:287).



Steps in the modeling process		Qualitative methods potentially useful
Conceptualization	Problem definition	Techniques that can be used for problem identification and elaboration of a dynamic hypothesis • interviews • oral history • focus groups • hermeneutics • discourse analysis • content analysis
	System conceptualization	

The vast majority of stakeholders of eHealth systems recognised the importance of eHealth in providing support to the management of patient records. However, the diffusion of Health Information Technology (HIT) solutions within healthcare remain limited. Several nonlinear factors influence the acceptance of technology and the use of information by the end-users. The long-term sustainability of eHealth systems is influenced by the technical, social, organizational, and economic factors. The overall research problem addresses how eHealth implementation factors interplay to influence technology and information use to ensure long-term sustainability in resource-constrained settings. Refer to Chapter 1 for details of problem definitions and theme selection of the research study. The time horizon of ten years is selected for this system dynamics modelling based on eHealth implementation experience in the developing countries and recommendations from literature. The implementation of eHealth is fairly new in LMIC so the time horizon of ten years is sufficient for this study (Oluoch and de Keizer, 2016).

Formulation

This stage requires the detailed structure and selected parameter values with units and measurement scales. It includes specification of structure, decision rules, estimation of parameters, behavioural relationships, and initial conditions, and tests for consistency with the purpose and boundary (Sterman, 2000). Although qualitative data appears to be less useful at this stage of modelling, Luna-Reyes & Andersen (2003) argued the appropriateness of using qualitative data to elicit parameters and nonlinear relationships (Table 4.6). Interviews, focus group discussion are the most common methods to elicit critical information from individuals, groups or texts (Luna-Reyes & Andersen 2003). The identification of meanings and connection of key structures and formulations can be guided by grounded theory and ethnographic decision modelling. “Formulation of nonlinear functions is a highly qualitative process” (Luna-Reyes & Andersen 2003:289).

Table 4.6 Formulation and potential qualitative methods (Luna-Reyes & Andersen 2003:289).

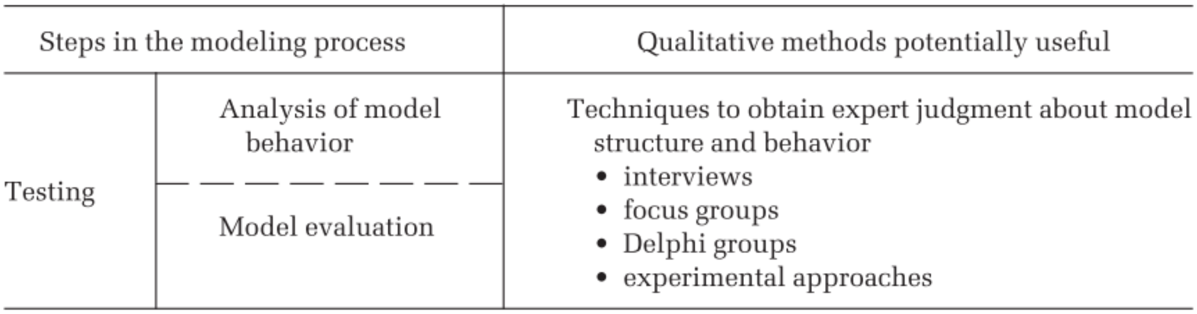
Steps in the modeling process		Qualitative methods potentially useful
Formulation	Model formulation	Techniques to obtain parameters and policies: • interviews • focus and Delphi groups • content analysis • participant observation Techniques to guide model formulation: • grounded theory • ethnographic decision models

The eHMIS and SmartCare documents acquired from the FMOH, eHMIS database, interviews and focus group discussions with users and project staffs were used as sources of data in addition to literature reviews to define the structure and parameters of the model. The units are defined and values are assigned to the model parameters based on the eHMIS database and estimation from the qualitative data.

Testing stage and model validation

This stage addresses the structural-verification test to examine if the structure generates the model behaviour (Luna-Reyes & Andersen 2003). It includes a comparison to reference modes, robustness under extreme conditions, sensitivity and other tests (Sterman, 2000). As shown in the Table 4.6, interviews, focus groups, Delphi groups and experimental approaches are applicable at the test stage of system dynamics modelling (Luna-Reyes & Andersen 2003). The details of validation process followed in this research study is discussed in Chapter 4.7.

Table 4.7 Testing and potential qualitative methods (Luna-Reyes & Andersen 2003:291).



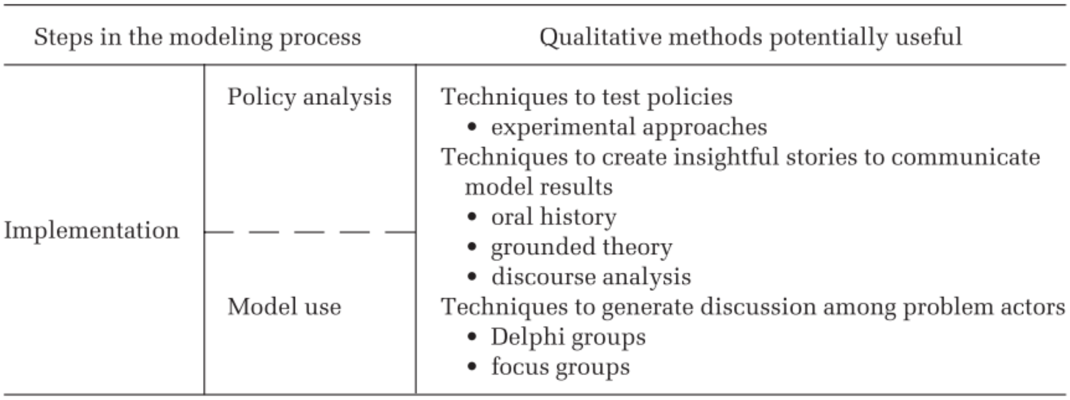
Steps in the modeling process		Qualitative methods potentially useful
Testing	Analysis of model behavior	Techniques to obtain expert judgment about model structure and behavior • interviews • focus groups • Delphi groups • experimental approaches
	Model evaluation	

Policy analysis and implementation

This stage is a qualitative process that requires describing the model to individuals (Table 4.8). Policies can be tested through scenario specification, policy design, “what if” analysis, sensitivity analysis, the interaction of policies, an experimental approach (Sterman, 2000; Luna-Reyes and Andersen, 2003). The simulation results, as well as the formulation of model variable and structures along the modelling process, can be understood with the help of oral history and grounded theory (Luna-Reyes & Andersen 2003).

The focus group and Delphi discussions generate meaning of the results of the policy experiments (Luna-Reyes & Andersen 2003). The focus group discussions are part of the modelling process at this stage of the study. The simulation results of sustainable eHealth implementation and the possible policy alternatives to ensure the long-term sustainability of eHealth in developing countries are discussed with relevant parties.

Table 4.8 Implementation and potential qualitative methods (Luna-Reyes & Andersen 2003:292).



Steps in the modeling process		Qualitative methods potentially useful
Implementation	Policy analysis	Techniques to test policies • experimental approaches Techniques to create insightful stories to communicate model results • oral history • grounded theory • discourse analysis Techniques to generate discussion among problem actors • Delphi groups • focus groups
	Model use	

4.6. Model Validation

Model validation is a process of building confidence in the soundness and usefulness of a model with respect to its purpose (Forrester & Senge 1980:6; Barlas 1994:2). A model is developed for a specific purpose. Therefore, in system dynamics, validity refers to the usefulness of a model with respect to its purpose; i.e., the validity of internal structure of the model, instead of output behaviour (Barlas 1994:3). If the philosophical approach of the research takes relativists, functional and holistic position, model validation becomes informal, subjective and qualitative (Barlas 1994:3; (Barlas and Carpenter, 1990)).

“The model validation is inherently a social, judgmental, and qualitative process” (Barlas & Carpenter 1990:148). The ultimate objective of validation in system dynamics is to extend confidence to persons not directly involved in constructing the model and to transfer the confidence in model’s usefulness as a policy tool (Forrester & Senge 1980). System dynamics models are tested against a diversity of empirical evidence seeking to disprove and develop confidence in the model validity as it withstands tests (Forrester & Senge 1980). The validity of a model cannot be absolutely proven but can be judged against the purpose of the model (Barlas and Carpenter, 1990).

System dynamics methodology has been criticized for not employing formal, objective, quantitative model validation procedures (Barlas and Carpenter, 1990). But Barlas & Carpenter (1990) argued that the model validation approach depends on the philosophical view of knowledge and models. The two opposing philosophies of science follows two different philosophies of model validation. The logical empiricist, foundationalism philosophy of model validation assumes a model to be an objective and absolute representation of the real system; therefore validation is viewed as a strictly formal, algorithmic, reductionist, and "confrontational" process. On the other hand, a relativist, functional, holistic philosophical approach assumes model as one of many possible ways of representing a real system; as a result, the validation process follows semiformal, conversational process (Barlas and Carpenter, 1990). The system dynamics model validation holds the relativist philosophy of science for model validation to the problem of theory confirmation. The system dynamics model validation approach is semiformal, relative, holistic, social process (Barlas and Carpenter, 1990).

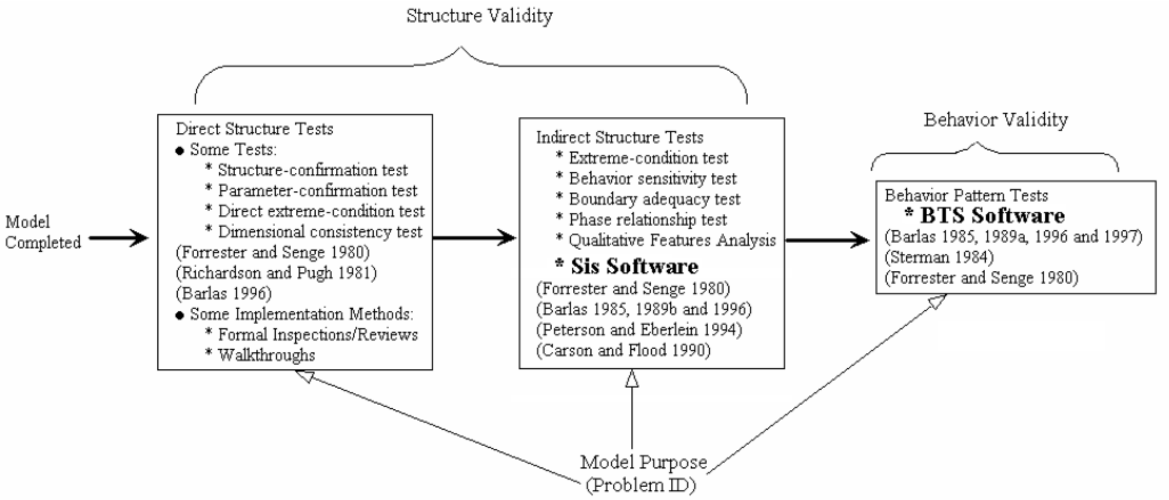


Figure 4.4 Logical Sequence of Formal Steps of Model Validation (Barlas 1996:194).

In the formal and quantitative model validation process, the concept of statistical significance has little relevance (Barlas 1994).The accept/reject decision of statistical significance test is against the relativist/holistic philosophy of system dynamics (Barlas 1994). The three stages of model validation discussed by Barlas (1994) are dependent on the purpose of the model, and the tests are in the logical order of validation that the validity of model structure should be tested first before the behaviour accuracy (See Figure 4.4).

4.6.1. Tests of model structure

The model structure tests aim at establishing confidence in a model structure by directly assessing the structure and parameters of the model without examining relationships between structure and behaviour (Forrester and Senge, 1980). The two categories of tests that are designed to evaluate the validity of model structure are direct structure tests and structure-oriented behaviour tests (Barlas 1994).

Direct structure tests

Direct structure tests assess the validity of the model equations or logical relationship either empirically or theoretically (Barlas 1994). Both empirical and theoretical tests are important in a direct structure validation (Barlas 1994). In empirical structure tests, the model equations are compared against knowledge from the real system being modelled (Barlas 1994). The model equations are compared against generalized literature knowledge on the system in the theoretical structure tests (Barlas 1994). Structure- and parameter-verification tests are interrelated direct structure tests that both strive to describe the real decision-making processes of system dynamics models (Forrester and Senge, 1980).

Structure - verification test indicates the direct comparison of the structure of the model equations that represent the real system against the structure of the real system (Forrester and Senge, 1980; Barlas, 1994). Structural-verification test can also be done as theoretical structure test by comparing the model structural equation against knowledge in the literature (Barlas 1994). A structurally valid model should not contradict the knowledge about the structure of the real system (Forrester and Senge, 1980).

Parameter - verification test compares the conceptual and numerical parameters of the model (constant) against the knowledge of real systems (Forrester and Senge, 1980; Barlas, 1994). Parameters are constants values; whereas variables change in value over time and depend on parameters of a more enduring nature (Forrester and Senge, 1980). Certain concepts considered as parameters (constants) to address short-term issues may be treated as a variable for a long-term view (Forrester & Senge 1980:12). The parameters of the model are linked to the elements in the real system to ensure conceptual confirmation (Barlas, 1996).

A direct extreme-condition test is the evaluation of the model equations under extreme conditions and assessing the credibility of resulting values against knowledge/anticipation of what would happen under a similar condition in real life (Barlas, 1996). It is relatively easy to anticipate the behaviour of real system under extreme –conditions (Barlas 1994). The extreme-condition test is powerful to discover flaws in model structure and reveal omitted variables; moreover, it enhances the usefulness of a model by enabling a system to operate outside historical conditions (Forrester and Senge, 1980).

Dimensional consistency test is a theoretical and internal consistency test that evaluates the ability of the model to pass the test without including any dummy “scaling” parameters that have no meaning in real life (Barlas 1994). The test checks the left and right side of the equation for dimensional consistency (Barlas, 1996).

Structure-oriented behaviour test

Structure-oriented behaviour tests are an indirect assessment of the model structure validity by applying certain behaviour tests on model-generated behaviour patterns (Barlas 1994).

Extreme condition (indirect) tests compare the model-generated behaviour of selected parameters against observed (anticipated) behaviour of the real system under the same extreme-condition, also known as stress testing (Barlas, 1994, 1996).

Behaviour sensitivity tests determine the parameters to which the model is highly sensitive and comparing the sensitivity level of the real system to the change in the corresponding parameters (Barlas, 1994, 1996).

Modified-behaviour prediction compares the behaviour of a modified version of the real system with the simulated behaviour of the model with similar modifications (Barlas, 1994, 1996).

Phase-relationship test compares the phase relationship between pairs of variables obtained as a result of model simulation with an observed or expected phase relationship of the real systems (Barlas, 1996).

Tests of behaviour pattern

After the test on model structure validity, then the behaviour pattern test can be applied to test the accuracy of the model to reproduce the major behaviour patterns observed in the behaviour of the real system (Barlas 1994). The emphasis on behaviour pattern test is the ability to predict patterns (periods, frequencies, trends, phase lags, amplitudes, etc.) rather than point prediction (Barlas 1994). The symptom-generation test examines the model’ ability to recreate the symptom of difficulty that motivated the construction of the model (Forrester & Senge 1980:19).

Case study research of two eHealth systems is used to estimate the parameters of a system dynamics model. The empirical evidence from these two cases of eHealth systems, eHMIS and SmartCare, are also used to perform the model validation and verification tests in this PhD research project. The next section discusses the detail processes of case study research followed in this PhD research project.

4.7. Case study research

The generalizability of the research findings is one of the key factors in natural science research; however, research studies that have elements specific to a group of people or institution cannot be addressed with predefined deductive procedures or deductive modelling (Gillham, 2000). The relevant condition in developing research strategies, according to Yin are (Yin, 1989:16; Yin 2014:9):

- The type of research questions
- The extent of control an investigator has over the actual behavioural events
- The degree of focus on the contemporary events as opposed to entirely historical events.

The case study method allows investigators to retain the holistic and meaningful characteristics of real-life events (Yin, 2009:2). This PhD research project seeks to understand the factors of sustainable eHealth implementation and their dynamic relationship holistically in social, organizational, economic and technical dimensions. This actually covers the use of case study method. Moreover, Yin (2009:2) recommends the use of case studies as a prefered method when:

- The research questions are “how” and “why” type
- The level of control over the events is limited
- The focus is on the contemporary phenomenon within a real-life context.

The case study research is recommended when the boundaries between the phenomenon and context are not clearly evident (Yin, 2009:18). This PhD research project aims to improve the sustainability of eHealth systems; however, the boundary between the case (eHealth) and the operating environment or context is not evident. The influence of users, social surroundings, organizational culture, and infrastructure play a key role in the sustainability of eHealth beyond the quality of the technology. The boundaries between the technology and organizational, social and economic factors are blurred that it is difficult to draw a clear line of boundary. In this aspect, case study research is a preferred method to carry out the research study of this nature within a real-life context.

The “how” and “why” research questions favour the use of case study research (Yin 2014:10). The explanatory nature of this research study with “how” and “why” questions favour the use of case study as a prefered research method. The research study enjoys direct observation and systematic interviews for evidence gathering on the contemporary events, in addition to the document and artefact evidence. The researcher has little control over the actual behavioural events; yet has access to the contemporary events. Case study research is a prefered approach when a researcher has access to full variety evidence - documents, artefacts, interviews, and observations - without full control over the contemporary event (Yin, 1989:20). As a result, a case study research is prefered over other research strategies for this study.

The implementation of eHealth within a healthcare facility is complex as multiple stakeholders are involved. Furthermore, the control over the phenomenon is minimal. The successful implementation of eHealth system in one healthcare facility does not guarantee the same result somewhere else. As a result, the study of sustainable eHealth implementation requires extensive understanding of the actual context surrounding the organizational environment. Case study research emphasizes the study of the phenomenon within its real-world context (Yin, 2012:5). The research study requires an in-depth understanding of the context and the complex relationship among the variables that influence the sustainability of the eHealth implementation further than the study of an isolated variable (eHealth) that makes a case study a preferred research method for this study (Yin, 2012). Furthermore, the importance and use of various sources of evidence to understand the complexity of eHealth implementation in this PhD research project favours the use of case study research (Yin, 2012).

Case study research helps to explain complex causal links in real-life interventions and also to describe the real-life context in which an intervention has occurred (Yin, 1989:23). A case study research definition covers the scope and features of a case study as indicated below (Yin, 1989:23; Yin, 2014:16).

A case study is an empirical inquiry that

- *Investigates a contemporary phenomenon in depth within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident.*
- *copes with technical distinctive situations in which there will be many more variables of interest than data points;and as one result*

- *relies on multiple sources of evidence are used.*
- *benefits from the prior development of theoretical proposition to guide data collection and analysis.*

A case study research has been criticised for introducing bias and lack of strong basis for scientific generalization; hence research that uses a case study must work hard to avoid the influence of bias on findings and conclusions (Yin, 1989:21). Case study research can only be generalised to the theoretical proposition and not to populations (Yin, 1989:21). Furthermore, to avoid criticism of single case study to make conclusions, multiple case studies can be used under different condition to strengthen the findings (Yin, 1989:21). The lengthy narratives in the case study research make the document unreadable; however, this can be avoided (Yin, 1989:21).

A research design is a plan that guides the investigator in the process of collecting, analysing, and interpreting observations (Yin, 1989:2). It addresses five important components (Yin, 1989:29):

- *Research questions:* mostly “how” and “why” question for case study research.
- *Research proposition (optional):* specific issues that should be examined within the scope of the study.
- *Unit (s) of analysis:* the primary case under investigation.
- *The logical link between the data and propositions.*
- *Criteria for interpreting the results.*

The quality of research design addresses the following aspects: construct validity, internal and external validity, as well as reliability also apply to case study research (Yin, 1989:27).
Williams (2002) integrated system dynamics modelling and case study research methods in a model-based theory building research for requirements engineering process modelling and improvements. In a study of complex relationship through a systems dynamics modelling, a case study research offers an extensive observation of cases under investigation. Therefore, using a case study in a system dynamics modelling will enhance understanding of complex relationship among different variables.

Williams (2002) integrated system dynamics modelling and case study research methods in a model-based theory building research for requirements engineering process modelling and improvements. During the study of a complex system, a case study research offers an extensive observation of the interplay between elements of the cases under investigation. The use of several sources of data in the case study research supports the estimation of model parameter values in the systems dynamics modelling processes. Therefore, a case study research may enhance understanding of the complex relationship between different variables and supports different phases of a system dynamics modelling processes.

Some researchers have concerns with a case study research and disdain the method because of following methodological issues.

Rigorousness. A case study research method has been criticized for lacking systematics procedures to be followed allowing equivocal evidences to influence the direction of the findings and conclusions (Yin, 2009). In recent years, increasing number of case study methodological texts such as Yin (2009) are providing specific procedures to make case study research rigorous.

*Confusion with teaching cases***.** In contrary to case study research methods, teaching case studies alter certain evidences deliberately to elaborate points effectively (Yin, 2009). Even though biases may exist in other research methods, they occur frequently in case study research (Yin, 2009). However careful and fair reporting of evidences, can reduce the bias in case study research.

Generalization. Generalizations from a single case are often questioned in the case study research; however, the same question can be extended to experimental research for generalizing based on a single experiment (Yin, 2009). Case study research is generalizable to theoretical propositions not to the entire population (Yin, 2009). In this sense, Yin (2009) indicated that the case study does not represent a "sample," and the investigator's goal is to expand and generalize theories (analytic generalization) and not to enumerate frequencies (statistical generalization). In multiple cases, a previously developed theory is used as a template to compare the empirical results of the case study (Yin, 2009).

Unmanagable level of effort. A case study research denounced that it can potentiallly take a long time and result in a lengthy narratives, massive and unreadable documents (Yin, 2009). However, Yin (2009) claims that there are alternative ways of presenting case study well and do a high-quality case study in short period of time using telephone and internet.

Comparative advantage. The advantage of case study over other research methods is not clear, so case study and other non-experimental methods have been criticised recently (Yin, 2009). However, the randomized controlled trial is limited in explaining “why” and “how” research questions which are well addressed by case study research (Yin, 2009). Case study research can complement the use of other research methods (Yin, 2009).

4.7.1. Cases selection and description

A case is a bounded entity having a blurred boundary between the case and its contextual condition. eHMIS and SmartCare are the two eHealth cases selected for this research study. Yet it is difficult to explicitly draw the boundaries between the cases and the settings. For example, eHealth has hardware and software running on the hardware. One can further argue that the software is the application software or the operating system and the application software together. Obviously, it is very difficult to draw a clear boundary between the operating system from the application software to describe the cases. Moreover, the hardware can further be classified as computers and network infrastructure. Since the failure of one component means the failure of the whole system; the boundary of the case is blurred. The components of the eHealth are connected to each other that it is difficult to show the border between the cases and the operating environment.

Selection of cases

Several eHealth applications have been developed, piloted and implemented in Ethiopia. Electronic Community Health Information System (eCHIS), Electronic Health Management Information System (eHMIS), Electronic Human Resource Information System (eHRIS), Electronic Integrated Financial Management Information System (eIFMIS), Electronic Laboratory Information System (eLIS), Electronic Logistic Management Information System (eLMIS) and EMR are some of the eHealth applications in Ethiopia (FMOH 2016).

There are reports of telemedicine activities in all African countries except South Sudan, but countries like South Africa, Kenya, Uganda, Botswana, Ghana, and Ethiopia reported more than five papers on telemedicine activity (Mars, 2013; Scott and Mars, 2013). The first telemedicine implementation has failed in Ethiopia and South Africa for similar reasons; this includes lack of change management plan, poor project management, connectivity problem and staff turnover (Shiferaw and Zolfo, 2012; Mars, 2013). The systematic literature review of Jahangirian & Taylor (2015) showed that Kenya, Uganda and South Africa are the most involved African countries in eHealth projects followed by countries like Kenya and Ethiopia. The selection of Ethiopia as a case study country is associated with the following reasons.

- Ethiopia is one of the developing countries that have involved in the implementation of several eHealth systems (Jahangirian and Taylor, 2013; Mars, 2013; Marshall, Lewis and Whittaker, 2013).
- There have been a number attempts to implement different eHealth systems in Ethiopia; such as telemedicine, eHMIS, EMR, eLMIS, eLIS, eIFMIS, eHRIS, eCHIS and a number of mHealth projects (Mars, 2013; Marshall, Lewis and Whittaker, 2013; FMOH, 2016).
- The researcher has practical experience of working in the implementation of eHealth systems in Ethiopia, specifically eLMIS.
- Ethiopia showed strong commitment to implement eHealth systems by producing information revolution roadmap to support informed decision making and improve healthcare services delivery (FMOH, 2016).
- There are reports of wide ranges of success levels in terms of eHealth implementation.
- Getting research data is one of the main challenges in the eHealth studies. However, the researcher’s established relationship with the FMOH-Ethiopia made access to research data relatively easy.

Electronic Health Management Information System (eHMIS) and SmartCare (EMR), were two of several eHealth systems developed and implemented in Ethiopia to improve healthcare service delivery. These two electronic health systems were selected for the case study research for the following reasons. First of all, eHMIS was probably the only eHealth system which was pushed for the nationwide implementation in Ethiopia. It had been operational in the country for a longer period of time since 2008 than other eHealth applications. The large-scale implementation and relatively long operational period were the key factors for the inclusion of eHMIS for a case study in this research. Furthermore, eHMIS regarded as a successful system by the wide group of stakeholders. Accessibility of eHMIS documents and reports were additional factors that favoured the selection of eHMIS for this research study. The vast experience acquired from the implementation of eHMIS was believed to benefit the effort of explaining the dynamic elements of successful eHealth implementation.

The FMOH started the development and pilot implementation of SmartCare in 2009 with the support of the Tulane University Technical Assistance Project in Ethiopia (TUTAPE) (Tilahun and Fritz, 2015a). However, compared to eHMIS, the diffusion of SmartCare was limited. According to the FMOH assessment in 2014, the implementation effort was only partially successful in Addis Ababa (FMOH, 2014a). The difference in the perception of stakeholders on the success level of the eHMIS and SmartCare believed to give a good learning platform for this study by giving the opportunity to validate the proposed model in different scenarios. Hence both eHMIS and SmartCare are included as cases for this research study. The two systems have a long track record in Ethiopia since 2010 and believed to represent high and low diffusion scenarios within healthcare facilities in Ethiopia.

The country background

Ethiopia, the Federal Democratic Republic of Ethiopia under the 1994 constitution, is situated in the Eastern part of Africa also known as the Horn of Africa (EPHI, 2014). The country shares borders with Eritrea, Djibouti, Somalia, Kenya, the Republic of South Sudan and Sudan. Ethiopia is administratively structured into nine Regional States (i.e., Tigray, Afar, Amhara, Oromiya, Somali, Benshangul-Gumuz, South Nations, Nationalities and People (SNNP), Gambela, and Harari) and two City Administrations, namely Addis Ababa and Dire Dawa administration councils (CSA and ICF, 2012). The regional states and city administrations are further divided into 817 administrative Woredas (districts), two "special" Zones and seven "special” Woredas all further subdivided into 16,253 local administrations called Kebele (EPHI, 2014).

Ethiopia is the second most populous country in Africa with a population of 90 million in June 2015, according to the projection of the Central Statistical Agency (CSA) based on the 2007 national census (CSA, 2015). The projected data indicated that Ethiopia is the least urbanised country that about 81% of the total population lives in the rural area (CSA, 2015). According to the World Bank open data, the Gross Domestic Product (GDP) of Ethiopia was USD $72.374 Billion in 2016 (World Bank, 2016). The World Bank report showed that Ethiopia’s total health expenditure accounts to 4.9% of the countries GDP in the year 2014 which is lower than the average health expenditure of Sub-Saharan Africa, 5.5% of the total GDP (The World Bank, 2017).

The economy of Ethiopia had been showing significant growth over the past decade. From 2004 to 2016, the country’s economy had been growing at the annual average rate of 10.7% (The World Bank 2017). The percentage of the population living below the national poverty lines (national Poverty headcount ratio) has declined from 45.5% in 1996 to 29.6% in 2010 (The World Bank 2017). Ethiopia is a developing country with a growing economy and several eHealth implementation activities mainly funded by international donors. The eHealth implementation in Ethiopia is a good representation of eHealth implementation in a resource-constrained environment. The potential contribution of an electronic health system is massive to empower the healthcare service delivery in Ethiopia who strives to provide quality healthcare care to its large population with limited healthcare budget and scarce healthcare professionals.

Ethiopian health care system and status

Aiming at promoting health and well-being of Ethiopians, the FMOH providers and regulates a comprehensive package of promotive, preventive, curative and rehabilitative health services of the highest possible quality in an equitable manner. The major health-related problems of the country are associated with preventable communicable diseases, reproductive health-related problems and nutritional disorders (EPHI, 2014). The quality, availability, and equity of healthcare service delivery in Ethiopia are challenged by poor infrastructure and the shortage of skilled healthcare workers (EPHI, 2014).

The FMOH is committed to supporting the healthcare service delivery by implementing electronic health systems (FMOH, 2016). Information Revolution document was published by FMOH aiming at maximizing the availability, accessibility, quality, and use of health information through the appropriate use of ICT to improve the access, quality, and equity of healthcare delivery at all levels (FMOH, 2016). The transformation in the culture of health data use, and the implementation and scale-up of health information systems are the two pillars of information revolution for sustainable HIS governance (FMOH, 2016).

The health sector in Ethiopia is structured in a three-tier healthcare delivery system as shown in Figure 4.5.

Level 1: This primary level is established on the Woreda/District level and includes of a primary hospital (covers 60,000-100,000 people), health centres (15,000-25,000 population) and Health Posts (3,000-5,000 population) (EPHI, 2014). The primary health care unit is composed of five satellite health posts, one health centre and one primary hospital, which are connected to each other by a referral system (EPHI, 2014).

Level 2: The secondary level comprises a general hospital covering a population of 1-1.5 million people. It provides inpatient and ambulatory services and serves as a referral centre for primary hospitals and training centres for health officers, nurses, emergency surgeons and other categories of health workers. The facility is staffed by around 234 workforces.

Level 3: The tertiary level has a specialised hospital covering a population of 3.5-5 million people. It is staffed by around 440 professionals and serves as a referral centre for general hospital and provides inpatient services.

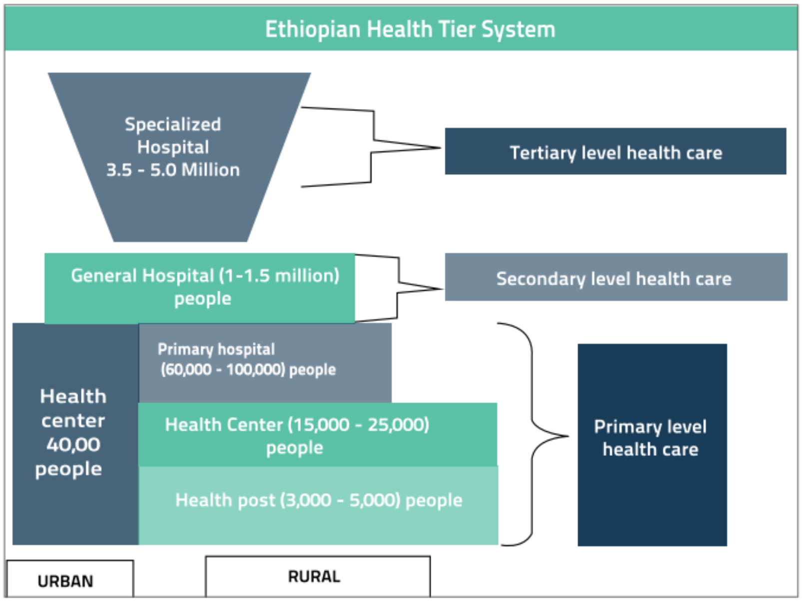


Figure 4.5 Healthcare tire system in Ethiopia (FMOH 2015:142).

Description of eHMIS and SmartCare

Electronic Health Management Information System (eHMIS) in Ethiopia.

Health Management Information System (HMIS) routinely generates information of health indicators to support decision-making processes at each level of the health system to improve the performance of healthcare service delivery and thereby the health status of the population (Ethiopian Federal Ministry of Health, 2014). Since the implementation of a reformed paper-based HMIS in 2008, the routine collection of a large amount of data has triggered for the need of efficient ways of data collection, analysis, and reporting processes. One region, South Nations, Nationalities and People Region (SNNPR), only generates over 2 million HMIS data points every month (Wannaw and Azim, 2013). To improve the quality of HMIS data for better health-related decision making, the FMOH together with John Snow, Inc. (JSI) and TUTAPE has implemented HMIS in Ethiopia. In 2010, the electronic HMIS (eHMIS) was implemented nationally to track healthcare related performance indicator from health facility to the FMOH level. eHMIS is an automated HMIS that helps to accurately and timely collect, aggregate, store, analyse and evaluate health-related data from health facility to federal level (SNNP RHB & USAID JSI, 2015).

eHMIS is an application for data management system that helps to improve public health-related decision making. eHMIS helps to accurately and timely collect, aggregate, store, analyse and evaluate health-related indicators from health facilities to federal level (Wannaw and Azim, 2013). eHMIS has been implemented in Ethiopia nationwide by the two FMOH partners at all level of the healthcare organization to support tracking of evaluation and monitoring indicators electronically. The first eHMIS application, eHMIS-1, is implemented by JSI in SNNPR. The second application, eHMIS-2, is implemented by TUTAPE in the rest of the regions in Ethiopia. These two applications have similar functionality but technically different. Both projects are funded by donors and implemented by the FMOH partners. The eHMIS information is aggregated and different reports are generated electronically to monitor health performance at the FMOH level. Sadly, the two eHMIS applications are not interoperable at the FMOH level to generate national report automatically. Hence the national aggregation report is compiled manually, which adds unnecessary work burden on FMOH staffs.

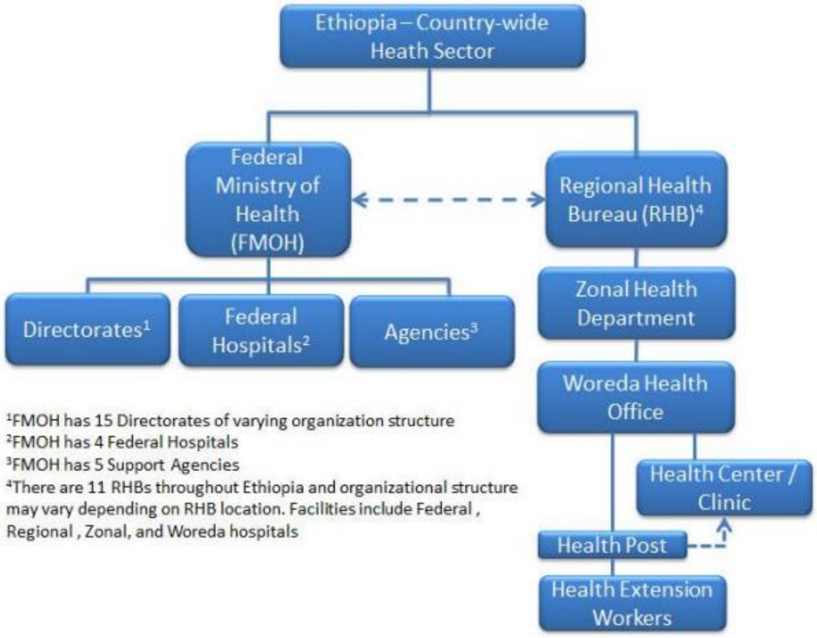
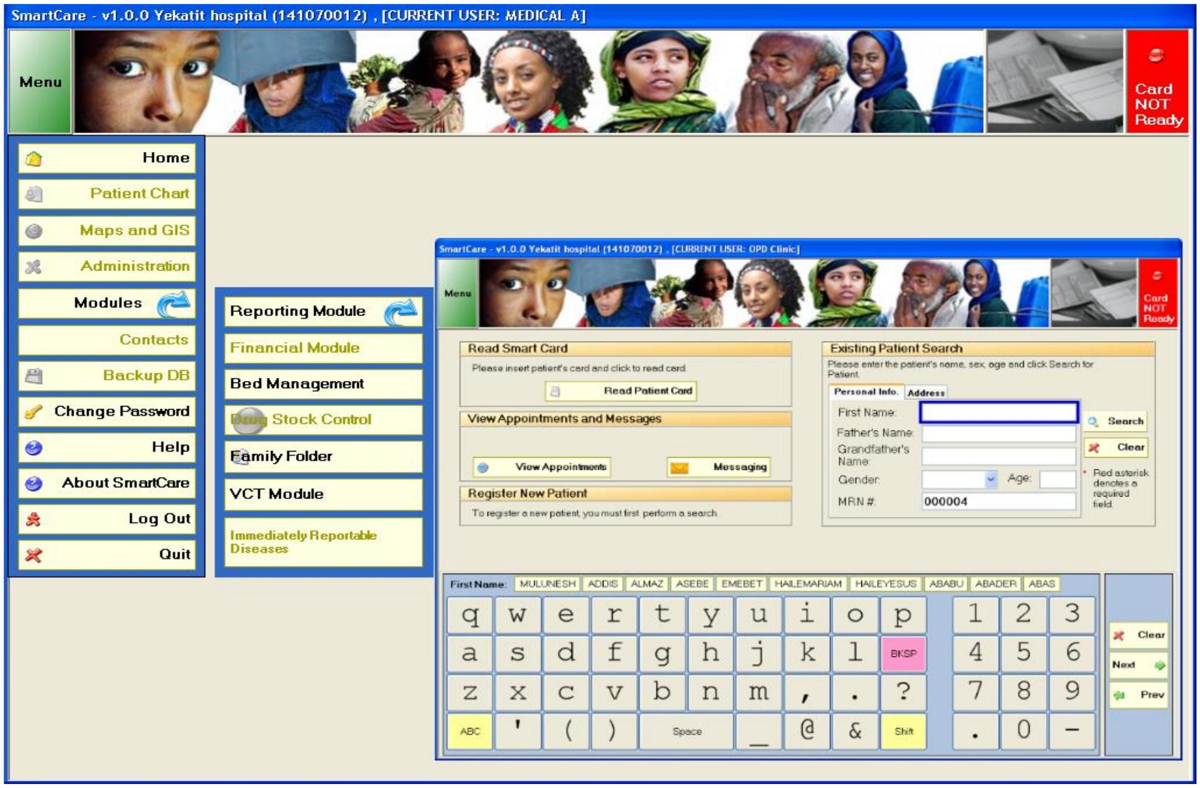


Figure 4.6 Ethiopia health sector organizational chart (Balanced Scorecard Institute 2013:12).

Health-related data reporting structure of HMIS flows from health facilities to administrative offices through the organizational hierarchy (Ethiopian Federal Ministry of Health, 2014). The reporting chain of the health sector is from health posts to health centres, Woreda Health Office, Zonal Health Department (ZHD), Regional Health Bureau (RHB), and Federal Ministry of Health (FMOH) as shown in Figure 4.6.

SmartCare – the Electronic Medical Record (EMR) in Ethiopia.

SmartCare is an integrated EMR system to capture the electronic format of patients' medical record (See Figure 4.7). SmartCare is one of several electronic health record software applications designed to improve patient safety and quality of care in health facilities. SmartCare is in use in three African countries (Zambia, Ethiopia and South Africa) and presumably is the largest electronic medical record (EMR) system in Africa (Mweebo, 2014; Tilahun and Fritz, 2015a).The information in an EMR includes documents relating to the past, present and/or future physical and mental health and condition of a patient, medical test reports, multimedia images, treatments, medication, financial and demographic information. The EMR enables to capture or transmit, receive or update, store or retrieve patient data securely in real-time at the point of care or distant locations to provide quality healthcare services.



SmartCare - v1.0.0 Yekatit hospital (141070012) , [CURRENT USER: MEDICAL A]

SmartCare - v1.0.0 Yekatit hospital (141070012) , [CURRENT USER: OPD Clinic]

Please insert patient's card and click to read card.

Please enter the patient's name, sex, age and click Search for Patient.

To register a new patient, you must first perform a search.

MRN #: 000004

Red asterisk denotes a required field.

Figure 4.7 SmartCare in Ethiopia (FMOH, CDC and TUTAPE, 2011).

SmartCare also enables us to transport patient-level data from facilities to higher administrative levels (woreda, zone, region and federal) by using a computer network or a database called transport database. With this, administrators and policymakers are able to get first-hand patient-level information for better decision and policy making. The system also has advanced applications like messaging service (e-mailing reports) and reporting epidemic diseases in the healthcare facilities (FMOH, CDC and TUTAPE, 2011).

The clinical and non-clinical services in health facilities are managed in different SmartCare modules. Some modules of SmartCare application include (FMOH, CDC and TUTAPE, 2011):

- *Registration module* is used by the Medical Record unit (MRU) to capture personal details, addresses and other patient information.
- *Outpatient Department (OPD) module* is used to manage patients consulted on different clinics of an outpatient department such as general adult OPD, ophthalmology, dental clinic, psychiatric, physiotherapy and other specialty clinics. There are four processes in this module, namely general examination, diagnosis, prescription and laboratory orders.
- *Inpatient module* is used to manage the admission, follow-up and discharge process of patients who have been admitted to the health facility.
- *Tuberculosis (TB) module* captures data for patients with tuberculosis infection in the intensive and continuation phases of anti-TB treatment.
- *Paediatrics module* registers information related to children whose age is less than or equal to fourteen. The module incorporates Paediatrics examination, paediatrics growth monitoring and immunization, paediatrics diagnosis, prescription and laboratory order functionalities.
- *HIV/AIDS module* is used in the ART clinic to manage data pertaining to patients with HIV/AIDS infection.
- *Antenatal care (ANC) module* is used to manage information about the pregnancy follow up of pregnant women.
- *Postpartum module* is used to manage health information of mothers immediately after the birth of a child.
- *Labour delivery module* captures health data of mothers during labour and delivery.
- *Pharmacy module* is composed of two major components, i.e., dispensary and drug stock control. This module is used to receive prescriptions of patients from clinics, dispense drugs to patients, and manage drugs at dispensary and store.

- *Laboratory module* enables end-users to receive laboratory test requests from different clinics, record test results and send the results to the requesting clinics. It includes test categories such as haematology, serum chemistry, urine analysis, immunology, microbiology, radiology, parasitology and other laboratory tests.
- *eHMIS module* is used to pool data elements of the health management information system (HMIS) from the SmartCare server to generate monthly, quarterly, and annual HMIS reports.
- *Finance module* manages financial transaction and deductions from the patients' initial deposit at each point of service.
- *Administration modules* are mainly used by Information Technology (IT) technical personnel to administer the SmartCare software and overall computer network in the facility.

The next section discusses the design of research instrument used to collect data from end-users and project teams from the FMOH and partner organization.

4.8. Research instrument design

The structured and semi-structured questionnaires were used to elicit information from stakeholders. An extensive literature review was conducted to identify known factors of technical, organizational, social and economic constructs that influence the success of eHealth technologies to develop research questionnaire. The semi-structured instrument was used to elicit information in the focus group sessions to learn the social, technical, organizational and economic factors of eHMIS and SmartCare systems. Informants of the focus group discussions have wider and deeper understanding of the two eHealth systems implementation and operation processes. The instrument was used to guide the discussion in order to elicit as much information as possible.

The data collection instruments were first drafted based on the findings of an extensive literature review. The TAM and IS success models were used in the design of the socio-technical factors of the research instruments. The questionnaires were later updated based on the inputs captured from the focus group discussions. A focus group team composed of eHMIS project teams evaluated the data collection instruments ability to address the two eHealth systems in the local context of Ethiopia. The team recommended to preparing the questions in both English and Amharic languages. The Amharic language is a national language of Ethiopia. Furthermore, the team has amended some of the terms used in the questionnaires to avoid confusion and removed questions that appear to be redundant. The questionnaires were further refined by the second focus group meeting with experts from academia and business. The team evaluated the questions alignment with the research objective. Moreover, the team ensured that one question addresses a single issue only to avoid confusion to the respondents.

The structured questionnaire targeted the end-users of the two systems. The end-users are those who have a first-hand experience of using the eHMIS and SmartCare systems. These group of users may not have detail technical understanding of the system and the implementation process, but they have practical experience in using the systems. The structured questionnaire was an appropriate tool to conduct a face-to-face interview with end-users' to capture their experience in using the eHMIS and SmartCare systems. The structured questionnaire explores users' experience on the eHMIS and SmartCare systems in terms of technical quality, social and behavioural factors, use of technology and use of information.

The questions in technological factors are presented in three sub-groups: system quality, information quality, and services quality. Each subgroup contains six questions (See Appendix 4.1). The questions in the behavioural and social factors are organised in three sub-groups: perceived usefulness, perceived ease of use and influence of social environment. The first two sub-groups address the individual perception of the behavioural and social factors, whereas the third section addresses the social elements of the organization. The sub-groups consist of six questions each (See Appendix 4.1). The technology and “information use” factors of the questionnaire involves of three sub-groups, namely Intention to use, actual use and user satisfaction. Three questions used to elicit the intention to use, four questions to explore the actual use, and five questions to understand the level of user satisfaction (See Appendix 4.1). All the questions are positively worded. It is recommended to design either positively or negatively worded questionnaire instead of mixed questions to avoid confusion to respondents and to avoid mistakes during data analysis at the later phase.

A study of system usability scale testing of two software applications involved 172 employees of Intel® Corporation (Finstad, 2010). The scale sensitivity study showed that the five-point Likert scale is apparently prone to contribute to inaccurate measures causing data loss; moreover, it seems not sensitive enough to record the true evaluation of a system. The result of the study indicated that the 7-point Likert item is more likely to record the respondent's accurate evaluation, and easier to use because it is compact (Finstad, 2010). The study also found that a 7-point Likert item has higher perceived accuracy and ease of use in addition to its objective accuracy (Finstad, 2010). The study recommended the use of 7-point Likert item instead of the 5-point Likert item in the study involving system usability test (Finstad, 2010). As a result, the structured questionnaire in this study used a 7-point Likert scale. Reliability, validity, and sensitivity are described as the key properties of Likert scales (Cummins and Gullone, 2000).

The semi-structured questions are designed to capture in-depth phenomena of eHMIS and SmartCare implementation in Ethiopia. The questions in the data collection instrument are divided into three sub-sections to facilitate the data collection process during the focus group discussions. The questions are grouped under a socio-technical, techno-organizational and techno-economic dimensions. Eight questions in the socio-technical dimension addresses technical factors, behavioural and social factors, technology use, impact of technology on social and behavioural factors, the impact of technology on information use, influence of social factors on technology and information use, the benefits of eHealth systems, and the impact of eHealth benefits on social and behavioural factors (See Appendix 4.2).

Similarly, the techno-organizational questions discussed under eight questions to guide the focus group discussion. The questions focus on management support, infrastructure, skill, workflow process, change management, culture, project management, and policy (See Appendix 4.2). The techno-economic factors are addressed under six guiding questions. The questions address key stakeholders and their role, funding sources, cost categories, cost estimation, benefit categories and benefit estimation (See Appendix 4.2).

4.8.1. Sample selection

In this research study, eHMIS and SmartCare were selected for the case study research. There are two eHMIS applications, eHMIS-1 and eHMIS-2, implemented by the two partners of the FMOH. eHMIS-1 is implemented by JSI in SNNPR and eHMIS-2 is implemented by TUTAPE in the rest of the regions in Ethiopia. A purposeful sampling method is followed to make selection. A purposive sampling is a non-probability sample that the sample selection follows judgmental or quota sampling to describe the dimensions of the population and the objective of the study (Cooper and Schindler, 2001).Since eHMIS-1 is implemented in only one region, SNNPR was automatically selected for eHMIS-1 related data collection. There were eight regions or/and two city councils to choose from that have implemented eHMIS-2. After discussing with personnel from the FMOH and partner organizations, it was decided to include one of the two city councils as a regional study was already included for eHMIS-1. The health facilities in a city council are believed to have better ICT infrastructure and skilled workforce, because of the health facilities' physical proximity to the city. Addis Ababa city council was chosen for eHMIS-2 related data collection. This selection was motivated by easy access to research data and the use of Amharic language (which is also spoken by the PhD researcher) as a working language within health facilities in Addis Ababa city council.

The next step was the selection of health facilities for the collection of research data for eHMIS. The selection of health facility followed purposive sampling based on recommendations from personnel from Addis Ababa RHB, partner organizations, and FMOH. The health facility selection was motivated by the availability of operational eHMIS, eHMIS reporting performance, ICT infrastructure availability, health facility's management support level, and distance from Addis Ababa. In the purposive selection process, the team included poor, medium and good performing health facilities to gain a holistic understanding of eHMIS systems. All available eHMIS users in the health facilities were interviewed.

The selection of SmartCare study sites was also based on recommendations of personnel from the Federal Ministry of Health - Health Information Technology Directorate and partner organizations. Four hospitals in Addis Ababa were selected for this study. Two were described as successful in using the SmartCare, mainly because of strong support from the health facility management. Whereas, the other two hospitals described not showing the same level of success in terms of using SmartCare. These two hospitals were believed to lack strong support and commitment from the health facility management.

From a total of 23 selected health facilities, the data was accessed from 18 (78%) as indicated in Table 4.9. An empirical evidence was collected through interviews with end-users, and focus group discussions with project team of partner organizations and Health information Technology Directorate (HITD) of the FMOH.

Table 4.9 The health facilities selected and accessed for the case study.

Regions	Health facility type	Targeted health facilities	Accessed health facilities	eHealth applications	Remark
Addis Ababa	Hospital	4	3	eHMIS and SmartCare	1 hospital could not be accessed.
	Health Centre	9	8	eHMIS	1 health centre could not be accessed.
SNNPR	Hospital	2	2	eHMIS and SmartCare	All health facilities accessed.
	Health Centre	8	5	eHMIS	3 health facilities could not be accessed.
Total		**23**	**18**		

4.8.2. Data collection

The qualitative data collection methods in the social science consist typically of interviews, focus groups, Delphi groups, observation, participant observation, and experimentation (Luna-Reyes and Andersen, 2003). The two data collection methods, interviews and focus group discussions, were used to gather information from eHMIS and SmartCare users, project implementers and project owners in Ethiopia. In this study, the FMOH partners represent non-government entities or agencies that work in line with the FMOH goals and objectives by actively involving in the design, development, and implementation of eHealth technologies to improve the healthcare service delivery. The project owners depict the FMOH in this case, who is the key stakeholder of eHealth implementation and responsible for successful project implementation and long-term sustainability by providing leadership directions and act as a “champion” to the project.

A structured questionnaire described in the previous sub section and Appendix 4.1 was used to carry out a face-to-face interview with a key informants to capture in-depth phenomena and experience in using eHMIS and SmartCare systems in their day to day activities. The researcher travelled to healthcare sites in two regions of Ethiopia (i.e., Addis Ababa and SNNPR) to visit the eHealth technology implemented and used by the health facilities. The end-users of eHMIS and SmartCare were interviewed face-to-face. Moreover, observations were made how end-users operate the system in their day-to-day work activity and the availability of ICT infrastructure. It was observed that the informants struggled to clearly understand the technical terms related to ICT systems. Hence, the face-to-face interview method gave flexibility as it allow clarification of definition, elaboration on topics, and collection of respondent’s explanations in their own words

(Luna-Reyes and Andersen, 2003). Eventually, the face-to-face interview with the end-users gave this PhD researcher an opportunity to capture any issues raised by the respondents which were not included in the interview questionnaire.

Table 4.10 The health facilities and departments visited in Addis Ababa and SNNPR.

SN	Types of health facility	Addis Ababa City Council		SNNPR	
		Number of health facilities visited	**Number of individuals interviewed**	**Number of health facilities visited**	**Number of individuals interviewed**
1	Health Centres	8	8	5	6
2	Hospitals	3	7	2	3
3	Woreda/District Health Office	0	0	1	1
4	ZHB*	0	0	1	1
5	RHB**	1	5	1	1
6	FMOH***	1	8	0	0
	Total	**13**	**28**	**10**	**12**

** Zonal Health Bureau; ** Regional Health Bureau; *** Federal Ministry of Health*

The interview sections with each eHealth technology users took approximately 20 min to 45 min. A total of 13 health facilities and departments were visited in Addis Ababa and 28 informants were interviewed. In SNNPR, a total of 10 health facilities and departments were visited in Hawassa city and Kembata and Tembaro Zone. A total of 12 informants were interviewed in this region. All the interviews were conducted between July 2016 and August 2016 in the premises of the health facilities and health departments. The type of health facilities and departments, the number of facilities and informant included in this study are summarised in Table 4.10.

Further research data was collected from the teams of respondents from project implementers and project owners with two separate focus group sessions. The teams of project implementers are a group of individuals who are directly involved in the design, development and implementations of eHMIS and SmartCare. The project owners are project team members from FMOH who operate and maintain the system. The focus group is a panel of people, led by a facilitator or moderator with guided questions on a specific topics (Cooper and Schindler, 2001). A total of three separate sessions of focus group discussions were conducted with teams from FMOH, experts from academia and industry, and project members of the FMOH partners in Ethiopia. The researcher moderated all focus group discussions to elicit information from groups of respondents which lasted between 85 and 135 minutes. All focus group discussions were audio recorded.

The first focus group discussion consisted of three informants from the project team of eHMIS implementing partner of the FMOH. The informants were active eHMIS project members who involved in the project management, software development, implementation, training, and support activities. The discussion was conducted in Pretoria and lasted for 135 minutes.

The second focus group discussion was conducted with two informants from academia and one from health technology industry at the premises of University of Pretoria, Pretoria, South Africa. The session lasted for 85 minutes. The main focus of the discussion was checking the alignment of research instrument with the research objectives and ensuring the clarity of the questionnaires to avoid confusion to respondents.

The third focus group session was performed in the boardroom of FMOH, Addis Ababa, Ethiopia with a total of seven participants from the Health Information Technology Directorate (HITD) of the FMOH who are the owners of the eHMIS project. The focus group discussion was performed in two rounds for a total of 170 minutes (first round 50 minutes and second round 120 minutes). The focus group members were composed of project leads, software developers, software analysis, infrastructure and system supports, and Geographic Information System (GIS) experts who were actively involved in the design and implementation of eHMIS.

The same semi-structured questionnaire was used to guide the first and third focus group discussion sessions. The discussions were conducted in Amharic, the official language of Ethiopia, for both focus group one and three. The second focus group session was conducted in English and the discussion was focused on the validating research instrument and the system dynamics model variables. Table 4.11 summarises the focus group discussion sessions conducted in this research study.

eHMIS and SmartCare documents were obtained from FMOH and the FMOH partner organizations for review and to understand the entire process of system implementation. eHMIS databases were also obtained for additional information.

Table 4.11 The focus group discussion sessions.

Focus group	Organization	Number of focus team	Time (minutes)	Date	Venue	Language
1	MOH partner organizations, Ethiopia	3	135	27-Jun-16	Pretoria	Amharic
2	Academia, South Africa	3	85	1-Jul-16	University of Pretoria, Pretoria	English
3	FMOH, Ethiopia	7	50	19-Jul-16	FMOH boardroom, Addis Ababa	Amharic
	FMOH, Ethiopia	7	120	21-Jul-16	FMOH boardroom, Addis Ababa	Amharic

4.8.3. Data Analysis

The qualitative data analysis techniques such as hermeneutics, discourse analysis, grounded theory, ethnographic decision models and content analysis can be helpful in translating the tests obtained through qualitative data collection techniques into a system dynamics model (Luna-Reyes and Andersen, 2003). “Ethnographic decision models are qualitative analysis oriented towards specific decisions or policies in the system to understand why a person makes a decision in determined circumstance” (Luna-Reyes & Andersen 2003:285). The goal of Ethnographic decision models is to set the smallest set of rules to build a model that can predict 80% of the decisions (Luna-Reyes and Andersen, 2003).

Grounded theory shares the same goal with system dynamics in the illustration of relationships among factors in a targeted system and the linking of concepts obtained from qualitative data to generate meaningful theories (Luna-Reyes and Andersen, 2003). In this study, theoretical frameworks that explain phenomenon through systematically interrelated statements of relationship are developed using grounded theory (Chilisa, 2012).

All interviews and two focus group discussion sessions were conducted in a local language, Amharic. The audio recordings of the focus group discussions were transcribed and later translated into English. All interview data from the end-users are analysed and described statistically (See Appendix 4.3). Field notes and data from document review are analysed together with information from the focus group discussion using ATLAS.ti software (See Appendix 4.4). ATLAS.ti is a powerful software for the qualitative analysis of large bodies of textual, graphical, audio and video data (ATLAS.ti, 2019). It helps to systematically arrange, reassemble, and manage data in creative ways (ATLAS.ti, 2019).

The qualitative data analysis followed a rigorous coding process in line with research questions and objectives. Codes are descriptive or inferential meaning assigned to information compiled during a study (DeCuir-Gunby, Marshall and McCulloch, 2011). The codes were initially developed from existing theory and concepts (theory-driven) mainly from literature and model such as TAM and IS success model (DeCuir-Gunby, Marshall and McCulloch, 2011). The initial list of codes from the literature is shown in Appendix 1. The initial codes (theory-driven) were reviewed and revised within the context of data through repeated reading of raw data. Through iterative coding processes, a codebook developed with a list of codes, definitions, and examples (See Appendix 4.4). The codes were assigned to the transcript data as a process of focus group data analysis. The connection between ideas and concepts are examined through the coding processes. Figure 4:6 shows the circular processes of coding applied in this research.

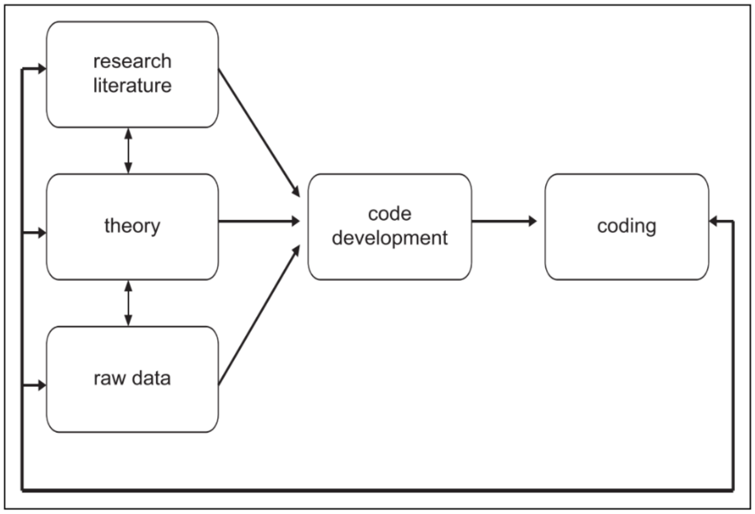


Figure 4:6 Circular process of coding (DeCuir-Gunby, Marshall and McCulloch, 2011)

Using multiple coders to analyse interview data necessitates establishing interpreter reliability or the consistency in scoring between multiple ratters (DeCuir-Gunby, Marshall and McCulloch, 2011). To ensure the reliability of the code, the researcher discussed the codes with three other fellow researchers once a week, for 4 sessions for a total of 4 hours. The group consensus were used to establish reliability (DeCuir-Gunby, Marshall and McCulloch, 2011). Multiple interpretations of the data and inconsistency in the coding protocols were rectified through discussion with the group. The consensus had been reached on the code labels, definitions and allocations to the raw data. The conversation explored the ability of the code to capture the concepts in the raw data.

The final codes and code groups generated from the data analysis are translated into a system dynamics model of a CLD and later to a SFD. Vensim is a powerful software package for model building and graphical presentations of complex models (Ventana Systems, 2015). Vensim is more flexible in the appearance of the model diagram, easily mix stock and flow and causal loop elements (Ventana Systems, 2015). Vensim is also very strong in terms of capacity, performance and functionality (Ventana Systems, 2015). The simulation speed is fast, the sensitivity analysis is both fast and powerful (Ventana Systems, 2015). There are no practical limits on model size, and it is easy to extend the base capabilities using external functions of the Vensim DLL (Ventana Systems, 2015). Therefore, Vensim DSS Version 6.3D is selected to model and simulate the system dynamics model in this research study. The equations are filled for each of the variables and texted for a direct structure test. Direct. The model is simulated over 15 years with one-year time-step for the different values of the parameters (Parv et al., 2012). The details of each analysis methods are discussed in the following chapters together with the models and simulation results.

4.9. Research Ethics

Ethics and research integrity clearance has been obtained from Faculty of Engineering, Built Environment and Information Technology, University of Pretoria on 30 May 2016 (See Appendix 4.6). The names and details are kept confidential to protect the identity of informants. Each participating informants completed a consent form. The recordings of the focus group discussions are stored in a secured folder in an external hard disk.

4.10. Conclusions

This research study falls dominantly in the constructivist paradigm. The context and setting dependency of sustainable eHealth implementation in this study supports the ontological assumption of the constructivist paradigm. Ontological assumption argues that reality is limited to the context, space, time and individuals in a given situation. The epistemological assumption of the research agrees with the subjectivity of knowledge and social constructionism. Knowledge is socially constructed and dependent on the content, context and individuals experience. Both the ontological and epistemological assumptions of this research study support the position of the constructivist research paradigm.

This research is a model-based theory building study rooted in grounded theory. Methodologically, this study mainly applies qualitative research methodology which is a common methodology in the interpretive approach. Qualitative studies consider programs as dynamic and developing; and aim at describing the dynamic process and the holistic effects of the system elements (Patton, 2002). It requires detailed observations, thick description, in depth inquiry, interviews to capture people's personal experiences and perspectives, documents review and case studies. In this dominantly qualitative research approach, a system dynamics modelling is applied to develop a nonlinear and dynamic model of sustainable eHealth implementation.

The DSR aims at contributing new knowledge to the body of science knowledge from the experience of eHealth implementation in resource-constrained settings. The DSR generates knowledge in the form of constructs, models, methods, and instantiations to define, communicate, understand and solve the problems and demonstrate the feasibility of an artefact to its intended purpose in order to produce better design theory (Hevner et al., 2004; Hevner and Chatterjee, 2010; Kuechler and Petter, 2017).

Healthcare is recognised as a complex system. System dynamics simulation method is an interdisciplinary modelling approach that helps to understand the structure and dynamics of the complex system. The study is explanatory in its nature that combines both the system dynamics modelling and the case study research approach to strengthening the learning process of the dynamic interaction among factors of sustainable eHealth implementation. An iterative system dynamics modelling process was applied based on the findings of the literature review and data from the empirical evidence.

eHMIS and SmartCare two electronic health systems are selected for the case study research. The empirical evidence was obtained from purposefully selected health facilities in Ethiopia that have implemented eHMIS and SmartCare systems. The end-users of eHMIS and SmartCare in the selected health facilities were the main informants in a face-to-face interview with the researcher. Besides, a total of three focus group discussion were conducted with the project members of the FMOH partner organizations, the FMOH project teams, and experts from academia and industry. Furthermore, data from the eHMIS database, eHMIS and SmartCare document archives, observations and informal discussion are used in this research study.

The data collection instruments were first drafted based on the findings of an extensive literature review and later updated based on the inputs captured from the focus group discussions. The structured and semi-structured questionnaire were used to elicit information from stakeholders. The structured questionnaire targeted the end-users of the both eHMIS and SmartCare. The semi-structured instrument was used to elicit information in the focus group sessions to learn the social, technical, organizational and economic factors of eHMIS and SmartCare systems.

The selection of eHMIS and SmartCare implementing health facilities was purposive sampling based on recommendations from personnel from Addis Ababa RHB, partner organizations, and FMOH. The researcher travelled to healthcare facilities in two regions of Ethiopia (i.e., Addis Ababa and SNNPR) and performed a total of 40 face-to-face interviews with the end-users of eHMIS and SmartCare were. Three separate sessions of focus group discussions were conducted with teams from FMOH, experts from academia and industry, and project members of the FMOH partners in Ethiopia.

All interview data from the end-users are analysed and described statistically. Field notes and data from document review are analysed together with information from the focus group discussion using ATLAS.ti software. Vensim DSS Version 6.3D is used to model and simulate the system dynamics model. Ethics and research integrity clearance has been obtained from Faculty of Engineering, Built Environment and Information Technology, University of Pretoria.

The next three chapters discuss a system thinking and system dynamics simulation results of the PhD research project. The simulation results of socio-technical and techno-organizational factors of sustainable eHealth acceptance are presented in Chapter 5 and 6 respectively. The systems thinking results of techno-economic factors of sustainable eHealth acceptance are discussed in Chapter 7. The first research objective which is to assess the influence of socio-technical factors on the sustainable use eHealth systems is addressed in Chapter 5. The model validation and verification processes, sensitivity analysis and policy analysis are also addressed.

5. SIMULATION RESULTS OF SOCIO-TECHNICAL FACTORS OF SUSTAINABLE EHEALTH IMPLEMENTATIONS

“Humans have multiple identities and can fluidly switch between them without conscious thought” (Snowden & Boone, 2007:3).

5.1. Introduction

The dynamic socio-technical interactions are the major sources of unintended consequences during eHealth implementation that can sometimes undermine quality and safety and can lead to implementation failure (Harrison, Koppel and Bar-Lev, 2007). The different success levels of an electronic health system in various health departments indicate the influence of social structure on the successful implementation of technology (Reddy, Pratt, Dourish, & Shabot, 2003). The unpredictability and intellect nature of humans make modelling of human complex systems very difficult (Snowden and Boone, 2007). Ludwick & Doucette (2009) indicated that the socio-technical factors perhaps directly influence the eHealth implementation success. Understanding the individual components of a socio-technical system and the interplay between them helps to expose the causes of particular eHealth implementation or use problems.

The interaction of people through technology to create community results in a socio-technical system (Whitworth & Sylla 2012). The socio-technical system involves complex interaction among the social subsystems (people, tasks, and relationships), technical subsystems (technologies, techniques, task performance methods, work settings) and their social and organizational aspects of a system (Baxter & Sommerville, 2011:4-5; Harrison, Koppel, & Bar-Lev, 2007). In this section the sustainability of eHealth technology is addressed from the perspective of sustainable use of eHealth technology by the end-users in healthcare facilities. The long-term sustainability of eHealth systems cannot be ensured without a sustained use of technology and information for decision making.

The socio-technical system dynamics model of sustainable eHealth implementation focuses on maximizing eHealth acceptance, increases the use of information for decision making and reduces the rejection of technology by end-users. Sauer (1994) indicated that the social and behavioural factors might be the main reasons for information systems failures and these may be more than the technical factors. The socio-technical factors significantly influence the acceptance of technology and the use of information for decision making which are the immediate outputs of sustainable eHealth implementation (Aqil, Lippeveld and Hozumi, 2009).

The social practices in the healthcare domain are highly institutionalized; as a result, the socio-technical elements play a prominent role in the implementation of HIT solutions (Reddy et al. 2003). The socio-technical interaction is an interplay between a new HIT and the adopting organization's existing socio-technical conditions such as technologies, workflows, culture, and social interaction (Harrison et al. 2007). Petrakaki, Cornford, & Klecun (2010) argued that the "socio-technical changing" is a continuous process but not static or discrete post and pre-implementation "impacts" or notions of discrete changes.

This section seeks for the possibility of understanding and assessing the dynamic relations between social and technical factors during eHealth implementation to facilitate technology acceptance by the end-users. The elements of socio-technical factors of eHealth implementation discussed in Chapter 2.7 serve as a basis to the socio-technical system dynamics model of eHealth acceptance. Moreover, the results of the case studies of two eHealth applications, focus group discussions and interview data are discussed and used to develop the system dynamics simulation model of socio-technical factors in this thesis. The model shows the dynamic interaction and critical feedbacks of the socio-technical factors of eHealth technology implementation to facilitate technology acceptance and information use. It aims to maximize the acceptance of technology and the use of information for decision making by benefiting policymakers as well as stakeholders involved in the design, implementation and operation of eHealth systems.

This chapter of the report thus answers the first research question stated in Chapter 1.5.1 namely "how the socio-technical factors influence the sustainable use of eHealth systems?" The concept model discussed in Chapter 3 and the qualitative system dynamics model building research method outlined in Chapter 4 is used in this section. The dynamic hypotheses associated with the research question are developed through one balancing and four reinforcing loops in the causality diagram (Figure 5.1). A dynamic hypothesis is an explanation of the reference mode behaviour and should be consistent with the model purpose (Sterman, 2000). A dynamic hypothesis creates an understanding of the feedbackloops by eliciting and testing the consequences of the feedback loops (see Chapter 4).

A system dynamics approach applied in this study seeks for the possibility to unlock the dynamic nature socio-technical elements of eHealth acceptance. This chapter addresses the CLD, SFD and the model equations of the system dynamics model of socio-technical factors of eHealth acceptance. The socio-technical factors of technology acceptance are illustrated using the two cases of electronic health systems in Ethiopia, eHMIS and SmartCare. The qualitative data obtained through interviews, document review and focus group discussions are used to illustrate and validate a system dynamics model of socio-technical factors of eHealth systems. The system dynamics model tests, verification, validation and simulation results are discussed in detail. The simulation results addressed technology acceptance, information quality and users satisfaction as key elements of sustainable eHealth implementation. Sensitivity analysis is also performed to ensure model robustness. The what-if scenario analysis intended to show alternative policies to improve acceptance of eHealth technology, information quality and users' satisfaction through socio-technical factors of eHealth systems.

The next section will address the socio-technical system dynamics model of eHealth acceptance. It captures the dynamic interaction of socio-technical factors of sustainable eHealth systems use through the CLD. The CLD of a socio-technical model of eHealth acceptance is developed by applying a systems thinking approach to the findings of the literature studies, mainly TAM and IS success models. Besides, the evidence from the preliminary interview, focus group discussions discussed in Chapter 4 and the researcher's experience in the field of eHealth implementation is used to create the CLD. The model boundaries are defined and the CLD is discussed with one balancing and three reinforcing loops. These causal loops describe the dynamic hypotheses and illustrate the socio-technical factors of sustainable eHealth use. The dynamic hypotheses loops are constructed based on individual and social factors that influence technology acceptance to address the first research question. In system dynamics, dynamic hypotheses capture the interactions among different variables/parameters, causes of dynamics and determining the important feedback in the strategic model through CLD (Design, Rashedi and Hegazy, 2016).

The system dynamic concepts of socio-technical factors of sustainable eHealth use is published in the proceedings and presented on the IAMOT conference in 2016, Orlando, Florida.

Fanta, G., Pretorius, L., & Erasmus, L. (2016). A System Dynamics Model of eHealth Acceptance: A Socio-technical Perspective. In Technology & Future Thinking. In IAMOT. Orlando.

5.2. Socio-technical system dynamics model of eHealth acceptance

System dynamics is an interdisciplinary approach to enhance the learning process in complex systems (Sterman, 2000). It supports a dynamic system modelling effort, which is constructed as continuous feedback systems that evolve over time (Schwaninger & Grösser 2008). The complexity, nonlinearity, and feedback loop structures of social and physical systems in the real world can be represented adequately using the system dynamics modelling method (Forrester, 1994). The system dynamics process begins with understanding the system problem, but the process continues seeking to improve the system performance (Forrester, 1994). This study attempts to propose a solution to the socio-technical problems towards the acceptance of technology and the use of information for decision making.

The implementation of eHealth in the developing world is mainly funded by the international donor organizations (Jahangirian and Taylor, 2015; Quaglio *et al.*, 2016). The successful eHealth implementation effort is influenced by several factors. Cresswell and Sheikh (2012) indicated that the eHealth implementation effort fails for many reasons such as economic, social, technological and organizational factors. One of the major problems of eHealth success is the lack of acceptance by the end-users and weak use of information for decision making (Aqil, Lippeveld and Hozumi, 2009). The acceptance of eHealth technology by the end-users is one of several obstacles to the sustainability of eHealth. eHealth technology should be used by the end-users to demonstrate sustainability. Yet, several eHealth systems fail to demonstrate acceptance by end-users because of social, behavioural and technological factors (Sauer, 1994; Aqil, Lippeveld and Hozumi, 2009).

The socio-technical factors play a significant role in influencing technology acceptance and information use by the end-users in healthcare facilities (Reddy *et al.*, 2003; Aqil, Lippeveld and Hozumi, 2009). The dynamic interplay between social and technical factors during eHealth implementation impacts the acceptance of technology and information use. Seeking to understand the dynamic relationships and feedback loops of socio-technical factors in the process of eHealth implementation may help to facilitate acceptance of the technology. An improvement in the acceptance of technology and information use by end-users can support the effort of sustainable eHealth implementation in resource-constrained settings.

The causal loop diagram (CLD) and stock and flow diagram (SFD) are the basic diagrammatic tools of system thinking and system dynamics (Sterman, 2000). The CLD is an important approach to represent the interdependency and feedback processes of systems (Sterman, 2000). A CLD representation of an iterative system dynamics model shows the complex interplay among socio-technical elements during eHealth implementation and use within a healthcare facility. The proposed system dynamics model in this thesis indicates the dynamic interaction and critical feedbacks of the socio-technical factors of eHealth technology implementation and use. The feedback loops represent the circular causality between the model variables which are characterised as either reinforcing or balancing loop. The loops of the dynamic hypotheses guide the direction of the study to answer the research questions.

The five stage system dynamics modelling processes discussed in Chapter 4.5 are followed in the course of developing the socio-technical model of eHealth acceptance to address the research questions stated in Chapter 1.5.1. The problem articulation and boundary selection is followed by the development of dynamic hypotheses. The model formulation translates the system description into the level and rate equations to formulate simulation model.

5.2.1. Model boundary

The boundaries are set around the key endogenous and exogenous variables of socio-technical factors in healthcare institutions during the implementation and use of eHealth technologies. The technology refers to the eHealth technology implemented in a healthcare institution and the social group include individual end-users and their social networks. The lists of endogenous, exogenous and excluded variables that are used in the development of the socio-technical model of eHealth acceptance are shown in Table 5.1. The ‘adopted population’ refers to the total number of clinical and administrative staffs within eHealth adopting healthcare organization.

Table 5.1 Boundary chart of socio-technical model of eHealth acceptance.

Endogenous	Exogenous	Excluded
Acceptance rate	Adopted population	Legal
Adjustment time	Contact rate	Political
Change in perception to use	Delay time	Financial
Difference in perception	Effectiveness of training	Organizational culture
Dissatisfaction rate	Frequency of use	Labour-force
Individuals’ intention to use	Incentives	Organizational structure
Information quality	Period of use	Ethical
Inhibitors	Potential users	Infrastructure

Intervention rate	Productivity improvement rate	Workflow process
Intervention step	Reduce work burden	
Promoters	Services quality	
Satisfaction rate	System quality	
System flaw	Time to intervention	
System usefulness and ease of use	Time to training	
Technical flaws	Trials before termination	
Technological quality		
Termination rate		
Termination step		
Termination time		
Actual users		
Dissatisfied users		
Individual perception to use		
Satisfied users		
Terminated users		

5.2.2. The dynamic hypotheses of socio-technical factors of eHealth acceptance

The dynamic hypothesis is a working theory that describes the behaviour of the system problem and provides an endogenous explanation of a phenomena under study (Sterman, 2000). Forrester and Albin (1997) described dynamic hypothesis as an explanation of the reference mode behavior and should be consistent with the model purpose. The dynamic hypothesis serves as a theory that links the model structure to a behaviour in real-world system (Oliva, 2003). The dynamic hypothesis in this study focuses on the relationship between the social and technological factors of eHealth implementation to ensure sustainable use of eHealth technology and the information product to make informed decisions in resource constrained settings.

The dynamic hypotheses describe the influence of the socio-technical factors towards the sustainable use of eHealth systems through four dynamic loops (See Figure 5.1). The CLD of a socio-technical model of eHealth acceptance depicted in Figure 5.1 is developed by applying the systems thinking approach to the findings of the literature studies. Besides, the evidence from the preliminary interview, focus group discussions (Appendix 4.4) and the researcher’s experience in the field of eHealth implementation is used to create the CLD. The CLD of a socio-technical model of eHealth acceptance consists of four feedback loops. Three reinforcing loops and one balancing loop are used to explain the behaviour of the socio-technical dynamics of eHealth acceptance in this model.

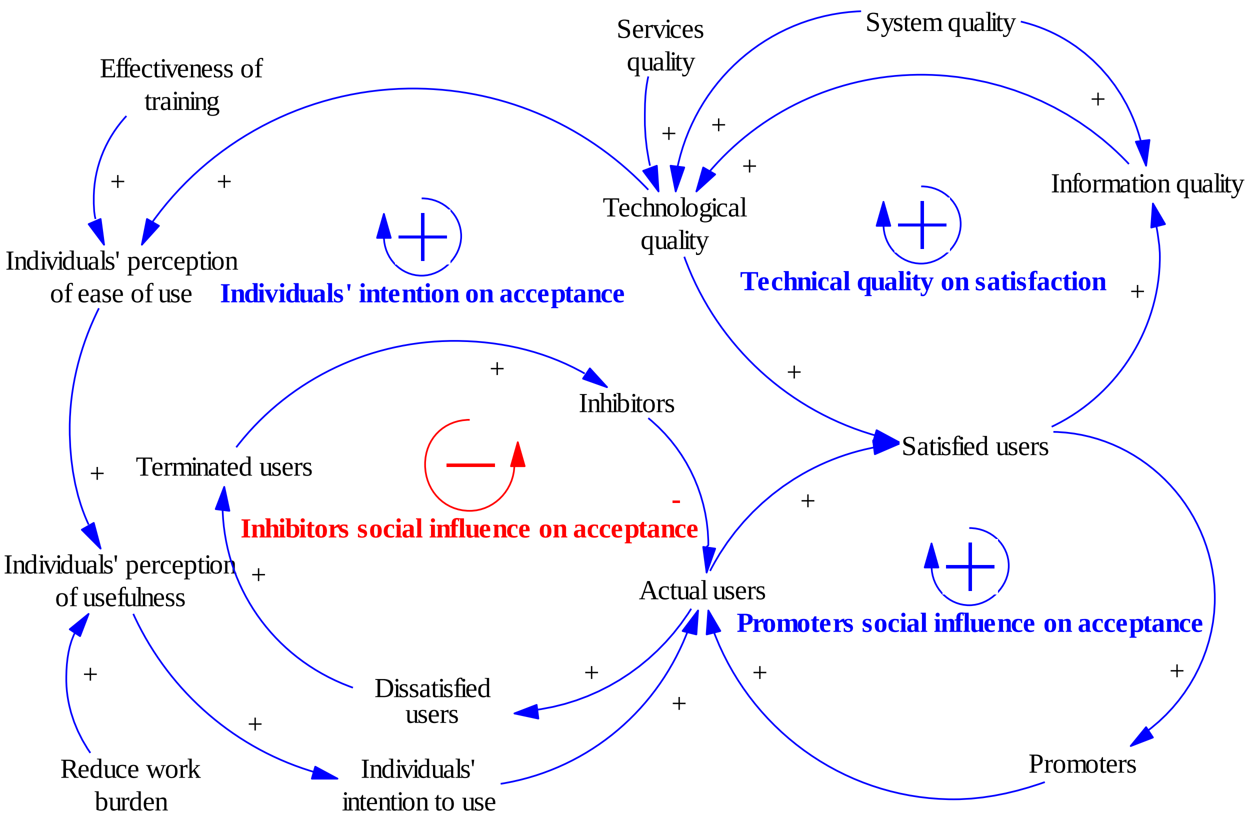


Figure 5.1 CLD of the socio-technical model of technology acceptance.

The reinforcing loops describe the interplay between the socio-technical factors to facilitate acceptance of eHealth systems and users' satisfaction. It shows the influence of satisfied users on their social network of end-users and the intention of individual users towards increasing the technology acceptance. Furthermore, the reinforcing loop depicts the potential impact of technological quality in driving the satisfaction of users to the higher level. To the contrary, the balancing loop shows the dynamic influence of rejected users on the behaviour of the social circle to hinder the acceptance of eHealth systems.

The balancing loop

The balancing loop, '*inhibitors social influence on acceptance'*, describes the negative influence of rejected or terminated users towards acceptance of the technology (Figure 5.2). The loop illustrates the influence of the terminated users towards increasing inhibitors and finally hindering technology acceptance by actual users. An increase in the number of 'actual users' could possibly increase the number of 'terminated users'. As more people try to use the technology, those users dissatisfied with the technology could reject and terminate to use the technology. The increasing number of terminated users boosts the number of inhibitors. '*Inhibitors'* are a group of users who propagate the negative information about the technology within their social circle that could potentially hinder the acceptance of technology by the potential users.

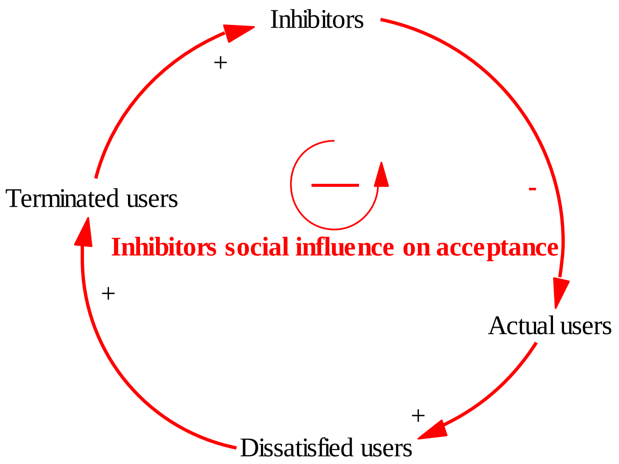


Figure 5.2 CLD of inhibitors' social influence on use of technology.

An increase in the number of 'inhibitors' results in a drop in the number of 'actual users' of the technology. The CLD shows the connection between the terminated users and their social influence on the actual use of technology. The loop follows the following dynamics interaction: 'terminated users' – 'inhibitors' – 'actual use' (Figure 5.2). '*Terminated users'* are users who stopped using the technology (Chen 2011). These users are the former users who have terminated using the technology (Mutingi & Matope 2013). '*Actual users'* refer to the members of an organization who begin using the technology and have the first-hand experience of the technology (Chen, 2011; Mutingi and Matope, 2013). The dynamic interplay between the terminated users and the social influence of inhibitors on the actual use of technology is shown in Figure 5.2.

Reinforcing loops

The first reinforcing loop (*Information quality on satisfaction*) illustrates the influence of *'technological quality'* on the satisfaction of users (Figure 5.3). The loop describes the positive influence of system, service and information qualities on the 'technological quality'. The better the quality of technology, the higher the number of 'satisfied users'. It further indicates the positive impact of satisfied users in improving the information quality. The reinforcing loop depicts the dynamic relationship between the following socio-technical factors: 'technological quality' – 'information quality' – 'satisfied users' (Figure 5.3). '*Satisfied users'* represent users who are using the system happily because the system is useful to perform their tasks and easy to use. '*Technological quality'* represents the quality of the product (systems), the quality of production (information) and the quality of supporting services (Aizstrauta and Ginters, 2015).

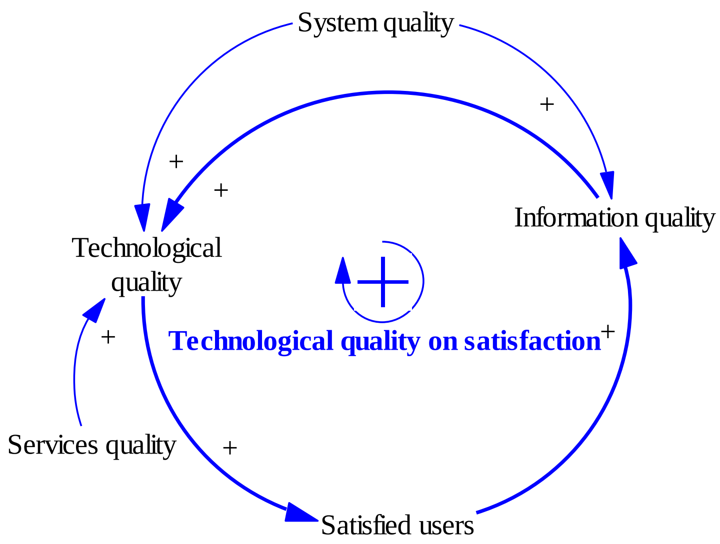


Figure 5.3 CLD of technological quality influence on users' satisfaction.

The '*promoter' social influence on the acceptance of technology'* is the second reinforcing loop that demonstrates the social influence of satisfied users towards promoting the actual use (Figure 5.4). The loop depicts the promotion of social influence of satisfied users to drive the number of the actual users. The rising number of 'satisfied users' increases the number of 'promoters' who in turn drive a number of actual users. The loop shows the dynamic interaction between 'satisfied users' – 'promoters' – 'actual users' (See Figure 5.4). *Promoters* refer to a group of satisfied users who spread the positive word of mouth about the usefulness of the technology that may influence their social circle to facilitate technology acceptance.

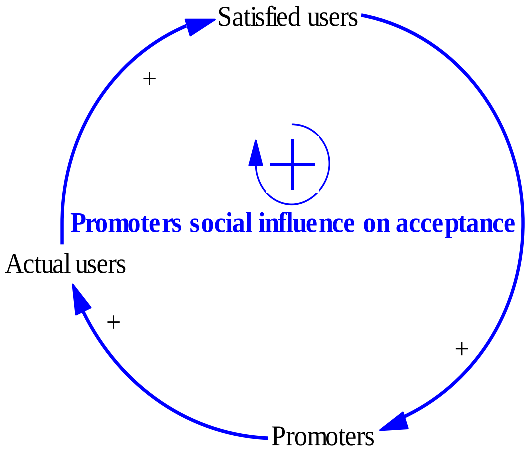


Figure 5.4 CLD of promoters' social influence on acceptance of technology.

The third reinforcing loop, '*individuals' intention on acceptance of technology*, describes the dynamic interplay between the socio-technical factors that influence individuals' intention towards technology acceptance (Figure 5.5). '*Individuals' intention to use'* is the level of one's behavioural intention to use a specific technology (Tobergte and Curtis, 2013). As per the TAM, the perceived ease of use and the perceived usefulness of technology are the two core determinants that influence individuals' intention towards technology acceptance (Davis, 1989). '*Individual perception of usefulness'* represents the usefulness of technology as perceived by end-users (Venkatesh and Davis, 2000). Likewise, '*Individuals' perception of ease of use'* refers to the ease of technology or user-friendliness as perceived by the end-users (Venkatesh and Davis, 2000).

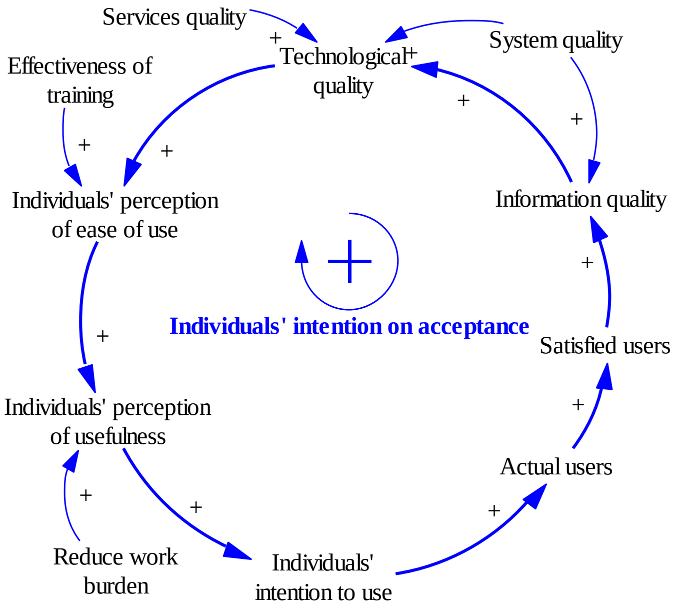


Figure 5.5 CLD of Individual's intention on technology acceptance.

Research studies indicated that perceived ease of use appears to influence the users' intention to use the technology through the perceived usefulness of the healthcare technologies (Ward, 2013). Hence, an increase in the perceived ease of use also increases the perceived usefulness of technology. High perceived usefulness leads to increase in the 'individual's intention to use' the technology. The greater the individual's intention to use the technology in turn leads to an increase in the number of 'actual users' contributing to the growing number of 'satisfied users'. The more satisfied the users are with the technology, the better will be the 'information quality' and the 'technological quality' in general. The following section discusses the development processes of SFD and the system dynamics simulation model equations of socio-technical factors of eHealth acceptance.

5.3. A system dynamic model of socio-technical factors of eHealth acceptance

Through iterative system dynamic modelling processes, the CLD is translated and extended into stocks and flows diagrams (SFD) as shown in Figure 5.6. The SFD differentiates stock variables from flow variables to develop a more detailed view of the system. Besides, the SFD enables to create a computer simulation model of the system which is not possible with the CLD. The proposed system dynamics model shows the dynamic interaction and critical feedbacks of the socio-technical factors of eHealth technology implementation and use. The concept of the Bass diffusion model is used as a basis to construct a system dynamics socio-technical model of eHealth acceptance (Sterman, 2000). The theoretical models such as the TRA, TAM and IS Success Model are incorporated to develop the SFD (See Chapter 3.4). A system dynamics modelling approach is used seeking the possibility to unlock the dynamic nature socio-technical elements of eHealth acceptance.

The three key factors that influence the acceptance rate as illustrated in the causal loop are captured to as 'inhibitors', ‘promoters’ and ‘individuals’ intention to use’ as shown in Figure 5.6. A causal loop that demonstrates the influence of technological quality on the satisfaction of end-users is also captured as a factor influencing ‘satisfaction rate’ (See Figure 5.6). Stock and flow variables, as well as the units of model parameters, are carefully identified in the process of converting the CLD into SFD. The feedback loops and logical flows of the CLD and are incorporated in the SFD either stock, flow or variable. For example, ‘actual users’, ‘satisfied users’, ‘terminated users’ are identified as stocks and linked to each other logically as depicted in the CLD.

The SFD of a socio-technical model of eHealth acceptance developed in this thesis demonstrates the dynamic process of socio-technical elements. The system dynamics model of eHealth acceptance in Figure 5.6 is explained in five sub-models. The five sub-models describe the process of eHealth acceptance by explaining the dynamic interaction between the socio-technical elements of eHealth technology. The model shows the rate of technology acceptance, i.e., the rate at which ‘potential users’ become ‘actual users’. Then the ‘actual users’ either turn to ‘satisfied users’ or ‘dissatisfied users’ based on their experience of the system. The model further depicts the possibility of dissatisfied users to become ‘terminated users’ if their dissatisfactions are not addressed on time with some type of intervention to convert them to satisfied users.

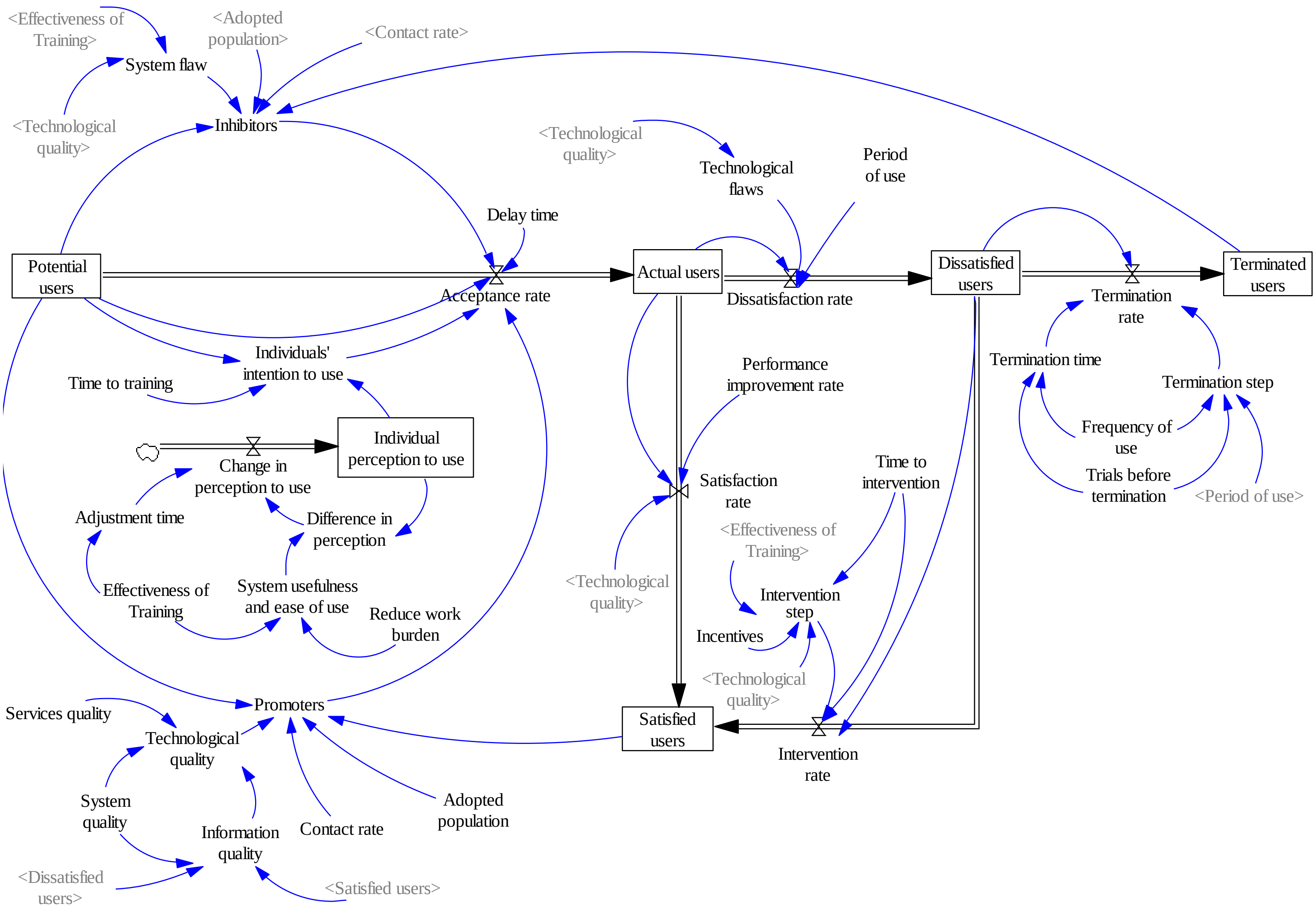


Figure 5.6 Stock and flow diagram of the socio-technical model of technology acceptance.

Vensim is an interactive computer simulation software environment which allows users to conceptualize, document, simulate, analyze, and optimize models of dynamic systems (Ventana Systems, 2012b). Vensim DSS Version 6.3D software is used for the development, simulation, and exploration of System Dynamics models in this research study. The system dynamics model has been simulated over fifteen year's horizon with a yearly time-step for the different values of the parameters. Parv et al. (2012) used a timeline of ten years to capture the indirect costs that would emerge at later stages of eHealth implementation. The simulation time horizon of fifteen years is selected for this system dynamics modelling because eHealth is a relatively new field in the developing countries (Coleman, 2016).

Recently, the FMOH is considering to replace eHMIS with the District Health Information Software 2 (DHIS2) system. DHIS2 is an open-source solution and the next evolution of DHIS. It is a next-generation data collection, aggregation and reporting tool. DHIS offers similar services like eHMIS with some enhanced system functionalities such as web-based functionality, GIS-enabled and an open-source solution (Program Health Information Systems-SA, 2015).

5.3.1. The rate of technology acceptance

The *acceptance sub-model* shows how the potential users become actual users through the rate of acceptance which is influenced by the individual's intention to use, promoters and inhibitors social groups (Figure 5.7). *Potential users* are individuals within an organization who possibly need to use the current system to perform their jobs (Mutingi and Matope, 2013). The potential users could be a part of the whole staffs within the organization. The promoters and inhibitors are opposing social influences on potential users towards technology acceptance. The promoters refer to users who support technology acceptance through the word of mouth. However, inhibitors imply users who delay the acceptance of technology by influencing the social circles. The individuals' intention to use and the social influence of promoters impacts the rate of acceptance positively; whereas the inhibitors hinder the rate of acceptance through the negative word of mouth.

The net social influence on the technology acceptance rate is calculated as the difference between 'Promoters' and 'Inhibitors'. The net social influence on technology acceptance rate becomes negative when there are more 'Inhibitors' than 'Promoters'. The rate of technology acceptance is the sum of 'Individuals' intention to use' and the net social influence of 'Promoters' and ‘Inhibitors’ on potential users. When the impact of ‘Inhibitors’ is greater than that of ‘Promoters’ and ‘Individuals’ intention to use’, the net value of technology acceptance rate will be below zero. However, the negative rate of technology acceptance is not logical in this model. Therefore, the value of technology acceptance rate is set to zero when the net result is below zero (See Equation 5.1).

Acceptance rate =IF THEN ELSE (Individuals’ intention to use + Promoters > Inhibitors, MIN (Potential users / Delay time, Individuals’ intention to use + Promoters - Inhibitors), 0)
(Units: Persons/Year) *(5.1)*

The value of the acceptance rate at any given time should not be greater than the potential users. Because it leads to negative potential users. Hence the maximum acceptance rate cannot be bigger than the minimum potential users. The minimum function (MIN) takes care of this logic by shifting the acceptance rate to the ‘Potential users’ divided by ‘Delay time’ whenever the number of potential users is lower than the acceptance rate (See Equation 5.1). ‘Delay time’ represents the average time elapsed for potential users to become actual users.

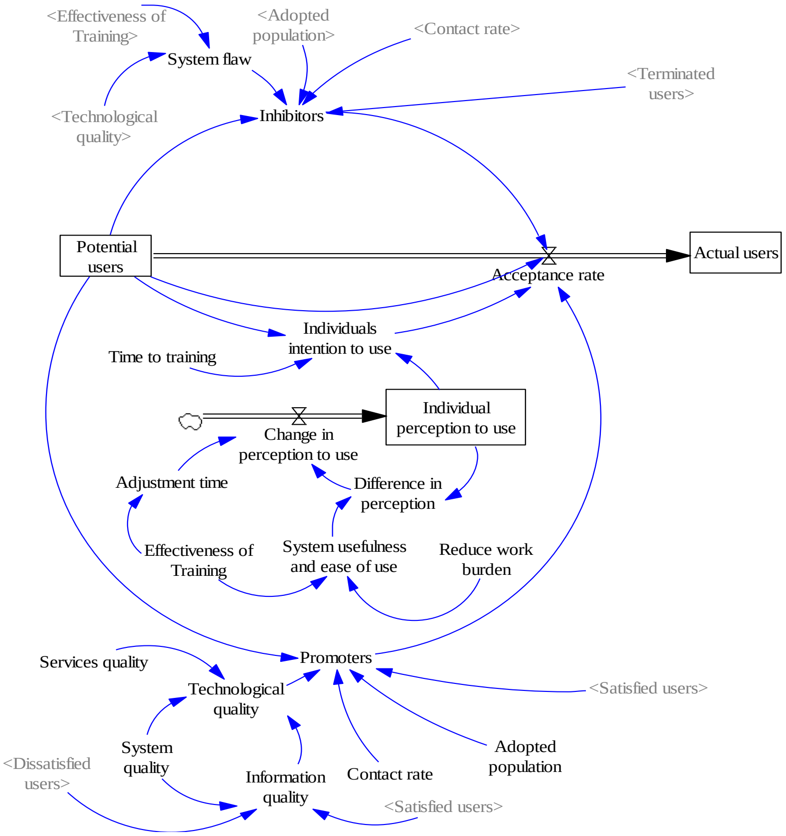


Figure 5.7 Acceptance sub-model of the socio-technical model of eHealth acceptance.

The social influence of 'Promoters' come from satisfied users of the technology (See Equation 5.2). On the contrary, the social influence of 'Inhibitors' emanate from the terminated users (See Equation 5.3).

*Promoters = Satisfied users * Contact rate * Technological quality * Potential users / Adopted population (Units: Persons/Year) (5.2)*

*Inhibitors =Terminated users * System flaw * Contact rate * Potential users / Adopted population (Units: Persons/Year) (5.3)*

'Individuals' intention to use' is the behavioural intention to use a specific technology which develops from the potential user's perception of technology usefulness and ease of use (See Equation 5.4). 'Individuals' intention to use' develops from the 'Individuals' perception to use' which results from 'Change in perception of technology' (See Equation 5.5). 'Change in perception of technology' refers to the rate of change of individuals' perception of the system usefulness and ease of use. *'Effectiveness of training'* measures the success level of training provided to the end-users to create awareness and facilitate the learning processes of a technology (Al-Mamary, Shamsuddin and Aziati, 2014). The ease of use is facilitated by the effectiveness of training and communications about the benefits of technology creates awareness of the usefulness of technology. 'Time to training' refers to the time delay to conduct a training to the potential users regarding the technology use and benefits.

*Individuals intention to use = Potential users * Individual perception to use / Time to training (Units: Persons/Year) (5.4)*

Individuals' perception to use = INTEG (Change in perception to use) (Units: Dimensionless) (5.5)

The number of 'Potential users' drop at the rate of technology acceptance as the 'Potential users' become 'Actual users' (Equation 5.6). The 'Actual users' either become 'Satisfied users' or 'Dissatisfied users' based on the experience of using the technology. Therefore, the 'Actual users' is equal to 'Acceptance rate' less 'Satisfaction rate' and 'Dissatisfaction rate' (Equation 5.7).

Potential users = INTEG (-Acceptance rate) (Units: Persons) (5.6)

$$\text{Actual users} = \text{INTEG}(\text{Acceptance rate} - \text{Dissatisfaction rate} - \text{Satisfaction rate}) \quad \text{(Units: Persons)} \tag{5.7}$$

5.3.2. Information quality

The technology with poor system quality can only produce poor information quality. The quality of information is critical in the process of informed decision-making (Aqil, Lippeveld and Hozumi, 2009). The dissatisfied users are also contributors to information quality problems in addition to system quality issues. On the contrary, satisfied users contribute to improved information quality as indicated in the focus group discussions. Therefore, the information quality is described as a function of system quality, satisfied users and dissatisfied users as shown in Equation 5.8.

$$\text{Information quality} = \text{System quality} * \text{Satisfied users} / (\text{Dissatisfied users} + \text{Satisfied users}) \quad \text{(Units: Dimensionless)} \tag{5.8}$$

According to IS success model (Petter, Delone and Mclean, 2012), ‘Technological quality’ is an average effect of ‘System quality’, ‘Information quality’, and ‘Services quality’ (Equation 5.9). ‘Technological flaws’ represents technological quality problems which contribute to the dissatisfaction of ‘Actual users’ (Equation 5.10). However, ‘System flaws’ includes the level of training inadequacy in addition to ‘Technological flaws’ that drives ‘Inhibitors’ (Equation 5.11).

$$\text{Technological quality} = (\text{Information quality} + \text{Services quality} + \text{System quality})/3 \quad \text{(Units: Dimensionless)} \tag{5.9}$$

$$\text{Technological flaws} = 1 - \text{Technological quality} \quad \text{(Units: Dimensionless)} \tag{5.10}$$

$$\text{System flaw} = 1 - (\text{Technological quality} + \text{Effectiveness of Training})/2 \quad \text{(Units: Dimensionless)} \tag{5.11}$$

5.3.3. Satisfaction with the use of technology

The *satisfaction sub-model* explains the process of converting ‘actual users’ to ‘satisfied users’ at a rate of satisfaction (Figure 5.8). ‘Satisfaction rate’ refers to the rate at which 'Actual users' become 'Satisfied users', i.e., the rate at which ‘Actual users’ enjoy the benefits from the technology. The rate of satisfaction is influenced by the quality of technology and the ability of technology to improving the productivity of users (Equation 5.12).

*Satisfaction rate = Actual users * Technological quality * Productivity improvement rate (Units: Persons/Year)* *(5.12)*

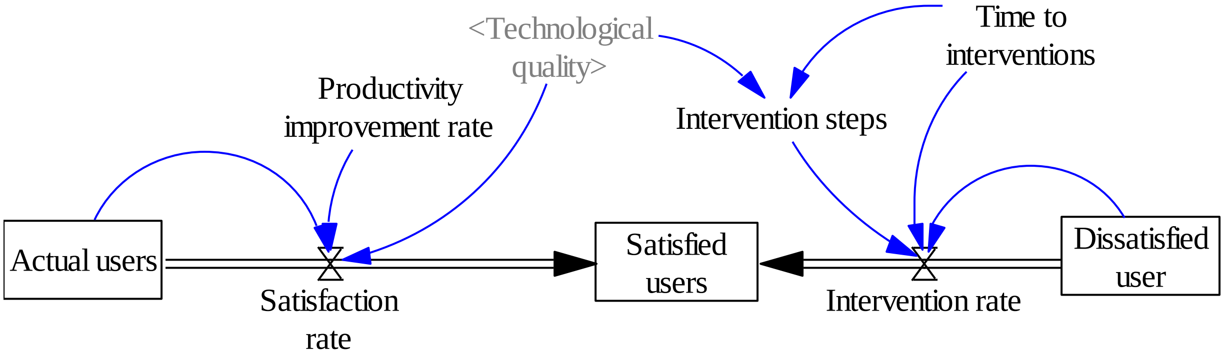


Figure 5.8 Satisfaction sub-model of the socio-technical model of eHealth acceptance.

‘Satisfied users’ believed to promote the values of technology through the word of mouth to influence ‘Potential users’ become ‘Actual users’. ‘Actual users’ who benefit from the technology become ‘Satisfied users’ through ‘Satisfaction rate’; besides ‘Dissatisfied users’ become ‘Satisfied users’ through ‘Intervention rate’ (Equation 5.13).

Satisfied users = INTEG (Intervention rate + Satisfaction rate) (Units: Persons) *(5.13)*

5.3.4. Dissatisfaction with the use of technology

The *dissatisfaction sub-model* explains the conversion of ‘actual users’ to ‘dissatisfied users’ (Figure 5.9). ‘Dissatisfied users’ represent unhappy users of the system either the system is not easy to use or not useful in supporting their jobs. The ease of use problem usually reduces with the longer the period of use. When ‘Actual users’ use the system for long durations, they gain experience which makes the system easy to use. However, ‘Technological flaws’ lead to unhappy users. Hence high technological problems and the period of use are key variables that could influence the rate of users’ dissatisfaction (Equation 5.14). Greater technological problems will result in a higher rate of dissatisfaction. However, a longer period of system use by 'Actual users' leads to more experienced users making the system easy to use.

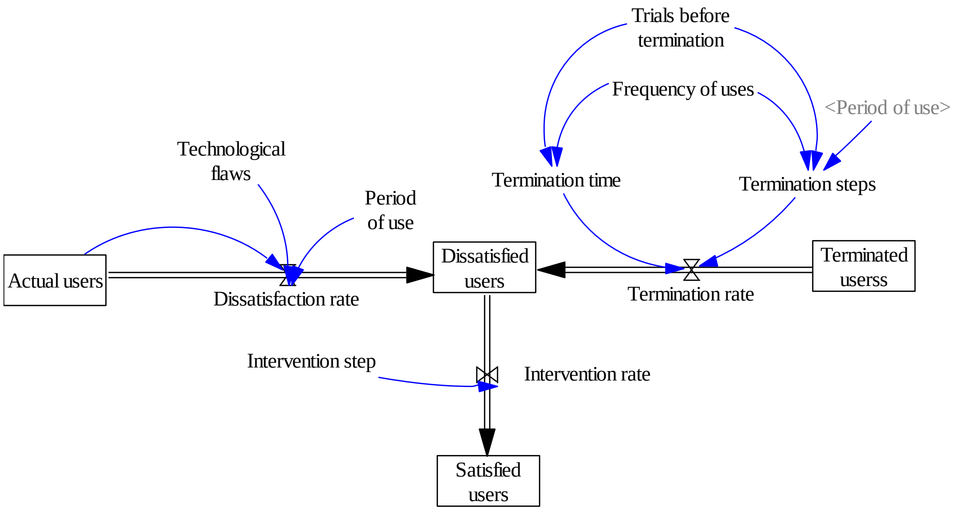


Figure 5.9 Dissatisfaction sub-model of the socio-technical model of eHealth acceptance.

*Dissatisfaction rate = MIN (Actual users * Technical flaws / Period of use, Actual users / Period of use) (Units: Persons/Year)* (5.14)

'Actual users' who are unhappy with the technology become 'Dissatisfied users' at the pace of 'Dissatisfaction rate' (Figure 5.9). Some of 'Dissatisfied users' may become 'Satisfied users' through an 'Intervention rate' and other groups of 'Dissatisfied users' become 'Terminated users' at the speed of 'Termination rate'. So 'Dissatisfied users' are the net result of 'Dissatisfaction rate' less 'Intervention rate' and 'Termination rate' (see Equation 5.15).

Dissatisfied users = INTEG (Dissatisfaction rate-Intervention rate-Termination rate) (Units: Persons) (5.15)

'Dissatisfied users' do not consider the system as an important tool to their jobs. Hence in the volunteer use circumstances, 'dissatisfied users' do not use the system regularly because using the system is the least priority task to them. In the case of mandatory system use conditions, 'dissatisfied users' continue using the system but without concern for the quality of the information product. 'Dissatisfied users' use the system when they feel the importance of a system for their work and stop using when it is inconvenient to use. Such irregular use of system contributes to the poor quality of information due to incomplete data entry to the electronic system.

5.3.5. Intervention processes

The intervention sub-model illustrates the process of converting 'Dissatisfied users' to 'Satisfied users' (See Figure 5.10). 'Intervention rate' refers to the rate at which dissatisfaction of end-users is addressed through management and policy interventions. ‘Dissatisfied users’ may become ‘Satisfied users’ if their concerns in relation to the use of technology are quickly addressed. The time required to implement the intervention measures (referred as ‘Time to intervention’ in this model) is an important factor in the success of proposed interventions. If the time required to implement intervention measures is long, ‘Dissatisfied users’ will be forced to use the technology that does not fully meet their needs for longer periods. This could lead ‘Dissatisfied users’ terminate to using the technology. Therefore, good intervention measures should be implemented timely to address the concerns of ‘Dissatisfied users’ to convert them to ‘Satisfied users’. ‘Intervention rate’ can be represented with ‘Dissatisfied users’, ‘Intervention step’ and ‘Time to intervention’ (see Equation 5.16).

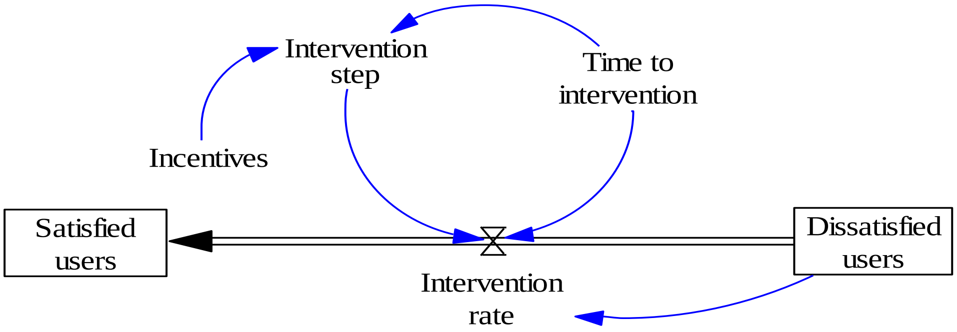


Figure 5.10 Intervention sub-model of the socio-technical model of eHealth acceptance.

*Intervention rate = Dissatisfied users * Intervention step / Time to intervention*

(Units: Persons/Year) *(5.16)*

‘Intervention step’ is a step function that returns 0 until ‘Time to intervention’ and then returns the height (Technological quality + Effectiveness of Training + Incentives) / 3) beyond the Time to intervention (See Equation 5.17).

Intervention step = STEP ((Technological quality + Effectiveness of Training + Incentives) / 3, Time to intervention) *(Units: Dimensionless)* *(5.17)*

5.3.6. Termination of use

The termination sub-model describes the conversion of ‘Dissatisfied users’ to ‘Terminated users’ because of the delay or absence of intervention actions to address users’ concern (See Figure 5.11). If the users’ dissatisfaction is not addressed timely with proper intervention measures, they may terminate to use the technology. ‘Termination rate’ implies the rate at which ‘Dissatisfied users’ quit using the technology due to various barriers to the use of the technology (Mutingi & Matope 2013). ‘Dissatisfied users’ may be willing to try the technology for some time even if they are not fully satisfied with the technology. This trial time before termination is represented by the ‘Termination time’. 'Termination time' is the time at which ‘Dissatisfied users’ are willing to use the technology before deciding to stop using it. ‘Termination rate’ can be represented by ‘Dissatisfied users’, ‘Termination step’ and ‘Termination time’ (See Equation 5.18).

*Termination rate = Dissatisfied users * Termination step / Termination time*
(Units: Persons/Year) *(5.18)*

If ‘Intervention time’ takes longer than ‘Termination time’, ‘Dissatisfied users’ begin to stop using the technology to become ‘Terminated users’. However, when ‘Intervention time’ is shorter than ‘Termination time’, it might be possible to convert ‘Dissatisfied users’ to ‘Satisfied users’ through intervention measures to minimize the number of ‘Terminated users’.

‘Termination step’ represents the time at which ‘Dissatisfied users’ start to stop using the technology. The RAMP function returns zero until ‘Termination time’ (i.e., Trials before termination/Frequency of use), and slopes upward with the magnitude of (Frequency of use*Period of use - Trials before termination) / (Frequency of use*Period of use) until ‘Period of use’ and then holds a constant value. The slope indicates the ratio of the number of time the system is used by end-users after ‘Termination time’ and the total number of time the technology is used. The dissatisfied users begin termination if the Period of use is greater than Termination time. Equation 5.19 describes the Termination step in the model.

*Termination step = IF THEN ELSE (Period of use > Trials before termination/Frequency of use, RAMP ((Frequency of use*Period of use-Trials before termination) / (Frequency of use*Period of use), Trials before termination/Frequency of use, Period of use), 0)*
(Units: Dimensionless) *(5.19)*

'Termination time' is the time at which ‘Dissatisfied users’ are willing to use the technology before deciding to stop using it. Therefore, the shorter the ‘Termination time’ means the ‘Dissatisfied users’ can only be willing to try for a smaller duration. As a result, shorter ‘Termination time’ leads to high ‘Termination rate’. ‘Termination time’ is a ratio of ‘Trial before Termination’ and ‘Frequency of use’ (See Equation 5.20).

Termination time = Trials before termination / Frequency of use
(Units: Year) *(5.20)*

‘Trails before termination’ refer to the number of times (measured in counts) the ‘Dissatisfied users’ are willing to using the technology before they quit. The bigger the ‘Trials before termination’, the greater the ‘Termination time’ is. ‘Dissatisfied users' commitment to continue using the system depends on the frequency of technology use. ‘F*requency of use’* is the rate at which the end-users use the system to accomplish their jobs. ‘Dissatisfied users’ that use the system more frequently tend to become ‘Terminated users’ quicker than less frequent ‘Dissatisfied users’. The higher the ‘Frequency of use’ means, the shorter the ‘Termination time’ and eventually leading to higher ‘Termination rate’.

‘Terminated users’ are individuals who stopped using the system (See Equation 5.21). These individuals are previous users who have no more interest in using the system (Chen, 2011; Mutingi and Matope, 2013).

Terminated users = INTEG (Termination rate) *(Units: Persons)* *(5.21)*

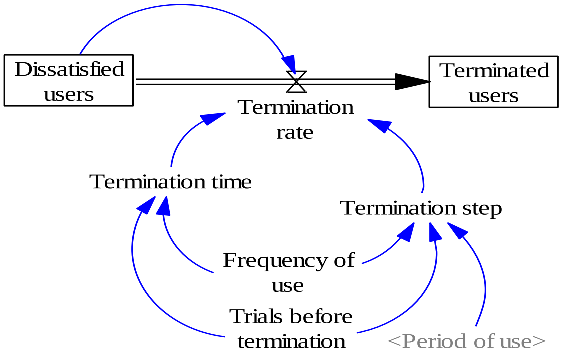


Figure 5.11 Dissatisfaction sub-model of the socio-technical model of eHealth acceptance.

‘Satisfied users’ are meaningful users of a technology contributing to the sustainability of technology. Although all ‘actual users’ use the technology, ‘satisfied users’ are considered to be regular consumers of the information generated by the system to make informed decisions (Aqil, Lippeveld and Hozumi, 2009). ‘Satisfied users’ use the technology for a longer period of time; contrarily ‘dissatisfied users’ may terminate quickly if the cause of dissatisfaction is not addressed timely through intervention measures (Tilahun and Fritz, 2015a). Therefore, end-users satisfaction is necessary for long-term sustainable use of technology. ‘Dissatisfied users’ may be willing to continue using the technology irregularly for a short period of time before they decide to terminate the use. The willingness comes either from the mandatory use of technology or the end-users willingness to give it a try (Venkatesh and Davis, 2000).

Non-regular system use can introduce data quality problems by supplying delayed or incomplete information (Appendix 4.4, Code Groups: Information quality). The influence of users’ satisfaction on the quality of information is also one of a novel contributions of this study. As shown in Table 2.11, literature findings indicated the influence of information quality on users’ satisfaction; however, the impact of end-users’ satisfaction level on ‘information quality’ is therefore also a further unique contribution of this study. Besides, ‘dissatisfied users’ may terminate to use the technology hindering ‘acceptance rate’ by propagating the negative word of mouth to ‘potential users’.

In summary, the long-term sustainable use of eHealth systems is impacted by users’ satisfaction and information quality which influence each other as described by the socio-technical model of eHealth acceptance. Hence it is not only the acceptance of technology but also the satisfaction of end-users and the quality of information that need to be addressed to implement sustainable eHealth systems. The next section discusses the eHMIS and SmartCare cases used in this research study. The simulation results of the two cases are discussed focusing on acceptance rate, users’ satisfaction and information quality.

5.4. Discussions of the socio-technical factors of technology acceptance

The two eHealth case studies of eHMIS and SmartCare addressed in this PhD research project have different technology use characteristics. The two electronic systems differ in the level of implementation success, the level of social factors influence on the users, the required level of workflow processes changes and the frequency of technology use among the health facilities and various departments of the health facilities in Ethiopia. One of the two cases is considered a success by many respondents, while the other has been described as a failure. The use of these two distinct cases in this study has a significant contribution to the validation and verification of the system dynamics model to build confidence in the socio-technical model of technology acceptance. The empirical evidence from these case studies enabled to compare and contrast the possible success factors and to enhance the confidence in the model.

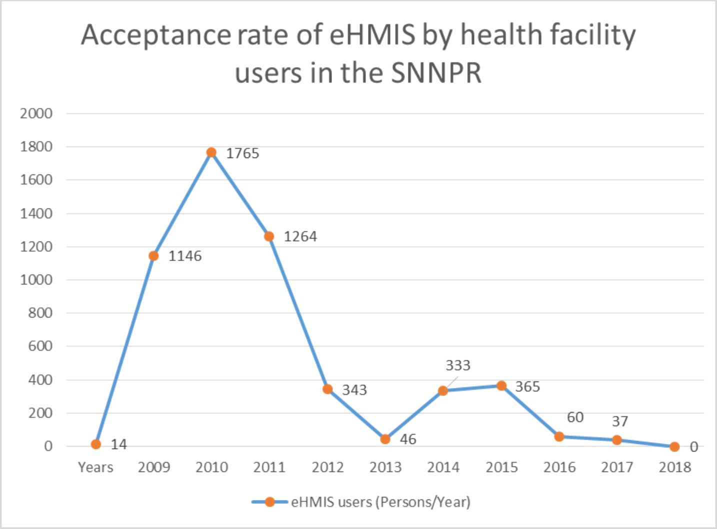
5.4.1. eHMIS in Ethiopia

HMIS is expected to produce relevant, timely, accurate and complete health information for health program managers, providers and stakeholders to support decision making that helps to improve the health service and health status (FMOH 2011). However, the paper HMIS system was characterized by a lack of accurate, timely and complete reports; consequently affecting effective management and decision-making at all levels of the healthcare system (FMOH 2011). The parallel reporting formats of programmatic and donor-supported health systems create an increased administrative workload. At the lower levels, data is collected primarily for reporting purposes with very limited use of data for decision-making (FMOH 2011). In 2015, eHMIS was implemented nationally in more than 3,000 health facilities and health administrative offices in Ethiopia (Wannaw and Azim, 2013).

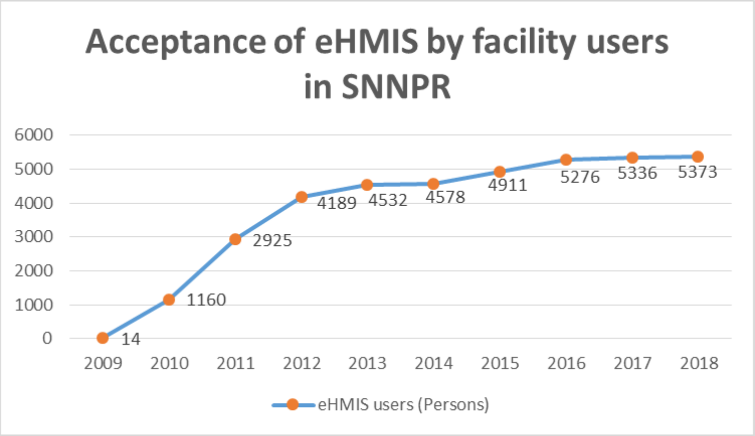
As of June 2016, the eHMIS-2 database shows a total of 25,191 private and public health facilities in Ethiopia. Of these health facilities, 830 are in Addis Ababa city council, 366 are in Afar region, 5454 are in Amhara region, 764 are in Beneshangul Gumuz region, 103 are in Dire Dawa city council, 288 are in Gambella region, 85 are in Harari region, 10201 are in Oromia, 3919 are in SNNPR, 1238 are in Somali region and 1212 are in Tigray region. Health facilities in Addis Ababa city council, one of the case study sites, include 21 hospitals of which 8 are private and 13 are public, 97 health centres and about 680 private health facilities.

The eHMIS-1 database indicates that as of June 2016, there were approximately 5620 private and public health facilities of which 4859 were public and 761 were private and NGO health facilities in the SNNPR. The SNNPR is a case study site with 55 hospitals (48 public, 4 private and 3 NGOs); 732 health centres (708 public and 2 NGOs); 4103 health posts. The implementation of eHMIS-1 started in 2010. As of January 2018, the eHMIS-1 database contains an exhaustive list of health facilities (6513) compared to 3919 health facilities in the SNNPR in eHMIS-2 database. Therefore, the data from eHMIS-1 is applied in the data analysis of eHMIS implementation.

The trend of eHMIS acceptance rate by users in SNNPR health facilities is summarised in Figure 5.12 (a). It shows the rate at which health facilities in the SNNPR began sending their monthly reports through eHMIS. Mostly, there is one eHMIS focal person (eHMIS user) at each of the health facilities; therefore, it is appropriate to use the number of report sending facilities as a proxy indicator to the number of eHMIS users.



(a)



(b)

Figure 5.12 (a) Trend of eHMIS acceptance rate by health facility users in the SNNRP. (b) Total number of eHMIS users in the SNNPR health facility (Source: eHMIS database, 2018; Appendix 4.5).

The graph shows that the number of eHMIS users rapidly increases in the early years and collapses to the minimum in 2014 following the absence of health facilities ready to implement eHMIS (Figure 5.12 (a)). In the following years, another new but smaller rapid growth of eHMIS acceptance had begun and started to drop down after year 2016 (Figure 5.12 (a)). The new eHMIS acceptance rate after 2014 may have been triggered by a newly constructed health facilities and a functional readiness of existing health facilities to implement eHMIS.

Figure 5.12 (b) shows the cumulative eHMIS users in the SNNPR. It follows the classical S-shaped growth pattern (Figure 5.12 (b)). The eHMIS-1 database holds a total of 6513 health facilities in the SNNPR as of January 2018. Of those facilities, 5373 health facilities have been sending monthly HMIS data (Figure 5.12 (b)). Figure 5.12 (a) shows the pattern of using an electronic system to send monthly HMIS data by health facilities in the SNNPR. However, "nationally, only one of five (19 %) of health centres and hospitals report HMIS data electronically (eHMIS). The majority (33 %) of government managed health facilities are most likely to have eHMIS compared with 3% of private for-profit health facilities." (EPHI et al. 2016:33).

The focus group discussion with a partner of the FMOH as part of the research approach discussed in Chapter 4 indicated that there are 154 Woredas/districts in the SNNPR and at least one urban health centre at each of these Woredas/districts. The eHMIS system is fully implemented in the Woreda health offices as well as the urban health centres at each Woreda. All 19 Zonal and Special Woredas' health bureaus also implemented the eHMIS. Moreover, the eHMIS was implemented and functional at all Regional Health Bureaus and the Federal Ministry of Health. eHMIS is fully implemented in the FMOH, RHB, Zonal Health Bureau (ZHB), and Woreda Health Office of the SNNPR. However, the focus group members indicated that the facility level implementation of eHMIS is only about 25% in the SNNPR. The rest of health facilities (75%) are not sending out their HMIS data electronically.

5.4.2. SmartCare in Ethiopia

The pilot implementation of SmartCare was started in Dire Dawa, Ethiopia in 2008. In 2014, a total of 12 hospitals and more than 67 health centres implemented the full package of EMR in 4 Regions (Tigray, Oromia, Amhara and Harari) and 2 city councils (Addis Ababa and Dire dawa) (FMOH, 2014b). The SmartCare was implemented in all service delivery units in parallel to the existing paper-based system with a plan to become fully electronic at the later stage. However, the SmartCare implementation was accompanied by several challenges as it had progressed from the pilot phase of implementation to full-scale operations. As the implementation of SmartCare progressed from the pilot to operations phase, the network infrastructure began to fail apart, the capacity of the central SmartCare server began to fall short and the system began to run slow forcing users to return back to the paper-based systems.

The SmartCare system was implemented in the following service units.

- Registration (Medical record unit - MRU)
- Outpatient department (OPD)
- Maternal and Child Health (MCH) mainly for immunization
- Laboratory
- Pharmacy
- Emergency
- Minor-Operations room (Minor-OR)
- Psychiatry

The research studies on the acceptance and satisfaction of SmartCare users (Tilahun and Fritz, 2015; Biruk et al., 2014) focus on health professionals. Yet health professionals at different departments showed a different level of acceptance based on the workload and the usefulness of the technology (Appendix 4.4, Code Groups: Actual use). In another study, Berhe et al (2017) evaluated the readiness of Smartcare at healthcare institutions level. The case of the SmartCare system selected in this study has a different level of acceptance by end-users in different service units of the Gandhi Memorial Hospital. Therefore, the case study in this PhD research project is unique in terms of assessing the acceptance of SmartCare and eHMIS at a department level instead of a health facility level. Furthermore, the empirical evidence gathered from the departments in the Gandhi Memorial Hospital contribute to the novelty of the study in terms of assessing the technology acceptance by users in different departments (See Appendix 4.4).

Medical record unit (MRU)

The data analysis of interview data with the end-users of SmartCare in the Gandhi Memorial Hospital indicated that SmartCare users in the medical record service unit seemed to accept and own the system more than any other service units. The MRU users were convinced by the importance of SmartCare in the day-to-day work operations. Besides, they indicated that a patient registration module of the SmartCare system is easy to use. The SmartCare system makes the registration of a new patient and searching for existing patient medical record easy. The medical records of visiting patients were located easily by search with the patient medical record number. If a patient had lost the medical record number, the patient record could be searched with the patient's full name and/or phone number.

The service processes in the MRU follows two separate processes for a new patient and existing patient. On arrival to the hospital, the biographic information of a new patient is captured with the patient registration module of the SmartCare system whereas the patient medical record is searched for an existing patient in the SmartCare database. Once the patient medical record is found, the patient's medical file is allocated to a proper service unit and the paper medical record file together with the patient is sent to the service unit. The system also captures the service unit in which the patient is allocated to trace the location of a paper medical record file at the end of patient services.

During interview with the end-users, the PhD researcher in this thesis discovered that SmartCare users in the MRU seem to understand the benefits of the system to their work (See Appendix 4.4). They are comfortable in using a patient registration module of the SmartCare. They acquire ICT skills to comfortably use the system through training. Moreover, they indicate the system as easy to use and describe the use of technology reduces their work burden and improves the speed of the healthcare services delivery process. The users in this service unit described that they are able to find a medical record of a visiting patient by searching the database using a full name, phone number and/or residential address in the absence of the medical record number.

During a demonstration of the registration process of a new patient and the retrieval of an existing patient's medical record to the researcher, the medical record of a visiting patient that could not be found in the electronic system was located during a manual search of the paper records. The visiting patient could not remember the medical record number, hence the search was performed by full name, phone number and address of the patient, but the medical record could not be found in the Smartcare database. Finally, the MRU officer decided to search the medical record manually from the lists of paper records and the medical record file was located.

The explanation was that a patient arrived to the hospital for the first time as an emergency patient. Since the patient arrived with an ambulance in a critical condition, it was a family member who gave the patient details for registration. Unfortunately, the patient details supplied during registration was not accurate. Instead of her correct first name 'Belaynesh', she was registered with her nickname 'Belay'. Moreover, the phone number found in the system did belong to a family member. As a result, the MRU officer was not able to find the visiting patient's medical record in the SmartCare database. The head of the MRU updated the correct patient details in the SmartCare system after the reasons were explained to the department head. The patient details can only be updated by the head of the MRU. Other regular users in the MRU could not edit patient details to protect the integrity of patient information.

During interviews, the MRU users indicated that they were pleased with the service offered by the technical support team. The ICT support team visited or supervised the MRU every day and gave a quick response whenever help was required. The MRU could only access the patient registration module of the SmartCare system. The users in this department did not have the privilege to see the medical details of patients on the system. The MRU officers indicated that the system enabled them to quickly locate and trace the location of the paper patient medical records, to avoid the missing file problems and to organise the patient medical record systems in a better way. Benefits of the SmartCare were well recognised by the users of the MRU. They indicated that the system improved the performance of their work. In general, SmartCare was perceived as easy to use and useful by the MRU users.

Outpatient department (OPD)

The physicians believed that the SmartCare system had a potential to improve the management of patient medical record in the OPD. However, the physicians' workload in the OPD was very high in that 30-40 patients were seen by one doctor per day. Hence, they appeared to feel the system as a burden instead of a supportive tool. Capturing the patient medical information of such a high number of patients every day both on the paper and electronic systems put extra workload on the physicians. Furthermore, the users indicated that it was almost impossible to capture patient data with the electronic system during emergency time. The physicians resisted from accepting the SmartCare system because of the additional workload the system put to their busy schedule as described by the end-users and focus group discussion. The end-users in the OPD described SmartCare as a burden instead of a system that can improve their performance.

Furthermore, the missing diagnostic lists were another drawback in using the SmartCare system in the OPD. Two months after the implementation of SmartCare, the missing functionalities were noticed and reported to be included in the SmartCare system. Yet after a year, the requests could not be delivered. In general, the missing functionalities of the system, the excessive workload of end-users and the absence of quick technical support service to fix software issues were the key reasons for the low acceptance of SmartCare system in the Gandhi Memorial Hospital.

The paper and electronic systems were running in parallel in the hospital. Therefore, the physicians were expected to complete both paper and electronic systems which adds extra workload on the OPD users. The interviewed physician was an experienced user of SmartCare and had been actively using the system since internist and resident in the Ayder Hospital, Ethiopia. Moreover, she indicated that the system could be helpful if all medical practitioners use the SmartCare system. However, the high volume of patients and the two parallel systems (paper and electronic systems) put a burden on the physicians hindering the usability of the SmartCare in the OPD of Gandhi Memorial Hospital. Opposed to the high-level acceptance of SmartCare by end-users in the MRU, the acceptance of SmartCare by physicians in the OPD was very low.

Pharmacy department

The pharmacy service unit seemed to be one of the departments that had not endorsed the SmartCare system fully. The system did not have a comprehensive list of drugs and the laboratory supply lists were missing which were described as a fast moving items in the pharmacy dispensary. The pre-loaded drug lists on the SmartCare system were not accurate that the expiry date of the drugs in the system did not match with the available stock. Generally, the pharmaceuticals commodities were not captured correctly in the SmartCare system. The interviewed pharmacist was very dissatisfied with the pharmacy model of SmartCare system and indicated that he was no more using it as the system did not add any value to his work.

The pharmacist further indicated that the dispensing pharmacy module of SmartCare was not linked to the drug store system in the hospital. Besides, the system could not track end to end pharmaceutical commodities flow within the hospital. As a result, stocks received from the hospital store did not reflect on the dispensary module of SmartCare. The system required all the information to be entered into the system manually at the Pharmacy dispensing unit which was time-consuming and discouraging to already busy pharmacists.

Another problem indicated by the pharmacist was that the physicians did not send the medicine prescriptions electronically through the SmartCare system. Therefore, drug dispensation was performed based on the paper prescriptions which were kept in the dispensary unit to be transferred to the electronic system afterwards. However, all dispensed items were not captured on the digital system due to unavailability of the items in the pre-loaded lists or high workload. The pharmacists usually did not have time to enter all the dispensed drugs and laboratory supplies in the SmartCare system. The frequent interruption of electric power was described as another problem in using SmartCare in the pharmacy department. There was no backup generator to supply electricity during commercial power failures in the dispensary pharmacy unit. As a result, there was a large volume of backlogs data of dispensed medicines that were not captured in the electronic system. The commercial power disruption happened frequently even in the capital city, Addis Ababa.

The other weakness of the SmartCare system was the lack of system security. For example, SmartCare users of the pharmacy dispensary service unit could make changes to the number of pharmaceutical commodities available in the hospital store service unit. The SmartCare security feature did not restrict unauthorized access to facility store data. The pharmacists in the dispensary unit could change the number of commodities received from the hospital store resulting in poor data quality.

In summary, the SmartCare system misses some drugs and laboratory supplies in the pre-loaded commodity lists. The dispensed transactions were only captured partially in the electronic system due to high workload, frequent power failures and missing list of drugs and supplies in the pre-loaded commodity lists. Therefore, the pharmaceutical data in the SmartCare system could not be used for any kind of decision making. The pharmaceutical reports generated from the SmartCare system were not comprehensive, trustworthy or useful to make pharmaceutical logistics decision makings.

The missing functionalities and errors of SmartCare reported to the technical support team could not get fixed timely. The support service team was not responsive to reported issues. The respondent said, “I don’t see the value of this electronic system, I still use the paper as you can see and I am very busy to use an electronic system in parallel.” This confirmed the influence of ‘services quality’ on the satisfaction of end-users as described in the model (See Figure 5.9). The dissatisfaction of end-users due to low ‘services quality’ is discussed in Chapter 5.3.4. In addition to missing drugs and laboratory supplies in the pre-loaded lists, SmartCare system failed to integrate with other exist electronic system which has exhaustive ART drug lists, for example, ART drug management system (EDT). This relates to the influence of 'system quality' on the acceptance of technology.

Laboratory department

SmartCare had been used for the nine months in the laboratory service unit. The laboratory users captured the lab test results on paper and then transferred the test results to the SmartCare system before returning the test results on paper to the prescribing physician. The end-user indicated SmartCare as easy to use the system. Both the paper and electronic systems were used in parallel, but the end-user did not consider it as a burden. Contrary to the laboratory users, the physicians in the OPD considered the dual systems (paper and electronic) as a burden. This was a confirmation to an influence of work burden on acceptance of technology through individuals' intention to use technology as described in the model (See Figure 5.7). The laboratory department had low work burden compared to OPD so the use of both paper and electronic system did not make them complain. Furthermore, OPD users capture far more data on SmartCare compared to laboratory users.

The laboratory user questioned the value of the electronic system because the doctors did not use the electronic system to prescribe laboratory tests. Moreover, the doctors never looked the laboratory results captured electronically in the SmartCare system. Explaining some of the problems in using SmartCare, the laboratory technician indicated that the patient medical record number on the SmartCare system and the paper file differ. When such cases were encountered, the paper medical record file would be returned to the MRU for correction. Some other times, two or more patients got the same medical record number or patient identification number. This confirmed the impact of system quality on the level of users' satisfaction as described in Chapter 5.3.3.

It is observed that using SmartCare was easy for end-users in the laboratory service unit, but the end-users were not convinced with the value of using the system. The user argued that SmartCare did not add any value to improve the laboratory service unit or to the hospital as a whole. The laboratory data were captured on SmartCare regularly but neither the physicians nor the laboratory department or the hospital management had used the information for any kind of decision making. Despite its ease of use, users in the laboratory department were not happy because the system did not add value to improve their performance. This is in line with the model parameter discussed in Chapter 5.3.3 that end-users' satisfaction was not only influenced by system quality (ease of use) but also the value it added to the end-users (improve performance).

Maternal and Children Health (MCH)

The maternal and children health (MCH) service unit had been using the system for three months. The workload in the department appeared slightly lighter than other departments. The average patient load was only 10-15 per day and the highest patient volume was 20 patients per day on Fridays. The users captured the information first on paper and transfer to the electronic system later. Although both the paper and the electronic systems were running in parallel, like the laboratory departments users, the MCH users did not consider it as a burden.

The electronic system was used to set an appointment for immunization and capture day-to-day registration in the MCH departments. The users in the MCH service unit indicated that using the SmartCare had improved the department's work performance. Moreover, the system helped to avoid the missing file problems. The end users in the MCH were satisfied users as they had recognized the value of using SmartCare system.

The end-users in the after delivery care service unit said that SmartCare failed to handle the registration of twins birth. The design of SmartCare system considered only single baby birth. The reported missing functionality is not rectified timely. Similarly, the OPD users indicated that the lists of antenatal care of gynaecological diagnosis system are not comprehensive. In general, the response of a technical support team in addressing missing functionalities and reported errors is very slow. The impact of system and services quality on the acceptance and satisfaction of users was discussed in Chapter 5.3.1 and 5.3.3.

In summary, the level of success and acceptance of the SmartCare varied within the same hospital in different service units. The ability of SmartCare modules to meet the requirements of the service units (usefulness) significantly influenced the acceptance of SmartCare by the end-users. Moreover, the level of workload in the departments influenced the ease of use and the user's intention to use the SmartCare technology as indicated in the model (See Chapter 5.3.1). The ability of SmartCare to improve the users' work performance and to address the specific needs of the service unit had critically affected the level of acceptance and satisfaction of end-users. The model captured the influence of work performance improvement on satisfaction and usefulness on acceptance in Chapter 5.3.3 and 5.3.1 respectively.

The service units with lower workload found the SmartCare system easy to use (high acceptance) compared to service units with a high workload. The model captured the impact of workload on acceptance rates as depicted in Figure 5.7. Although some end-users described SmartCare as easy to use, the usefulness of the system to performing their jobs was not recognised by these users. This has significantly reduced the satisfaction level of end-users leading to users' dissatisfied with the Smartcare system as indicated in the model (See Chapter 5.3.3. and 5.3.4).

In general, eHMIS is low in the frequency of use as the system is only used to report monthly public health monitoring and evaluation data. On the other hand, SmartCare is used daily almost in all departments to facilitate a day-to-day healthcare services delivery process in the health facilities. Moreover, the level of workflow process changes required in the implementation of these two systems varies. The workflow process changes associated with the implementation of eHMIS is lower than that of SmartCare.

Table 5.2 Characteristics of eHMIS and SmartCare acceptance.

Descriptions	eHMIS	SmartCare
Frequency of technology use.	Low	High
Changes in the workflow processes.	Low changes	High changes
Level of social influence.	Low	high
The rate of technology acceptance.	High	Low
Level of information quality.	Low	Very low
Benefits to the departments in the health facility.	Similar benefits to all departments	Varies level of benefits to departments

Similarly, the main challenge of eHMIS is not the acceptance of technology by the end-users but the quality of information product. Conversely, SmartCare has low acceptance by end-users of most departments. The SmartCare consists of several modules to be utilized by different departments of the health facility. Therefore, the benefit of SmartCare varies from department to department within the same health facilities. As a result, the acceptance level of SmartCare varies based on the level of benefits the system is able to offers to the departments. Table 5.2 summarises the distinct features of eHMIS and SmartCare that may influence technology acceptance by the end-users as observed by the researcher.

5.4.3. The rate of eHMIS and SmartCare acceptance

The three key factors that influence the rate of eHealth acceptance come from individual intention, social promotion, and social inhibitions as discovered by the literature review and data collected (See Chapter 5.3.1). The influence of these three factors on the acceptance rate is demonstrated in the causes tree (See Figure 5.13). The causes tree is uniquely developed in systems thinking as part of a Vensim model to show the dynamic influence socio-technical variables on technology acceptance. The qualitative analysis of focus groups (Appendix 4.4) with ATLAS.ti, interview data (Appendix 4.3), TAM and IS success model variables were key inputs in the systems thinking processes. As 'potential users' become 'actual users' through the rate of acceptance, the number of 'potential users' reduce gradually at the rate of acceptance until all 'Potential users' become 'actual users'.

According to the focus group discussion with the FMOH, users who accepted electronic system developed skills to use the technology comfortably and to fix minor technical and operational problems to ensure the continuous use of technology (See Appendix 4.4, Code Groups: Actual use). The focus group discussions with the FMOH and the FMOH partners also confirmed that individuals' intention to use the technology and the influence of social circle on the end-users play critical role to the acceptance or rejection of technology (See Appendix 4.4, Code Groups: Social).

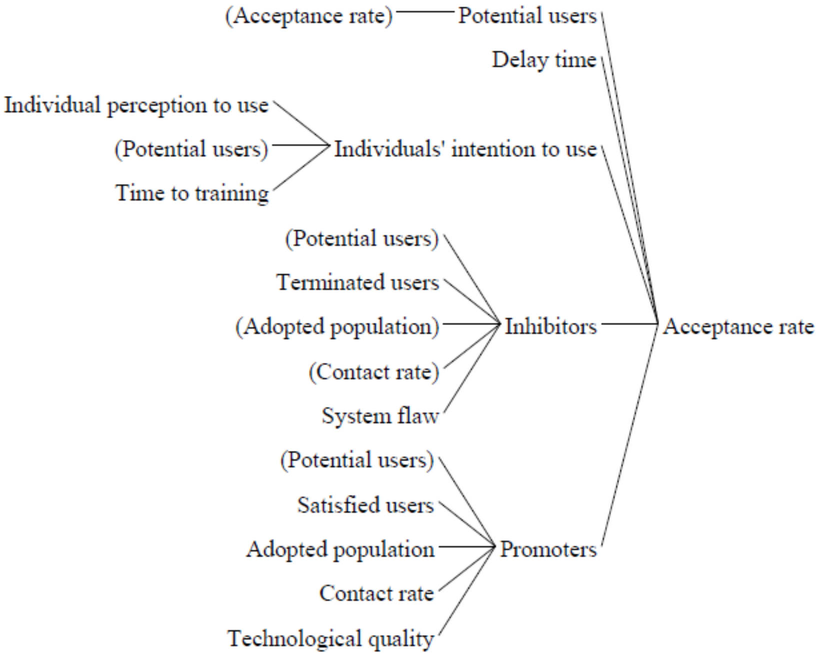


Figure 5.13 Causes tree of acceptance rate of potential users.

5.4.3.1. The individuals' intention to use eHMIS and SmartCare technologies

The individuals' intention to use is one of the three factors that influence technology acceptance (See Figure 5.13) and it develops from the potential users' perception of the technology's usefulness and ease of use. The user perception of ease of use and usefulness of technology are the two main drivers of technology acceptance according to TAM (Davis, 1989). According to the focus group discussions, the perception of technology acceptance developed from the ICT skills level of the end-users, the understanding of the benefit of technology and the burden of technology use as perceived by end-users (See Appendix 4.4, Code Groups: Individuals' intention to use). The focus group members indicated that those who understood the benefit of the technology were usually volunteering users of technology; however, they might reject to use the technology due to lack of ICT skills (See Appendix 4.4, Code Groups: Actual use).

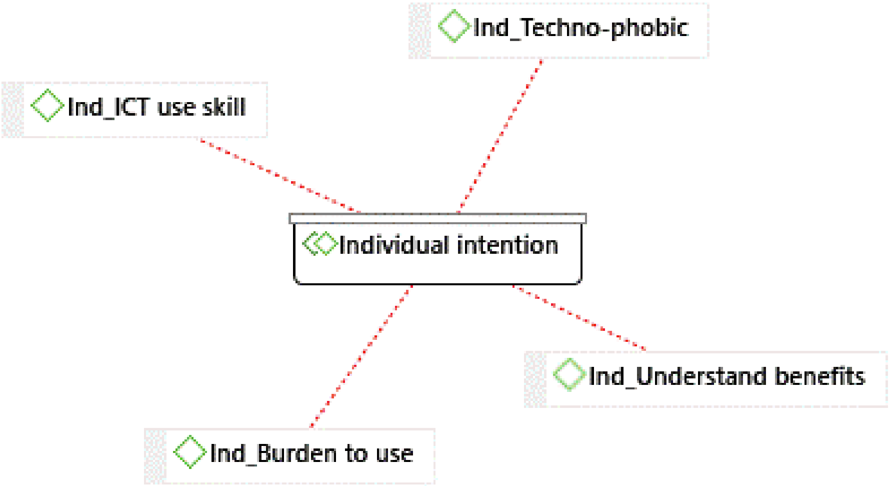


Figure 5.14 Factors that influence the individuals' intention to use eHMIS and SmartCare (Appendix 4.4, Code Groups: Individuals' Intention to use).

The main determinants of volunteer acceptance of technology were level of ICT skills (associated with ease of use) (See Appendix 4.4, code: Ind_ICT use skill) and understanding of the benefits (linked to technology usefulness) (See Appendix 4.4, code: Ind_Understand benefits). Moreover, the eHMIS and SmartCare users' perception may develop from the techno-phobic behaviour of individuals (See Appendix 4.4, code: Ind_Techno-phobic) and the perception of system use as a burden (See Appendix 4.4, code: Ind_Burden to use) instead of supportive tool to execute day-to-day tasks. Factors that influence the individual intention to use eHMIS and SmartCare shown in Figure 5.14 developed from an iterative and rigorous coding process of qualitative data analysis using Atals.ti software (See Appendix 4.4). The parameters that influence individuals' intention to use to influence technology acceptance are shown in Figure 5.14. The four parameters that influence individuals' intention to use are extracted from the interview data and discussed in detail (Appendix 4.4, Code Groups: Individuals' Intention to use).

The four parameters - burden to use, ICT use skill, techno-phobic, and understand benefits - that influence the individuals' intention to use eHMIS and SmartCare which are coded through a qualitative analysis in ATLAS.ti as depicted in Figure 5.14 are discussed below (Appendix 4.4, Code Groups: Individuals' Intention to use).

Burden to use

Members of the FMOH focus group members indicated that the trend in Ethiopia healthcare system showed that the users perceived electronic systems as a secondary and additional workload to an already busy schedule of healthcare workers (See Appendix 4.4, Code Groups: Individuals' intention to use). The end-users did not consider electronic systems as a helpful tool that strengthens the healthcare system but perceived as a burden. The focus group also explained the physicians' perceive using SmartCare was a burden that added additional burden on healthcare workers. The SmartCare was not considered as part of a solution that could facilitate and support the physicians' task but considered as an additional workload that put extra pressure on end-users (See Appendix 4.4, code: Ind_Burden to use). This perception might come from the lack of ICT skills that was related to lack of ICT training in the physicians training programs. Generally, SmartCare was seen as an additional task by physicians, instead of a tool that made their work easy.

The focus group discussions with the FMOH further highlighted that the SmartCare system was not considered as an important technology that aided the physicians' task (See Appendix 4.4, Code Groups: Individuals' intention to use). "The medical devices, such as a thermometer and statoscope are regularly used by physicians for their work, but end-users do not see SmartCare as useful as one of the medical devices." (See Appendix 4.4, code: Ind_Burden to use). One of the focus group members believes that "SmartCare system might have some benefits to physicians to make an informed decision when the previous patient returns. However, it comes at the expense of the physicians extra time and effort".

Another focus group member indicated that individuals who considered the system as a burden usually tried to use the system before making a decision to stop using the technology. The focus group discussion further reiterated that electronic health technology is considered as a burden when a group of users who tried to use the system is not satisfied with the system's ability to meet their needs (See Appendix 4.4, code: Ind_Burden to use). The physicians thought the use of the SmartCare system was a duplication of efforts and considered it as a burden. Therefore, they preferred to work with a paper system in which they were familiar with instead of moving to the digital systems.

A focus group discussion with the FMOH partners indicated that managers in the health facility were usually too occupied with political and other administrative assignments that they hardly had time to use or make a follow up on the electronic health systems (See Appendix 4.4, code: Ind_Burden to use). The informants further described that the ICT skills of end-users influence the end-users' perception of system ease of use that can affect technology acceptance. The end-users' perception of ease of use develops not only from the system quality or design issues but also from the end-users ICT skills level. This is captured as 'effectiveness of training' in the model as a variable that influences technology acceptance (See Chapter 5.3.1).The FMOH members of the focus group explained that the system ease of use is an important element of electronic systems.

ICT use skill

Many electronic systems are designed and developed with advanced users in mind; however, in developing countries like Ethiopia, physicians had very limited ICT skills (See Appendix 4.4, Code: Ind_ ICT use skill). Therefore, the system design should accommodate end-users with very limited skill in using computer systems. The focus group discussion with the FMOH further indicated that eHealth was relatively a new technology in Ethiopia so it would be too early to force clinicians to adjust themselves towards using a sophisticated electronic system. Instead, the technical team should take responsibility to design and develop a system that could be utilized by the available level of end-users' skill. The system design and development process must consider the low skill level of the users.

The level of end-users' skill to use SmartCare (EMR) was low in Ethiopia that posed a problem with acceptance of SmartCare (See Appendix 4.4, Code: Ind_ ICT use skill). The lack of capability and willingness to analyse data and disseminate the information by the eHMIS users was also highlighted as problems with the data management process and acceptance of eHMIS. The ICT skills shortage indicated by the focus group discussion was mainly as arise from a lack of effective training. Therefore, the model variable, 'effectiveness of training', captured skill related factors of technology acceptance (See Chapter 5.3.1).

A focus group member from the FMOH argued that "some physicians did not have ICT skills to use computers even if they were highly educated" (See Appendix 4.4, Code: Ind_ ICT use skill). Some group of doctors who participated in the online forum to diagnose dermatological problems through teledermatology system were not familiar with a computer keyboard, email systems and uploading the digital pictures to the online forum. This group of users did not have exposure to digital and internet services. On the contrary, in a very remote town of Afar region, people at health post level were eagerly using computers. Although these people were not highly educated, they had a strong desire to use electronic technology. These users were convinced by the benefits of electronic technology. As a result, they took initiatives to ask the RHB for maintenance service support persistently. The users of these facilities showed strong commitment towards using the patient registration module of the SmartCare system. The level of education did not show relationship with ICT skill or technology acceptance of eHMIS and SmartCare.

Techno-phobic

The focus group discussion with the FMOH explained the association of technology acceptance problem with the individuals' techno-phobic behaviour (See Appendix 4.4, Code: Ind_Techno-phobic). Techno-phobic individuals did not want to use the electronic system even when smart and well-designed electronic solutions were presented to them. "Techno-phobic physicians were not familiar with computer keyboards so they did not want patients or colleagues see their slow typing skills. The physicians' intention to hide their poor ICT skills led to resistance to SmartCare use by the physicians." as described by one focus group member. The techno-phobic users had very low drive to try the technology solution. Likewise, the techno-phobic individuals were reluctant to begin using the system. These group of users quickly resisted and rejected when the technology solution is presented to them (See Appendix 4.4, Code: Ind_Techno-phobic).

The focus group discussion with a partner of the FMOH described that the Health Information Technology (HIT) professionals were trained and assigned at health facilities to bridge the ICT skill gaps (See Appendix 4.4, Code: Impl_Training). Besides, the introduction of HIT professionals changed the culture and trend of allocating older and unskilled people at the MRU in health facilities. Now the FMOH endorsed the importance of assigning competent staffs at the MRU where capturing the patient information began. The accurate registration of patient record at the MRU improved the overall quality of healthcare data. Generally, the focus group team indicated that “the trained younger generations had a higher tendency of technology use than the older generations” (See Appendix 4.4, Code: Impl_Training). The younger HIT professionals were quick to learn and easily understand electronic technology.

One member of the FMOH focus group team believed that ICT skills and willingness to use electronic health system was not strongly related to the level of education, because less educated users in some health facilities showed stronger interest towards the SmartCare patient registration module in the Afar and Harar region; while highly educated physicians resisted to accept the teledermatology systems (See Appendix 4.4, Code: Impl_Training). In general, the use of electronic health systems in Ethiopia has challenges not only from the end-users but also from a top management position.

Understand benefits

The focus group discussion with the FMOH highlighted that the willingness to use a system increased with the recognition of system benefits or usefulness by the end-users (See Appendix 4.4, Code: Ind_Understand benefits). A member of the focus group discussion with a partner of the FMOH indicated that the majority of managers used the system without understanding the benefits. The system was used only to meet the reporting performance requirements and to avoid criticism from bosses. This group of people had no or little interest in the system. On the contrary, the focus group highlighted that “some managers have a strong commitment to using the electronic system to support their tasks. For example, a hospital CEO drove two days to collect computers from the project office and began to use eHMIS” (See Appendix 4.4, Code: Ind_Understand benefits).

The mandatory or voluntary use technology developed from the ICT skills level of end-users and the understanding level of the technology benefits. The focus group discussion with the FMOH highlighted that end-users with low experience in using computers and electronic technologies might not be voluntary users even if they understand the usefulness of technology to their job.

This is mainly due to the fear of technology (techno-phobia) that develops from the lack of skills and experience in technology use. Hence the technology use became mandatory to this group of user. The main determinants of volunteer technology use were ICT skills (not educational level) and understanding the benefits of technology (See Appendix 4.4, Code Groups: Individuals' Intention to use).

The focus group discussions with the FMOH and a partner organization indicated that creating awareness about the benefits of technology through training and workshops should be emphasized in the implementation process (See Appendix 4.4, Code: Impl_Training). Moreover, designing an easy-to-use system, continuous on the job training, and quick technical services give confidence to end-user and make the technology easy-to-use (See Appendix 4.4, Code: Impl_Training, Code Groups: Individuals' Intention to use, Code Groups: Services quality). The system design of easy-to-use eHealth systems should put into consideration the low-level ICT skills of end-users in developing countries. Similarly, the design should follow the existing workflow processes to maximize technology acceptance by the end-users. The influence of training, services quality and systems quality on acceptance of technology is demonstrated in the socio-technical model of eHealth acceptance (See Chapter 5.3.1).

5.4.3.2. The influence of social circles on the use of eHealth systems

The influence of social networks of colleagues on potential users can either be a positive or negative towards technology acceptance. The negative social influence prohibits potential users from accepting technology; whereas positive social influence promotes the use of technology. As indicated in the model above (See Figure 5.1 in Chapter 5.2.2), the positive social influence has a reinforcing effect, on the other hand, the negative influence has a balancing effect on the rate of acceptance. After an iterative and rigorous coding process, the focus group discussion data on the influence of the users' social circle within the work environment on technology acceptance is constructed into three codes: expert users' influence, supervisors influence, and culture of teamwork (See Figure 5.15). ATLAS.ti software is used to code and analyse the focus group qualitative data (See Appendix 4.4). The three social influence parameters - expert users influence, supervisors influence, and influence of teamwork culture - that impact the acceptance rate are discussed in line with the empirical data gathered and qualitatively analysed in ATLAS.ti in this research study are discussed below.

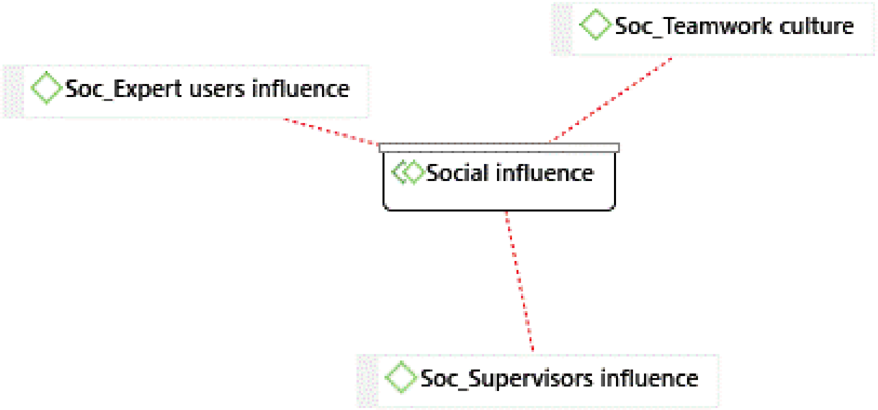


Figure 5.15 Factors of social influence to the acceptance of eHMIS and SmartCare (Appendix 4.4, Code Groups: Social).

The expert users influence

The focus group discussion with the FMOH highlighted the influence of well-motivated and good performing expert individuals on potential users to improve the overall system acceptance within the health facility. On the contrary, unmotivated and poorly performing expert individuals minimized the overall technology acceptance within the health facility. The behaviour and performance of expert individuals influenced the technology use behaviour of potential users. For example, the majority of eHMIS users were mainly from the Planning and Programming Department (PPD) in the FMOH, but there was only one eHMIS data manager (expert user) at the FMOH level. “When the data manager resigned from the FMOH, the system started to collapse immediately due to the absence of individual expert influence” as described by a focus group member. Hiring and training a replacement took time affecting the technology and information use of eHMIS (See Appendix 4.4, Code: Soc_Co-worker influence). The individual expert’s behaviour, skill and performance might significantly influence the behaviour of potential users in accepting the technology and using information for decision making.

The supervisors influence

The influence of supervisors on the social circles to facilitate acceptance of technology started with the process of technology selection (See Appendix 4.4, Code: Soc_Supervisor influence). The top managers significantly influenced technology selection processes. The knowledge and skills of end-users were indicated to be relatively low to make a contribution in the process of technology selection. Therefore, the decision of selecting electronic health technology in Ethiopia was exclusively made by the top managers without involving the end-users. Once the technology selection decision was made, “all the employees of FMOH were required to use the technology whether they understand the benefit or not” (See Appendix 4.4, Code: Soc_Supervisor influence).

The focus group members believed that the top managers influenced the use of technology by recognising champion users, and acknowledging the exemplary and successful work of end-users to encourage other potential users to begin using the technology (See Appendix 4.4, Code: Soc_Supervisor influence). The top managers could reduce end-users resistance and increase meaningful use of electronic health technology in health facilities through rewards and recognition (See Appendix 4.4, Code: Soc_Supervisor influence). So the influence of supervisors on the potential users was not only limited to technology selection but also technology use behaviour through awards and recognition.

The influence of teamwork culture

HMIS data management processes required teamwork that involved different departments within health facilities. The focus group discussion with the FMOH revealed a poor teamwork culture in the data management process had contributed to the data quality problems. The clinicians cared only about their department's data points, but they did not consider themselves as part of the HMIS data management team. Hence they hardly involved in the entire data management process. The clinicians’ felt the data management processes, i.e., data collection, digitalization of information and data quality assessments, were the responsibilities of HMIS focal persons (See Appendix 4.4, Code: Soc_Supervisor influence). The weak culture of teamwork in the process of HMIS data management contributed to poor data quality at the health facility level. A strong commitment from the data generating team (clinicians) was needed to ensure data quality. Lluch (2011) indicated that the traditions of healthcare structures are strongly hierarchical which does not support teamwork, moreover, healthcare professionals have autonomy.

The focus group discussion with the FMOH indicated that the HMIS focal person and clinicians who were the source of HMIS data did not communicate well and lacked a culture of teamwork (See Appendix 4.4, Code: Soc_Supervisor influence). The program people were the source of data, they recorded all the information on the registry form. The focus of the program people was clinical work and they did not consider data management as their mandate. Although the clinicians played a leading role in the data collection stage, they were not actively involved in the data management process. The HMIS focal persons know that the process of HMIS data management is their primary responsibility (See Appendix 4.4, Code: Soc_Supervisor influence). However, the weak culture of teamwork in the process of HMIS data management affected the technology and information use within health facilities (Rippen *et al.*, 2013).

The focus group team further highlighted the influence of teamwork culture on data quality and technology use. An arithmetic error in summing up the data points was one of the major HMIS data quality problems (See Appendix 4.4, Code Groups: Information quality). The discrepancy between data points on the manual registers placed at each service units and the data reported through the electronic system was another source of data quality problems (See Appendix 4.4, Code: Soc_Supervisor influence). This was an indication of miss communication among team members involved in the process of HMIS data management. The team generated HMIS data and those compiled did not have a culture of working as teamwork.

The social influences are captured as ‘inhibitors’ and ‘promoters’ in the socio-technical model of eHealth acceptance (See Chapter 5.3.1). The lack of teamwork culture was associated with the ‘inhibitors’ whereas the influence of expert co-workers was reflected as ‘promoters’ in the model (See Figure 5.7 in Chapter 5.3.1). Supervisors had both inhibiting and promoting influence on technology use as captured in the mode. The following section describes the simulation results of eHMIS and SmartCare acceptance and discusses in relation to the focus group discussion and literature findings.

5.5. The simulation results of technology acceptance rate

The simulation results in this section show changes in the rate of technology acceptance with respect to changes in different exogenous variables. The changes in an individual’s intention to use, inhibitors and promoters social influence, technological quality, and interventions are simulated to observe the behaviour in the rate of eHealth acceptance. The two cases (eHMIS and SmartCare in Ethiopia) are simulated separately to study the behaviour of technology acceptance rate (Appendix 4.5). The focus group discussion and interview data used in the system dynamics model development, tests, validation and verification of socio-technical factors of eHealth acceptance is presented in Appendix 4.3 and 4.4.

Vensim DSS Version 6.3D is used to develop and simulate the system dynamics model. Vensim is flexible, fast and powerful software package for model building, simulation and sensitivity analysis (Ventana Systems, 2015). The model equations are developed and filled for each of the variables and validated with direct and indirect structure test (See Appendix 5.1 and 5.2). The model and equations were developed by the author originally in Vensim as a unique contribution of this simulation research study. Direct structure tests assess the validity of the model equations or logical relationship either empirically or theoretically (Barlas 1994). Indirect structure tests involve specialized simulation runs and can provide indirect information about possible flaws in model structures (Barlas, 1996).

5.5.1. The simulation results of eHMIS acceptance rate

A system dynamics model of the socio-technical factors of technology acceptance is simulated with TIME STEP of 1 year for a period of 15 years as explained in Chapter 4.8 and Chapter 5.4.1 and 5.4.2). The implementation of eHMIS and SmartCare was planned annually in phased approach. Therefore, a 1 year time step is chosen for simulation.

The simulation values assigned to the model to study the behaviour of eHMIS acceptance are described in Table 5.3. The potential users of eHMIS in the SNNPR are 6500 users as observed in the eHMIS database. The total number of HMIS sending facilities was 6500 (See Chapter 5.4.1). The total number of clinical and administrative staffs within eHMIS adopting healthcare organization are denoted as ‘adopted population’. According to Sudhakar et. al (2017), a specialized hospital is staffed by an average of 440 professionals, a general hospital is staffed by an average of 234 professionals, primary hospital is staffed by an average of 53 healthcare workers, a health centre is staffed by an average of 20 health personnel and two health extension workers serve a health post. As of June 2016, the eHMIS-2 database contained 48 public hospitals; 708 public health centres and 4103 health posts in the SNNPR. The total ‘adopted population’ was estimated with the information about the number of health facilities and the number of healthcare workers (4103 * 2 + 708 * 20 + 41* 53 + 6*234 + 1*440 = 26,383). Therefore, the ‘adopted population’ was estimated to be 26,383 in this simulation model (See Chapter 5.4.1).

The values in Table 5.3 were based on the empirical evidence gathered from interview data (summarised in Appendix 4.3), focus group discussions (Appendix 4.4), eHMIS database (Appendix 4.5), and the report from the FMOH. The interview data of end-users perception of eHMIS usefulness in terms of improving performance and the satisfaction level indicated 0.88 (88%) improvement in an average of 2.92 years (See Appendix 4.3). According to the end-users survey, the system had been improving the performance of end-users at a rate of 88%/2.92 Year = 0.3 (30%) per annum. Therefore, the introduction of eHMIS improved the end-users' reporting performance at a rate of 30% per year (See Appendix 4.3).

Table 5.3 Simulation values of socio-technical dynamics of eHMIS acceptance.

Variable	Initial Value	Unit
Adopted population	26000	People
Potential users	6500	People
Contact rate	20	People/Year
Delay time	2	Year
Effectiveness of training	0.56	Dimensionless
Frequency of use	120	1/Year
Incentives	0.2	Dimensionless
Performance improvement rate	0.3	Dimensionless
Period of use	5	Year
Reduce work burden	0.94	Dimensionless
Services quality	0.8	Dimensionless
System quality	0.8	Dimensionless
Time to intervention	2	Year
Time to training	1	Year
Trials before termination	240	Dimensionless

The implementation of eHMIS started in 2010 and the implementation was still going until 2017. The implementation planned incrementally starting with most ready urban health facilities and progressing to remote facilities. Based on the focus group data, the average delay in the implementation of eHMIS is estimated to be 2 years (See Appendix 4.4, Code Groups: eHMIS). The average period of use of an eHMIS system in SNNPR was 3 years (See Appendix 4.3). The eHMIS is used to submit monthly aggregated health monitoring and evaluation reports so the frequency of use for eHMIS is relatively low (on average 10 times a month or 120 times a year). According to the FMOH assessment reports EPHI et al. (2016) and FMOH (2011, 2013 and 2014), the trained HMIS focal persons were 54% in 2016. Training is a key factor to build the ICT skills of eHMIS users. The focus group team indicated low ICT skills as a key factor that deters the acceptance of eHMIS in Ethiopia (See Appendix 4.4, Code: Ind_ICT use skill).

The ability of technology to reduce workload as perceived by the end-users is another important factor of technology acceptance as indicated by the focus group discussion (See Appendix 4.4, Code: Ind_Burden to use). This factor drives the perception of the system ease of use and usefulness in the early years of eHMIS acceptance. The majority of eHMIS users (23 of 40, 60%) strongly predict that eHMIS can reduce the work burden (See Appendix 4.3). The average score of end-users response predicts eHMIS to reduce the work burden by 94% (6.6 out of 7) (See Appendix 4.3). Therefore, the parameter value of 0.94 is assigned to 'reduce work burden'. This model parameter is believed to be one of the driving factors to a strong perception of usefulness and ease of use leading to strong intention to use eHMIS in the SNNPR.

eHMIS users tolerate the system problems and are willing to try the system for a long period despite their dissatisfaction. This could probably be as a result of the low frequency of use and the mandatory nature of eHMIS use. eHMIS was used 10 time a month on average by end-users, hence it was typically used 120 time a year. In this model, the 'trials before termination' is estimated to be two years trial which is 240 times (2 years x120 times/year) (See Appendix 4.4, Code: Use_Technology use).

The three key factors that influence the acceptance rate of eHealth are 'individuals' intention to use', 'social promotion' and 'social inhibitions' as discussed in section 5.3.1. The influence of these three factors on the eHMIS acceptance rate is demonstrated in Figure 5.13. The rate of eHMIS acceptance is simulated with the model parameter values shown in Table 5.3. The eHMIS acceptance rate graph (See Figure 5.16) exhibits similar behaviour as an eHMIS rate of acceptance in SNNP shown in Figure 5.12 (a). The simulation result shows that eHMIS acceptance rate increases rapidly and reaches at the maximum point in a short period. Then the acceptance rate begins to drop as the majority of 'potential users' become 'actual users'.

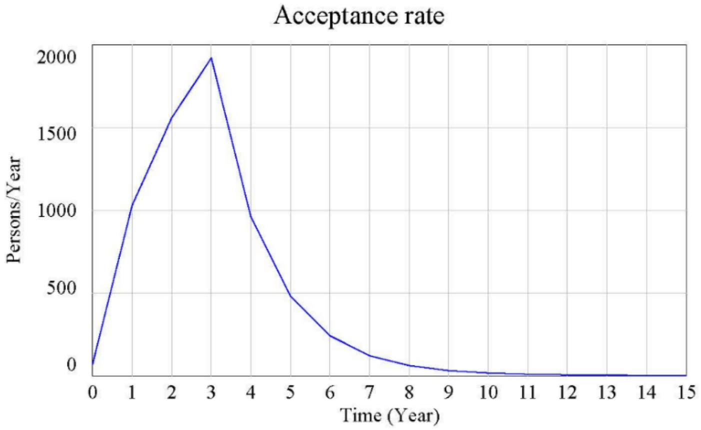


Figure 5.16 The 'acceptance rate' of eHMIS.

Figure 5.17 shows that the 'individuals' intention to use' the technology (red) is a dominant factor in the early years of technology acceptance followed by the promoters (brown) and inhibitors (green) in the later phases of technology acceptance cycle. The ‘individuals’ intention to use’ develops from the effectiveness of training and communication about the technology to the ‘potential users’. Training increased potential users’ understating of the system benefits or usefulness which was mentioned as one of the important factors that influenced technology acceptance by the focus group members. The focus group members from the FMOH highlighted that the willingness to use the system increased as the benefits or usefulness of the system was well understood by the ‘potential users’ (Appendix 4.4, Code Groups: Benefits). Besides, the effectiveness of training increased the end-users ICT skills level to lead to an improved perception of ease of use (Appendix 4.4, Code: Ind_ICT use skill). The ‘individuals’ intention to use’ was also influenced by the ability of technology to ‘reduce work burden’ of end-users which was linked to the perception of usefulness (Appendix 4.4, Code: Use_Burden).

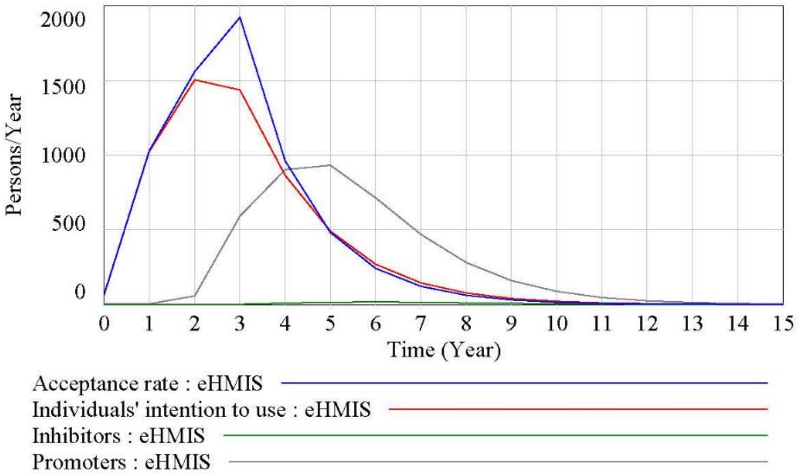


Figure 5.17 The influence of ‘individuals’ intention to use’, ‘promoters’ and ‘inhibitors’ on eHMIS acceptance rate.

The social influence grows in the later phases of eHMIS use as shown in brown (promoter) and green (inhibitors) lines in Figure 5.17. The expert users, supervisors and the culture of teamwork were indicated to influence the behaviour of technology users by the focus group team (Appendix 4.4, Code Groups: Social). The positive word of mouth from satisfied users played a key role in promoting eHMIS use among potential users. On the contrary, the terminated users of eHMIS propagated the negative word of mouth that hinders acceptance of technology (Appendix 4.4, Code Groups: Satisfaction).

The influence of Individuals’ intention on eHMIS acceptance

The effectiveness of training, the ability of technology to reduce work burden, and the quality of technology as perceived by the ‘potential users’ were important elements in building the individuals’ intention to use (Appendix 4.4, Code Groups: Individuals’ Intention to use). Training and communication shaped the ‘potential users’ perception of technology usefulness and ease of use. The influence of ‘individuals’ intention to use’ was high on the acceptance rate of eHMIS in the early years of the implementation. The end-users of eHMIS had a high expectation that the technology could 'reduce work burden' (See Appendix 4.3). This understanding had developed from effective training and communication (Appendix 4.4, Code: Impl_Training). Furthermore, good system and services quality levels also contributed to high ‘individuals’ intention to use’ driving the rate of acceptance in the early years of implementation (Appendix 4.4, Code Groups: Individuals’ Intention to use). The ‘potential users’ developed the intention to use based on the technology usefulness and ease of use through training and communication (Davis, 1989).

The influence of promoters on eHMIS acceptance

‘Actual users’ experience with the technology makes them either satisfied or dissatisfied users. The user satisfaction comes from the system quality, information quality, services quality and improved work performance from the system use. ‘Actual users’ become ‘Satisfied users’ if the system has a good ‘technological quality’ that improves end-users work performance. Once the technology is accepted by the ‘potential users’, the focus must be to keep the end-users satisfied. Happy users can spread the benefits of technology to other ‘potential users’ to speed up technology acceptance. As more ‘potential users’ become ‘actual users’ the promotional social influence also increases (See Chapter 5.3). In the case of eHMIS, the promoters’ social influence was strong as the system exhibited good technological quality and improve the work performance (See Appendix 4.3).

The influence of inhibitors on eHMIS acceptance

Inexperienced ‘actual users’ may not be comfortable with system use at the beginning that may lead to dissatisfaction. Besides, the users’ satisfaction level is determined by the usefulness of technology to improve the work performance of ‘actual users’. Unsatisfied users may terminate to use the technology, leading to the spread of negative word of mouth that can decrease the rate of acceptance. Therefore, it is necessary to address the users' dissatisfaction through intervention measures as early as possible to increase acceptance of technology in the later phases of technology use. The interventions include improving system quality, services quality, information quality, training and incentives in the form of finance, promotion or award (See Chapter 5.3). The number of 'dissatisfied users' and 'terminated users' of eHMIS were low compared to SmartCare due to system ease of use, ability to improve end-users performance and low frequency of use (Appendix 4.4, Code Groups: eHealth).

5.5.2. The simulation results of SmartCare acceptance rate

The same system dynamics simulation model of the socio-technical factors of technology acceptance (Figure 5.6) with different parameter values depicted in Table 5.4 are used to study the behaviour of SmartCare acceptance in the Gandhi Memorial Hospital, Ethiopia. The model is simulated with a time step of 1 year for 15 years but different simulation values in Table 5.4 using Vensim. Vensim is used for developing, analyzing, and packaging dynamic feedback models (Ventana Systems, 2015).

The values of model variables are derived from the case of SmartCare implementation in Gandhi Memorial Hospital. The SmartCare aims to automate the services of all departments in the hospital. There are about 320 supportive and technical staffs in the hospital known as the 'adopted population' in the simulation model. The technical staffs are mainly clinicians that include specialists, general practitioners, nurses, laboratory technicians, pharmacists and others. The support staffs comprise administrative and finance officers, cashiers and medical record unit (MRU). The potential users of SmartCare are technical and MRU staffs who are 200 in number (See Chapter 5.4.2). The acceptance of SmartCare varied from department to department due to the difference in the level of work burden, ICT skills and benefits of the system in each department.

The lack of quick response from the technical support team to address critical system quality issues, frequent failure of electric power, information security issues and lack of completeness were some of the reasons for the lack of SmartCare acceptance by the pharmacy, emergency, and outpatient and after delivery care service units (See Appendix 4.4). The MCH and MRU described the SmartCare system as useful and easy to use that had improved the performance of the departments. The users of the laboratory service unit found the system easy to use but not useful. The focus group members believed that the low level of ICT skills of the users also contributed to the weak acceptance of SmartCare in the hospitals (See Appendix 4.4).

The SmartCare users in various service units at Gandhi Memorial Hospital indicated different levels of system quality based on the ability of the system to meet their department's need. The pharmacy, outpatient and after delivery care service units indicated that the SmartCare system lacked some key functionalities. On the other hand, the users were satisfied with the quality of SmartCare modules of the MRU, MCH and Laboratory departments. The emergency, minor operations and psychiatry departments had mixed reaction towards the quality of SmartCare system because the system was not electronically integrated with other electronic systems. Therefore, the system quality of SmartCare implementation in the Gandhi Memorial Hospital was estimated to be 0.4 (40%).

The first line technical support was generally good for minor operational related technical issues because of dedicated and locally available technical support team. However, the support to software related security and missing functionality issues was described as very poor by the OPD, pharmacy and after delivery departments. Besides the lack of printers in the OPD, the frequent electric power interruption and lack of backup power sources were weaknesses of the service qualities. Based on the evidence from different service units, the services quality of SmartCare system in Gandhi Memorial Hospital was estimated 0.3 (30%).

The total medical and support staffs of Gandhi Memorial Hospital were 320, i.e., the adopted population in the simulation models. The potential users (technical staffs and MRU staffs) were 200 in total. There were five OPD serving an average number of 150 patients every day. Therefore, the average patient load per an OPD was 30 patients per day. An end-user in the OPD used a SmartCare system 30 times a day which was about 7500 times a year (50 week/year x 30 time/days X 5 days/week). As a result of the heavy workload, weak technical support service and weak typing skill, the end-users were not willing to use for more than ten weeks, i.e., 1500 times, before stopping to use.

The SmartCare implementation in Gandhi Memorial Hospital was planned in 2014 according to the project implementation schedule but only to be implemented in 2016 after 2 years of delay. There were no financial and promotional incentives awarded to SmartCare users in the Gandhi Memorial Hospital, hence 'incentives' was set to zero.

SmartCare users in the OPD, emergency and pharmacy departments indicated that the system put extra workload to the users instead of reducing the burden (Appendix 4.4, Code: Use_Burden). The users in the laboratory and after delivery care departments did not see the value added by the system (Appendix 4.4, Code Groups: Benefits). SmartCare users in two of ten service delivery units believed that the system could reduce work burden. The estimated performance improvement rate was 0.2 (20%). Therefore, the ability of the SmartCare system to reduce the work burden of the users was low. The initial values of key parameters used to simulate the technology acceptance of SmartCare system are presented in Table 5.4. Appendix 5.2 shows the detail parameters, values and equations for the simulation of socio-technical model with the case of SmartCare.

Despite the different levels of Smartcare acceptance by the departments in the Gandhi Hospital, SmartCare implementation in Gandhi Hospital has the following strengths.

- Availability of technical support staff in the hospital
- Quick first line technical support
- Good internet connection
- Availability of computers.
- Strong support from the top management.

Table 5.4 Simulation values of socio-technical dynamics of SmartCare acceptance.

Variable	Initial Value	Unit
Adopted population	320	People
Potential users	200	People
Contact rate	20	People/Year
Delay time	3	Year
Effectiveness of Training	0.4	Dimensionless
Frequency of use	7500	1/Year
Incentives	0	Dimensionless
Performance improvement rate	0.2	Dimensionless
Period of use	1	Year
Reduce work burden	0.2	Dimensionless
Services quality	0.3	Dimensionless
System quality	0.4	Dimensionless
Time to intervention	4	Year
Time to training	2	Year
Trials before termination	1500	Dimensionless

The acceptance rate of SmartCare was lower than that of eHMIS. The low acceptance of SmartCare was associated with a high workload of clinician users and the parallel operations of the paper and electronic systems (Appendix 4.4, Code: Use_Burden). Moreover, the inability of the SmartCare system to meet users' needs, slow response of the support team (mainly second-line technical support) to users' enquiry, lack of system integration with existing electronic systems, and lack of benefit to the users as the system was not fully functional in all departments were other concerns indicated by the end-users (Appendix 4.4).

The strengths of SmartCare implementation indicated above increased the users' intention to use the system in the early years of technology acceptance in the Gandhi hospital. However, the problems discussed earlier affected the acceptance rate in the later phases of SmartCare implementation. As a result, the acceptance of SmartCare dropped significantly after year two. The low acceptance rate after the second year was associated with the heavy workload, weak technical support service and weak ICT skill. The overshoot and collapse in Figure 5.18 were due to the end-users unwillingness to use for more than ten weeks because of the aforementioned reasons and the high frequency of system use. Figure 5.18 showed the slowdown in the acceptance of technology in the later phase of implementation. The optimism from the potential users of the SmartCare system could not last long for the system failed to satisfy the end-users as they began to utilise it for their daily tasks.

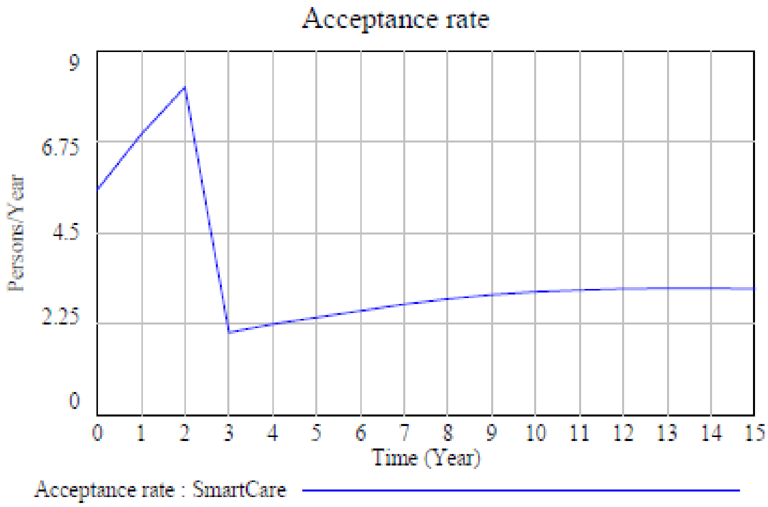
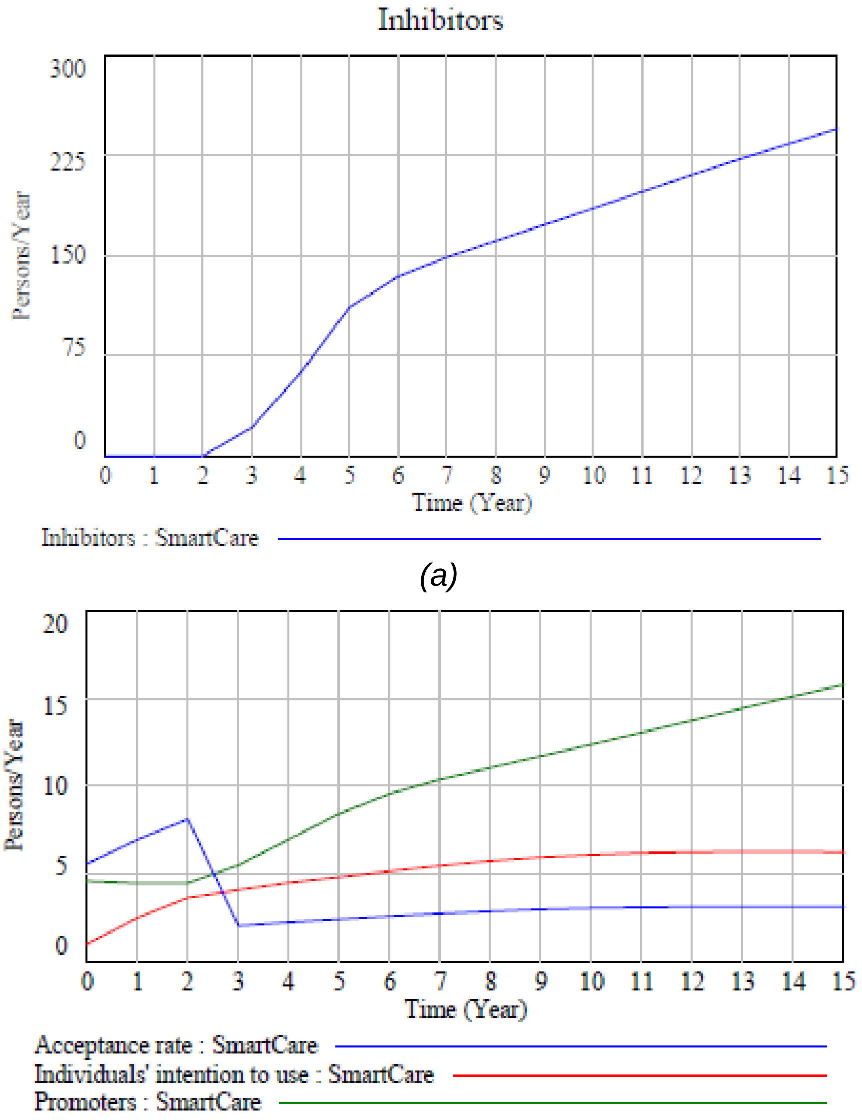


Figure 5.18 The 'acceptance rate' of SmartCare.

The focus group discussion with the FMOH indicated that as the implementation of SmartCare was expanded to other departments, previously installed system was falling apart. The simulation graph (Figure 5.19 (a)) showed that inhibitors became dominant in the later phases of implementation slowing down 'acceptance rate' as more and more users were dissatisfied and even stopped using the system. The individuals' intention to use the system was also low compared to eHMIS even in the early years of SmartCare implementation (red colour in Figure 5.19 (b)). The potential users were not convinced of the benefits, and system use was not easy because of workload and the mandatory paper system in parallel. Unlike eHMIS, the promoters' social influence was the dominant SmartCare acceptance factors than the individuals' intention even in the early years of Smartcare use. These could relate with the happy users in MRU and MCH departments. In general, social inhibitors were stronger than the social promoters in the later phases in the case of SmartCare acceptance.



(a)

(b)

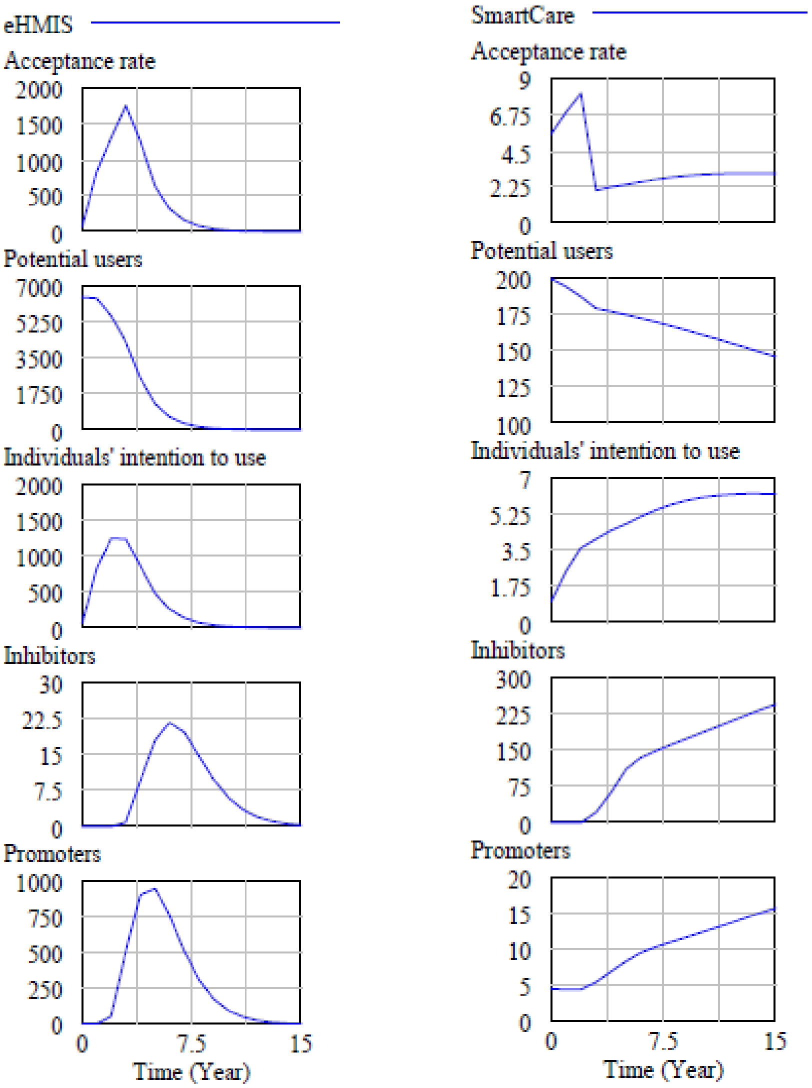
Figure 5.19 (a) The influence of 'inhibitors' on SmartCare 'acceptance rate'. (b) The influence of 'individuals' intention to use', 'promoters' and 'inhibitors' on SmartCare 'acceptance rate'.

According to TAM, the users' perception of ease of use and usefulness of the SmartCare system drive the users' intention to accept a technology. The end-users attitude to use SmartCare was a cumulative effect of a system's ability to reducing the workload of the users, understanding of technological quality, and the effectiveness of training and communications. These factors drive the acceptance rate of the SmartCare system.

The social influence of 'actual users' on the 'potential users' (green colour in Figure 5.19 (b)) grew with an increase in the number of 'actual users'. The social influences might have a promoting or an inhibiting effect on 'potential users'. The higher the 'actual users' level of satisfaction, greater the social influence of 'promoters' in using technology. On the other hand, the social influence of 'inhibitors' became dominant as the number of dissatisfied users increases. In general, as the number of 'actual users' increased, the social influence of 'promoters' or 'inhibitors' also increased in the later phases of SmartCare use (Figure 5.19 (a) and (b)).

Figure 20 (a) and (b) compared the acceptance of eHMIS and SmartCare systems and the corresponding factors that influence technology acceptance respectively. Once the users began to use the system and gained experience, the level of satisfaction or dissatisfaction with the system played a key role in driving the social influence (promotion or inhibition). The level of benefits from the system use was a key determinant of end-users satisfaction. The system, service, and information quality also influenced the level of users' satisfaction. The satisfaction level of SmartCare users varied across the departments of Gandhi Memorial Hospital. The system was more useful to some departments and a burden to others as explained by the end-users (See Chapter 5.4.2). The individuals' intention to use and the social influence of 'promoters' were lower in the SmartCare compared to eHMIS (See Figure 5.20 (a) and (b)). Oppositely, the social influence of 'inhibitors' was high within SmartCare users than the eHMIS users (See Figure 5.20 (a) and (b)). As a result, the overall acceptance of eHMIS was by far better than the SmartCare system (See Figure 5.20 (a) and (b)).

The influence of 'inhibitors' was high in SmartCare compared to that of eHMIS as shown in Figure 5.20 (a) and (b) respectively. The 'inhibitors' dominance was due to a large number of dissatisfied and terminated SmartCare users. Quick intervention measures were needed to avoid a complete failure of the SmartCare system in Gandhi Memorial Hospital. The proposed intervention measures included improving system quality, services quality, awarding financial incentives and job promotions, and offering on the job training. On the other hand, the influence of 'promoters' on the ‘potential users’ was strong in eHMIS than SmartCare. The ‘promoters’ dominance in eHMIS was due to large number of satisfied eHMIS users than SmartCare users.



(a) *(b)*

Figure 5.20 (a) Factors influencing eHMIS acceptance. (b) Factors influencing SmartCare acceptance.

Eventually, eHMIS users accepted the system at a faster rate than SmartCare users. The individuals’ intention to use eHMIS was strong in driving the early years of technology acceptance. The good intention to use eHMIS was a result of the system ease of use and a better understanding of the system benefits. Moreover, the social influence of ‘promoters’ was stronger in eHMIS as most of the users were relatively satisfied with the technological quality and performance improvements achieved by using eHMIS. The influence of ‘promoters’ on technology acceptance grew as more 'actual users' became ‘satisfied users’. Therefore, the rate of technology acceptance was facilitated through strong individuals' intention to use technology and promotional social influence.

The effectiveness of training could make the use of technology easy and communicating the benefits of technology to the 'potential users' might create a strong intention to use in the early years of technology implementation. Unfortunately, individuals' intention to use SmartCare was weak, as a result, the acceptance rate was low in the early years of technology use. Because of end-users' frustration with the benefits of technology, there was a high dissatisfaction and termination rate by SmartCare users. This resulted in strong 'inhibitors' influence leading to a low rate of SmartCare acceptance.

As the number of 'actual users' grew in both eHMIS and SmarCare, the social influences became stronger in terms of impacting the rate of technology acceptance in the later years of technology use. In the early years of technology use, the social influence was low due to a small number of 'actual users' in both systems. Hence the individuals' intention to use technology had a dominant influence on the rate of technology acceptance (See Figure 5.20 (a) and (b)). The 'potential users' that were informed about the benefits of technology and developed ICT skills through effective training to use technology, showed strong intention to use. Moreover, good system and services quality level helped to build strong individuals' intention to use (Appendix 4.4, Code Groups: Individuals' Intention to use).

To facilitate technology acceptance in the early years of technology use, the focus should be on the effectiveness of training and communication to create awareness about the benefit of technology and develop users' skill to use technology. Involving 'potential users' as early as possible in the process of technology design and implementation also contributed to strong individuals' intention to use. Users' involvement in the process of technology design and implementation, and effective training increased the rate of acceptance rate in the early years of implementation (See Appendix 4.4). The training and communication efforts drive the perceived ease of use; whereas users engagement influences the perception of technology usefulness (Wang and Liu, 2005).

A better technological quality through an improved system and services quality facilitated technology acceptance not only in the early years of technology use but also in the later phases of technology use (See Appendix 4.4). The satisfaction level of 'actual users' had a bigger impact on social influence. Satisfied users promoted the use of technology, whereas dissatisfied users inhabited through the words of mouth. Therefore, to facilitate technology acceptance in the later phases of technology use, the 'actual users' should be kept satisfied. In summary, the rate of technology acceptance improved by building strong individuals' intention to use in the early years and ensuring users' satisfaction in the later phases of technology use. The next section describes the simulation results of users' satisfaction and dissatisfaction rate in both eHMIS and SmartCare.

5.6. The simulation results of users' satisfaction

The level of end-users' satisfaction determines the acceptance of technology through the promoters' social influence as indicated in Figure 5.4. An increase in 'satisfied users' promotes the use of technology by influencing 'potential users' through the word of mouth. The focus group discussions with the FMOH indicated that satisfaction of end-users is achieved when the use of electronic health systems improve the quality of healthcare services provision, improve informed decision-making, enable users to perform their tasks quickly and increase the work performance of end-users (Figure 5.21). The focus group discussion was qualitatively analysed, the results were organized and Figure 5.21 was constructed in ATLAS.ti. The focus group team argued that the satisfaction of end-users and patients are also an indication of established technology use. Figure 5.21 describes factors that influence the satisfaction level of SmartCare and eHMIS users.

Figure 5.21 Factors influencing 'user's satisfaction'.

SmartCare should enable easy access to patient medical records and the system should fulfil the stakeholder's requirements to ensure users' satisfaction. The focus group discussion with the FMOH stressed that a patient wants to get improved quality of healthcare services from the doctor. "If a technology contributed to a better patient healthcare services experience and greater patient satisfaction, It is evidence of established technology use. Moreover, if a sick patient is encouraged to visit the health facility again without waiting until the sickness is in critical condition, it is an indication of improved technology use."

The focus group with the FMOH links the satisfaction of end-users to the ability of electronic systems to a realization of the anticipated benefits. eHMIS and SmartCare users who enter data into the electronic systems were not satisfied with the system because the benefit of their data collection effort was not visible. The focus group member asked "Can you imagine how much frustrated the doctors will be if they enter data to the electronic system but do not really see the benefits of their data entry effort?" Information was rarely used to make decisions (improve performance) at the data entry level leading to dissatisfied users. The causes tree of users' satisfaction in Figure 5.22 is constructed using Vensim and demonstrates factors that influence eHMIS and SmartCare users' satisfaction.

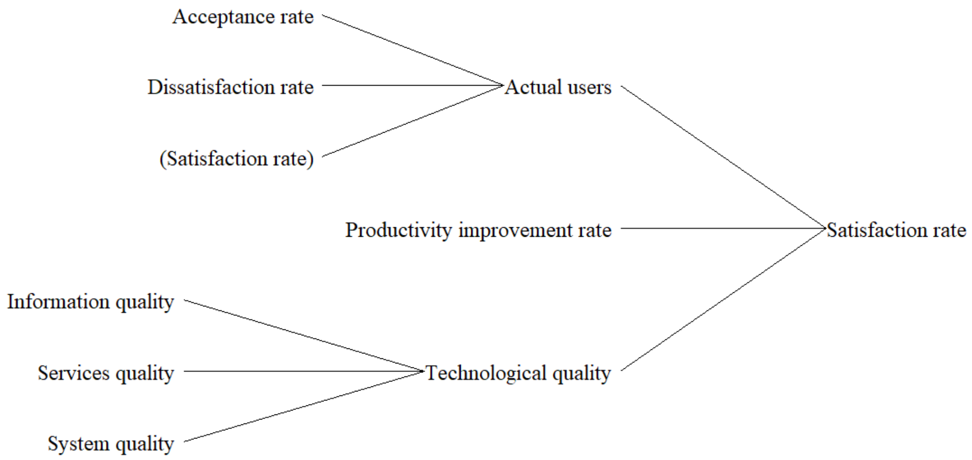


Figure 5.22 The causes tree of users' satisfaction.

Information from the eHMIS system might be used to make decisions at a regional or national level, yet the use of information at the data entry level is very low. Electronic health systems support the effort of creating healthy and informed citizens by providing health-related information for timely and accurate decision making. It also improves healthcare services delivery and enables the monitoring and evaluation of progress and improvements towards better healthcare services. Smartcare and eHMIS systems can make end-users and patients happy if the above objectives are achieved.

The focus group discussion with the FMOH indicated that the users are dissatisfied with SmartCare because the technology solution is considered as a burden by users. Furthermore, the technology could not fulfil user needs or improve their work performance. Users with low experience in using computers and electronic technologies may not be voluntary users even if they understand the usefulness of the technology to improve work performance. This is mainly because of the fear of technology.

Figures 5:23 shows that the simulated users' level of satisfaction rate was higher than the dissatisfaction rate in eHMIS. However, the opposite is true for the SmartCare system (See Figure 5.24). The results were obtained by simulating the socio-technical system dynamics model of technology acceptance (See Figure 5.6) using Vensim software. The system dynamics model is originally developed by the author through a literature review, qualitative and quantitative data obtained in the process of this system dynamics modelling research study.

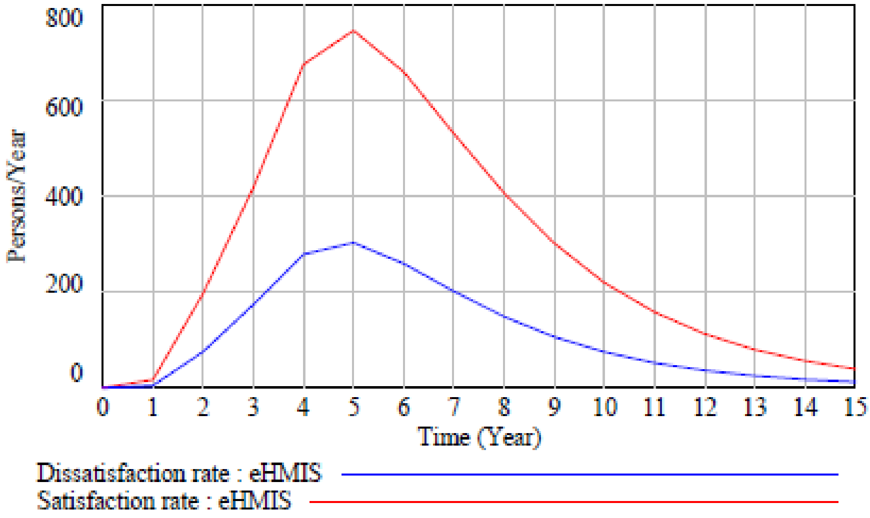


Figure 5.23 eHMIS users' satisfaction and dissatisfaction rate.

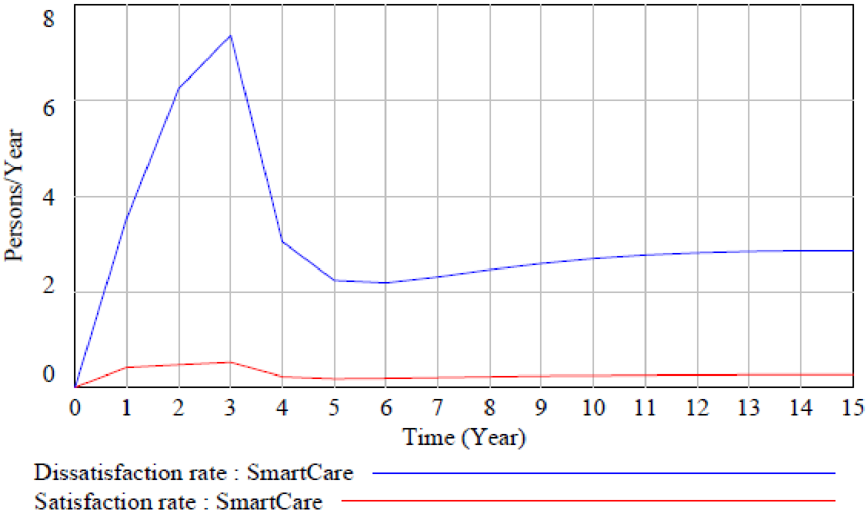


Figure 5.24 SmartCare users' satisfaction and dissatisfaction rate.

The level of users' satisfaction is associated with system benefits that can be achieved by the use of systems. The higher users' satisfaction level of eHMIS than SmartCare seems to be due to the well-recognised benefits of eHMIS than that of SmartCare. eHMIS had end-users dedicated to the data management and operation processes of the system. Besides, the end-users were less burdened with the system use due to less frequent use of eHMIS to submit monthly aggregated health systems monitoring and evaluation data to the centeral data repository. Conversely, SmartCare users are clinicians with busy workload treating 30-40 patients a day and capturing the medical records of all patients daily. SmartCare users need to capture patient medical records, prescriptions, laboratory test results, dispensed medicine and other health information daily. Therefore, the frequency of SmartCare use is higher than that of eHMIS. As a result, end-users indicated that the use of SmartCare is a burden. Moreover, it was used in parallel with paper system putting additional work burden on clinical users of SmartCare.

The SmartCare modules serve different departments of a healthcare facility and the level of benefits and users satisfaction vary within departments in the Gandhi Memorial Hospital case study. In general, the smilulated satisfaction rate is by far lower than the dissatisfaction rate (Figure 5.24). Satisfied users use the information product of a system to make decisions to improve their performance and healthcare services delivery in their day-to-day activities. However, the information use from the SmartCare system is significantly low in all departments of Gandhi Memorial Hospital. The satisfaction level also has influence on the quality of information product. Dissatisfied SmartCare users indicated that they only use the system when they have time to do so. As a result, there was a large volume of data backlog that was not entered into the system. This led to data quality problems because of incomplete information on the Smartcare system. The ultimate goal of implementing an electronic system is to produce quality information to make accurate decisions to improve healthcare services. The next section address the information quality factors of eHMIS and SmartCare implementation and the simulation results.

5.7. The simulation results of information quality

The data quality problems of eHMIS and SmartCare may emerge from any level of data management processes. Data collection, data entry, data analysis, reporting, information dissemination and information use stages can contribute to the data quality problem (Aqil, Lippeveld and Hozumi, 2009). The focus group discussion with the FMOH highlighted that data entry without the meaningful use of information for decision making at the health facility level was the main source of information quality problems of eHMIS (Appendix 4.4, Code: Use_Information Use). There was a bulk volume of raw data that was not used for any kind of decision making due to data quality issues. The focus group further discussed that the quality of HIMS data and the use of information for decision decreased as one went down from the FMOH to the health facilities (Appendix 4.4, Code Groups: Information quality). The quality of data was strongly linked to the use of information for decision making. The focus group members argued that data quality indicated the level of information use in the health facilities. Similarly, the use of information to make decisions was an indication of the end-users satisfaction level.

The processes of HMIS data collection in the health facilities as explained during the focus group discussion with the partners of the FMOH was as follows (Appendix 4.4, Code: Impl_Data management). HMIS focal person manually collected data from the paper records at each service delivery points of the health facility. The data collected from each service points was entered into eHMIS. In the context of eHMIS, information was mainly used by the planning and program department. eHMIS focal persons hardly received information from the clinicians, hence they needed to go and collect data from the paper record at each service point and key-in into the electronic system. It was the responsibility of eHMIS focal person to collect, analyse, generate and disseminate information in the usable format to decision-makers.

The focus group discussion with the FMOH highlighted that the HMIS data was not accurately captured in the eHMIS database at the health facilities. The majority of data discrepancies were related to arithmetic errors at the time of data collection from the paper health records. The difference between data collected from the paper record and the information reported through the electronic system posed a data quality problem. It was indicated that the weak teamwork culture between the clinicians who generate HMIS data and the HMIS focal person who compile and report through eHMIS (electronic system) resulted in poor data quality at health facility level or entry point (Appendix 4.4, Code Groups: Information quality).

The focus group discussion with the FMOH further indicated that the lack of willingness and a shortage of capacity to analyse data, to generate a report and disseminate the information for decision making was a shortfall in the data management processes. The management conducted a regular supportive supervision to improve the data quality of eHMIS. Moreover, the data quality assessment team in health facilities met every month to verify the quality of HMIS data before using the information for decision-making. The regular meeting of HMIS focus person with the monitoring and evaluation team aimed at improving the quality of data and the appropriateness of the reporting formats generated from the eHMIS (Appendix 4.4, Code Groups: Satisfaction).

The report generated from eHMIS was mainly used for planning, monitoring and evaluation and management decision making. The focus group discussion with the partners of FMOH described that the information in eHMIS was password protected to secure information from illegal access by unauthorized users. Only authentic users with correct login credentials were able to access the system. However, during the health facility visit, the end-users were observed sharing one username and password among all other users in the facility. The lack of proper and strong system security contributed to the data quality problem. Sharing of credentials among end-users caused lack of accountability for wrong data entered into the system (Appendix 4.4, Code Groups: Information quality).

A focus group discussion with the FMOH indicated that SmartCare system stored personal health information of a patient, hence information access was allowed to only legitimate users. Personal health information is sensitive, therefore, strong attention is given to secure data and protect from illegal access. The system security issues require serious attention to improve data quality and establish accountability during data quality auditing of the electronic system (Appendix 4.4, Code Groups: Information quality).

The quality of information generated from the eHealth system must be satisfactory for the information to be used for decision making (Appendix 4.4, Code Groups: Satisfaction). The socio-technical system dynamics model (Figure 5.6) developed in this thesis describes the influence of users' satisfaction and system quality on information quality. It also shows the influence of feedback from information quality on the users' satisfaction. Satisfied users contribute to improved data quality, whereas dissatisfied users impact the quality of data negatively. As indicated earlier by the focus group team, dissatisfied users felt the system as a burden and did not use it regularly. These resulted in an incomplete set of data and poor data quality that could not be used for decision making. So the end-users did not benefit from technology use to improve the work performance that led to dissatisfaction. The dissatisfied users either failed to submit information timely or the date they provided was incomplete. Besides, dissatisfied users did not care about the accuracy of information as they hardly use the information product for decision making.

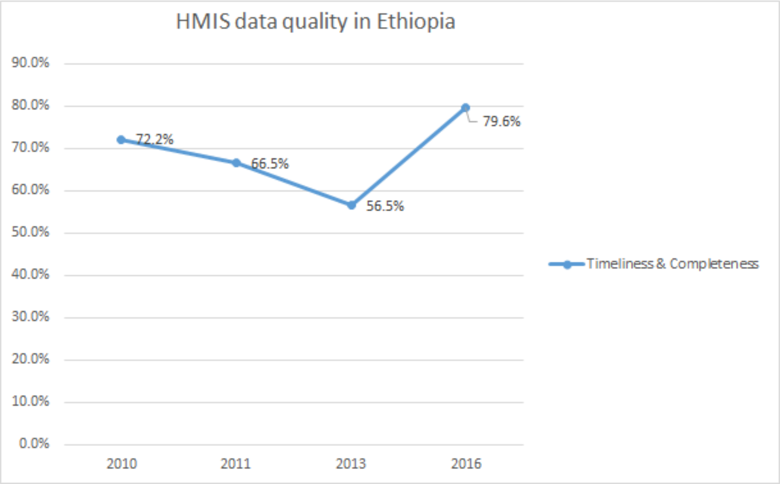


Figure 5.25 National level HMIS data quality in Ethiopia (Sources: EPHI et al. 2016; FMOH 2011; FMOH 2013; FMOH 2014).

The quality of data is assessed with respect to the completeness and timeliness of the reports available at the service delivery points of health facilities, Woredas, Zonal and regional offices (EPHI, FMOH and WHO, 2016). Report completeness refers to the number of reports received according to schedule from all reporting centres (EPHI, FMOH and WHO, 2016). Timeliness refers to the reports received within a defined schedule of a given reporting period (FMOH, 2014c). The national level HMIS data quality in Ethiopia is depicted in Figure 5.25.

HMIS data quality had been dropping at the start of technology use before it began to improve after 2013 (Figure 5.25). The decrease in data quality at the beginning may link to the change in the workflow processes and lack of experience in using electronic technology. The data quality improvement in the later phases of technology use could be related to increased ease of use as end-users gained experience in technology use and became familiar with the workflow processes. It may also link to users satisfaction as a result of benefits achieved by using eHMIS. The data quality improvement may also link to a continuous improvement of the eHMIS system quality to meet the end-users’ need based on the feedback from users.

The main purpose of implementing eHealth technology is to produce quality information that can support decision-making process to improve healthcare services delivery. The quality of information product impacts the satisfaction of users and the long-term sustainability of the technology. As shown in the causes tree of information quality (Figure 5.26), information quality is mainly influenced by system quality, satisfied users and dissatisfied users. The causes tree is developed using Vensim by applying systems thinking on factors that influenced information quality as reported in the literature and focus group discussion data (Appendix 4.4, Code Groups:

Information quality). Vensim is a powerful software package for model building and graphical presentations of complex models (Ventana Systems, 2015). Vensim is also very strong in terms of capacity, performance and functionality (Ventana Systems, 2015). The simulation speed is fast, the sensitivity analysis is both fast and powerful (Ventana Systems, 2015). There are no practical limits on model size, and it is easy to extend the base capabilities using external functions of the Vensim DLL (Ventana Systems, 2015).

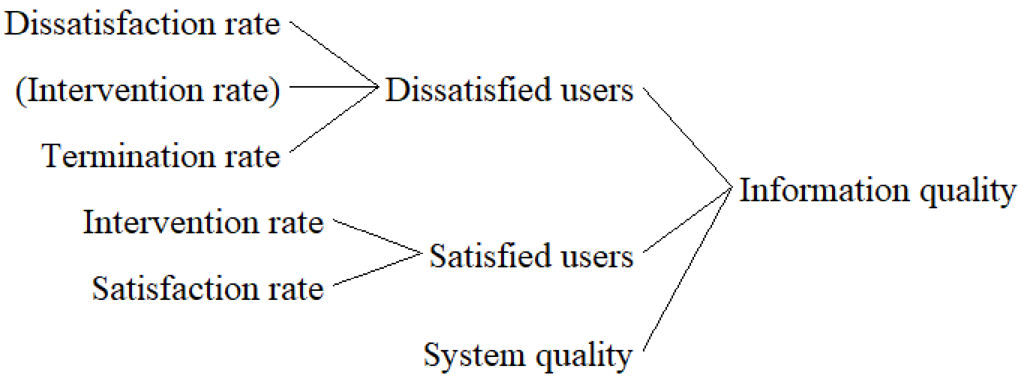


Figure 5.26 Causes tree of information quality.

The satisfied users and good system quality contributed to better information quality. Whereas, dissatisfied users compromised the overall data quality of the electronic health system as the dissatisfied users might fail to submit timely and complete data (Equation 5.22). An increase in the number of dissatisfied users will degrade the information quality. The more users' are satisfied, the better is the information quality. All variables that affect users' satisfaction level will have an impact on the quality of information. System quality has a strong direct influence on the quality of information product as indicated in the literature and confirmed by the focus group (See Chapter 2, Table 2.11).

$$\text{Information quality} = \text{System quality} * \frac{\text{Satisfied users}}{(\text{Satisfied users} + \text{Dissatisfied users})}$$

(Units: Dimensionless) (5.22)

The system quality focused on the system performance, capability, ease of use, and reliability (See Figure 5.27). Figure 5.27 was developed in ATLAS.ti by analysing the qualitative data gathered for this research study (Appendix 4.4). The focus group discussion with the FMOH indicated that system completeness was very critical in the implementation of an electronic health system. The SmartCare system failed to address all the requirements that the users needed to execute their tasks. For example, the SmartCare system implemented in Ayder Hospital, Mekele, Ethiopia did not have a complete list of diseases. When the clinical users encounter a type of disease not pre-loaded in the system, the users choose “others” from the disease lists of the electronic system and capture the detail descriptions of the disease on paper (Appendix 4.4, Code Groups: System quality). SmartCare was planned to be a national electronic medical record system, therefore the system must be complete in addressing the needs of all end-users. The completeness of the system to meet users’ requirements was an indication of systems capability. The system needs to address end-to-end processes.

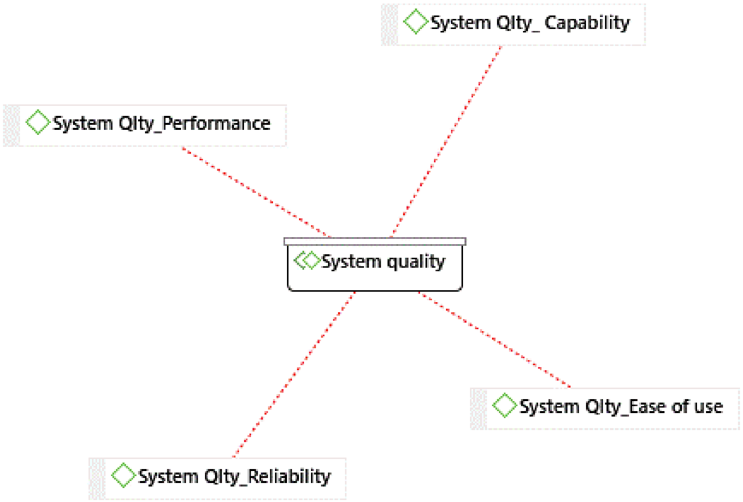


Figure 5.27 Factors influencing the system quality (Appendix 4.4, Code Groups: System quality).

The focus group discussion with the FMOH further indicated that the SmartCare system was not interoperable with the Laboratory Information System (LIS) developed by Polytech Company. The discussion highlighted that the LIS from Polytech was designed to interface with laboratory equipment to capture test results directly from the equipment. However, SmartCare system in Ayder Hospital, Ethiopia did not interface with the laboratory equipment and was not interoperable with the LIS. According to the focus group members, the SmartCare system lacked the capacity to cover end-to-end service delivery processes. The interoperability problem of SmartCare system was also associated with a system design issue. SmartCare was not designed to interface with medical devices such as laboratory equipment. SmartCare could have captured laboratory test results directly from laboratory machines, however, the design of SmartCare had not included interoperability functionalities (Appendix 4.4, Code Groups: System quality).

A member of the focus group discussion from the FMOH strongly believed that the SmartCare system had design problems and failed to meet an end-users need (Appendix 4.4, Code: SmartCare). Furthermore, the system was not comprehensive to address end-to-end workflow processes in the healthcare facilities. The design of the SmartCare system must be comprehensive and able to automate end-to-end workflow processes in healthcare facilities. The focus group discussion with the FMOH linked the problem of SmartCare with poor design rather than an implementation problem. The design problem of SmartCare was indicated as another system capability issue that had affected the system quality. The weak system security features of SmartCare was another system capability issue that made end-users doubt the quality of information generated from the system (Appendix 4.4, Code Groups: System quality).

The focus group discussion with the FMOH highlighted the importance of system ease of use or user-friendliness for improved system quality. The navigation screen or graphical user interface (GUI) design was not user-friendly or not easily understood by the eHMIS users. The focus group members discussed the ease of use as an important element of electronic systems quality to facilitate acceptance by end-users. Most electronic systems were developed with advanced users in mind which was not the case in Ethiopia. In developing countries like Ethiopia, physicians had very limited ICT skills. Therefore, a GUI of the system must be developed to accommodate users with very little skills in using computers. The focus group team further discussed that eHealth system was relatively a new technology so it was too early to ask clinician users to adjust themselves towards the advanced electronic system (Appendix 4.4, Code: Org_Workflow process). Therefore, it should be the responsibility of the technical team to design and develop a system that could be used by the skill level of end-users. The design process of eHealth systems must put the low skills level of the end-users into consideration to ensure the ease of use.

The focus group discussion with the FMOH highlighted that the systems were developed based on the experience of other countries and not fully customized into the local context. For example, eHealth systems used the Gregorian calendar instead of the Julian calendar used in Ethiopia. As a result, end-users struggled to set the proper reporting period according to Ethiopian fiscal reporting period. The conversion from the Gregorian calendar to Julian calendar caused dissatisfaction within the eHMIS users when generating reports. The focus group team emphasized the need for designing technologies in the local context. Both SmartCare and eHMIS planned to be national systems, yet they were not designed to fit into the local context or culture. The Ethiopian fiscal year calendar is different from the majority of the world. However, the systems used a Gregorian calendar instead of the (Julian) Ethiopian calendar. Therefore, generating a report in Ethiopian calendar was a challenge. Moreover, systems used the English language instead of a national language of Ethiopia, Amharic. The calendar and language factors affected the eHMIS and SmartCare ease of use. The calendar system and language factors should be designed in the local context to improve the ease of use (Appendix 4.4, Code: System Qlty_Ease of use). The ease of use is an important system quality attribute.

The focus group discussion with the FMOH described that the eHMIS system failed to execute commands quickly. The eHMIS at the FMOH was slow during the generation of a national HMIS report due to the interoperability problem between the two eHMIS systems (Appendix 4.4, Code: System Qlty_Performance). System performance was highlighted as an important system quality factors. The focus group discussion with partners of the FMOH indicated that eHMIS was still work in progress based on end-user feedback. Hence, improvements were still underway to continuously upgrade the system performance of eHMIS.

The focus group discussion with the FMOH indicated that system reliability was also necessary to ensure system quality. It was explained that a SmartCare system had only one EMR server at a health facility without a failover server as a backup in the event of server failure. The lack of a backup server was a major challenge to the sustainability of SmartCare (Appendix 4.4, Code: System Qlty_Reliability). The storage and processing capacity of the servers was not planned effectively to accommodate the growing volume of SmartCare data. The frequent failures of software in both eHMIS and SmartCare was a frustrating experience to users at health facilities and the FMOH levels. There was a routine of software failure and fix in the daily operation of both systems (Appendix 4.4, Code: System Qlty_Reliability).

The information quality for eHMIS and SmartCare systems was simulated and the results are presented in Figure 5.28. The eHMIS demonstrated better information quality than the SmartCare. The system quality influenced the information quality at the beginning followed by the satisfaction and dissatisfaction of users as the system use progresses. The values of system quality used in the system dynamics simulation model was obtained from the interview data for eHMIS (See Appendix 4.3 and Chapter 5.5.1) and focus group discussion and Gandhi Hospital case study data for SmartCare (See Appendix 4.4 and Chapter 5.5.2). The system quality of eHMIS was better than Smartcare, therefore eHMIS demonstrated better information quality level at the beginning of the system use (Figure 5.28).

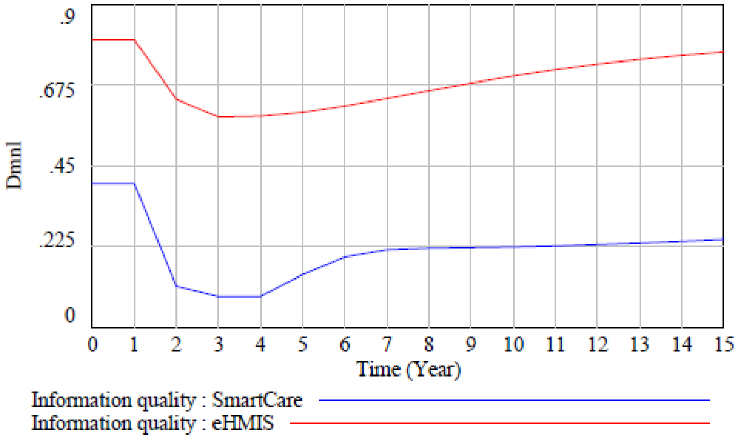


Figure 5.28 Information quality of SmartCare and eHMIS.

The sudden drop in the information quality in both SmartCare and eHMIS systems at the early years of technology use (Figure 5.28) can be associated with the satisfaction level of end-users. In the beginning, the users were not comfortable in using the technology due to system quality issues (ease of use), the lack of experience in using the electronic system and resistance to change. However, this ease of use problem improved as end-users became familiar with the technology and gained more experience in system use (Appendix 4.4: Code Groups: System quality).

In the case of eHMIS, the majority of end-users appreciate the benefits of the technology and the end-users are relatively satisfied. The survey of overall end-users satisfaction with eHMIS showed that 67.5% of users were strongly satisfied or satisfied with the system (See Appendix 4.3). In terms of ease of use, eHMIS users indicated that the system was easy to use and users' survey indicated that 80% of the users indicate the system was very easy or easy to use (See Appendix 4.3).

On the other hand, SmartCare users in Gandhi Memorial Hospital had different levels of benefit in each department. The group of users in the MRU and MCH benefited from the system and showed higher satisfaction levels. The other groups of SmartCare users in the Pharmacy, OPD, Laboratory, and Emergency departments did not benefit from the system, so they were dissatisfied. Similarly, the satisfied group of users described the system as easy to use; however, the dissatisfied group of users indicated the system as a burden.

Generally, the information quality of eHMIS was better than that of SmartCare because of its higher system quality level. The decline in the information quality at the beginning of eHMIS use recovered in the subsequent periods as the satisfaction level of eHMIS users rise. However, the low information quality of SmartCare at the beginning of system use was slow to recover in the later periods due to a low satisfaction level of SmartCare users in certain departments.

In summary, the decline in the information quality at the beginning of technology use was related to low system quality and low users satisfaction in the later phase. The low level of end-users satisfaction may relate to change resistance, lack of experience in technology use (low ease of use) or/and lack of clear understanding about the benefits of the system. The dissatisfied users did not use the system consistently leading to incomplete and inaccurate data. However, as end-users gained experience and became comfortable in using the electronic system, the level of satisfaction improved resulting in better data quality. Incomplete and inaccurate information could not have a meaningful impact on the processes of decision-making leading to a low level of users' satisfaction. Data quality was one of the major problems to the long-term sustainable use of eHMIS and SmartCare in Ethiopia.

The verification and validation of the system dynamics model outlined in Chapter 4.6 are used in the process of socio-technical model testing. The simulation results of the verification and validation tests of a socio-technical model of eHealth acceptance are addressed in the following section. The direct and indirect structure tests, sensitivity analysis, what-if and policy analysis are described in-depth as outlined by Barlas (1994, 1996) and discussed in Chapter 4.

5.8. The verification and validation of socio-technical model

The model testing process consists of model verification and validation processes (Pruyt 2013). Model verification ensures the correctness of codes and simulation that includes the verity of equations, consistently of units, an accuracy of numerical parameters (Pruyt 2013). In this simulation study, the model verification is addressed by direct inspection of equations, numbers, and units in addition to the verification of equations and units with simulation software (Vensim DSS Version 6.3D). The 'unit checks' were performed to ensure that the model is error-free using Vensim software package to verify the model correctness (Appendix 7.1 and 7.2).

The model validation process checks a wide range of tests to ensure the simulation model meets the study objective (Pruyt 2013). The model validation process is not the effort of proving the correctness of the model but it is the process of falsification of the model to build confidence in the model and its usefulness for the intended purpose (Pruyt, 2013; Barlas, 2016). It checks the credibility of the model to represent the real world. The validity of the model is judged against the purpose of the model because there might be other possible models capable of representing the real world situation in different ways. The model validation process of a socio-technical model of eHealth acceptance presented in this section follows the steps discussed in Chapter 4.6.

The model testing confirms the structural and behavioural validity of a model. The model structure tests aim at establishing confidence in a model structure by directly assessing the structure and parameters of the model without examining relationships between structure and behaviour (Forrester and Senge, 1980; Pruyt, 2013; Barlas, 2016). The two categories of tests that are designed to evaluate the validity of the model structure are direct structure tests and structure-oriented behaviour tests (Barlas 1994).

5.8.1. Direct structure tests

The model equations, the logical relationship of the model variables, dimensional consistency and the validity of parameters are assessed in the direct structure tests (Barlas 2016). In this PhD research project, the fundamental model structure adopts the Bass Diffusion Model and expands by incorporating the concepts of the TAM and IS Success Model as discussed in Chapter 3.3. The model structure is well supported by widely used and empirically validated models such as TAM, IS Success Model and TRA (Venkatesh & Bala, 2008; Venkatesh, Morris, Davis, & Davis 2003, Hale, Householder and Greene, 2003). Besides, the model structure was confirmed through focus group discussions with the FMOH and its partners in the implementation of eHMIS and SmartCare projects in Ethiopia (Appendix 4.3, 4.4 and 4.5).

Structure confirmation test

A structurally valid model should not contradict the knowledge about the structure of the real system (Forrester and Senge, 1980; Barlas, 2016). The ability of the model elements to reflect the real-world is discussed and reviewed with experts actively working in the eHMIS and SmartCare projects in Ethiopia (See Chapter 5.5 - 5.7). In this study, the literature findings with respect to the model variables were described during the focus group discussions and their applicability to eHMIS and SmartCare systems is assessed (See Appendix 4.3, 4.4 and 4.5).

The details of the model structure and basic equations of a system dynamics model of eHealth acceptance for long-term sustainable operations are discussed in Chapter 5.3. More comprehensive lists of the model variables, equations and values can be found in Appendix 5.1 and 5.2. The model variables were presented in two focus group discussion sessions to evaluate the structural validity of the model against the eHMIS and SmartCare projects in Ethiopia. The focus group members from the FMOH and partners of the FMOH confirmed that the model variables capture the reality in the two eHealth projects. The logic of model structure and the equations used in the model are supported by the literature study and the focus group members involved in the design, implementation and operation of the eHMIS and SmartCare systems in Ethiopia.

Dimensional consistency

The dimensional consistency checks the left and right side of the equations for dimensional consistency and the real-life meaning of the parameters. Each model equations are made to pass the dimensional consistency test. The model variables, values and equations are shown in Appendix 5.1 and 5.2. The ‘unit check’ functionality of Vensim DSS 6.3D is used to ensure the consistency of all variable units across the model (Appendix 7.1 and 7.2).

Parameter confirmation test

The conceptual and numerical parameters of the model (constant) were verified against the knowledge of real systems. The parameter values can be judged and estimated from interviews, expert opinion, focus groups, archival materials, direct experience, historical data etc. (Sterman, 2000). The parameters of the model are linked to the elements in the real system to ensure conceptual confirmation (Barlas, 1996).

The exogenous model parameter values of the two cases (eHMIS and SmartCare) in this PhD research project are judged by the focus group discussions, the interview data, the FMOH documents, and eHMIS database and experts opinion (See Appendix 4.3 and 4.4). eHMIS and SmartCare parameter, values and equations are shown in Appendix 5.1 and 5.2 respectively. The parameter values reflect the real-life condition of both eHMIS and SmartCare projects in Ethiopia. The following section discusses indirect structure tests. The test includes extreme-condition test, behaviour sensitivity test and boundary adequacy test.

5.8.2. Indirect structure tests

Indirect structure tests can be performed for the whole model or sub-models of the bigger model. It involves simulation to provide indirect information about possible flaws in model structures (Barlas 1996). Indirect structure tests include extreme-condition test, boundary adequacy test, and behaviour sensitivity test (Barlas 2016). The boundary adequacy, extreme condition, and sensitivity tests performed for indirect structure tests of the system dynamics model are presented in this section.

Boundary adequacy test

Boundary adequacy tests assess the appropriateness of the model boundary for the purpose of this study, i.e., to ensure the sustainable use of eHealth by understanding the influence of socio-technical factors. In general, the national level policy for the implementation and use of eHealth in Ethiopia was very supportive. The model boundary was set at healthcare institution level instead of a national level for this study. The socio-technical factors that influenced eHealth acceptance at health institution levels were included in the model boundary. The model boundary chart with endogenous, exogenous and excluded model variables are indicated in Table 5.1. The boundaries are adequately and appropriately set for this study within the context of socio-technical variable of eHealth acceptance at healthcare facilities.

This PhD research project focuses on the sustainable use of eHealth technology and information product. Without a sustainable use of eHealth at health facilities, it is not possible to ensure a national success in the implementation of eHealth. It was also confirmed through focus group discussions that the quality of information product can be improved by promoting information use at health facilities (Appendix 4.4., Code: Org_ICT culture). So the emphasis in this PhD research project is a sustainable use of technology and information product at health facilities by ensuring end-users satisfaction.

Extreme conditions test

The extreme conditions test assesses whether the model responds realistically to extreme input values. In this test, the plausibility of the model is examined when subjected to extreme policies, shocks, and parameters (Sterman, 2000). The extreme conditions test examines the feasibility of each decision rule (rate equation) by direct inspection when each input to the equation takes on its maximum and minimum values (Sterman, 2000). It further examines the response of the simulation behaviour to the inputs of extreme values to identify the precise source of the flaw (Sterman, 2000). The extreme conditions test can make “reality checks” possible and quickly uncover flaws that direct inspection may miss (Sterman, 2000; Barlas, 2016).

Extreme conditions of ‘services quality’ and ‘information quality’

Technological quality encompasses system quality, information quality, and services quality. The extreme conditions test of technological quality is performed by assigning the minimum (zero) and maximum (one) values to system and information quality. Table 5.5 shows the four cases used in extreme conditions test of technological quality.

Table 5.5 Extreme conditions of technological quality - eHMIS.

	Case 1	Case 2	Case 3	Case 4
System quality	0	0	1	1
Services quality	0	1	0	1

The first case (Case 1) of extreme conditions tested the simulation results of different model parameters when system and service qualities were set to a minimum value (zero). Acceptance rate was very low and dropped to zero quickly when both system and services quality were zero (See Figure 5.29 in grey colour). This model behaviour matched the expected real-life behaviour of the 'acceptance rate' with minimum system and services quality. A technology with a minimum system and services quality could not meet the end-users need, hence the 'acceptance rate' fell to the lowest value. In the beginning, there was a small rate of acceptance due to individuals’ perception to use which was developed through training and communications. However, the social influence of ‘promoters’ was lacking due to the dissatisfaction of end-users (in grey colour) with the technology (Figure 5.29 in grey colour). As a result, all ‘actual users’ became either ‘dissatisfied users’ or ‘terminated users’ because of the increasing social influence of ‘inhibitors’.

eHMIS-case 4 indicated the simulated behavioural response of the model parameters when system and service qualities were set to maximum value. The simulated ‘acceptance rate’ held maximum level (in blue colour) when both system quality and services quality were assigned the highest value (See Figure 5.29). The ‘acceptance rate’ attained its maximum level in a very short period of time and the peak value of ‘acceptance rate’ was achieved with the highest value of technological quality (See Figure 5.29 in blue colour). Moreover, all the ‘potential users’ become ‘actual users’ in a short period due to high rate of acceptance. The simulation graph confirmed the expected output that technological quality improved acceptance rate. Better technological quality resulted in a high rate of technology acceptance in healthcare sectors.

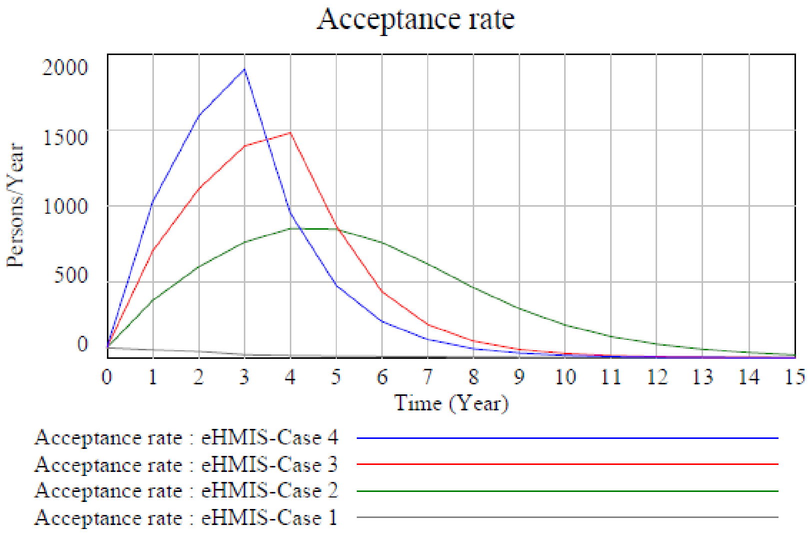


Figure 5.29 Extreme conditions test of technological quality on eHMIS ‘acceptance rate’.

eHMIS-case 2 represented the simulated behaviour of ‘acceptance rate’ (in green colour) when services quality was assigned a maximum value and system quality is set to a minimum value. As shown in Figure 5.29, the acceptance rate (in green colour) was relatively low and required longer duration to covert ‘potential users’ into ‘actual users’. The simulation result indicated the ‘acceptance rate’ (in green colour) was a result of very good services quality because system quality was set to the lowest value. The simulated ‘acceptance rate’ would have fallen to its minimum value if it would not have been for the good services quality which encouraged users to use the technology. The simulation result (case 2) showed the impact of services quality on the ‘acceptance rate of eHMIS technology.

The maximum value of system quality and a minimum value of services quality were depicted by eHMIS-case 3 and simulated as shown in Figure 5.29. The simulation results of eHMIS-case 3 (in red colour) indicated a greater acceptance rate than eHMIS-case 2 (in green colour) showing a stronger influence of system quality on technology acceptance rate than services quality. The simulation results of acceptance rate in eHMIS-case 3 reinforced the focus group discussions comment that eHealth technologies need to be designed to meet the end-users requirements (better system quality) than try to sustain a poor system with the help of strong services quality (Appendix 4.4, Code Groups: System Quality and Services Quality). A technology with good system quality required small level of technical support. High system quality reduced the burden of technical support team. When a system quality was good, the demand for technical support was minimum. The 'services quality' improved when the technical support team were not burdened (Appendix 4.4, Code Groups: Services Quality).

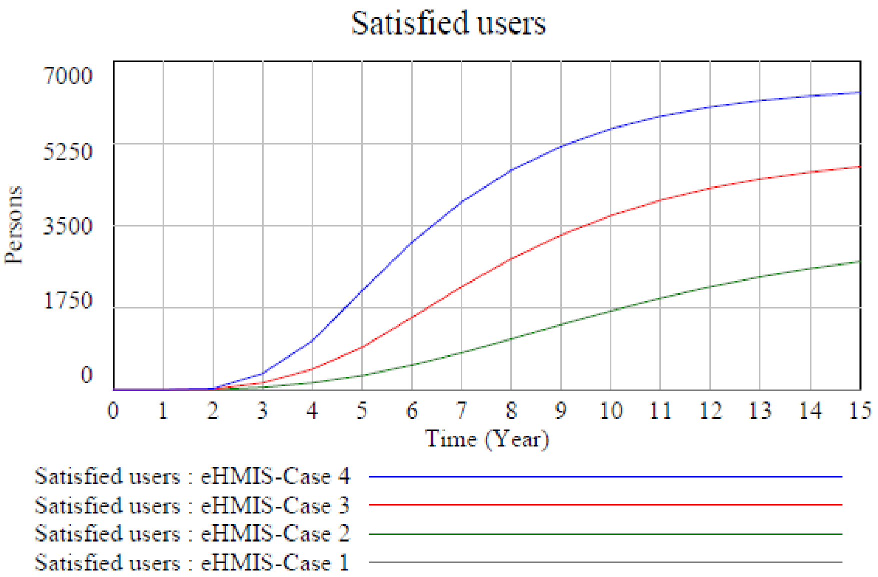


Figure 5.30 Extreme conditions test of technological quality on 'satisfied users' of eHMIS.

The simulated satisfaction level increased with an increase in system and services quality (Figure 5.30). eHMIS-case 1 (zero services quality and system quality) produced the smallest number of 'satisfied users' (in grey colour); conversely, eHMIS-case 4 (maximum services quality and system quality) had the highest number of 'satisfied users' (in blue colour). eHMIS-case 3 (system quality=1 and services quality=0) produced more simulated satisfied users (in red colour) than the simulated 'satisfied users' produced by eHMIS-case 2 (system quality=0 and services quality= 1) (in green colour). The focus group team indicated that the users' satisfaction was strongly influenced by system quality than services quality. A technology with high system quality did not require frequent technical support. Hence users were better satisfied by technology with good system quality and weak services quality than technology with weak system quality and good services quality. The simulation result that showed an increase in overall end-user satisfaction with increased technological quality was in agreement with the expected behaviour in real-life.

The simulated information quality results dropped to zero (in grey colour) in response to eHMIS-case 1 and held the maximum value of one (in blue colour) in response to eHMIS-case 4 (Figure 5.31). As observed in the end-users satisfaction and acceptance rate, the influence of system quality on information quality was higher than services quality. Therefore, the simulated information quality in eHMIS-case 3 (in red colour) was higher than that of eHMIS-case 2 (in green colour). The simulated information quality was maximum at the beginning in eHMIS-case 3 due to a maximum value of system quality; however, the simulation graph (in red colour) showed that the simulated information quality began to drop from its high value immediately (Figure 5.31). This decrease in the simulated information quality was related to poor services quality, i.e., zero in eHMIS-case 3.

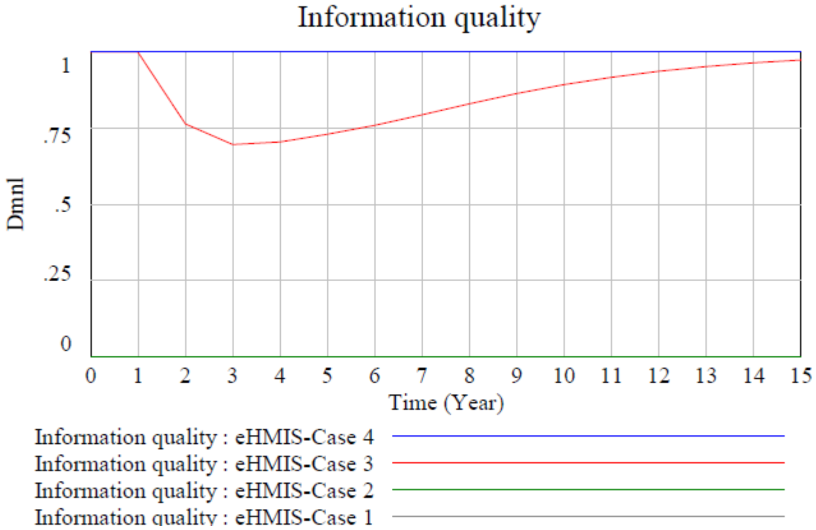


Figure 5.31 Extreme conditions test of technological quality on 'information quality' of eHMIS.

At the beginning of technology use, end-users did not have experience in using the technology, hence they needed strong technical support. However, services quality was zero in the case of eHMIS-case 3; hence the simulated information quality reduced significantly at the early years of technology use. However, the simulated information quality improved slowly through time as end-users gained more experienced in using the technology. The need for technical support services reduced as end-users became more comfortable in using the technology in the later years of technology use. Therefore, the simulation graph in Figure 5.31 reflected the real-life situation of eHMIS as indicated in Figure 5.25.

Extreme conditions of training effectiveness

The effectiveness of training and communication influenced the simulated 'acceptance rate' by changing the individuals' intention to use. The extreme conditions test was carried out by assigning the maximum value (one) and minimum values (zero) to 'effectiveness of training'. The simulation graph of 'acceptance rate' agreed with an expected response for effectiveness of training in real life (Figure 5.32). When the 'effectiveness of training' held the maximum value (one), the simulated 'acceptance rate' attained its maximum value (in blue colour) in a short period of time (Figure 5.32). On the contrary, the simulated 'acceptance rate' took long time to achieve its peak value (in red colour) when the 'effectiveness of training' was minimum.

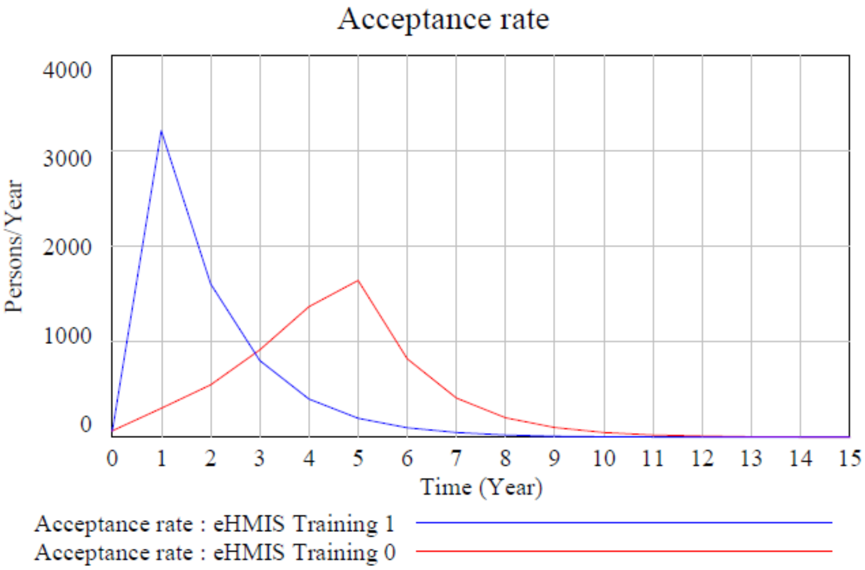


Figure 5.32 Extreme conditions test of training effectiveness on eHMIS 'acceptance rate'.

The 'effectiveness of training' influenced the simulated 'acceptance rate' mainly through the 'individuals' intention to use'. Figure 5.33 showed the changes in the simulated 'individuals' intention to use' to extreme conditions of 'effectiveness of training'. The simulated 'individuals' intention to use' technology was high (in blue colour) when the 'effectiveness of training' was maximum, i.e., one (Figure 5.33). Conversely, the simulated 'individuals' intention to use' was very low (in red colour) when the 'effectiveness of training' held the lowest value, zero (Figure 5.33).

The effectiveness of training and communication improved the individuals' intention to use new technology. Successively, 'Individuals' intention to use' influenced 'acceptance rate' in the early years of technology implementation. The changes in the simulated ‘acceptance rate’ and ‘individuals’ intention to use’ shown in Figure 5.32 and Figure 5.33 to changes in ‘effectiveness of training’ were in agreement with real-life. The focus group discussion confirmed that effective training and communication improved the perceived ease of use and of the usefulness of technology by increasing the individuals’ intention to use’ and ultimately ‘acceptance rate’ (Appendix 4.4, Code Groups: Individual and Code Groups: Benefits).

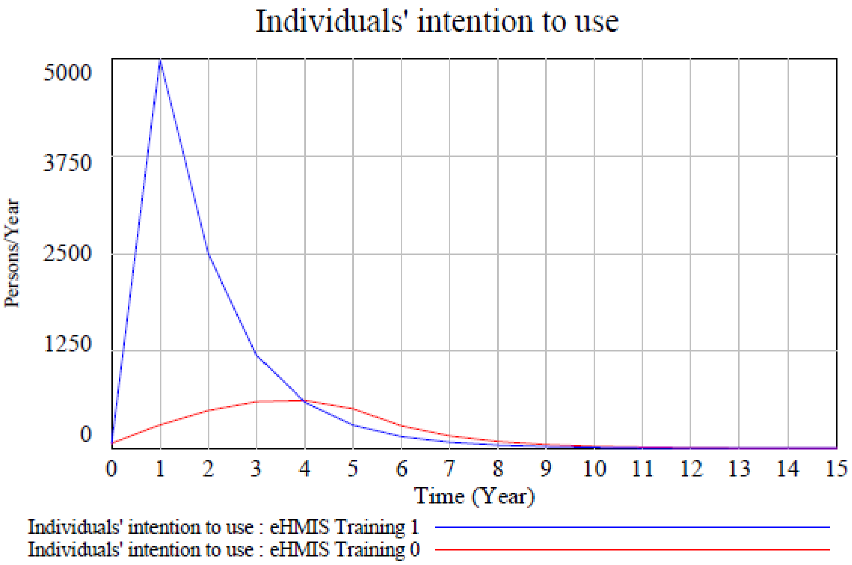


Figure 5.33 Extreme conditions test of ‘effectiveness of training’ on ‘individuals’ intention to use’ eHMIS.

<u>Extreme conditions of ‘performance improvement rate’</u>

The ‘performance improvement rate’ dictated the satisfaction level of ‘actual users’. An increase in the number of ‘satisfied users’ increased ‘acceptance rate’ through ‘promoters’. The simulation results produced the expected behaviour of ‘satisfied users’ with changes in the extreme values of ’performance improvement rate’ (Figure 5.34). The minimum value of ‘performance improvement rate’ resulted in a small number of ‘satisfied users’ over time (in blue colour). On the contrary, the maximum value of ’performance improvement rate’ produced the large number of simulated ‘satisfied users’ (in red colour) in a short period of time (Figure 5.34). The main reason for the low level of SmartCare users’ satisfaction was related to the inability of the system to improve the performance of end-users in most of the service delivery units.

The extreme conditions of ‘performance improvement rate’ also had an impact on ‘promoters’ through ‘satisfied users’. Satisfied end-users who were able to achieve performance improvement from the system use were able to promote the system acceptance through the positive word of mouth in their social circles. As showed in Figure 5.35, the lowest value of 'performance improvement rate' resulted in the lowest number of simulated 'promoters' due to lack of satisfaction by the 'actual users' (in blue colour). On the other hand, the maximum value of 'performance improvement rate' led to a large number of simulated 'promoters' due to a high level of satisfaction (in red colour). As a result, increase in 'performance improvement rate' improved the 'acceptance rate' through a social influence of 'promoters'; whereas low 'performance improvement rate' impacted 'acceptance rate' due to a large number of 'inhibitors'.

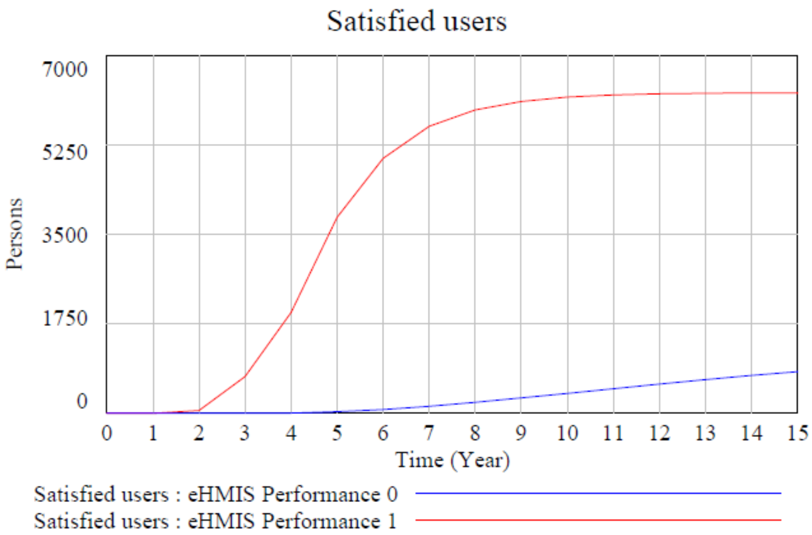


Figure 5.34 Extreme conditions of 'performance improvement rate' on 'satisfied users' of eHMIS.

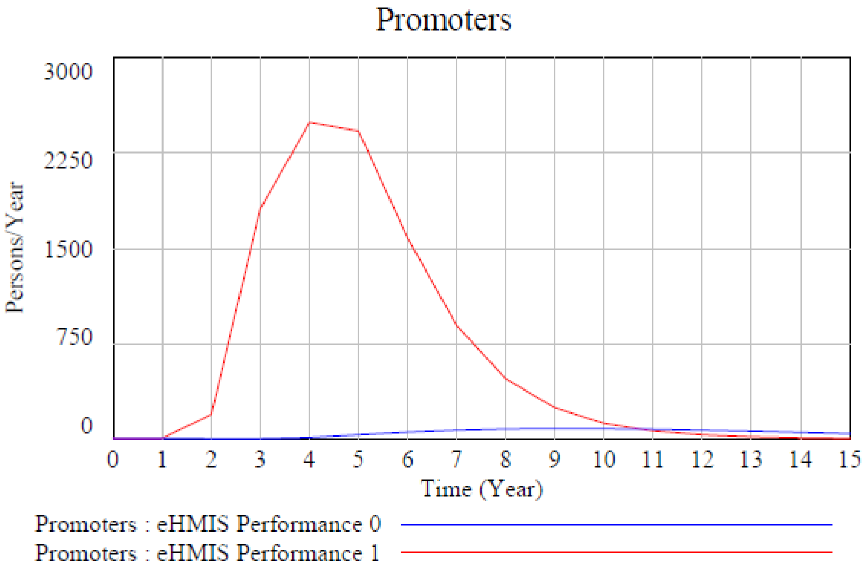


Figure 5.35 Extreme conditions test of 'performance improvement rate' on 'promoters' of eHMIS.

The following section addresses a univariate and multivariate sensitivity analysis of techno-organizational model of eHealth acceptance.

5.9. Sensitivity analysis

All models have limitations and must be tested to enhance confidence in the model (Sterman, 2000; Hekimo and Barlas, 2017). The uncertainty in the assumptions of the model variables can be tested to ensure the robustness of conclusions (Sterman, 2000; Hekimo and Barlas, 2017). Sensitivity analysis is performed by varying assumptions over the plausible range of uncertainty (Sterman, 2000; Hekimo and Barlas, 2017). The importance of sensitivity analysis includes (Sterman, 2000; Pruyt, 2013):

- Understanding of relationship between the structure and behaviour of complex dynamic systems.
- Testing the robustness by searching for errors in models.
- Guiding data collection efforts.
- Identifying inputs for which the output is sensitive.
- Identifying highly sensitive policy levers

The accuracy of estimated parameters can be improved by giving enough time and money to the data collection effort (Sterman, 2000). However, parameters should be estimated economically by creating a balance between accuracy, effort and cost. A parameter that strongly affects the behaviour may be a good candidate for additional data collection for a more reliable estimate (Sterman, 2000). Conversely, parameters with little effect can have an approximate estimate to save time and effort, without affecting the robustness of results (Sterman, 2000; Hekimo and Barlas, 2017).

Sensitivity analysis studies the effect of changes in input parameters on the outputs (Pruyt, 2013; Jadun *et al.*, 2018). An input parameter that triggers a big change in the output behaviour for a little change in the input side can be a good candidate for policy analysis (Sterman, 2000; Hekimo and Barlas, 2017; Jadun *et al.*, 2018). High sensitivity can be undesirable if it cannot be controlled , but it opens up more desirable dynamics if it can be controlled (Pruyt, 2013). Sensitivity analysis is essential in model testing and policy analysis (Pruyt, 2013). In model testing, sensitivity analysis assists to know which small changes to the model lead to large changes in behaviours, whereas in policy analysis, it helps to know where the largest policy leverage can be found (Pruyt, 2013).

The three types of sensitivity are numerical, behaviour mode, and policy sensitivity (Sterman, 2000; Pruyt, 2013; Hekimo and Barlas, 2017). Numerical sensitivity analysis evaluates the sensitivity of output values to the change in model assumptions, while the behaviour sensitivity focuses on sensitivity of output behaviour to alteration in parameter values (Sterman, 2000; Hekimoglu and Barlas, 2014). Policy sensitivity addresses change in the preference order of policies based on change in model parameters or structure (Pruyt, 2013).

Numerical sensitivity is exhibited by all models when a change in assumptions changes the numerical values of the results (Sterman, 2000; Jadun *et al.*, 2018). For example, changing the strength of system quality feedback in a socio-technical model of eHealth acceptance will change the acceptance rate for the eHealth system.

Behaviour mode sensitivity tests determine the parameters to which the model is highly sensitive by comparing the sensitivity level of the real system to the change in the corresponding parameters (Barlas, 1994, 1996). When a variation in assumptions changes the patterns of behaviour generated by the model, it’s an indication of behaviour mode sensitivity (Sterman, 2000). For example, if plausible alternative assumptions change the behaviour of a model from a smooth adjustment to oscillation or from S-shaped growth to overshoot and collapse, the model would exhibit behaviour mode sensitivity (Sterman, 2000; Hekimo and Barlas, 2017).

Policy sensitivity exists when a change in assumptions reverses the impacts or desirability of a proposed policy (Sterman, 2000). A model exhibits policy sensitivity when one set of assumptions that produced improvements led to a negative consequence under another set of assumptions (Sterman, 2000). Dynamic problems and related policy suggestions are typically discussed through the characteristics of behaviour patterns such as equilibrium levels, trends, periods and amplitudes of oscillations (Hekimo and Barlas, 2017).

There are different methods of sensitivity analysis in Vensim sensitivity simulation module (Hekimo and Barlas, 2017). The first step of sensitivity analysis is univariate, i.e., each parameter in the list is changed independently, while others are held constant at their original model values each (Hekimoglu and Barlas, 2014). In the multivariate method, all parameters are changed together. A univariate sensitivity analysis may not be sufficient to comprehensively study a nonlinear and complex model (Sterman, 2000). The nonlinear relationships among different model parameters can be better studied with a multivariate sensitivity analysis because simultaneous changes in more than one parameters’ values may create unexpected output change (Sterman, 2000). Therefore, a univariate should be followed by a multivariate method of sensitivity analysis (Hekimoglu and Barlas, 2014).

The selection of distribution function and the range of each parameters are the first steps of sensitivity analysis (Hekimoglu and Barlas, 2014). The parameter values are usually in the distribution range of ± 20% of the actual model value determined from the real system (Sterman, 2000). In order to do sensitivity simulations, Vensim provides a variety of different distributions to choose from (Ventana Systems, 2012b). The simplest distribution is the Random Uniform Distribution, in which any number between the minimum and maximum values is equally likely to occur. The Random Uniform Distribution is suitable for most sensitivity testing and is selected by default in Vensim (Ventana Systems, 2012b). The minimum and maximum values (a & b respectively) are chosen to bound each parameter.

A uniform distribution, sometimes also known as a rectangular distribution, is a distribution that has constant probability (Weisstein, 2019). The probability density function, P(x), and cumulative distribution function, D(x), for a continuous uniform distribution on the interval [a,b] are shown in Equation 5:23 & 5:24 respectively (Weisstein, 2019):

$$P(x) = \begin{cases} 0 & for\ x < a \\ \frac{1}{b-a} & for\ a \le x\ \le b \\ 0 & for\ x > b \end{cases} \tag{5.23}$$

$$D(x) = \begin{cases} 0 & for\ x < a \\ \frac{x-a}{b-a} & for\ a \le x\ \le b \\ 1 & for\ x > b \end{cases} \tag{5.24}$$

Table 5.6 Exogenous variables used in the sensitivity analysis *of socio-technical model of eHealth acceptance.*

Exogenous variables	eHealth Applications	Estimated Value in basic model	Proposed minimum value of variable	Proposed Maximum value of variable
System quality	eHMIS	0.8 (dimensionless)	0.6	1
	SmartCare	0.4 (dimensionless)	0.2	0.6
Services quality	eHMIS	0.8 (dimensionless)	0.6	1
	SmartCare	0.3 (dimensionless)	0.1	0.5
Effectiveness of training	eHMIS	0.56 (dimensionless)	0.36	0.76
	SmartCare	0.4 (dimensionless)	0.2	0.6
	eHMIS	0.3 (dimensionless)	0.1	0.5

Performance improvement rate	SmartCare	0.2 (dimensionless)	0	0.4
Trial before termination	eHMIS	240 (dimensionless)	190	290
	SmartCare	1500 (dimensionless)	1200	1800

The behaviour patterns of models variables are more important than their numerical values in system dynamics simulation study (Hekimoglu and Barlas, 2014). The proposed minimum and maximum values in Table 5.6 are used in performing univariate and multivariate sensitivity analysis using the random uniform distribution in Vensim. Moreover, a Random Uniform Distribution with 200 number of simulation is used to run the simulation model of socio-technical factors in this thesis.

5.9.1. Univariate sensitivity analysis of eHMIS and SmartCare

Sensitivity testing is the process of changing assumptions about the value of constants in the model and examining the resulting output for a change in values (Ventana Systems, 2012a; Hekimo and Barlas, 2017). The sensitivity analysis shown below are the result of univariate sensitivity analysis with 200 simulation runs by assigning parameter values using the random uniform distribution. The minimum and maximum boundaries of parameters values are shown in Table 5.6. In each simulation run, a parameter value is randomly selected between the minimum and maximum. A random uniform distribution is assigned for all variables to perform univariate sensitivity analysis.

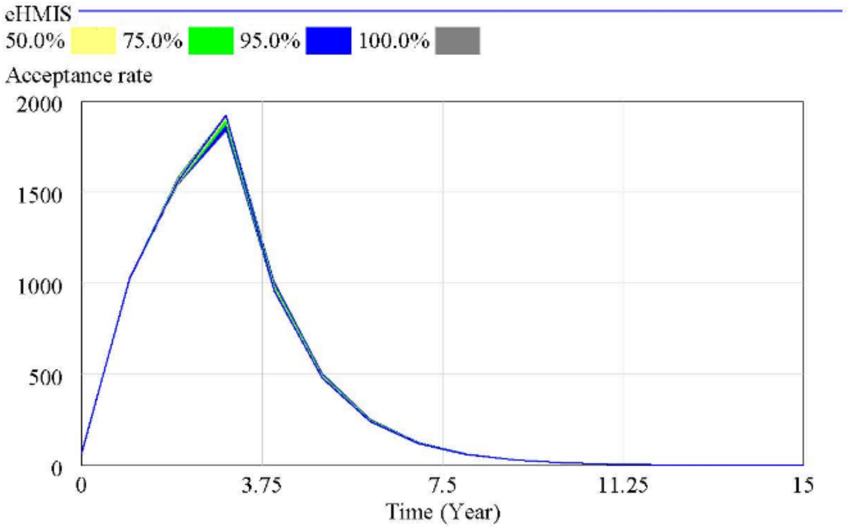
<u>The 'acceptance rate' of eHMIS and SmartCare (univariate sensitivity analysis)</u>

The simulated behaviour pattern of 'acceptance rate' of eHMIS and SmartCare due to changes in the 'system quality', 'services quality', 'effectiveness of training', 'performance improvement rate', and 'trial before termination' is discussed below.

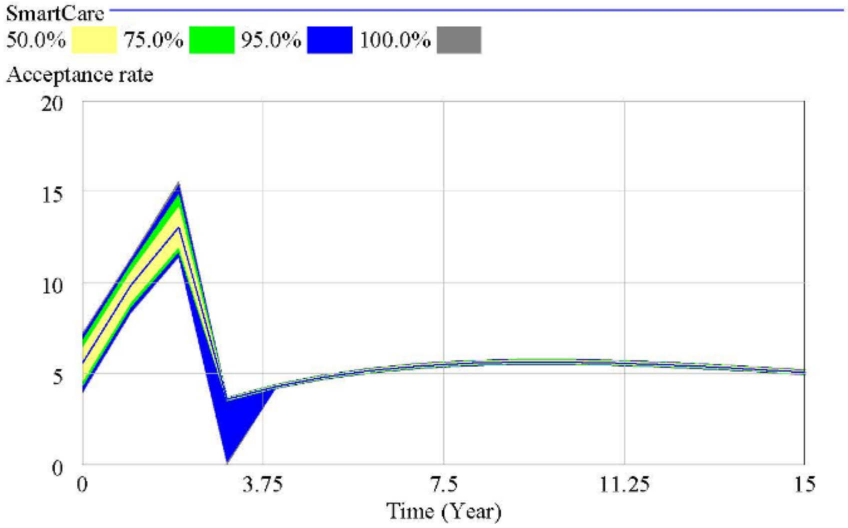
i. The 'acceptance rate' of eHMIS and SmartCare with uncertainty in 'system quality'

As shown in Figure 5.36 (a), there was no substantial change in the main essential behaviour pattern of simulated eHMIS 'acceptance rate' as a result of uncertainty in 'system quality'. The random changes in 'system quality' (0.6,1) resulted in the minimal eHMIS 'acceptance rate' variations (See Figure 5.36 (a)).

Figure 5.36 (b) showed a significant change in the behaviour of simulated SmartCare 'acceptance rate' as the 'system quality' varied from 0.2 to 0.6 in the early years. However, the major variation in the early years of implementation converged to the common equilibrium after 4 years (See Figure 5.36 (b)). Yet the main behaviour of the model remained unchanged.



(a)



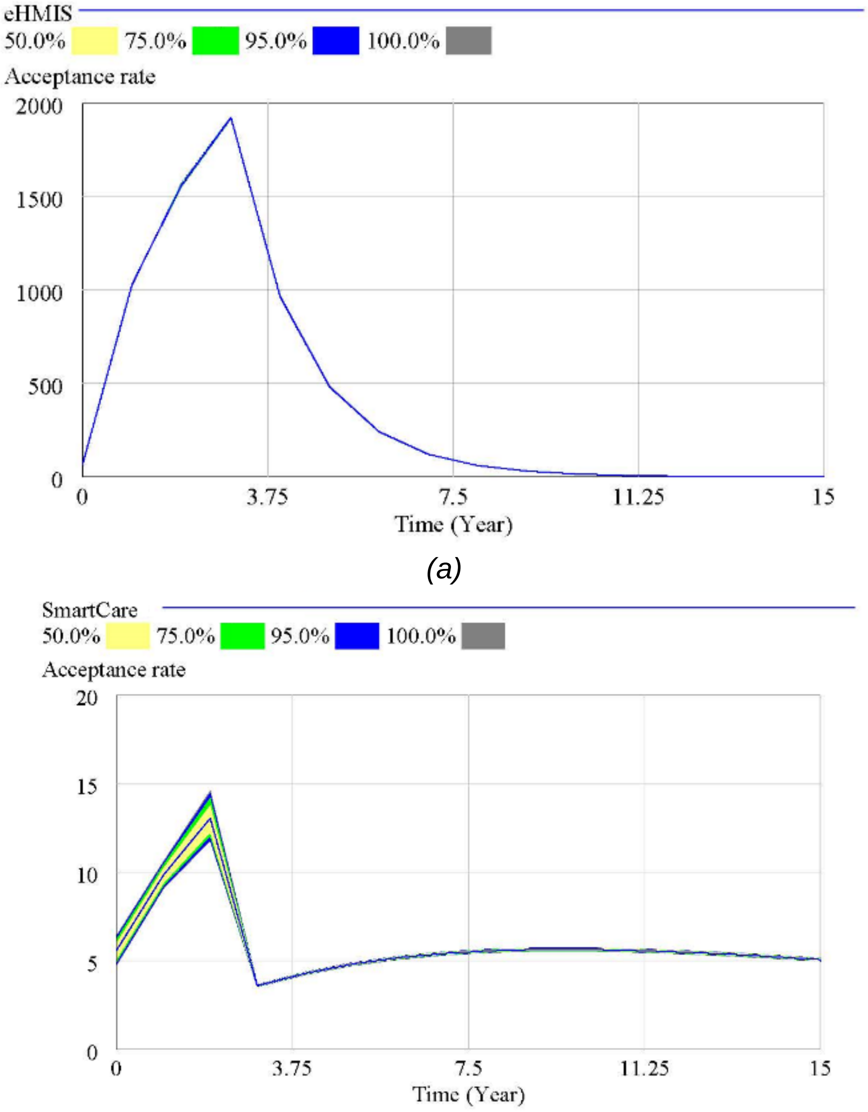
(b)

Figure 5.36 (a) eHMIS 'acceptance rate' under uncertainty in 'system quality' for interval (0.6,1). (b) SmartCare 'acceptance rate' under uncertainty in 'system quality' for interval (0.2,0.6).

The confidence bounds for 'acceptance rate' represented by 50%, 75%, and 95% and 100% in a sample of 200 simulations run. The information indicated that there was a 50% chance (yellow area) that SmartCare 'acceptance rate' would be between approximately 12 and 14 persons in year two (See Figure 36 (b)). The confidence intervals narrowed down as the number of 'potential users' reduced.

ii. The ‘acceptance rate’ of eHMIS and SmartCare with uncertainty in ‘services quality’

Figure 5.37 (a) showed that uncertainty in ‘services quality’ (0.6,1) did not essentially change the essential behaviour pattern and hardly had a numerical variation on eHMIS ‘acceptance rate’. Figure 5.37 (b) showed randomly changing ‘services quality’ resulted in a small numerical variation of SmartCare ‘acceptance rate’ at the beginning and stabilizes after year three. As the ‘system quality’ varied randomly between 0.1 and 0.5, the main behaviour of the model remained unchanged (See Figure 5.37 (b)).

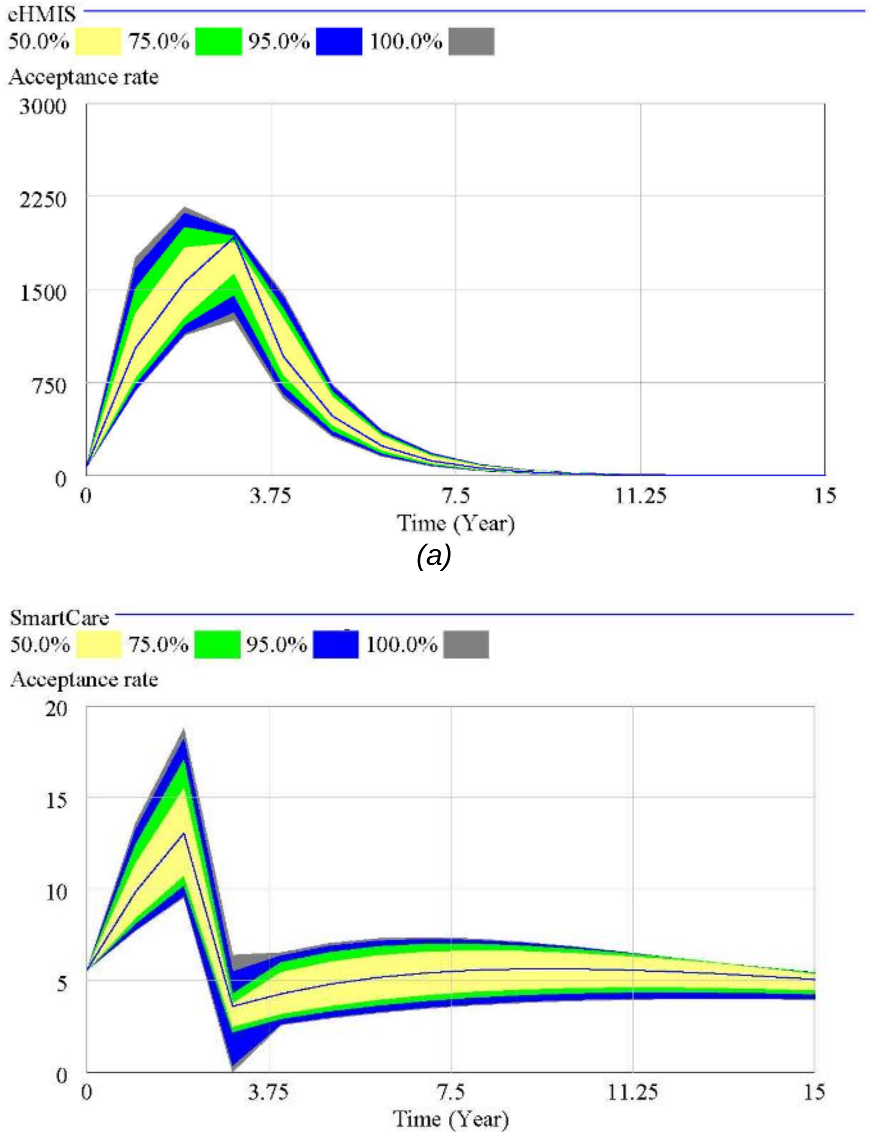


(b)

Figure 5.37 (a) eHMIS ‘acceptance rate’ under uncertainty of “services quality” for interval (0.6,1). (b) SmartCare “acceptance rate’ under uncertainty of ‘services quality’ for interval (0.1, 0.5).

iii. *The 'acceptance rate' of eHMIS and SmartCare with uncertainty in the 'effectiveness of training'*

In both cases, the main essential behaviour of the models remained unchanged with uncertainty in the 'effectiveness of training' (Figure 5.38 (a) and (b)). However, significant numerical variations were observed in both eHMIS and SmartCare cases. 'Effectiveness of training' can be a good candidate for policy analysis to maximize the 'acceptance rate' of both eHMIS and SmartCare systems as it is possible to have control over the variable.



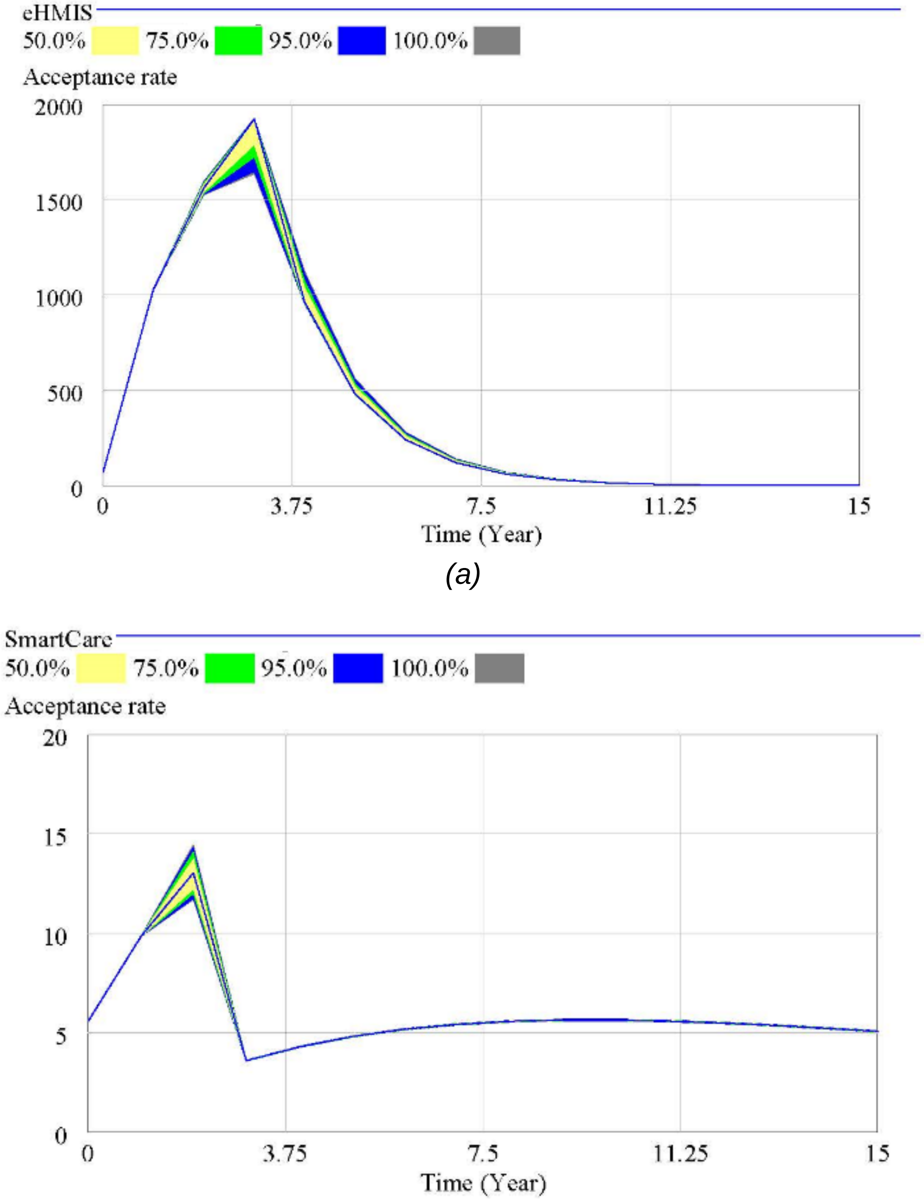
(a)

(b)

Figure 5.38 (a) eHMIS 'acceptance rate' under uncertainty of 'effectiveness of training' for an interval (0.36, 0.76). (b) SmartCare 'acceptance rate' under uncertainty of 'effectiveness of training' for an interval (0.2, 0.6).

iv. The ‘acceptance rate’ of eHMIS and SmartCare with uncertainty in ‘performance improvement rate’

Figure 5.39 (a) showed changes in simulated numerical values of ‘acceptance rate’ after 2 years as the ‘performance improvement rate’ varied from 0.1 to 0.5. Similarly, Figure 3.39 (b) showed numerical variations in ‘acceptance rate’ between 1.5 and 3 years under uncertainty in the ‘performance improvement rate’.



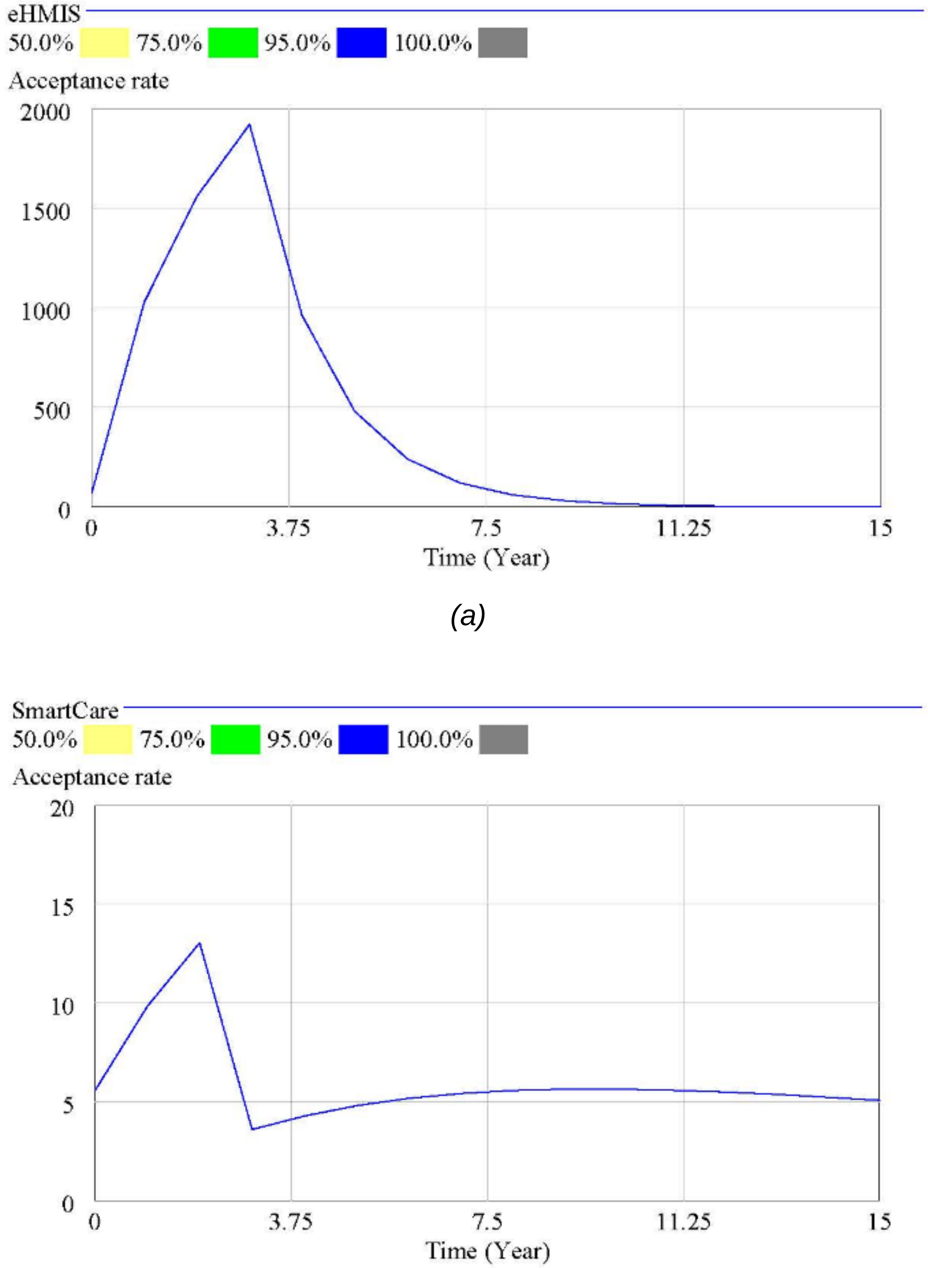
(a)

(b)

Figure 5.39 (a) eHMIS ‘acceptance rate’ under uncertainty of ‘performance improvement rate’ for an interval (0.1,0.5). (b) SmartCare ‘acceptance rate’ under uncertainty of ‘performance improvement rate’ for an interval (0,0.4).

v. The ‘acceptance rate’ of eHMIS and SmartCare with uncertainty in ‘trial before termination’

Figure 5.40 (a) and (b) showed that the main essential behaviour of the model remained unchanged in both cases. Besides, uncertainty in ‘trial before termination’ resulted in almost no changes in ‘acceptance rate’ in both eHMIS and SmartCare systems.



(a)

(b)

Figure 5.40 (a) eHMIS ‘acceptance rate’ under uncertainty of ‘trial before termination’ for an interval (190,290). (b) SmartCare ‘acceptance rate’ under uncertainty of ‘trial before termination’ for an interval (1200,1800).

In summary, the sensitivity analysis with random variations of 'system quality', 'services quality', 'effectiveness of training', 'performance improvement rate' and 'trial before termination' produced no fundamental change in the essential behaviour pattern of 'acceptance rate' of both eHMIS and SmartCare. However, uncertainty in these exogenous variables produced minor to significant numerical variations in the 'acceptance rate' of both systems.

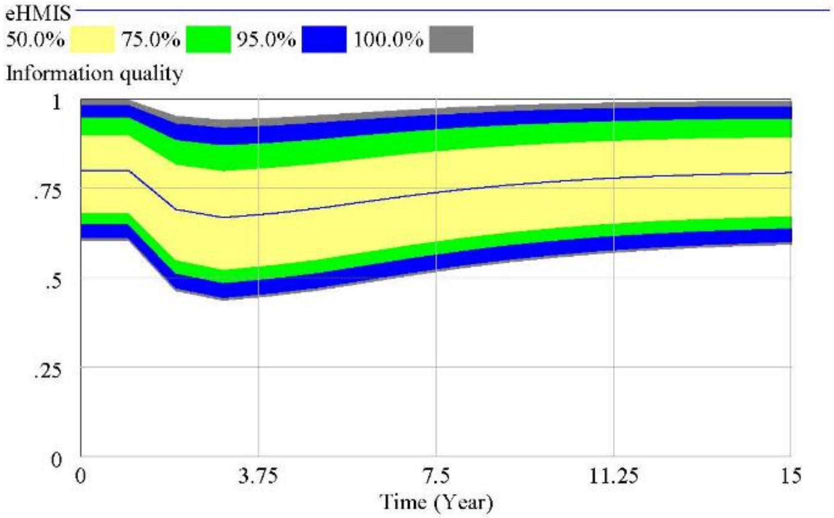
The change in 'effectiveness of training' produced significant variations in the simulated eHMIS and SmartCare 'acceptance rate'. Since it is possible to have control over 'effectiveness of training', the variable can be a good candidate for policy analysis to maximize the 'acceptance rate' of both eHMIS and SmartCare. The simulated 'acceptance rate' of eHMIS overshot in the early years of implementation and reached its maximum around year three before collapsing to zero about year ten in all cases. The pattern of the essential model behaviour of eHMIS 'acceptance rate' remained unchanged.

The 'information quality' of eHMIS and SmartCare (univariate sensitivity analysis)

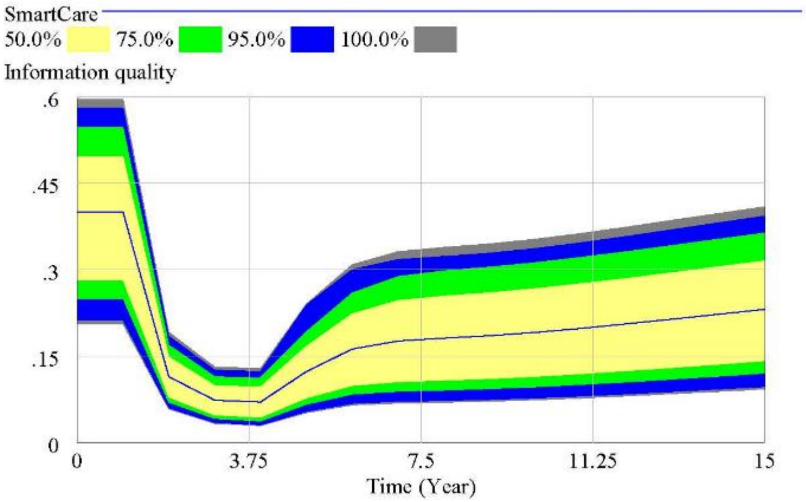
The simulated behavioural response of 'information quality' of eHMIS and SmartCare due to changes in the 'system quality', 'services quality', 'effectiveness of training', 'performance improvement rate', and 'trial before termination' is discussed below.

i. The 'information quality' of eHMIS and SmartCare with uncertainty in 'system quality'

Figure 5.41(a) and (b) showed significant numerical variations in the simulated 'information quality' of eHMIS and SmartCare right from the beginning under uncertainty in the 'system quality'. However, the essential original behaviour pattern was maintained in both cases.



(a)

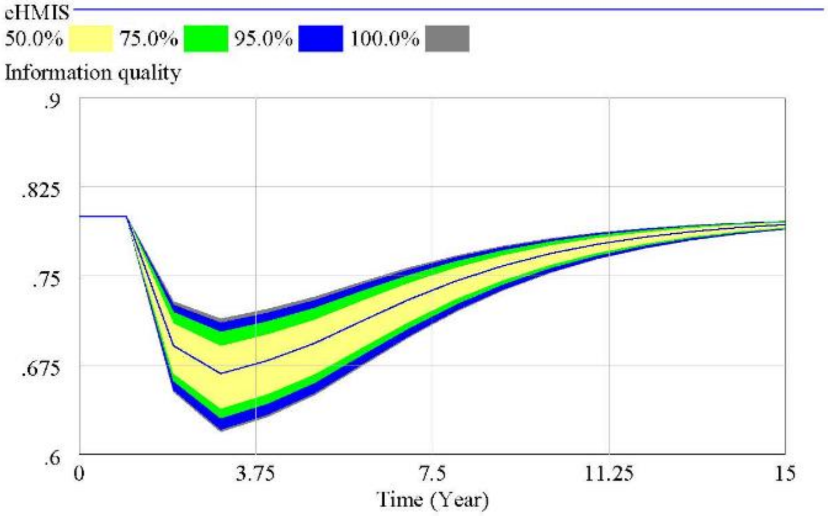


(b)

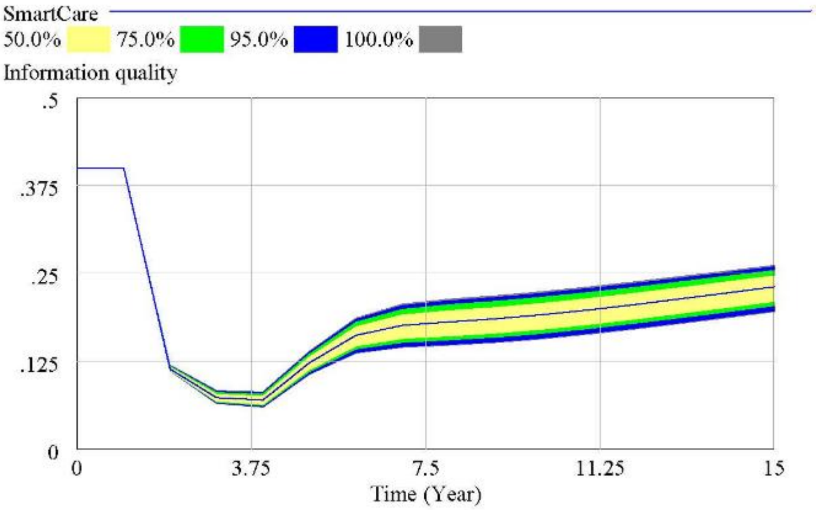
Figure 5.41 (a) eHMIS 'information quality' under uncertainty of 'system quality' for interval (0.6,1). (b) SmartCare 'information quality' under uncertainty of 'system quality' for interval (0.2,0.6).

ii. The 'information quality' of eHMIS and SmartCare with uncertainty in 'services quality'

Figure 5.42 (a) and Figure 5.42 (b) showed the effect of uncertainty in the 'services quality' on the simulated 'information quality' of eHMIS and SmartCare respectively. In both cases, the main essential behaviour of the models was not changed. However, significant numerical variations were observed in both cases (Figure 5.42 (a) and (b)).



(a)

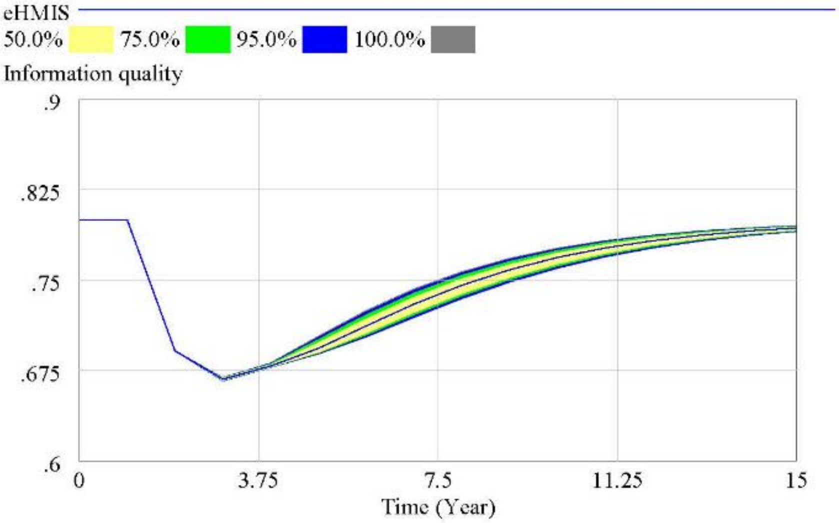


(b)

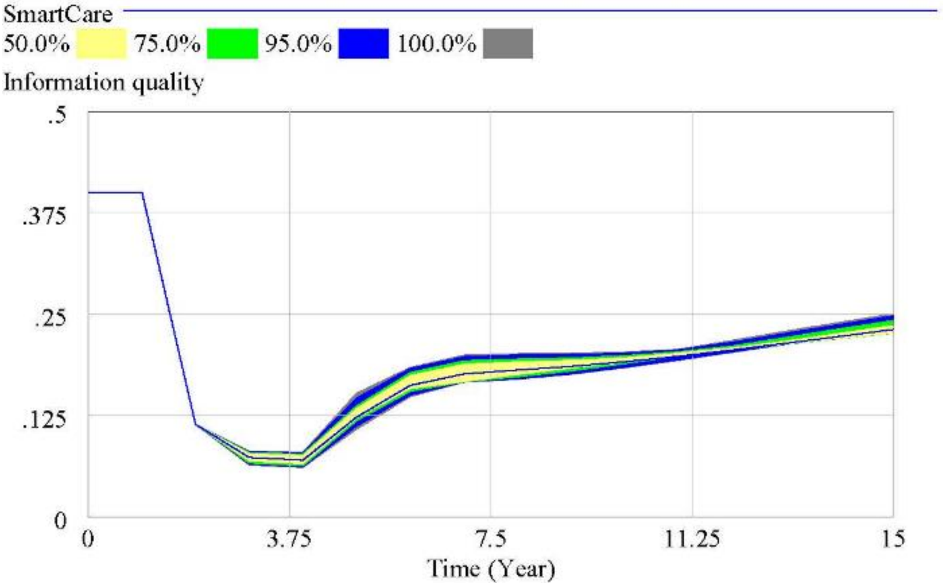
Figure 5.42 (a) 'Information quality' of eHMIS under uncertainty of 'services quality' for interval (0.6,1). (b) 'Information quality' of SmartCare under uncertainty of 'services quality' for interval (0.1,0.5).

iii. 'Information quality' of eHMIS and SmartCare with uncertainty in the 'effectiveness of training'

Figure 5.43 (a) and Figure 5.43 (b) showed the impact of uncertainty in 'effectiveness of training' on the simulated 'information quality' of eHMIS and SmartCare respectively. A minor numerical variation in the 'information quality' of eHMIS began about year four (Figure 5.43 (a)); whereas the numerical variations for the 'information quality' of SmartCare (Figure 5.43 (b)) began around year two under uncertainty in 'effectiveness of training'.



(a)

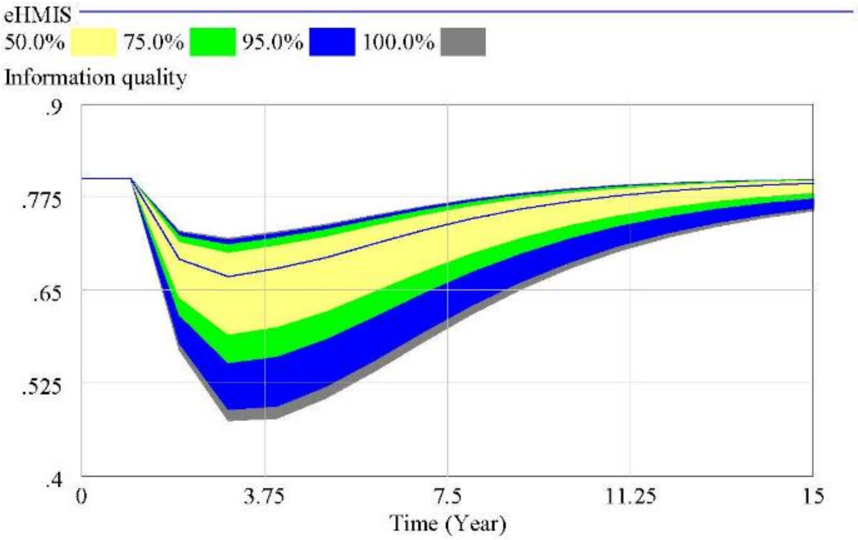


(b)

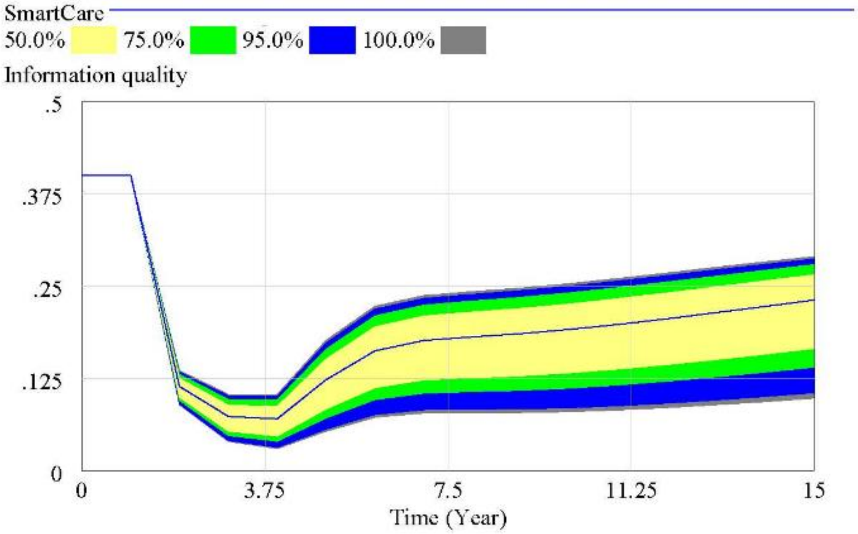
Figure 5.43 (a) 'Information quality' of eHMIS under uncertainty of 'effectiveness of training' for an interval (0.36,0.76). (b) 'Information quality' of SmartCare under uncertainty of 'effectiveness of training' for an interval (0.2,0.6).

iv. 'Information quality' of eHMIS and SmartCare with uncertainty in 'performance improvement rate'

The uncertainty in the 'performance improvement rate' had significant numerical variations on the simulated 'information quality' of both eHMIS and SmartCare (Figure 5.44 (a) and (b)). However, the essential original behaviour pattern was maintained in both cases.



(a)

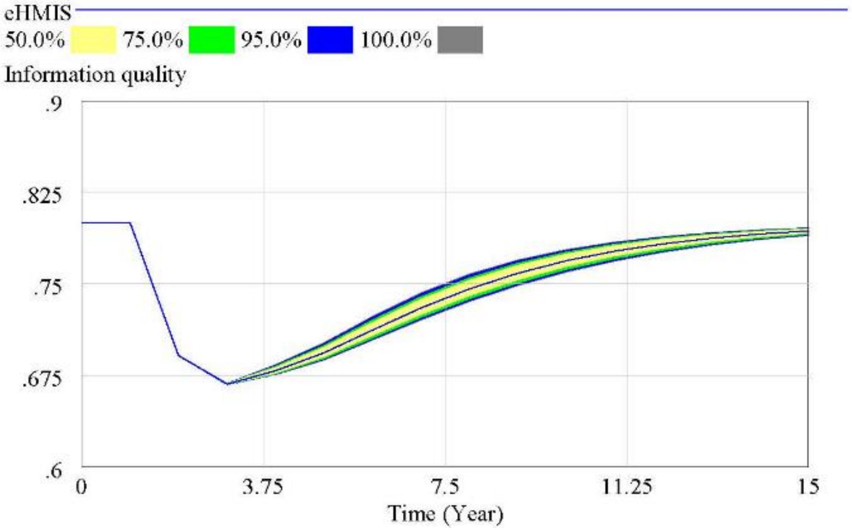


(b)

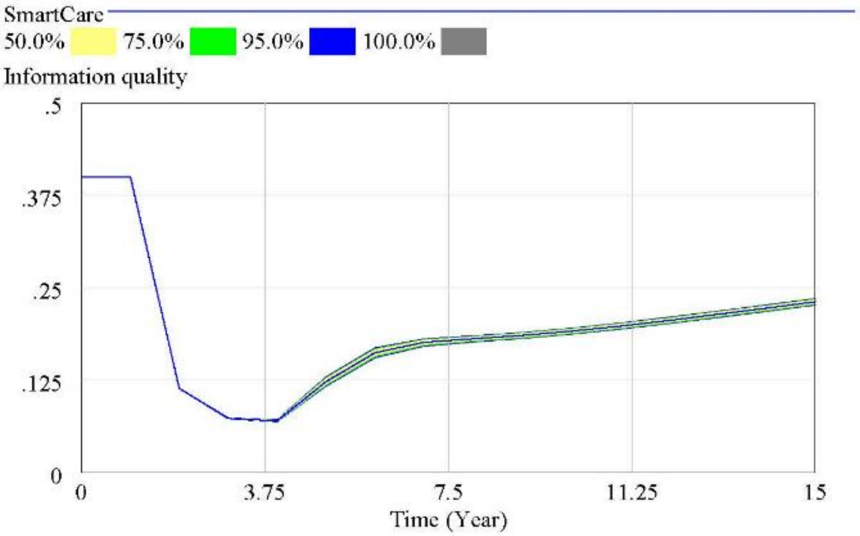
Figure 5.44 (a) 'Information quality' of eHMIS under uncertainty of 'performance improvement rate' for an interval (0.1,0.5). (b) 'Information quality' of SmartCare under uncertainty of 'performance improvement rate' for an interval (0,0.4).

v. 'Information quality' of eHMIS and SmartCare with uncertainty in 'trial before termination'

Figure 5.45 (a) and (b) showed the simulation pattern of 'information quality' of eHMIS and SmartCare respectively under uncertainty in 'trial before termination' as defined in Table 5.6. There was a minimal numerical variation but the essential original behaviour pattern was maintained in both cases.



(a)



(b)

Figure 5.45 'Information quality' of eHMIS under uncertainty of 'trial before termination' for an interval (190,290). (b) 'Information quality' of SmartCare under uncertainty of 'trial before termination' for an interval (1200,1800).

As observed in the simulated 'acceptance rate' of eHMIS and SmartCare, the general essential pattern of behaviour of the simulated 'information quality' of both eHMIS and SmartCare was not altered by changes in the random estimates of the exogenous variables. However, uncertainty in 'system quality', 'services quality', 'effectiveness of training', 'performance improvement rate' and 'trial before termination' produced from a small to significant numerical variations at different years. The simulated 'information quality' of both eHMIS and SmartCare demonstrated a similar essential pattern of behaviour that the simulated 'information quality' declined in the early years and improved in the later phases.

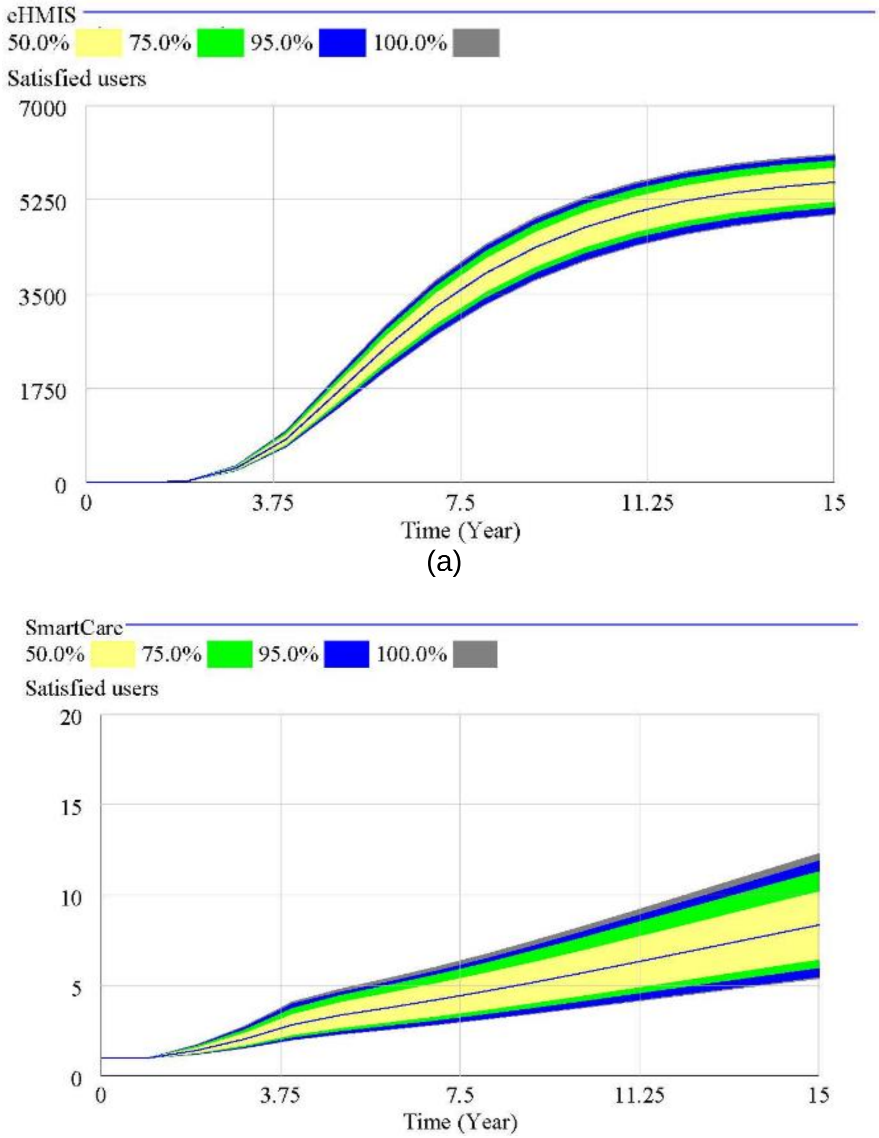
The simulated 'information quality' was numerically sensitive to changes in the 'system quality', 'services quality', 'and 'performance improvement rate'. These three variables could be good candidates for policy analysis.

<u>'Satisfied users' of eHMIS and SmartCare (univariate sensitivity analysis)</u>

The simulation pattern of behaviour of 'satisfied users' of eHMIS and SmartCare due to changes in the 'system quality', 'services quality', 'effectiveness of training', 'performance improvement rate', and 'trial before termination' is discussed below.

i. ‘Satisfied users’ of eHMIS and SmartCare with uncertainty in ‘system quality’

Figure 5.46 (a) indicated the simulated behaviour pattern of ‘satisfied users’ of eHMIS as ‘system quality’ varied in the range of (0.6,1). The numerical variation of the simulated ‘satisfied users’ was observed after 2 years, while the essential general pattern of behaviour was maintained with S-shaped growth (Figure 5.46 (a)). The fundamental original pattern of behaviour of the simulated ‘satisfied users’ of SmartCare remained unchanged with a gradual increase in the number of ‘satisfied users’ over time (See Figure 5.46 (b)).



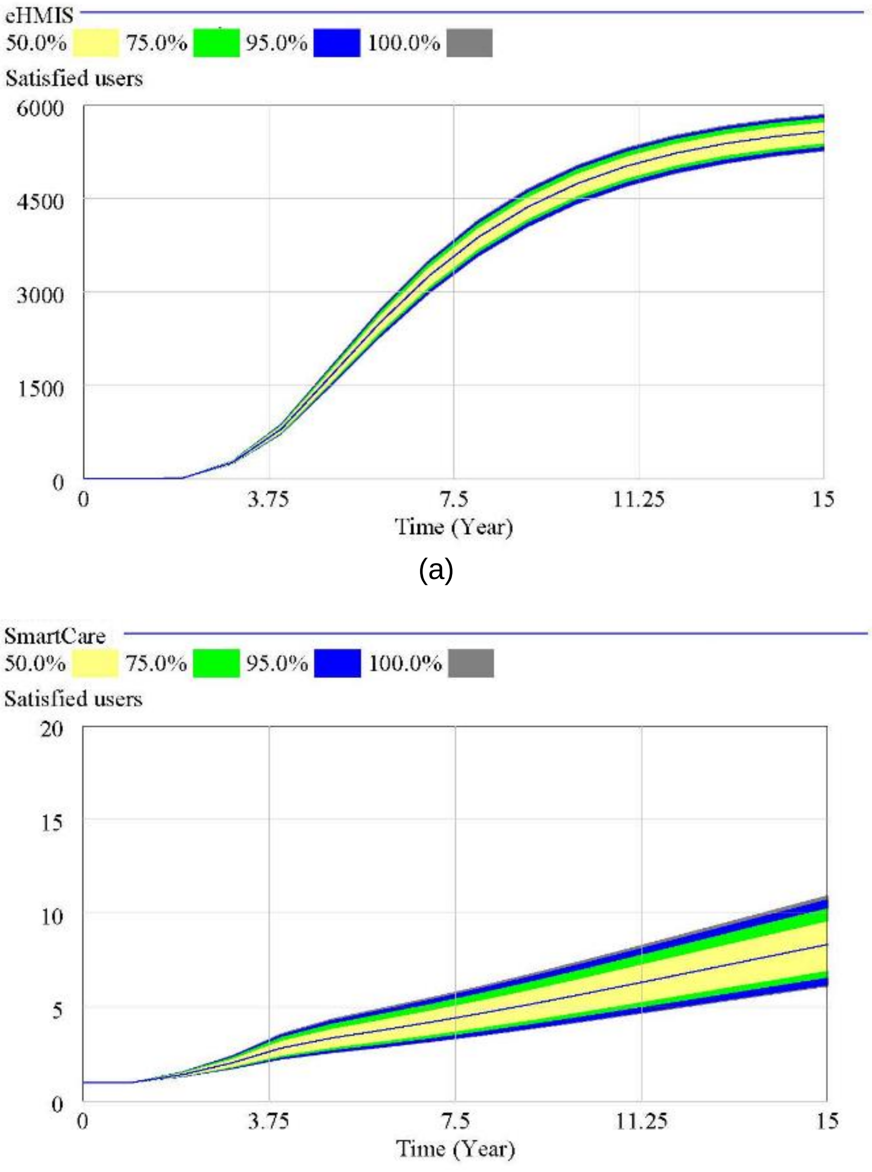
(a)

(b)

Figure 5.46 (a) ‘Satisfied users’ of eHMIS under uncertainty of ‘system quality’ for an interval (0.6,1). (b) ‘Satisfied users’ of SmartCare under uncertainty of ‘system quality’ for an interval (0.2,0.6).

ii. ‘Satisfied users’ of eHMIS and SmartCare with uncertainty in ‘services quality’

Uncertainty in the ‘services quality’ produced numerical variations in the simulated behaviour of ‘satisfied users’ of both eHMIS and SmartCare (Figure 5.47 (a) and (b)). However, the essential general pattern of behaviour of ‘satisfied users’ was maintained in both cases.



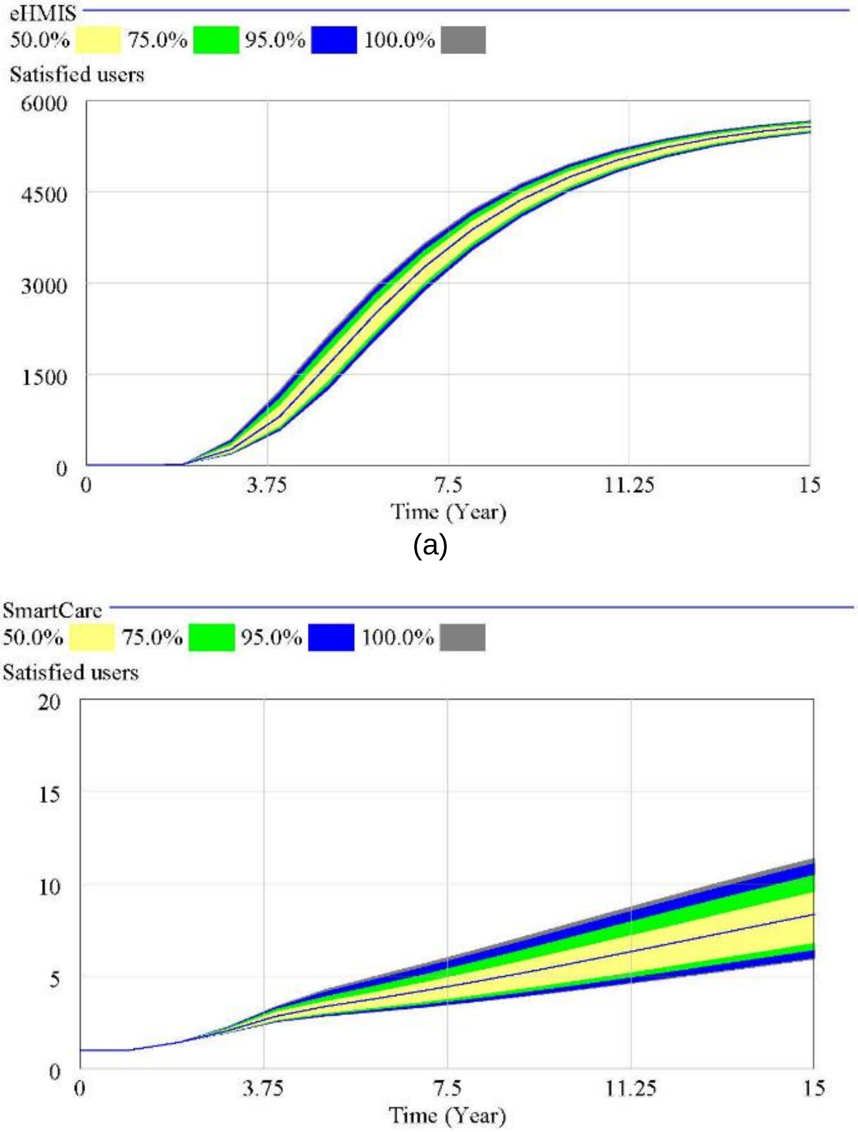
(a)

(b)

Figure 5.47 ‘Satisfied users’ of eHMIS under uncertainty of ‘services quality’ for interval (0.6,1). (b) ‘Satisfied users’ of SmartCare under uncertainty of ‘services quality’ for interval (0.1,0.5).

iii. ‘Satisfied users’ of eHMIS and SmartCare with uncertainty in the ‘effectiveness of training’

Figure 5.48 (a) and (b) showed the simulated general pattern of behaviour of 'satisfied users' due to changes in the ‘effectiveness of training’ in eHMIS and SmartCare respectively. The simulated behaviour pattern of ‘satisfied users’ of eHMIS was maintained with an important numerical variation after the second year (Figure 5.48 (a)). Similarly, the fundamental general pattern of behaviour of ‘satisfied users’ of SmartCare was not altered despite a significant numerical variation after year three (Figure 5.48 (b)).



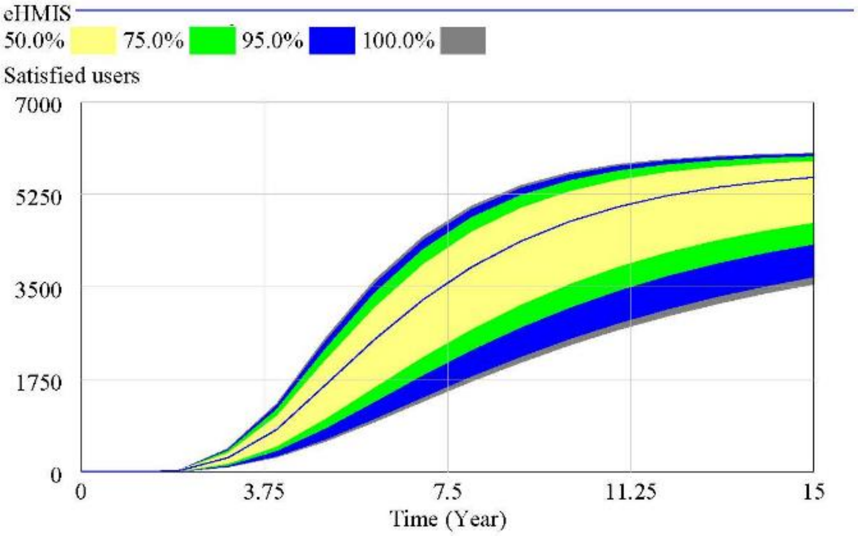
(a)

(b)

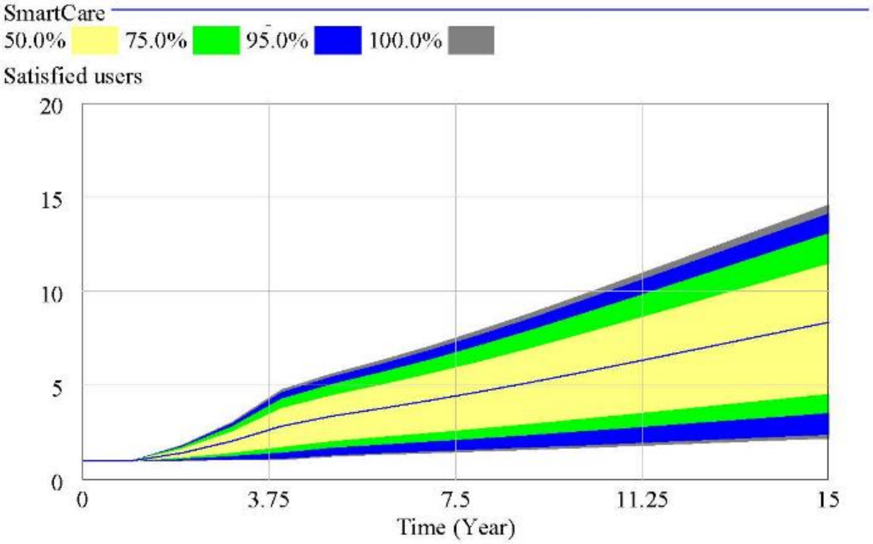
Figure 5.48 (a) ‘Satisfied users’ of eHMIS under uncertainty of ‘Effectiveness of training’ for interval (0.36,0.76). (b) ‘Satisfied users’ of SmartCare under uncertainty of ‘Effectiveness of training’ for interval (0.2,0.6).

iv. *'Satisfied users' of eHMIS and SmartCare with uncertainty in 'performance improvement rate'*

Uncertainty in the 'performance improvement rate' showed a significant numerical variation in the simulated number of 'satisfied users' of both eHMIS and SmartCare (Figure 5.49 (a) and (b)). The growth pattern of satisfied eHMIS users followed alternative paths after approximately year two; whereas the variation began after around 1.2 years in the 'satisfied users' of SmartCare (Figure 5.49 (a)). The overall essential pattern of behaviour remained unchanged in both cases.



(a)

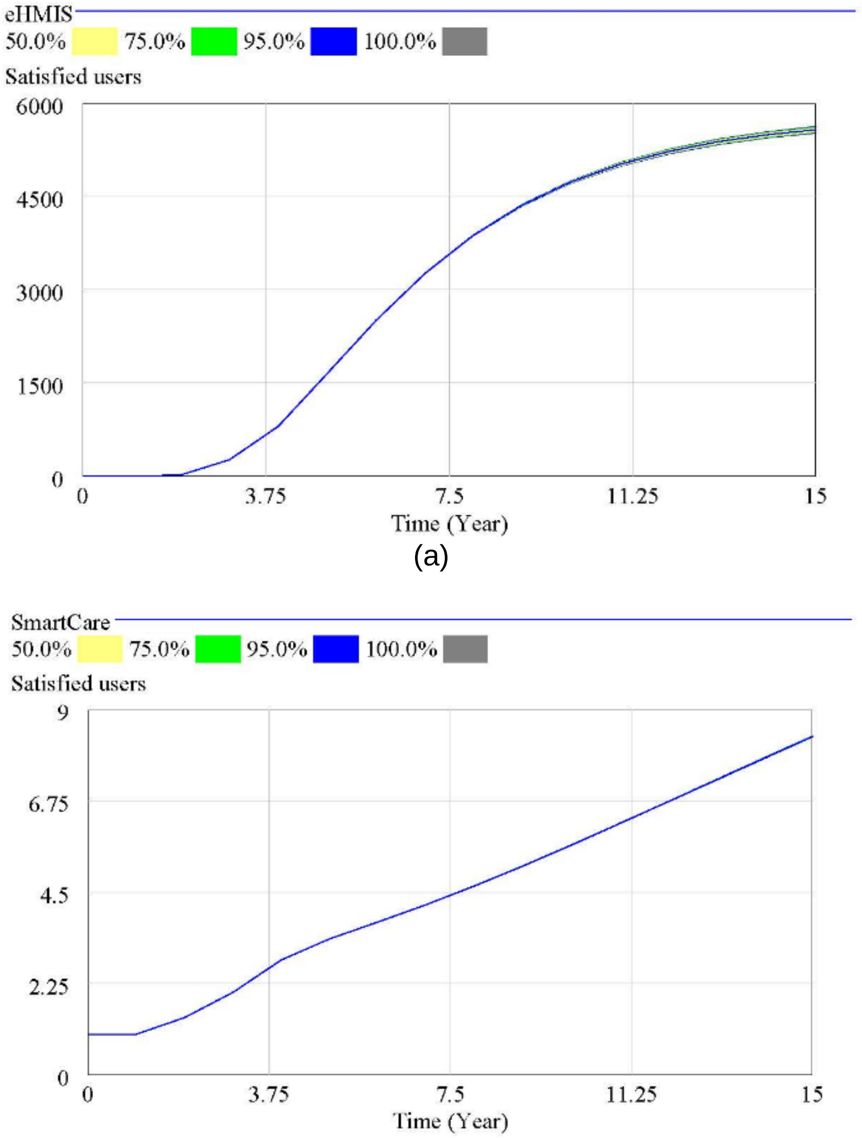


(b)

Figure 5.49 (a) 'Satisfied users' of eHMIS under uncertainty of 'performance improvement rate' for an interval (0.1,0.5). (b) 'Satisfied users' of SmartCare under uncertainty of 'performance improvement rate' for an interval (0,0.4).

v. *‘Satisfied users’ of eHMIS and SmartCare with uncertainty in ‘trial before termination’*

The simulated numerical and behaviour mode pattern for the ‘satisfied users’ of eHMIS and SmartCare was hardly sensitive to the value changes of ‘trial before termination’ parameter (Figure 5.50 (a) and (b)). The essential overall pattern of behaviour was maintained in both cases.



(a)

(b)

Figure 5.50 (a) ‘Satisfied users’ of eHMIS under uncertainty of ‘trial before termination’ for an interval (190,290). (b) ‘Satisfied users’ of SmartCare under uncertainty of ‘trial before termination’ for an interval (1200,1800).

The sensitivity analysis showed that the fundamental behaviour pattern of the simulated ‘satisfied users’ of eHMIS and SmartCare remained unchanged under uncertainty in the exogenous variables. However, the simulated ‘satisfied users’ showed numerical sensitivity to changes in ‘system quality’, ‘services quality’, ‘effectiveness of training’, and ‘performance improvement rate’. Specifically, significant numerical variations was produced under the ‘performance improvement rate’. The ‘performance improvement rate’ could be controlled by aligning the system functionalities with the end-user requirements through users’ involvement in the system development processes from the very beginning of system design.

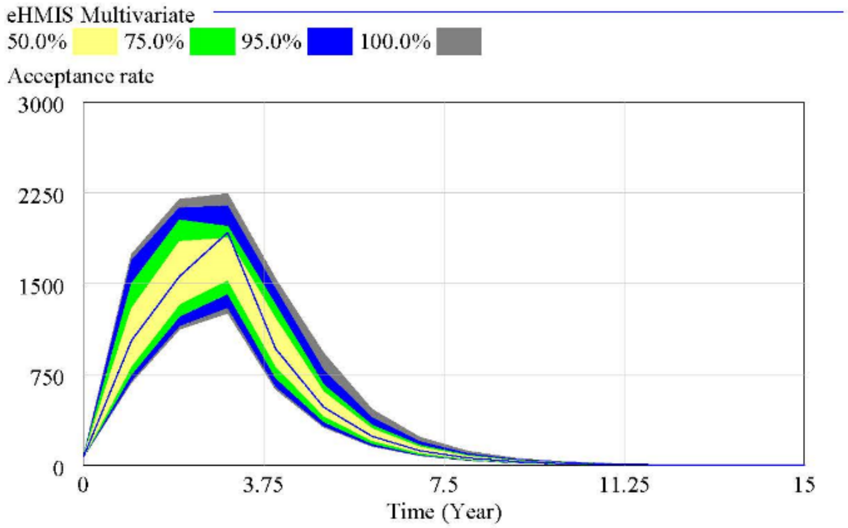
In summary, the behaviour mode sensitivity test revealed the model was essentially robust. The numerical variations indicated the possible policy interventions to improve ‘acceptance rate’, ‘information quality’ and the satisfaction of eHMIS and SmartCare users. The multivariate sensitivity analysis is discussed in the following section.

5.9.2. Multivariate sensitivity analysis of eHMIS and SmartCare

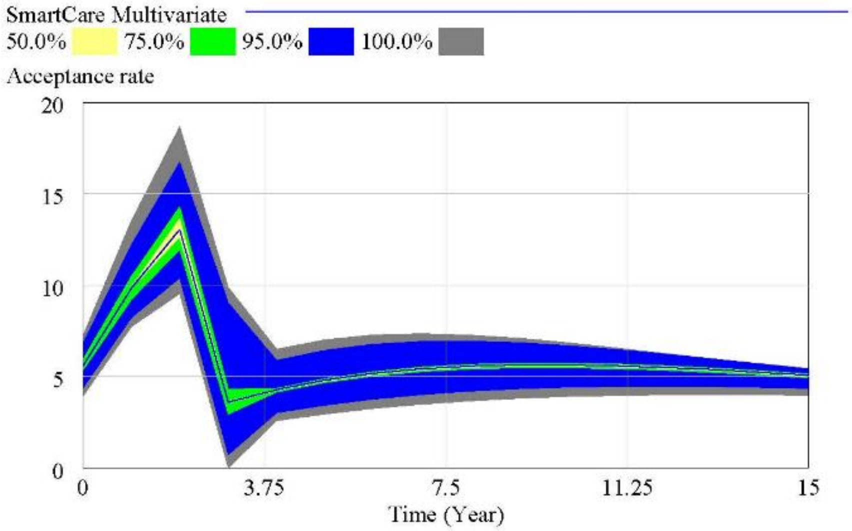
Sensitivity testing is the process of changing assumptions about the value of constants in the model and examining the resulting output for a change in values (Ventana Systems, 2012a; Hekimo and Barlas, 2017). All five exogenous parameters (See Table 5.6) were changed together to perform a multivariate sensitivity analysis. The number of simulations was set at 200 and a random uniform distribution is selected. The results of multivariate simulation analysis are presented below.

‘Acceptance rate’ of eHMIS and SmartCare (multivariate sensitivity analysis)

The multivariate sensitivity analysis of the ‘acceptance rate’ of eHMIS showed that the behaviour pattern of overshoot and decline essentially remained unchanged throughout the entire simulation under a random uniform distribution (Figure 5.51(a)). A similar pattern of unchanged behaviour was observed in the simulated “acceptance rate” of SmartCare (Figure 5.51(b)). However, a significant numerical variation demonstrated in both eHMIS and SmartCare indicated the possibility of policy interventions to improve ‘acceptance rate’.



(a)

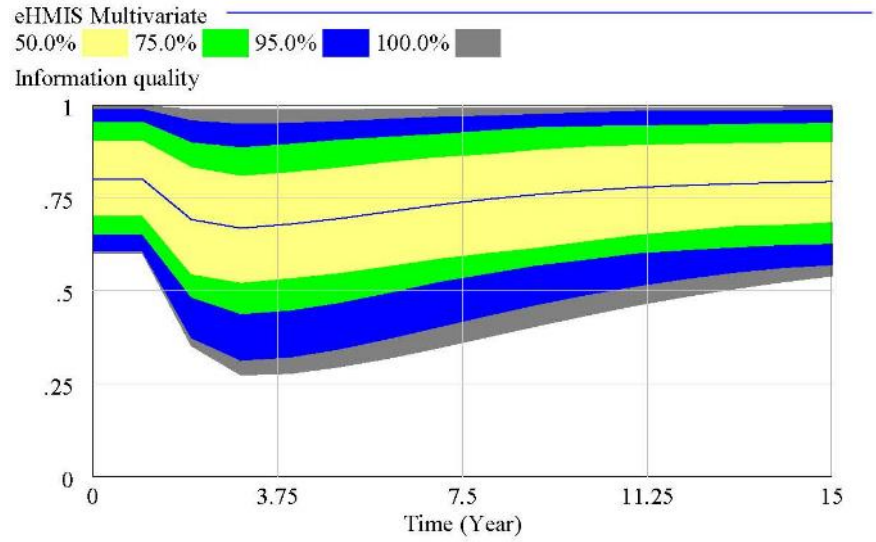


(b)

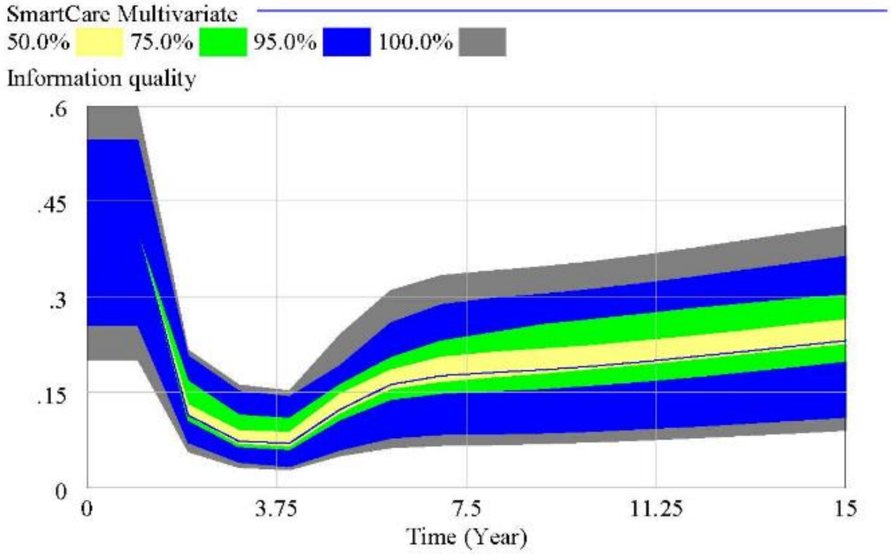
Figure 5.51 (a) A multivariate analysis of eHMIS ‘acceptance rate’ (b) A multivariate analysis of SmartCare ‘acceptance rate’.

<u>‘Information quality’ of eHMIS and SmartCare (multivariate sensitivity analysis)</u>

The simulated response of ‘information quality’ behaviour of both eHMIS and SmartCare, i.e., a decline followed by an increase in the later phases, essentially remained unchanged under uncertainty of multiple exogenous variables in the multivariate sensitivity analysis (Figure 5.52 (a) and (b)). However, the relative decline in the simulated ‘information quality’ of SmartCare was greater than that of eHMIS in the early years of technology use. The multivariate analysis also demonstrated a large numerical variation in both eHMIS and SmartCare.



(a)

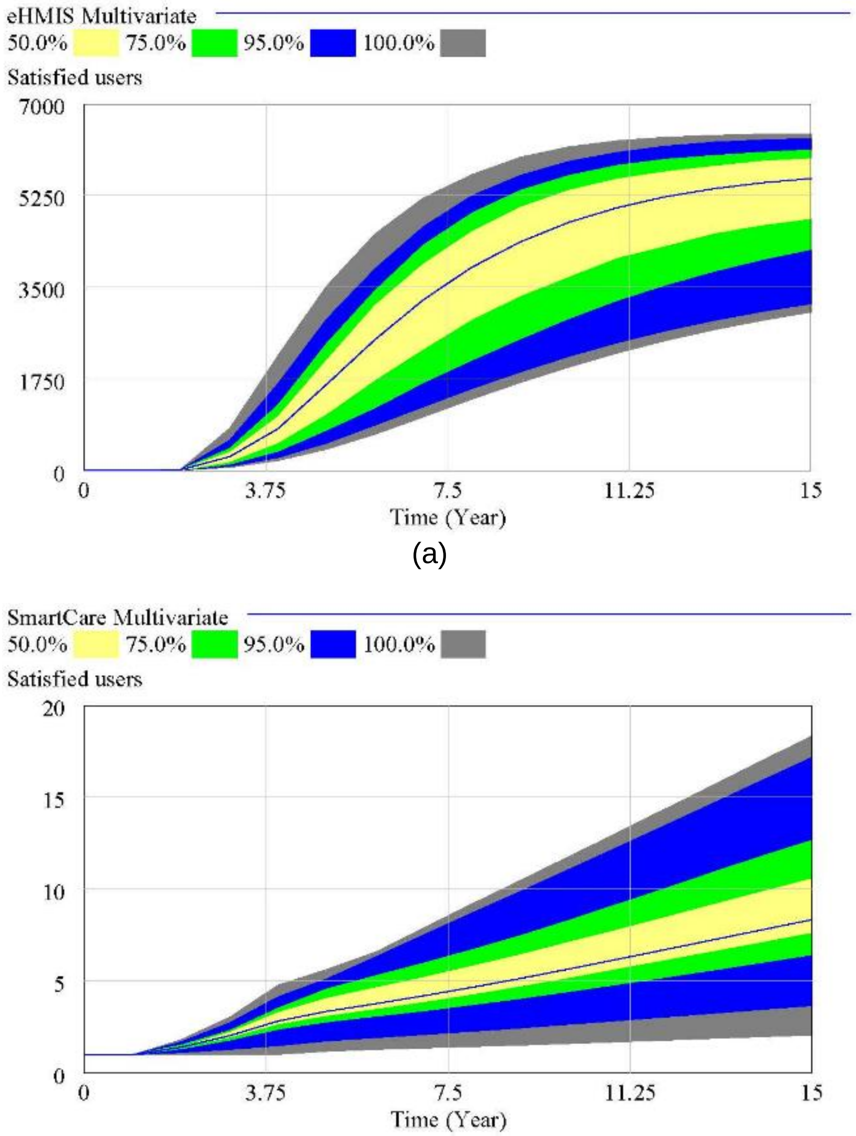


(b)

Figure 5.52 (a) A multivariate analysis of 'information quality' of eHMIS. (b) A multivariate analysis of 'information quality' of SmartCare.

'Satisfied users' of eHMIS and SmartCare (multivariate sensitivity analysis)

The behaviour pattern of 'satisfied users' of eHMIS and SmartCare followed the general S-shaped growth throughout the simulation (Figure 5.53 (a) and (b)). The simulated behaviour response of 'satisfied users' of eHMIS and SmartCare was essentially maintained throughout the uncertainties. However, the numerical variation was significantly high to the random changes of the exogenous parameters.



(a)

(b)

Figure 5.53 (a) A multivariate analysis of 'satisfied users' of eHMIS. (b) A multivariate analysis of 'satisfied users' of SmartCare.

In summary, the multivariate analysis demonstrated that the model was fundamentally robust in maintaining the simulated behaviour pattern of 'acceptance rate', 'information quality', and 'satisfied users'. The numerical variation to the uncertainty of exogenous variables can indicate the possibility for alternative policy design to improve technology acceptance 'information quality', and users' satisfaction. The next section will focus on the policy analysis and what-if scenario for alternative policies design to improve the sustainability of eHMIS and SmartCare systems.

5.10. Policy analysis

A policy is a decision rule, a general way of making decisions (Barlas, 2002). System dynamics deals with dynamic policy problems and has a potential in developing strategic models for policy analysis (Design, Rashedi and Hegazy, 2016). Policies represent rules for conscious human control (Barlas, 2002). Policy analysis is about the sensitivity of model behaviour to the policy parameters and/or policy structures (Barlas, 2002; Design, Rashedi and Hegazy, 2016). The system dynamic approach is perhaps the most promising simulation method for long-term policy analysis through quantitative simulations and qualitative conceptual models (Design, Rashedi and Hegazy, 2016; Lyons and Duggan, 2017).

Policy analysis may involve varying one or more of the model characteristics for the set of parameter values, function values, function shapes and forms of policy equations to examine the resulting behaviour (Barlas, 2002). System dynamics simulation provides a clearer understanding of possible long-term impacts of policies (Design, Rashedi and Hegazy, 2016). Like sensitivity analysis, numerical or pattern-oriented changes may be demonstrated in the policy analysis (Barlas, 2002). Pattern-oriented policy analysis is naturally much more important since the purpose of system dynamics studies is to improve undesirable dynamic behaviour patterns (Barlas, 2002). The goal of policy analysis is to identify changes in the model structure and parameters that can improve model behaviour (Sterman, 2000; Barlas, 2002).

The policy analysis in this research study focused on improving the performance of ‘acceptance rate’, ‘information quality’ and ‘satisfied users’ by varying selected exogenous parameters. These three factors were important factors to ensure sustainable use of eHMIS and SmartCare technologies and to improve healthcare services through informed decisions. As seen in the sensitivity analysis, ‘acceptance rate’, ‘information quality’ and ‘satisfied users’ were hardly sensitive to changes in the ‘trial before termination’. Moreover, it would be difficult to design a policy that can directly control the end-users' ‘trial before termination’. However, eHMIS and SmartCare implementing health facility could have control over ‘system quality’, ‘services quality’, ‘effectiveness of training’ and ‘performance improvement rate’. Therefore, these variables are varied in the simulations of the system dynamics model to test alternative policies.

Barlas (2002) discussed that the recommended policy should be realistic, considering the environment in which it would be implemented. An alternative policy should work under different environmental conditions and scenarios to demonstrate robustness (Barlas, 2002). The what-if scenario analysis discussed in the following section aims at improving the ‘acceptance rate’, ‘information quality’ and ‘satisfied users’ by varying the parameter values of ‘system quality’, ‘services quality’, ‘effectiveness of training’ and ‘performance improvement rate’.

5.10.1. What-if scenario analysis

The purpose of “what-if” simulation experiments were to examine the impact of exogenous variables on the performance of the technology ‘acceptance rate’, ‘information quality’ and ‘satisfied users’. Candidate exogenous variables for policy analysis were varied and tested in a different scenario for the alternative policies. Table 5.7 summarises the scenario-based experimental design for what-if analysis of technological quality, i.e., system and services quality.

Scenario 0 represents the business as usual scenario assuming the continuity of the current trend in the technological quality (system and services quality) of both eHMIS and SmartCare. Scenario-1 illustrates the case of 0.2 (20%) decline in the system and services quality of both eHMIS and SmartCare. In scenario 2, the ‘system quality’ drops by 0.2 (20%), whereas ‘services quality’ rises by 0.2 (20%) in both eHMIS and SmartCare (See Table 5.7). Scenario 3 shows a 0.2 (20%) increase in the ‘system quality’ and a 0.2 (20%) drop in the ‘services quality’. Scenario 4 illustrates the case of 0.2 (20%) increase in the system and services quality of both eHMIS and SmartCare.

Table 5.7 What-if experiments for technological quality.

Scenario	eHealth application	System quality	Services quality
0 (Base)	eHMIS	0.8 (base)	0.8 (base)
	SmartCare	0.4 (base)	0.3 (base)
1	eHMIS	0.6 (low)	0.6 (low)
	SmartCare	0.2 (low)	0.1 (low)
2	eHMIS	0.6 (low)	1.0 (high)
	SmartCare	0.2 (low)	0.5 (high)
3	eHMIS	1.0 (high)	0.6 (low)
	SmartCare	0.6 (high)	0.1 (low)
4	eHMIS	1.0 (high)	1.0 (high)
	SmartCare	0.6 (high)	0.5 (high)

The “what-if” simulation experiment analysis of base scenario for the ‘effectiveness of training’ of eHMIS and SmartCare is represented in scenario 0 (See Table 5.8). Scenario 1 and 2 describe the low and high parameter values of ‘effectiveness of training’ for eHMIS and SmartCare respectively (See Table 5.8).

Table 5.8 What-if experiments for 'effectiveness of training'.

Scenario	eHealth application		Effectiveness of training	
0 (Base)	eHMIS		0.56 (base)	
	SmartCare		0.4 (base)	
1	eHMIS		0.36 (low)	
	SmartCare		0.2 (low)	
2	eHMIS		0.76 (high)	
	SmartCare		0.6 (high)	

Table 5.9 summarises the parameter values of 'performance improvement rate' used in the "what-if" simulation analysis of eHMIS and SmartCare. Scenario 0 represents the base scenario; whereas scenario 1 and 2 respectively show the low and high cases for the 'performance improvement rate' of eHMIS and SmartCare (See Table 5.9).

Table 5.9 What-if experiments for 'performance improvement rate'.

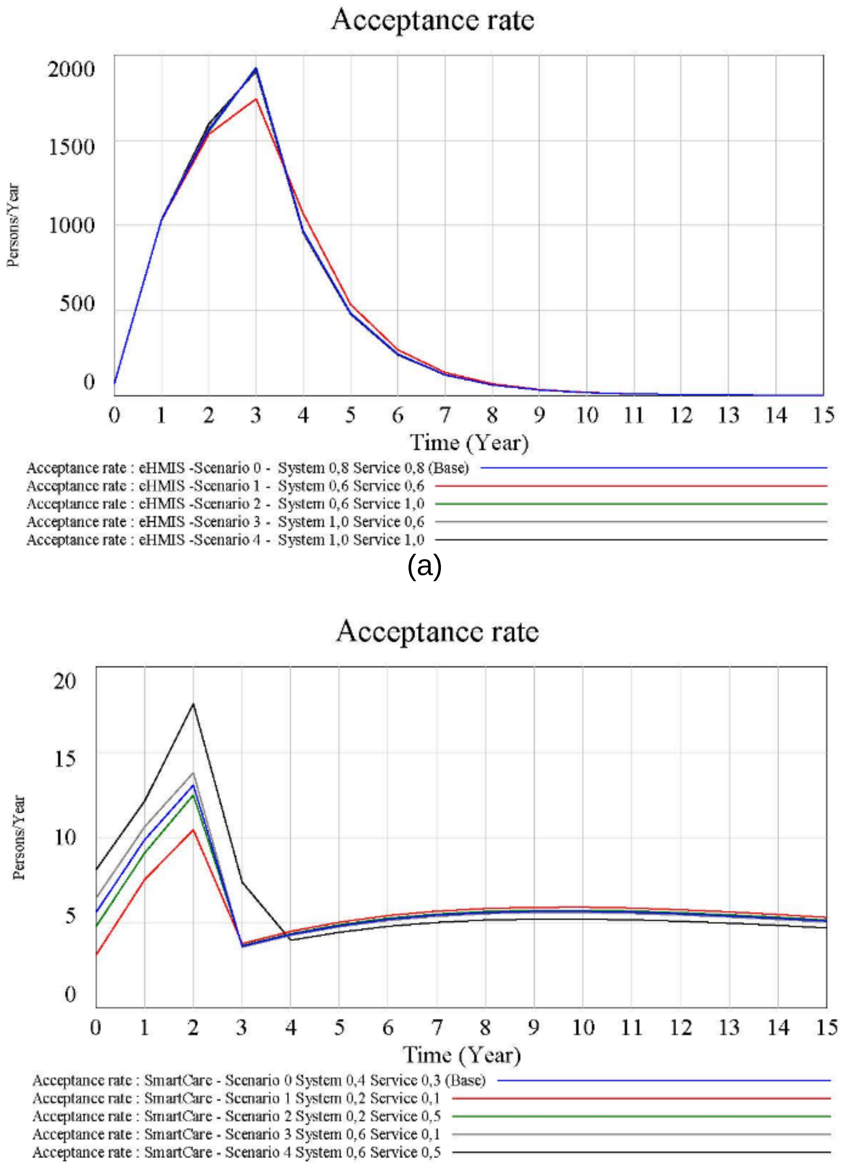
Scenario	eHealth application	Performance improvement rate
0 (Base)	eHMIS	0.3 (base)
	SmartCare	0.2 (base)
1	eHMIS	0.1 (low)
	SmartCare	0 (low)
2	eHMIS	0.5 (high)
	SmartCare	0.4 (high)

The "what-if" analysis for the simulated behaviour pattern of 'acceptance rate', 'information quality', and 'satisfied users' was carried out by increasing and reducing the values of the base scenario of selected exogenous variables by 0.2 (20%) for both eHMIS and SmartCare. In-depth discussion of what-if experiment analysis simulation results are discussed in the following section.

Improving the 'acceptance rate' of eHMIS and SmartCare

Improving 'acceptance rate' through system and services quality

The two exogenous elements of technological quality, i.e., system quality and services quality, were varied to assess their influence on 'acceptance rate'. Figure 5.54 (a) and (b) showed the response of simulated 'acceptance rate' behaviour as the system and services quality varied.



(a)

(b)

Figure 5.54 (a) A what-if analysis of 'acceptance rate' of eHMIS with respect to changes in system and services quality. (b) A what-if analysis of 'acceptance rate' of SmartCare with respect to changes in system and services quality.

In year two, the base scenario (in blue colour) of eHMIS and SmartCare showed a better simulated 'acceptance rate' than scenario 1 and 2 (in red and green colour respectively) (See Figure 5.54 (a) and (b)). Scenario 1 and 2 had a lower 'system quality' than the base scenario (See Table 5.7). However, scenario 3 and 4 (in grey and black colours respectively) had higher 'system quality' and a greater simulated 'acceptance rate' of eHMIS and SmartCare than the base scenario (See Figure 5.54 (a) and (b)).

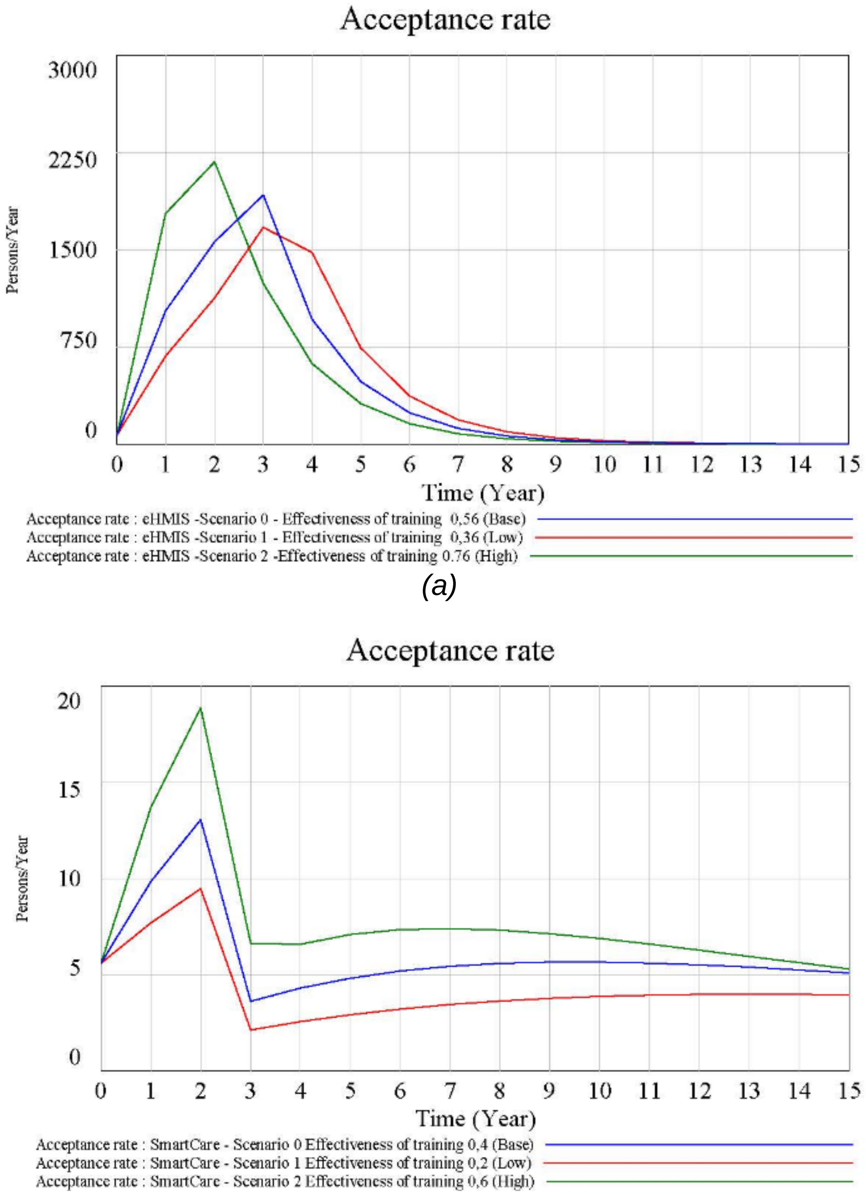
The biggest gap between the high and low values of the simulated eHMIS 'acceptance rate' was achieved in the third year (See Figure 5.54 (a)). On year three, the peak values of the simulated eHMIS 'acceptance rate' was 1927 Persons/Year and the lowest value was 1741 Persons/Year (See Figure 5.54 (a) in black and red colour respectively). On the other hand, the gap between the high and low values of the simulated SmartCare 'acceptance rate' was maximum in the second year. In this year, the highest simulated 'acceptance rate' of SmartCare was 18 Persons/Year and the lowest value was 10 Persons/Year (See Figure 5.54 (b)). The small gap between the maximum and minimum values of the simulated eHMIS and SmartCare 'acceptance rate' indicated the possible weak impact of system and services quality on 'acceptance rate'.

Increasing a 'system quality' by 0.2 (20%) (See Figure 5.54 (a) and (b) in grey colour) produced a greater simulated 'acceptance rate' than increasing 'services quality' by the same amount (See Figure 5.54 (a) and (b) in green colour). This showed that the impact of 'system quality' was stronger than 'services quality' in terms of improving the simulated 'acceptance rate' of eHMIS and SmartCare.

Improving 'acceptance rate' through 'effectiveness of training'

The influence of 'effectiveness of training' on 'acceptance rate' was significant in terms of changing the phase and the peak values of the simulated eHMIS 'acceptance rate' (See Figure 5.55 (a)). The improvement in the 'effectiveness of training' by 0.2 (20%) produced the peak simulated eHMIS 'acceptance rate' of 2177 Persons/Year in the second year (See Figure 5.55 (a)) scenario 2 in green colour). Scenario 2 achieved the highest value in shorter period of time compared to the peak value of the base scenario (scenario 0) of simulated eHMIS 'acceptance rate', i.e., 1922 Persons/Year in the third year (Figure 5.55 (a) in blue colour).

The maximum gap between the highest and the lowest points of simulated eHMIS 'acceptance rate' in the same period is achieved in the second year. In this year, scenario 2 recorded the peak of 2177 Persons/Year (See Figure 5.55 (a) in green colour); whereas scenario 1 showed the lowest simulated eHMIS 'acceptance rate' of 1126 Persons/Year in the same year (See Figure 5.55 (a) in red colour). This gap was higher than the one observed in the what-if analysis of system and services quality on 'acceptance rate'. Hence 'effectiveness of training' should be the focus of policy makers to improve eHMIS 'acceptance rate' by end-users. Conducting effective training and communicating the benefit of the technology to the potential users significantly increased 'acceptance rate' of eHMIS.



(a)

(b)

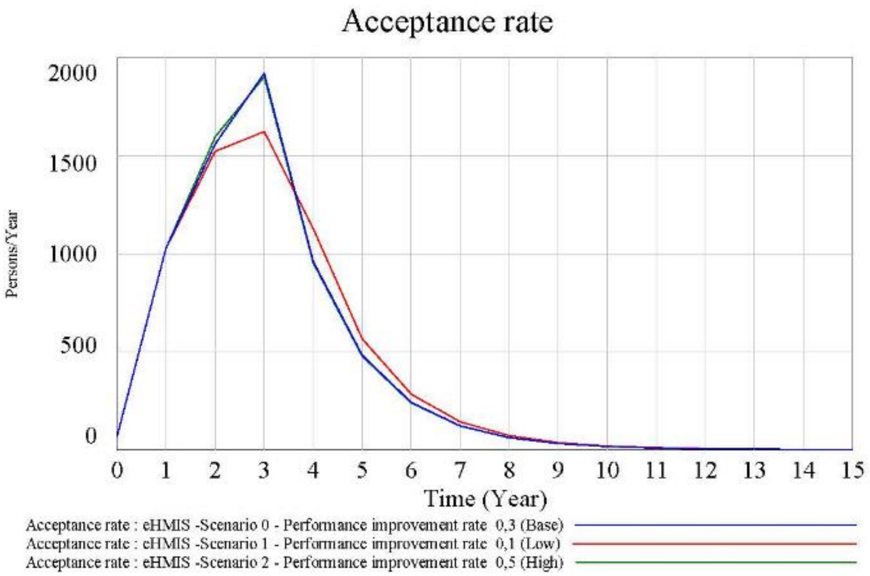
Figure 5.55 (a) A what-if analysis of 'acceptance rate' of eHMIS with respect to changes in the 'effectiveness of training'. (b) A what-if analysis of 'acceptance rate' of SmartCare with respect to changes in the 'effectiveness of training'

The base scenario of simulated 'acceptance rate' (in blue colour) was between scenario 1 and 2 (in red and green colours respectively) (See Figure 5.55 (b)). The maximum gap in the different scenarios of simulated SmartCare 'acceptance rate' was observed in year two. The peak value of simulated SmartCare 'acceptance rate' under scenario 2 was 18 Persons/Year and that of scenario 0 was 9 Persons/Year (Figure 5.55 (b)). This gap is higher than the one noticed in the simulated what-if analysis of system and services quality on 'acceptance rate'. Hence 'effectiveness of training' is a good variable to influence the 'acceptance rate' of SmartCare. The managers should focus on improving ‘acceptance rate’ through effective training (ease of use) and communication to raise end-user awareness about the benefits of technology (usefulness).

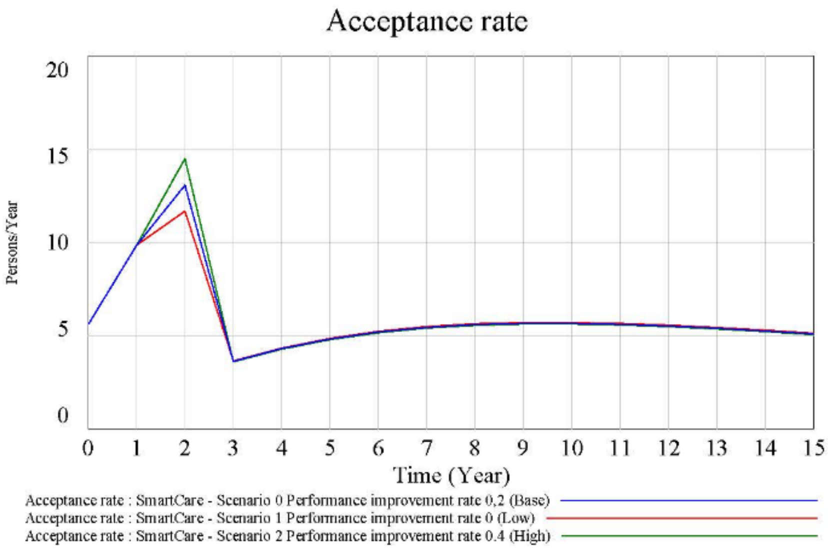
Improving ‘acceptance rate’ through ‘performance improvement rate’

The impact of different scenarios of ‘performance improvement rate’ on the simulated ‘acceptance rate’ of eHMIS and SmartCare depicted in Figure 5.56 (a) and (b). A 0.2 (20%) increase in the ‘performance improvement rate’ increased the simulated ‘acceptance rate’ of eHMIS to a peak value of 1596 Persons/Year (in green colour) from 1560 Persons/Year (in blue colour) on the third year (See Figure 5.56 (a)). Similarly, on the second year, the base scenario of simulated SmartCare ‘acceptance rate’, 13 Persons/Year (in blue colour), increased to 14 Persons/Year (in green colour) as shown in Figure 5.56 (b).

The drop in the ‘performance improvement rate’ by 0.2 (20%) reduced the simulated eHMIS and SmartCare ‘acceptance rate’ of the base scenario from 1560 and 13 Persons/Year (in blue colour) to 1523 and 11 Persons/Year respectively (in red colours) (Figure 5.56 (a) and (b)). The maximum gaps in the scenarios were observed in year three for simulated eHMIS ‘acceptance rate’ (1523 Persons/Year, 1596 Persons/Year) and for simulated SmartCare ‘acceptance rate (14 Persons/Year, 11 Persons/Year) in year two. These gaps were small compared to ‘system quality’, ‘services quality’, and ‘effectiveness of training’. This could be an indication of a relatively weaker impact of ‘performance improvement rate’ on the ‘acceptance rate’ of eHMIS and SmartCare.



(a)



(b)

Figure 5.56 (a) A what-if analysis of 'acceptance rate' of eHMIS with respect to changes in the 'performance improvement rate'. (b) A what-if analysis of 'acceptance rate' of SmartCare with respect to changes in the 'performance improvement rate'.

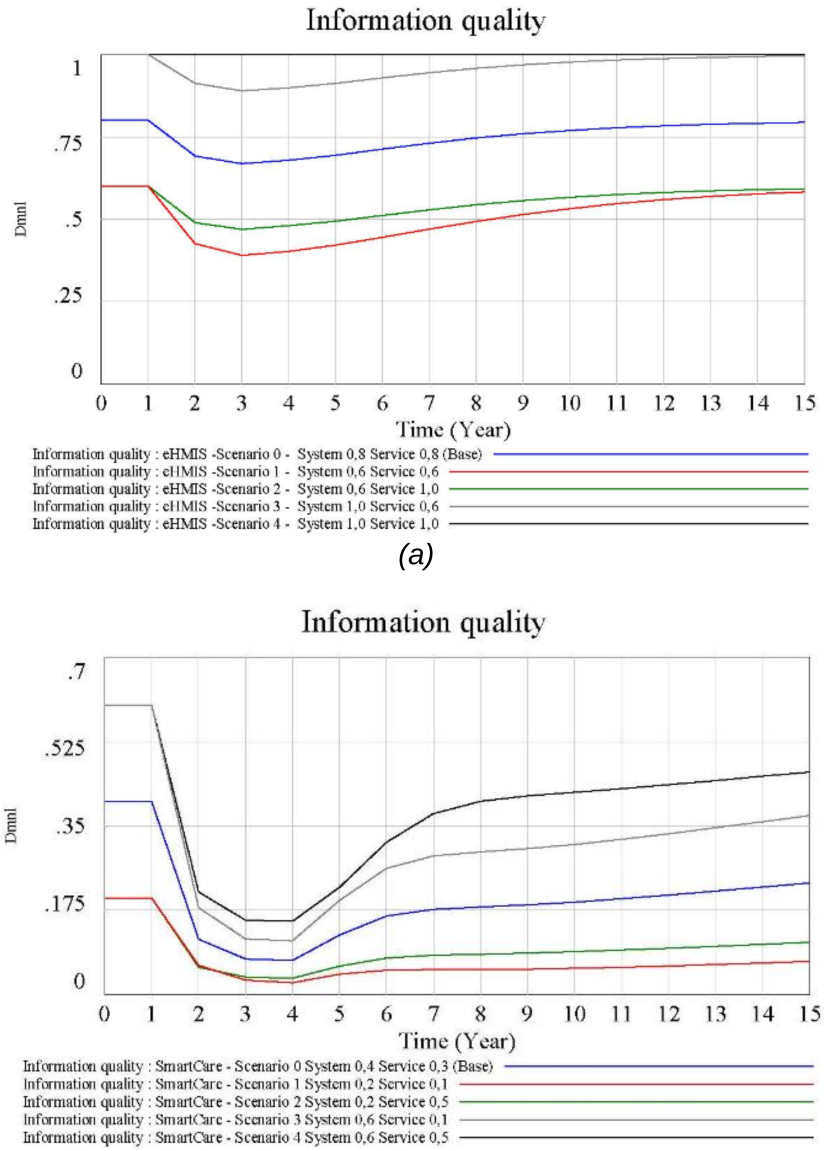
In general, The simulated 'acceptance rate' of eHMIS and SmartCare was better improved by increasing 'effectiveness of training' than improving 'system quality', 'services quality' or 'performance improvement rate'. Hence improving the 'effectiveness of training' should be the primary focus of policy makers to improve the 'acceptance rate' of technology. Conducting effective training and communicating the benefit of the technology to the potential users can significantly increase 'acceptance rate' of eHMIS and SmartCare.

Improving the 'information quality' of eHMIS and SmartCare

Improving 'information quality' through system and services quality

The system quality and services quality were varied as shown in Table 5.7 to assess the influence on the simulated 'information quality' of eHMIS and SmartCare (Figure 5.57 (a) and (b)). The base scenario (in blue colour) was used as a reference simulation behaviour of 'information quality' to test alternative policies by varying system and services quality (Figure 5.57 (a) and (b)).

The simulated 'information quality' of eHMIS and SmartCare behaviour response to a 0.2 (20%) lower 'system quality' was below the base scenario (in blue colour) as depicted in scenario 1 and 2 (in red and green colours respectively) (Figure 5.57 (a) and (b)). Despite a higher value of 'services quality', scenario 2 (in green colour) had low simulated 'information quality' of eHMIS and SmartCare due to lower 'system quality' (Figure 5.57 (a) and (b)). On the other hand, a high ‘information quality’ of eHMIS and SmartCare in scenario 3 and 4 (in grey and black colour respectively) were a result of a 0.2 (20%) increase in ‘system quality’ beyond the base scenario (Figure 5.57 (a) and (b)). Although the ‘services quality’ was lowered by the same value in scenario 3 (in grey colour), a higher level of ‘information quality’ of eHMIS and SmartCare was observed (Figure 5.57 (a) and (b)). This showed the stronger influence of ‘system quality’ on the ‘information quality’ compared to the ‘services quality’.



(a)

(b)

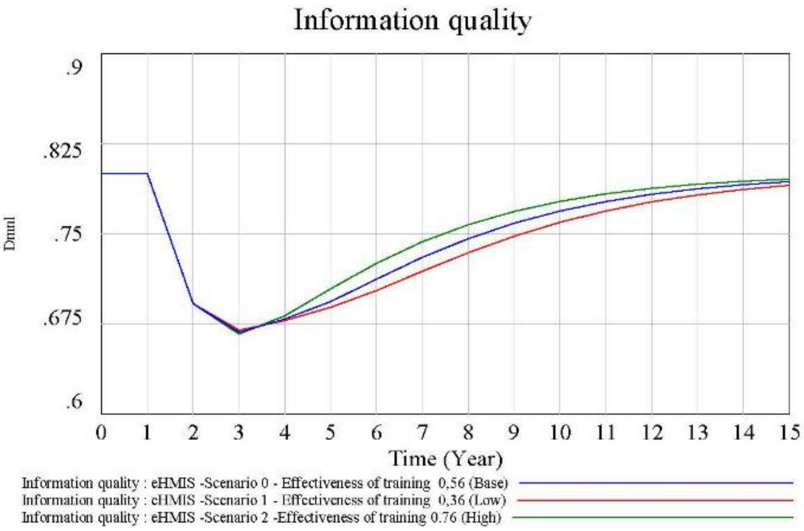
Figure 5.57 (a) A what-if analysis of ‘information quality’ of eHMIS with respect to changes in the system and services quality. (b) A what-if analysis of ‘information quality’ of SmartCare with respect to changes in the system and services quality.

Moreover, the maximum gap was observed in the third year between scenario 1 and 4 on the value of simulated ‘information quality’ of eHMIS (0.469 and 1 respectively) (See Figure 5.57 (a) in red and black colour). Similarly, higher gaps were detected in the value of simulated ‘information quality’ of SmartCare for different scenarios. For example, the ‘information quality’ of SmartCare was 0.02949 for scenario 1 and 0.1537 for scenario 2 in the third year. This difference widened in year fifteen with 0.06825 for scenario 1 (See Figure 5.57 (b) in red colour) and the 0.4614 for scenario 4 (See Figure 5.57 (b) in black colour). The big gap indicated a significant impact of ‘system quality’ and ‘services quality’ on 'information quality' of eHMIS and SmartCare. Specifically, ‘system quality’ had a stronger influence on ‘information quality’.

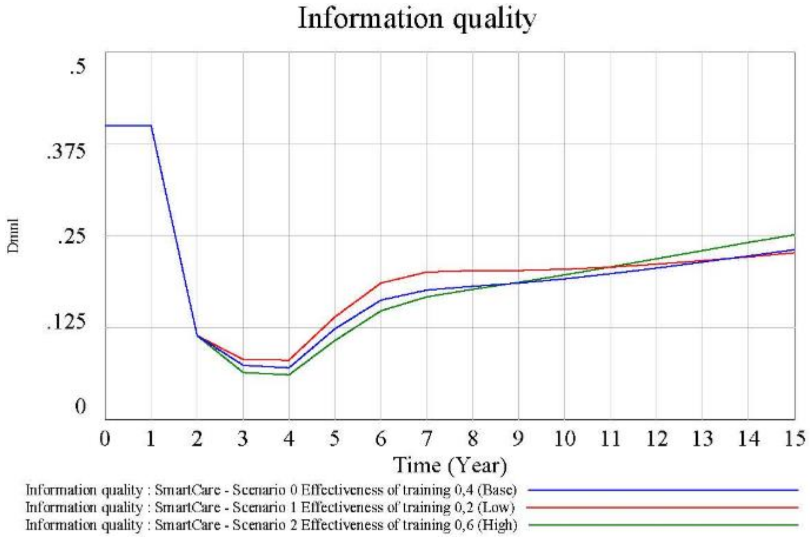
Improving ‘information quality’ through ‘effectiveness of training’

Figure 5.58 (a) and (b) showed the behavioural pattern of ‘information quality’ to the changes in the ‘effectiveness of training’. The simulation results indicated that the ‘effectiveness of training’ had a weaker influence on the ‘information quality’ compared to system and services quality (Figure 5.58 (a) and (b)).

The small changes in the simulated ‘information quality’ levels of both eHMIS and SmartCare for different scenarios of ‘effectiveness of training’ indicated the weak influence of ‘effectiveness of training’. Therefore, ‘effectiveness of training’ should not be the focus for ‘information quality’ improvement efforts. For example, in the third year, the lowest value of simulated ‘information quality’ of eHMIS and SmartCare was recorded under scenario 1 with the value of 0.6662 and 0.06354 respectively. Whereas in the same year, the highest value of simulated ‘information quality’ of eHMIS and SmartCare was achieved in scenario 2 with 0.6694 and 0.08139 respectively. The smaller gaps between the best and worst case scenarios indicated the weak influence ‘effectiveness of training’ on ‘information quality’.



(a)



(b)

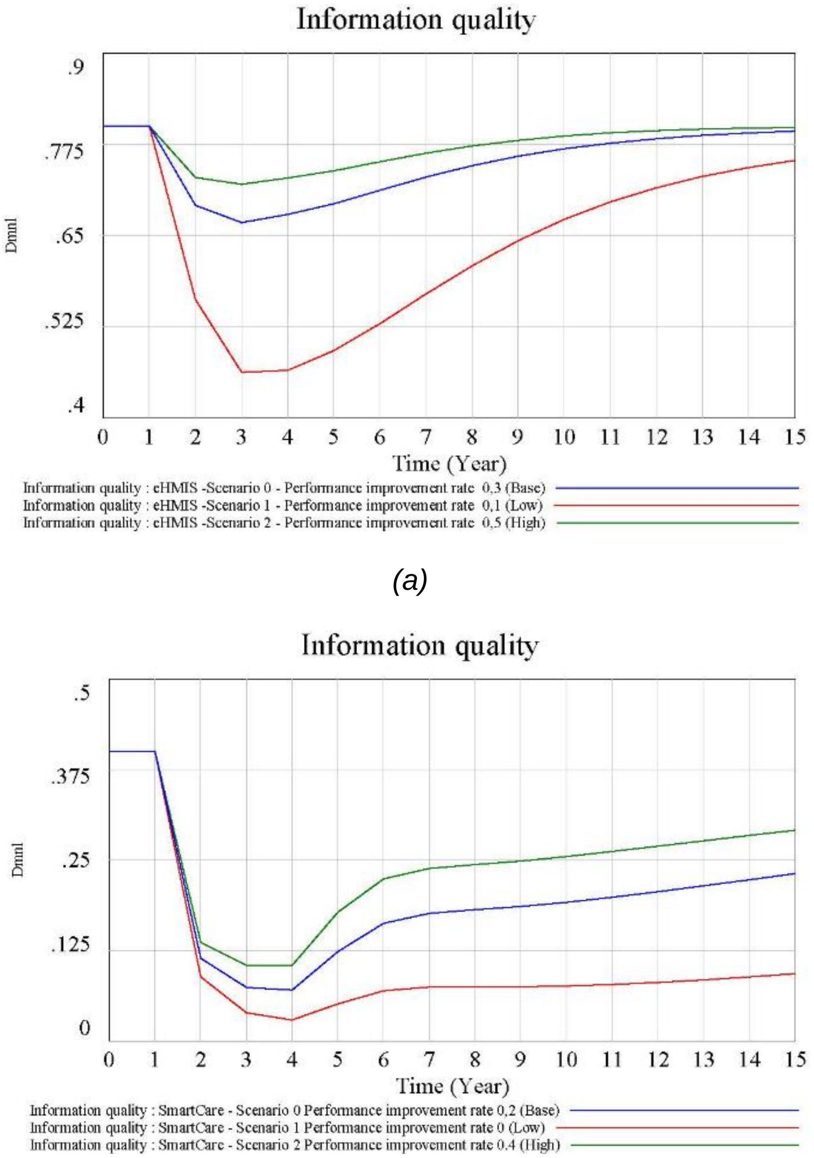
Figure 5.58 (a) A what-if analysis of 'information quality' of eHMIS with respect to changes in the 'effectiveness of training'. (b) A what-if analysis of 'information quality' of SmartCare with respect to changes in the 'effectiveness of training'.

Improving 'information quality' through 'performance improvement rate'

As shown in Figure 5.59 (a) and (b), an increase in 'performance improvement rate' by 0.2 (20%) showed improvement in the simulated 'information quality' of eHMIS and SmartCare as depicted in scenario 2 (in green colour) compared to the base scenario (in blue colour). Conversely, a drop in 'performance improvement rate' by a similar value resulted in lower simulated 'information quality' as shown in scenario 1 (in red colour) (See Figure 5.59 (a) and (b)).

On year three, a maximum gap in the simulated eHMIS 'information quality' was between scenario 1 (0.4622) and scenario 2 (0.7201) (See Figure 5.59 (a)). In the same year, the simulated 'information quality' of SmartCare for scenario 1 was 0.03822 and that of scenario 2 was 0.1039 (See Figure 5.59 (b)). The gap between the worst and best case scenarios increased as the year progressed. For example, in year fifteen the 'information quality' of SmartCare for scenario 1 was 0.09248 and that of scenario 2 was 0.291 (See Figure 5.59 (b)).

The gaps between the simulation results showed the moderate influence of 'performance improvement rate' on 'information quality'. The influence of 'performance improvement rate' on 'information quality' came through 'satisfied users' that directly influenced the quality of the information product (Figure 5.59 (a) and (b)).



(a)

(b)

Figure 5.59 (a) A what-if analysis of 'information quality' of eHMIS with respect to changes in the 'performance improvement rate'. (b) A what-if analysis of 'information quality' of SmartCare with respect to changes in the 'performance improvement rate'.

The final goal of implementing eHMIS and SmartCare systems was to produce quality information that could be used to make accurate decision to improve healthcare services. In general, the quality of an information product was critical for the sustainable use of electronic systems. This study confirmed that 'system quality' had the strongest impact on the simulated 'information quality'. Since the quality of information product could only be as good as the technology producing it, 'system quality' played a critical to ensure better 'information quality'. Furthermore, 'services quality' and 'performance improvement rate' showed a moderate influence on the simulated ‘information quality’. However, the influence of ‘effectiveness of training’ on the simulated ‘information quality’ was weak.

In summary, the effort of improving ‘information quality’ should focus on the development of the eHealth system with high ‘system quality’. High ‘system quality’ referred to reliability, ease of use, and the capability of a system that met end-users’ requirements.

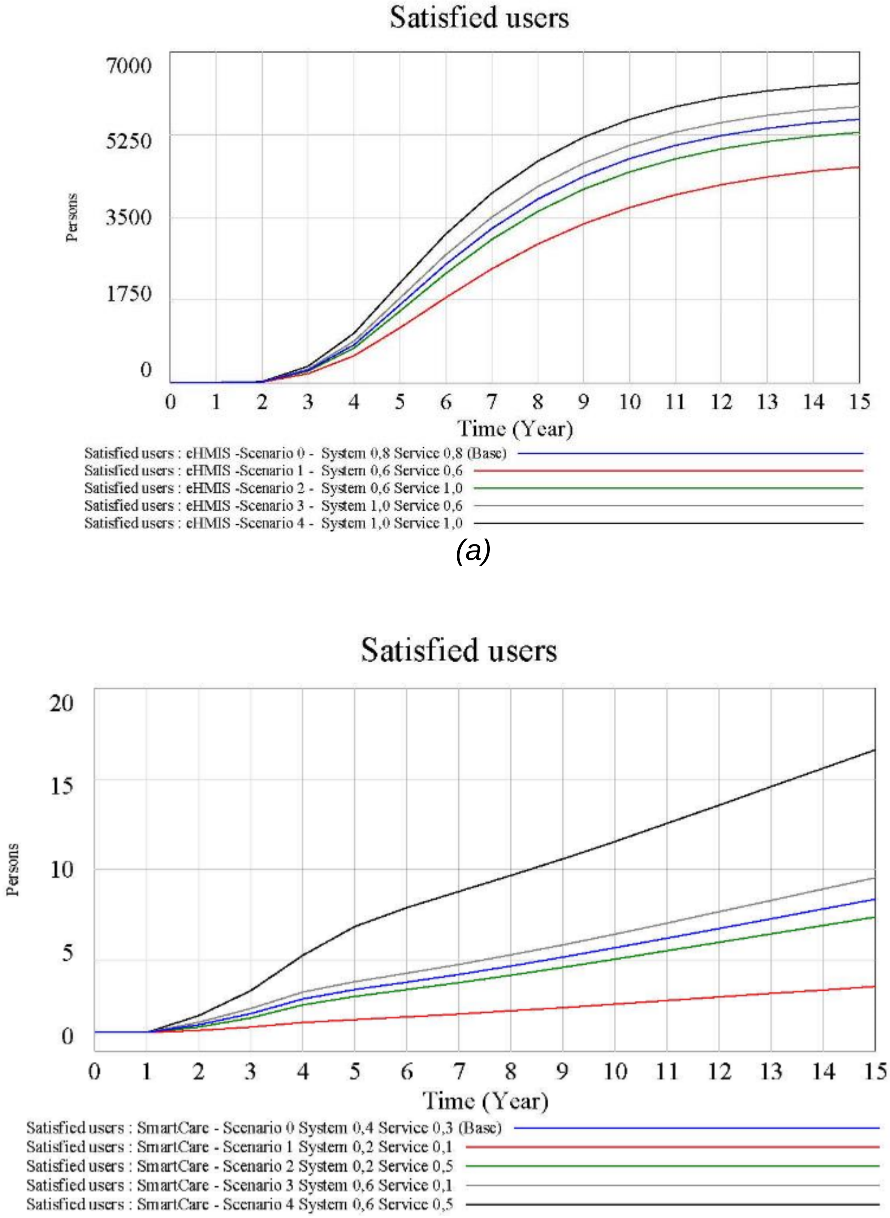
Improving the ‘satisfied users’ of eHMIS and SmartCare

Improving ‘satisfied users’ through system and services quality

Figure 5.60 (a) and (b) depicted the simulated response of ‘satisfied users’ of eHMIS and SmartCare to changes in the system and services quality. As shown in Figure 5.60 (a) and (b), the base scenario of simulated ‘satisfied users’ of both eHMIS and SmartCare (in blue colour) was lower than scenario 3 and 4 (in grey and black colours) but higher than scenario 1 and 2 (in red and green colours).

Both system and services quality had shown influence on the simulated ‘satisfied users’ of eHMIS and SmartCare (Figure 5.60 (a) and (b)). As shown in scenario 1 (in red colour), the decline in ‘system quality’ and ‘services quality’ by 0.2 (20%) from the base scenario (in blue colour) had dropped the simulated number of ‘satisfied users’ of eHMIS by 490 Persons in year five (See Figure 5.60 (a)). Likewise, the simulated number of ‘satisfied users’ of SmartCare had fallen from 2 Person in base scenario (in blue colour) to 1 Person in scenario 1 (in red colour) in the fifth year (See Figure 5.60 (b)). On the other hand, increase in the system and services quality by 0.2 (20%) from the base scenario as depicted in scenario 4 (in black colour) improved the simulated ‘satisfied users’ of eHMIS by 466 Persons and that of SmartCare by 3 Persons in the fifth year (See Figure 5.60 (a) and (b)).

Despite a 0.2 (20%) higher ‘services quality’, scenario 2 (in green colour) showed lower simulated ‘satisfied users’ of eHMIS and SmartCare than a base scenario (in blue colour) mainly due to a drop in ‘systems quality’ by 0.2 (20%) (Figure 5.60 (a) and (b)). On the contrary, an improvement in ‘system quality’ by 0.2 (20%) for scenario 3 (in grey colour) demonstrated a higher ‘satisfied users’ of eHMIS and SmartCare than a base scenario (in blue colour) despite a fall in ‘services quality’ by 0.2 (20%) (Figure 5.60 (a) and (b)). This indicates the influence of ‘system quality’ on ‘satisfied users’ is greater than that of ‘services quality’. If the system quality of the technology is good, the level of service support required will be minimal. Conversely, a low 'system quality' demands high 'services quality'. Hence ensuring high 'system quality' will have dual benefits in reducing the 'services quality' efforts and improving the users' satisfaction.



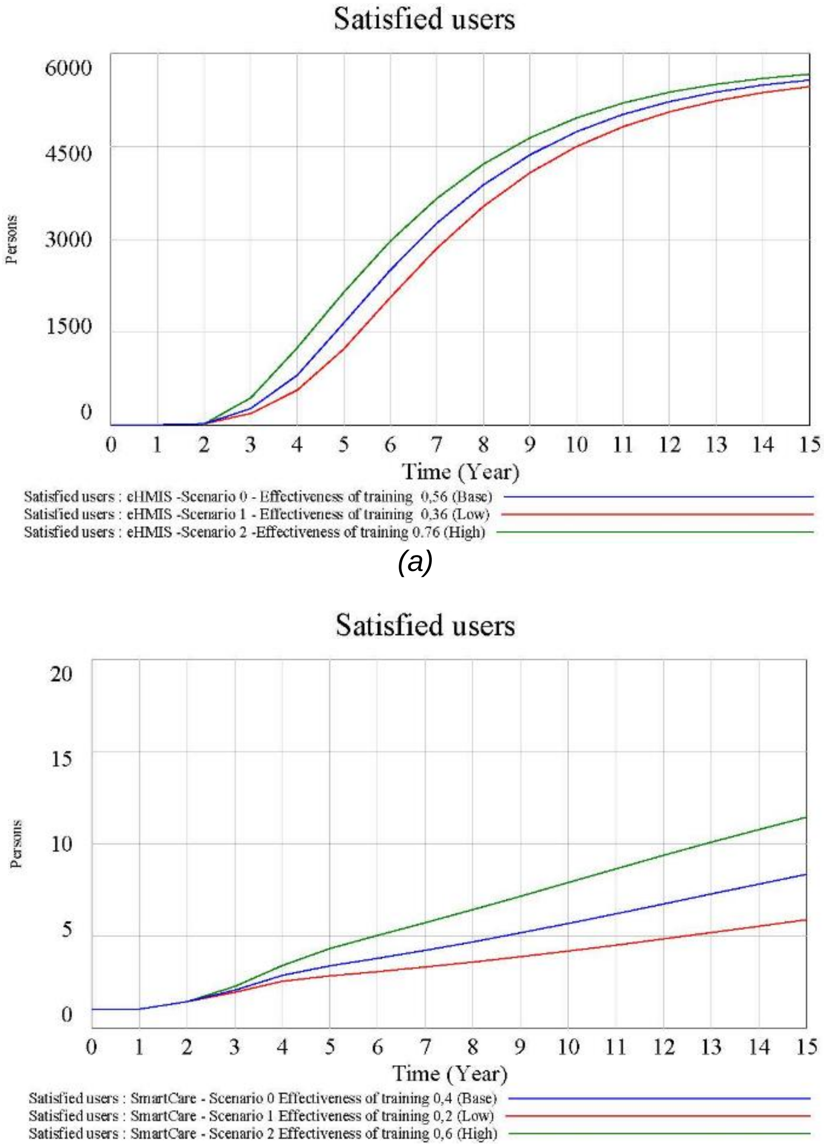
(a)

(b)

Figure 5.60 (a) A what-if analysis of 'satisfied users' of eHMIS with respect to changes in the system and services quality. (b) A what-if analysis of 'satisfied users' of SmartCare with respect to changes in the system and services quality.

Improving 'satisfied users' through 'effectiveness of training'

Figure 5.61 (a) and (b) show the impact of 'effectiveness of training' on the simulated 'satisfied users' of eHMIS and SmartCare when it is improved or weakened by 0.2 (20%) from the base scenario (in blue colour).



(a)

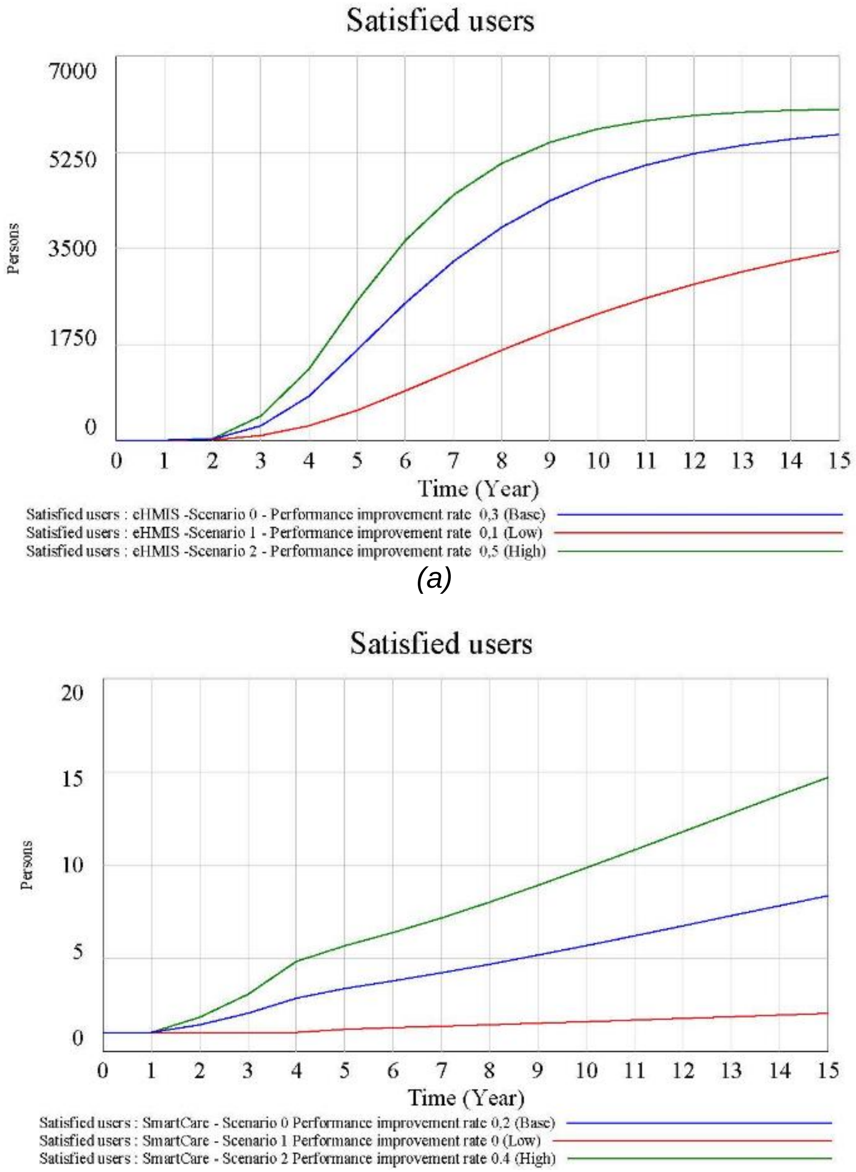
(b)

Figure 5.61 (a) A what-if analysis of ‘satisfied users’ of eHMIS with respect to changes in ‘effectiveness of training’. (b) A what-if analysis of ‘satisfied users’ of SmartCare with respect to changes in ‘effectiveness of training’.

On the fifth year, the decline in the ‘effectiveness of training’ by 0.2 (20%) from the base scenario reduced the ‘satisfied users’ of eHMIS by 421 Persons but had no significant impact on the ‘satisfied users’ of SmartCare (See scenario 1 in Figure 5.60 (a) and (b)). An increase in the ‘effectiveness of training’ by 0.2 (20%) from the base scenario as depicted in scenario 2 (in green colour) improved the ‘satisfied users’ of eHMIS by 498 Persons and that of SmartCare by 1 Person in the fifth year (Figure 5.60 (a) and (b)). The simulated behaviour pattern of ‘satisfied users’ in Figure 5.60, 5.61 (a) and (b) indicated that the ‘effectiveness of training’, ‘system quality’ and ‘services quality’ produced a similar level of influence on the ‘satisfied users’.

Improving 'satisfied users' through 'performance improvement rate'

Figure 5.62 (a) and (b) showed the simulated 'satisfied users' of eHMIS and SmartCare in response to improved or weakened 'performance improvement rate' by 0.2 (20%) from the base scenario (in blue colour), which was the reference behaviour.



(a)

(b)

Figure 5.62 (a) A what-if analysis of 'satisfied users' of eHMIS with respect to changes in 'performance improvement rate'. (b) A what-if analysis of 'satisfied users' of SmartCare with respect to changes in 'performance improvement rate'.

The decline in the 'performance improvement rate' by 0.2 (20%) from the base scenario reduced the 'satisfied users' of eHMIS by 1101 Persons and the 'satisfied users' of SmartCare by 2 Persons in the fifth year (See Figure 5.62 (a) and (b), scenario 1 in red colour). In the fifth year, an increase in the ‘performance improvement rate’ by 0.2 (20%) from the base scenario improved the ‘satisfied users’ of eHMIS by 896 Persons and that of SmartCare by 2 Persons (Figure 5.62 (a) and (b)). The simulated behaviour pattern of ‘satisfied users’ in Figure 5.62 (a) and (b) indicated that the ‘performance improvement rate’ had approximately twice more influence on the ‘satisfied users’ than ‘effectiveness of training’, and system and services quality.

The ‘performance improvement rate’ showed a stronger impact on ‘satisfied users’ compared to 'effectiveness of training', 'system quality' and 'services quality'. Increasing users’ satisfaction significantly depends on the capacity of eHMIS and SmartCare to enhance the work performance rate of end-users. Therefore, involving end-users in the early years of system development and implementation process supports the effort of addressing users’ needs and improves the work performance rate. The main factor that ensures end-users’ satisfaction is the eHMIS and SmartCare systems capability to improve end-users work performance. Moreover, improving ‘system quality’ and offering timely technical services can improve the satisfaction level of eHMIS and SmartCare systems users. Continuous training, workshops and on the job training contribute to the satisfaction of end-users.

5.11. Conclusions

This section of the PhD research project focused on assessing the influence of socio-technical factors on the sustainable use eHealth systems by answering the first research question “How do socio-technical factors influence the sustainable use of eHealth systems?” A systems thinking approach was applied to the technological dimension in the system, information, and services quality factors as indicated in the IS success model (DeLone and McLean, 2003); and the constructs of TAM in the social dimension (Venkatesh et al., 2003; Venkatesh and Bala, 2008). Moreover, the TAM and IS success models were combined to develop the technology use dimension of the theoretical framework. The interplay between the elements of eHealth success factors described in Appendix 1 and the feedback processes were captured by four feedback loops in the CLD of the socio-technical model of technology acceptance (See Figure 5.1).

The model boundaries were set and the dynamic hypotheses were represented by four feedback loops (Figure 5.1). The feedback loops representing the four dynamic hypotheses were used to describe the influence of the socio-technical factors towards the sustainable use of eHealth systems. Three reinforcing (positive) loops and one balancing (negative) loop were used to explain the interplay between the socio-technical dynamics of eHealth acceptance.

The reinforcing loops described the interplay between the socio-technical factors to facilitate acceptance of eHealth systems and users' satisfaction. It showed the influence of satisfied users on the social networks and the intention of individual users' towards using technology (Venkatesh *et al.*, 2003). Furthermore, the reinforcing loop depicted the potential impact of technological quality in driving the satisfaction of users to a higher level. On the contrary, the balancing loop showed the influence of rejected users on the behaviour of the social circle to hinder the acceptance of eHealth systems.

The CLD was expanded to develop the SFD of a socio-technical model of eHealth acceptance (See Figure 5.6) that demonstrated the dynamic relationship of socio-technical elements. The model described the rate at which the 'potential users' become 'actual users' (rate of technology acceptance). The 'actual users' become either 'satisfied users' or 'dissatisfied users' based on their experience with the system use. The model further depicted the possibility of 'dissatisfied users' to become 'terminated users' through intervention to make them 'satisfied users'.

The direct and indirect structure tests were used in the verification and validation tests of the socio-technical system dynamics model of eHealth acceptance. The literature findings and focus group discussions confirmed the structural validly of the model and the equations used in the socio-technical model of eHealth acceptance. The system dynamics model were made to pass the dimensional consistency test. The model parameter values of eHMIS and SmartCare were judged from the focus group discussions, the interview data, the FMOH documents, eHMIS database and experts opinion (Appendix 4.3, 4.4, 5.1 and 5.2).

The boundary adequacy test explained the validity of endogenous, exogenous and excluded model variables for this study. Extreme condition tests confirmed the plausibility of the model response to extreme input values (extreme policies, shocks, and parameters). The univariate and multivariate sensitivity analysis demonstrated that the model was essentially robust in maintaining the simulated behaviour pattern of 'acceptance rate', 'information quality', and 'satisfied users'. The numerical variations to the uncertainties in the exogenous variables indicated the possibility of alternative policy design to improve the simulated 'acceptance rate, 'information quality' and the users' satisfaction. The "what-if" simulation experiments were run to examine the impact of exogenous variables on the performance of the simulated 'acceptance rate', 'information quality' and 'satisfied users'.

The rate of technology acceptance, information quality, and users' satisfaction were the three key focus areas in the analysis of socio-technical factors influence on the sustainability of technology.

The sustainability of eHealth systems can be achieved when the technology is accepted by the end-users (Davis, 1989; Venkatesh and Davis, 2000), the quality of information product is at high level to make accurate decisions (Aqil, Lippeveld and Hozumi, 2009; FMOH, 2016), and the end-users are satisfied in using the systems and the information product (DeLone and McLean, 1992, 2003).

The acceptance rate of eHealth was the results of 'individuals' intention to use', social promotion, and social inhibitions (Chapter 5.3.1). TAM further described that the 'individuals' intention to use' developed from the end-users' perceptions of technology usefulness and ease of use. 'Promoters' and 'inhibitors' were the results of the social circles' influence on the 'potential users'. The end-users acceptance was described as the primary step of sustainable technology. The immediate output of implementing the sustainable eHealth system was to improve healthcare services delivery through the use of information product (Aqil, Lippeveld and Hozumi, 2009). The information product could only be achieved when the technology was used by the end users. Hence, not only technology use but also the level of information quality was critical for accurate decision-making.

The quality of information product was affected not only by the 'system quality' but also by users satisfaction as observed in the simulation results and empirical evidence (Appendix 4.3 and 4.4). The information quality was a function of system quality, satisfied users and dissatisfied users (Chapter 5.3.3 and 5.3.4). 'Satisfied users' improved the 'information quality' while 'dissatisfied users' reduced the quality of information product as indicated by the focus group (Appendix 4.4, Code Groups: Satisfaction). 'Satisfaction rate' represented the rate at which 'actual users' enjoy the benefits of the technology. The rate of satisfaction was influenced by the quality of technology and the ability of technology to improving the productivity of users (Chapter 5.3.3 and 5.3.4).

The two electronic systems in this case study research, eHMIS and SmartCare, differed in the level of implementation success, the level of social factors influence on the users, the level of workflow processes changes and the frequency of technology use among the health facilities and various departments of the health facilities in Ethiopia. The main challenge of eHMIS was not the acceptance of technology by the end-users but the quality of information product (EPHI, FMOH and WHO, 2016). Conversely, SmartCare had low acceptance by end-users in the majority of departments (Appendix 4.4, Code group: Actual use).

The users' perception to use technology had developed from the end-users' ICT skills of the, understanding of technology benefits, and the burden of technology use as perceived by end-users (Appendix 4.4, Code Groups: Benefits, Code: Ind_ICT use skill, and Code: Use_Burden). End-users who understood the benefits of the technology were usually volunteering users of technology. The lack of ICT skills by end-users led to rejection to use the technology. The main determinants of volunteer acceptance of technology appeared to develop from the high level of end-users ICT skills and understanding of the technology benefits. These findings agree with the two determinants of technology acceptance (ease of use and usefulness) as postulated by Davis (1989) and confirmed by several other studies. ICT skills and work burden linked to the ease of use; whereas the understanding of the benefits related to the usefulness of technology as perceived by the end-users.

The simulation results and focus group discussions confirmed that the influence of 'individuals' intention to use' on the acceptance rate of eHMIS was high in the early years of the implementation. The 'individuals' intention to use' developed from the effectiveness of training and communication about the technology to the 'potential users'. 'Effectiveness of training' improved end-users ICT skill and created awareness about the benefits of technology. The training and communication efforts drive the perceived ease of use; whereas users engagement influences the perception of technology usefulness (Wang and Liu, 2005). The simulation results confirmed that 'effectiveness of training' was a dominant factor to increase the 'acceptance rate' of both eHMIS and SmartCare.

The system dynamics simulation results confirmed that conducting effective training and communicating the benefits of technology played a key role in shaping the 'potential users' perception of technology usefulness and ease of use. The influence of 'effectiveness of training' was greater than that of 'system quality', 'services quality' or 'performance improvement rate' in improving technology acceptance. Hence improving the 'effectiveness of training' should be the focus of policymakers to increase 'acceptance rate' in the early years of implementation.

The simuation results further established that the dominant influence of 'individuals' perception to use' on technology acceptance shifted to the social factors over time. The social influence of 'promoters' and 'inhibitors' on acceptance of technology grew in later years of implementation based on the 'actual users' level of satisfaction with the technology. The positive word of mouth from satisfied users promoted the use of technology among potential users. On the contrary, the terminated users propagated the negative word of mouth among their social circles to hinder technology acceptance. Therefore, not only developing the 'individuals' intention to use' through training and communications but also ensuring the satisfaction of end-users play key to increasing technology acceptance.

The incorporation of dynamicity to TAM in the study of eHealth acceptance by adding time factors and applying system dynamics modelling was one of the unique contributions of this PhD research study. TAM did not put time factors into consideration in explaining the influence of individual perceptions and social factors on technology acceptance. However, this research study discovered the varying influence of individual perceptions and social factors through time on the acceptance of the technology. In the early years, the influence of ‘individuals’ intention to use’ on the acceptance rate of eHMIS was high. However, based on the ‘actual users’ level of satisfaction, the social influence of ‘promoters’ and ‘inhibitors’ grew in later years of implementation. This is an original contribution of this research study to the knowledge base in the study of eHealth acceptance in resources-constrained settings.

The long-term sustainability of eHealth implementation should not only focus on increasing the number of ‘actual users’ but also in keeping the end-users satisfied. The simulated ‘performance improvement rate’ confirmed a stronger impact on ‘satisfied users’ compared to 'effectiveness of training', 'system quality' and 'services quality'. The empirical evidence from focus group discussion, interview and case study also showed that the capacity of eHMIS and SmartCare to enhance the work performance of end-users strongly determined the level of users’ satisfaction. In addition to the heavy workload of end-users due to the shortage of workforce, the use of paper in parallel to the digital system caused dissatisfaction among SmartCare users (Appendix 4.4, Code Groups: Satisfaction, and Code: Use_Burden). At the time of technology introduction, the use of both paper and electronic systems, as well as slow data entry skill of users doubled the average patient consultation time, leading to the absence of individual-task fit (Tsiknakis and Kouroubali, 2009).

To improve work performance and reduce the work burden of end-users through digital systems can be achieved by involving all key stakeholders in the project as early as possible. Setting system requirements together with key stakeholders in the early phases of the project enhanced the technologies capacity to meet end-users’ need. The ability of technology to improve work performance and reduce the work burden could raise the end-users' satisfaction level. Moreover, improving ‘system quality’ and offering timely technical services could increase the satisfaction level of eHMIS and SmartCare systems users. Continuous training, workshops and on the job training contributed to the satisfaction of end-users.

The immediate goal of implementing and using eHealth systems was to have access to timely and quality data for decision making (Appendix 4.4, Code Groups: Information quality). Aqil, Lippeveld and Hozumi (2009) highlighted that the use of information for decision-making is an immediate output of eHealth implementation in healthcare organizations. The main benefits of using eHealth system are enhancing the internal organizational efficiencies such as improving the decision-making process and internal communications in the organization (Gorla, Somers and Wong, 2010). Therefore, information quality was one of the key factors to the sustainability of eHealth systems.

The system dynamics simulation results in this research study confirmed that 'system quality' had the strongest impact on 'information quality'. The influence of 'system quality' on 'information quality' was also reported in other studies (Gorla, Somers and Wong, 2010; Aggelidis and Chatzoglou, 2012). Since the quality of an information product could only be as good as the technology producing it, 'system quality' was critical in ensuring a high 'information quality' level as illustrated by empirical evidence. Furthermore, the system dynamics simulation results indicated that 'services quality' and 'performance improvement rate' had shown a moderate influence on 'information quality'. However, the influence of 'services quality' on 'information quality' came through 'system quality' and that of 'performance improvement rate' was through 'satisfied users' as described in the system dynamics model. The influence of 'effectiveness of training' on 'information quality' was weak as illustrated in the system dynamics simulation results. Dissatisfied users affected the accuracy, completeness and timeliness of data that in turn impacted information quality and the accuracy of decisions. The effort of improving 'information quality' should focus on developing high-quality systems, i.e., reliable, easy to use, and capable to meet end-users' requirements.

In summary, the long-term sustainability of eHealth requires acceptance of technology by the 'potential users', high information quality to make accurate decisions and a high level of satisfaction by end-users. The assessment of sustainable eHealth systems through acceptance of technology, information quality and users' satisfaction is an original contribution of this PhD research project to the body of knowledge. The significant influence of the 'effectiveness of training' to drive the 'acceptance rate' of eHMIS and SmartCare in the early years of implementation was also discovered. This PhD research project contributed to the body of knowledge by showing the different influence levels of 'individual intention to use' and social factors on eHMIS and SmartCare acceptance over time. System dynamic simulation simulation results showed the greater influence of 'individual intention to use' on technology acceptance in the early phases of implementation. The influence of promoting or inhibiting social influence on the rate of acceptance dominated in the later phases of eHMIS and SmartCare implementation.

The simulation results showed that increasing ‘information quality’ through improved ‘system quality’ should be the main focus of policymakers. The impact of ‘information quality’ on end-users satisfaction is indicated in the IS success mode (DeLone and McLean, 1992, 2003). However, the influence of end-users satisfaction on ‘information quality’ was another contribution of this PhD research project to the body of knowledge. Finally, the technology’s ability to improve the work performance rate can be enhanced by involving end-users in the early phases of implementation. Users’ involvement produce technology that increases the work performance and ensures high satisfaction level of end-users.

The socio-technical model of eHealth acceptance showed the possible areas of interventions to ensure the sustainability of eHMIS and SmartCare systems in Ethiopia. The systems acceptance was improved through effective training and communication. Whereas the ‘information quality’ was enhanced through ‘system quality’ and users satisfaction. The ‘system quality’ factors are discussed in Appendix 2.1. The ability of technology to improve work performance and reduce the burden of end-users increased end-users satisfaction. Therefore, involving key stakeholders as early as possible during eHealth implementation had contributed to develop eHealth systems that met the end-users needs and improved their work performance.

The next chapter discusses a system dynamics model of techno-organizational factors of eHealth acceptance. The techno-organizational factors of eHealth acceptance expands on the socio-technical model of technology acceptance discussed in this chapter by incorporating techno-organizational parameters of eHealth implementation ecosystems. It addresses the second objective of the research, which is to determine the effect of techno-organizational factors on the successful implementation and sustainable use of eHealth technology. The influence of techno-organizational factors on the sustainability of eHealth are discussed in detail. The simulation results and the empirical evidence are described. The techno-organizational model validation and verification processes, sensitivity analysis and policy analysis are also addressed.

6. SIMULATION RESULTS OF TECHNO-ORGANIZATIONAL FACTORS OF SUSTAINABLE EHEALTH IMPLEMENTATION

"Most situations and decisions in organizations are complex because some major change introduces unpredictability and flux" (Snowden and Boone, 2007:5).

6.1. Introduction

The ecosystem of sustainable eHealth implementation covers wider ranges of factors in technological, social, organizational and economic dimensions to promote meaningful and sustained use of information for decision making in healthcare settings (Musango and Brent, 2010). The successful implementation of eHealth is affected by several interrelated factors that go beyond technological elements. Because of organizational factors, the same eHealth system can exhibit different success level in different healthcare institutions. Organizational culture, structure, resources, work process flow, policy and support from management are the key elements of organizational factors in the process of eHealth implementation (Tsiknakis and Kouroubali, 2009; Aarts, Peel and Wright, 1998; Rippen et al., 2013). These organizational factors can deter the acceptance of eHealth technology if not carefully considered in the process of eHealth implementations.

The techno-organizational factors of sustainable eHealth implementation is explained in detail using system dynamics modelling technique in this chapter. The techno-organizational factors of eHealth acceptance discussed in Chapter 2.8 is used to develop the system dynamics model. A conceptual framework is developed to describe the techno-organizational dynamic of eHealth implementation to illustrate nonlinearity through feedbacks (See Figure 3.7 in Chapter 3). The CLD and SFD of techno-organizational dynamics are developed from the focus group data (Appendix 4.4), literature studies (Charter 2.8) and review of eHMIS and SmartCare implementation documents. The system dynamic model shows the dynamic interaction and critical feedbacks of the techno-organizational factors of eHealth technology implementation to ensure sustainability. The study aims to determine the effect of techno-organizational factors on the successful implementation and sustainable use of eHealth technology.

The adoption of ICT has shown significant progress in a banking sector where there is strong central control. However, in the healthcare organizations where there is high degree of autonomy, and much less central control, showed little progress towards eHealth adoption (Tsiknakis and

Kouroubali, 2009). This is an indication of organizational factors influence on the successful uptake of electronic systems. From the cases of two health Information Technology (IT) implementations, Rippen et al. (2013) indicated that the core factor for the success and failure of ICT use in healthcare was not only technology.

The techno-organizational factors deal with the dynamic interactions between the technological and organizational elements of sustainable eHealth implementation. Most businesses operate dominantly in the complex domain that requires an understanding of the context of the operating environment and the nonlinear dynamic interaction among organizational elements (Snowden and Boone, 2007). Although the complexity of healthcare organizations is recognised by several research studies, the proposed solutions fail to address the dynamic and nonlinear interaction between organizational and technological factors (Cresswell and Sheikh, 2012). Most eHealth implementation frameworks are modelled linearly that do not clearly reflect the dynamic complexity in real life (Adam and De Savigny, 2012). The techno-organizational factors of sustainable eHealth implementation addressed in this chapter focuses on the dynamic and nonlinear interactions of elements of organizational factors with technological factors.

The successful implementation of eHealth system is influenced by the settings of operating environment. The operating environment refers to organizational settings that influence the implementation and use of eHealth technology in healthcare facilities (Rippen et al., 2013). The healthcare team operates in the context of health institution which is influenced by the resources as well as values and practices of the organization (Aqil, Lippeveld and Hozumi, 2009). The organizational culture and resources available through the organization plays a key role in the successful implementation of eHealth (Aarts, Peel and Wright, 1998). The organizational dimensions addressed in this study are linked to factors internal to the organization, i.e., factors under the organization’s control (Aqil, Lippeveld and Hozumi, 2009; Gorla, Somers and Wong, 2010). Other environmental factors that influence eHealth implementation but outside the organizations’ control (external environment) are not in the scope of this research study (Maryati Mohd. Yusof *et al.*, 2008). The lack of proper fit of technology to the operating environment results in failure of eHealth implementation (Rippen et al., 2013).

The research report in this chapter focuses on answering the second research question, i.e., “How do the techno-organizational factors of resource-constrained settings affect the long-term sustainability of eHealth use? (See Chapter 1.5.1). The influence of techno-organizational factors on the acceptance of eHealth system is studied under four key areas. The three reinforcing loops and one balancing loop that describe the dynamic hypotheses associated with the research question are discussed in Chapter 6.3. A dynamic hypothesis is used to draw out and test the consequences of the feedback loops (Forrester and Albin, 1997).

A qualitative interview and focus group discussion data focusing on the techno-organizational factors of eHealth acceptance will be discussed in this chapter. The key techno-organizational factors that influence the sustainable implementation of eHealth systems such as resources readiness, management support, workflow alignment and organizational ICT culture are addressed in detail (See Appendix 4.4) The SFD, the model equation and the simulation results are described in section 6.3 (See Appendix 6.1 and 6.2). The model validation and verification tests are performed from the eHMIS and SmartCare cases to ensure the robustness the model in Chapter 6.10. The model simulation results are discussed from the technology acceptance, information quality and users' satisfaction perspective by varying selected exogenous variables and the concluding remarks are made.

The case study of techno-organizational dynamics of sustainable eHealth implementation is published in the PICMET proceedings and presented in the PICMET conference in 2017, Portland, Oregon.

Fanta, G. B., Pretorius, L., & Erasmus, L. (2017). Organizational Dynamics of Sustainable eHealth Implementation: A Case Study of eHMIS. In *2017 Portland International Conference on Management of Engineering and Technology (PICMET)* (pp. 1–9).

The next section addresses the model boundary and the dynamic hypotheses of the techno-organizational factors of eHealth acceptance. The model boundaries show the scope of this study and the excluded variables that could potentially influence the simulation model.

6.2. Model boundary

The model boundary chart of the techno-organizational model of eHealth acceptance (See Table 6.1) is an expansion of a model boundary for socio-technical model eHealth acceptance indicated in Table 5.1. Some of the excluded variables in Table 5.1 (socio-technical model) become endogenous and exogenous variables in the techno-organizational model of eHealth acceptance. Besides, additional endogenous and exogenous variables are included in this techno-organizational system dynamics model. The model boundary for the techno-organizational model of eHealth acceptance is described in Table 6.1.

The FMOH focus group team highlighted the importance of some excluded model variables such as political support and legal frameworks in the implementation of sustainable eHealth system nationwide. The focus group team indicated that not only the national politics of the country but also the organizational politics played a significant role in the selection of electronic health systems in Ethiopia. The technology selection decisions were not always motivated by the technical capability of the technology to meet the functional requirements but also by the political dynamics within the top management. The organizational policies were the reflection of national policies towards the implementation of eHealth systems. Yet, the final decision on the selection of the electronic health systems rested on the top management of the organization as described by the focus group team (Appenxix 4.4).

The focus group discussion with the FMOH highlighted that organizations might follow the national policy direction of strengthening the health information system through electronic systems. However, the decision of the electronic systems selection rested largely on individuals in the top management positions within the organization. This had a significant influence on the long-term sustainability of the electronic health systems. The organization’s top leadership might make a decision of acquiring an electronic health system due to different motives which could not be technically appealing. This type of influences from top management affected the sustainability of a system.

In summary, the focus group discussion highlighted the importance of the political will of the country and the dynamics of organizational politics in the implementation of eHealth systems. Besides the national policy of eHealth systems, the top management intention had a significant influence on technology selection. The impact of politics, legal frameworks, ethical issues and financial matters on sustainable eHealth implmentation was highlited by the focus group teams; however, these variables were outside the techno-organizational model boundaries.

The next section discusses the CLD, reinforcing and balancing loops that explain the dynamic hypotheses of techno-organizational factors of eHealth acceptance concerning the second research question. The CLD of techno-organizational factors of eHealth acceptance used the model boundary and parameters defined in Table 6.1.

Table 6.1 Boundary chart of techno-organizational model of eHealth acceptance.

Endogenous	**Exogenous**	**Excluded**
Acceptance rate	Adopted population	Legal
Adjustment time	Contact rate	Political
Change in perception to use	Delay time	Financial
Difference in perception	Desired workforce	Ethical
Dissatisfaction rate	Frequency of use	
Individuals intention to use	Incentives	
Information quality	Period of use	
Inhibitors	Potential users	
Intervention rate	Productivity improvement rate	
Intervention step	Reduce work burden	
Promoters	System quality	
Satisfaction rate	Time to intervention	
System flaw	Time to training	
System usefulness and ease of use	Trials before termination	
Technical flaws	Supportive organizational structure	
Technological quality	Desired workforce	
Termination rate	Power installation rate	
Termination step	Internet connection installation rate	
Termination time	Digital equipment installation rate	
Actual users	Power and digital equipment depreciation rate	
Dissatisfied users	Supportive Policy	
Individual perception to use	Familiarity with electronic systems	
Satisfied users	Average workforce turnover	
Terminated users	Rate of workforce training	
Effectiveness of Training	Desired infrastructure	
Organizational ICT Culture		
Workflow alignment		
Resources readiness		
Current workforce		
Workforce gap		
Management Support		
Current infrastructure		
Installation rate		
Depreciation rate		
Services quality		
Hiring rate		
Turnover rate		
Infrastructure gap		

6.3. The dynamic hypotheses of techno-organizational factors

The dynamic hypotheses of techno-organizational factors focus on the influence of organizational factors on the acceptance of eHealth systems in resource-constrained settings. The CLD for the techno-organizational model of eHealth acceptance depicted in Figure 6.1 is developed from the conceptual framework for organizational dynamics of eHealth acceptance shown in Figure 3.7 (See Chapter 3.5) and the CLD of the socio-technical model of technology acceptance (Figure 5.1). The CLD for techno-organizational dynamics of eHealth Implementation is discussed under three reinforcing (positive) loops and one balancing (negative) loop in this chapter.

The influence of resources readiness, management support, and change management on technology acceptance is addressed in the reinforcing loops while the balancing loop highlighted the impact of inhibitors on ICT culture within an organization. These important loops describe the organizational dynamics of sustainable electronic systems implementation within the health sector. The organizational framework for health IT indicated that clinician's workflow, resource availability and leadership support in the domain of use and environment were the reasons for success of an eHealth application (Rippen et al., 2013). The workflow process was also referred as clinical work (Aarts, 2012) and tasks (Tsiknakis and Kouroubali, 2009) in the organizational frameworks of 'effective' fit and FITT frameworks respectively.

Additional model variables are encompassed into a CLD of a socio-technical model of technology acceptance (See Figure 5.1) to develop a CLD for a techno-organizational model of eHealth acceptance (See Figure 6.1). All the techno-organizational variables shown in red and the associated links in Figure 6.1 represent newly added model parameters to the CLD of the socio-technical model. The organizational framework for health IT concluded that technology use and environment conditions of the organizational framework often influence each other either positively or negatively (Rippen et al., 2013). The CLD of the techno-organizational model is developed by applying systems thinking approach o the findings of the literature studies discussed in Chapter 2.8, the evidence from focus group discussions (Appendix 4.4) and the researcher's experience in the field of eHealth implementation.

The codes generated from the qualitative data analysis in ATLAS.ti and the relationship between the codes are used to represent the model variables and nonlinear relationships through the CLD of a techno-organizational model. The inhibitors influence on ICT culture illustrated the balancing effect of previous users of eHealth on the ICT culture to hinder acceptance of technology by potential users. The reinforcing influence of resources readiness, management support and change management on acceptance of technology by potential users is also depicted on the CLD (See Figure 6.1). The empirical evidence and literature findings are discussed in an integrated way to explain the CLD of a techno-organizational model of eHealth acceptance shown in Figure 6.1.

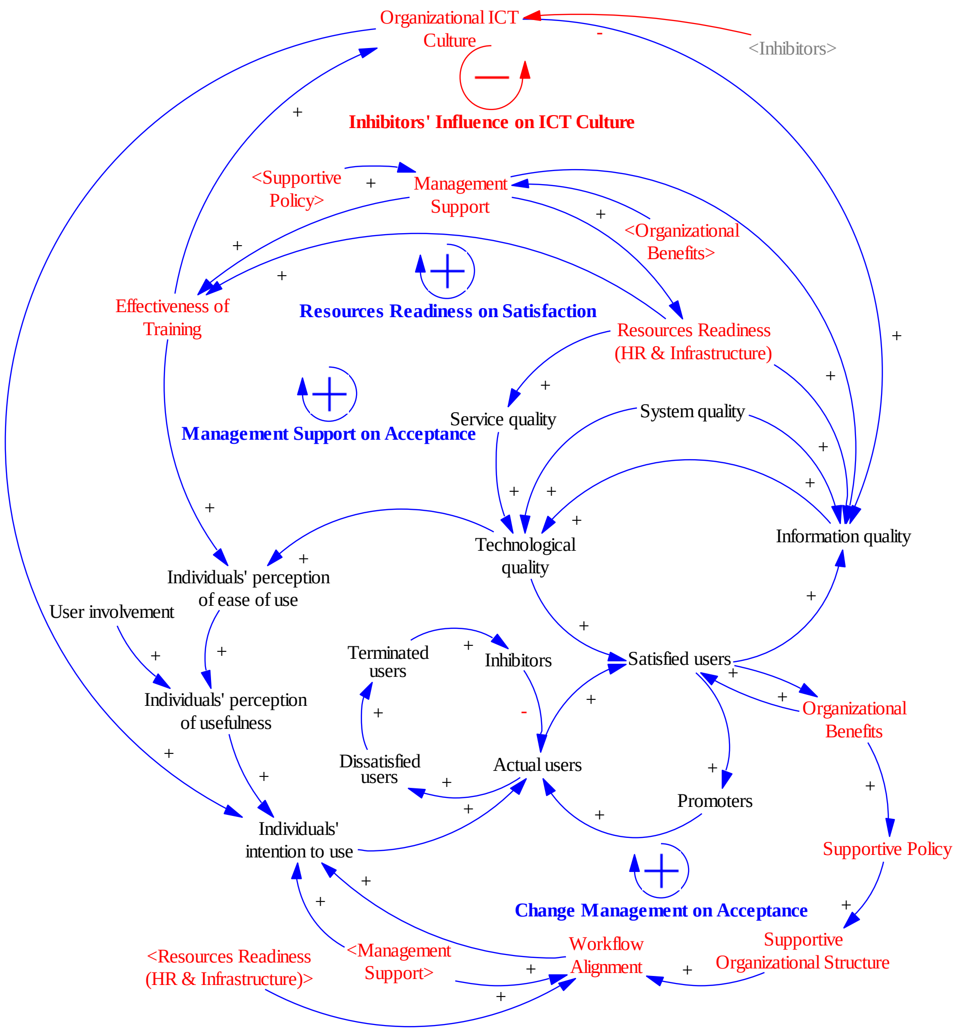


Figure 6.1 CLD for techno-organizational model of eHealth acceptance.

6.3.1. Reinforcing loops

<u>The influence of resources readiness on users' satisfaction</u>

One of the main difference between the implementation of eHealth systems in developed and developing countries is availability of resource necessary to the successful implementation of eHealth (WHO, 2011a). The resources readiness include availability of human resources, internet connectivity, network infrastructure, electric power and digital equipment such as computers, printers, scanners, etc. (Aqil, Lippeveld and Hozumi, 2009; WHO, 2011a; Bilbao-Osorio, Dutta and Bruno Lanvin, 2014). The adequacy and skill of human resource to operate and maintain an electronic health system is also another difference between developed and developing countries that can deter the success of eHealth implementation (Aqil, Lippeveld and Hozumi, 2009; WHO, 2011a).

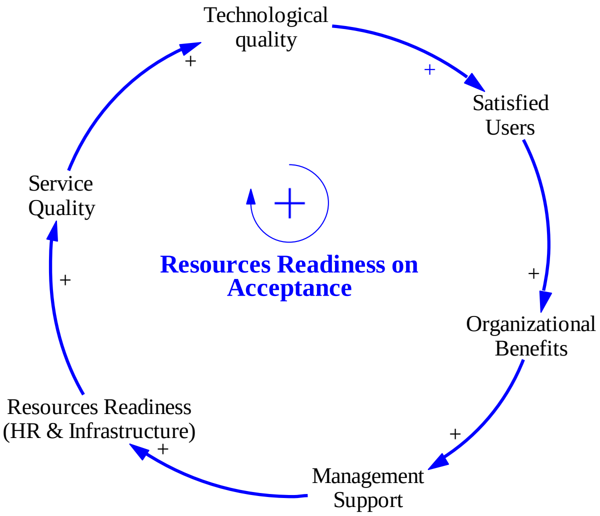


Figure 6.2 The influence of organizational resources readiness on users' satisfaction.

When the organizational benefits from technology and information use is evident, the end-users' intention to use the technology will be high (Aqil, Lippeveld and Hozumi, 2009). The top management gave strong support to the implementation and use of electronic system by allocating resources and workforce (Appendix 4.4. Code: Org_Resources readiness). The level of management support influenced availability of trained professional and maintenance tools to give technical services support (Appendix 4.4. Code: Services Qlty_Resource availability). The use of information leads to improved evidence-based decision-making (Aqil, Lippeveld and Hozumi, 2009). eHMIS enabled higher officials to get access to timely information to make fast and evidence-based decisions (Appendix 4.4. Code: Ben_Improve decision). The reinforcing loop in Figure 6.2 depicts how the 'ressources readiness' drives satisfaction of end-users.

The influence of management support on technology acceptance

Management support refers to the level of general support offered by top management which includes encouraging the use of a system, allocating resources, understanding the benefits of the system, intent to see the users are happy in using the system (Al-Mamary, Shamsuddin and

Aziati, 2014). Management support facilitated resource allocation including human resources and ICT infrastructure, and level of training according to focus group discussion with the FMOH (Appendix 4.4. Code: Org_Management support). This, in turn, had an impact on the 'service quality' to influence technology and information use (Appendix 4.4. Code Groups: Services quality). Gorla, Somers and Wong (2010) showed that service quality has the highest impact on the organizational benefits from electronic systems followed by 'information quality' and 'system quality'.

The focus group members of the FMOH partners categorized managers as a strong supporter, neutral, and resistant to electronic technology implementation and operation (Appendix 4.4, Code: Org_Management support). According to the focus group, most managers who supported eHMIS implementation had a well-developed culture of technology and information use. The focus group further highlighted that the management support increased the quality of data, and use of information for decision-making. The HIT people were trained and introduced to bridge the ICT skills gap (Appendix 4.4. Code: Impl_Training). The two variables of organizational factors (top management support and end-users training) are hypothesized to influence perceived usefulness and users satisfaction (Al-Mamary, Shamsuddin and Aziati, 2014). Figure 6.3 depicts the influence of management support on the acceptance of technology.

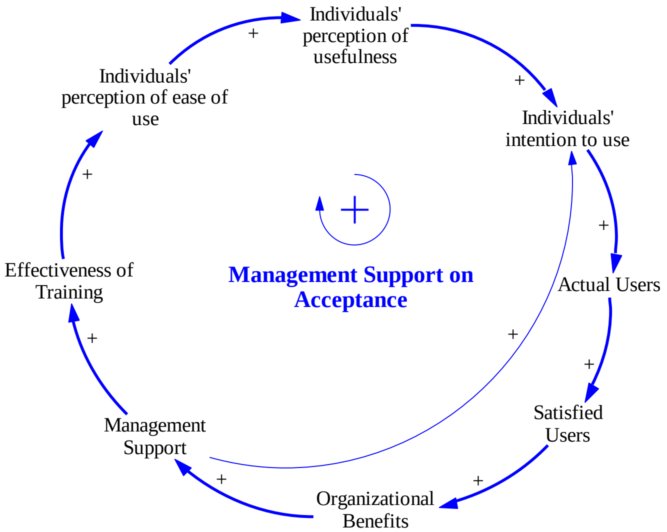


Figure 6.3 Influence of management support on technology acceptance.

<u>The influence of change management on technology acceptance</u>

This reinforcement loop highlights the importance of technology alignment with the organizational workflow processes to maximize the meaningful use of technology (See Figure 6.4). Organizational policy and leadership played a key role in building an organizational structure that promoted the use of technology. As pointed out by focus group members of the FMOH and the FMOH partners, the FMOH policy was fertile to promote the use of electronic systems to improve healthcare service delivery. The recent establishment of HITD as a Directorate in the MOH organizational structure indicated the leadership commitment to facilitate technology use (Appendix 4.4, Code: Org_Organizational structure).

The lack of skilled technical support team resulted in a low fit in the task-technology dimension (Tsiknakis and Kouroubali, 2009). Users training within an organization and HIT personnel training at higher education level helped to bridge the skill gaps as indicated by the focus group members of the FMOH. The FMOH focus group members explained that strong technical support and coaching (service quality) facilitated the change management processes. The focus group discussion with the FMOH partners indicated that training and communication served as agents of change management when HMIS moved from paper-based to electronics system (Appendix 4.4, Code: Impl_Change management).

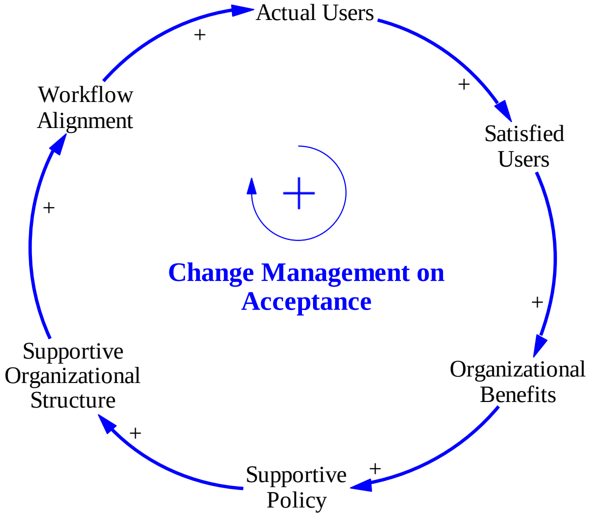


Figure 6.4 The influence of change management on technology acceptance.

6.3.2. The balancing loop

<u>Inhibitors' influence on ICT culture</u>

The rejected users could damage the ICT culture and the use of technology in health sector (Aqil, Lippeveld and Hozumi, 2009). The balancing loop in Figure 6.5 shows the negative effect of rejected users on the culture of information and technology use within a healthcare organization. Organizations that promote a culture of information perform better in the implementation and use of eHealth technology (Aqil, Lippeveld and Hozumi, 2009). The information culture of a healthcare organization influences the workflow process and affects the output of technology performance (Aqil, Lippeveld and Hozumi, 2009).

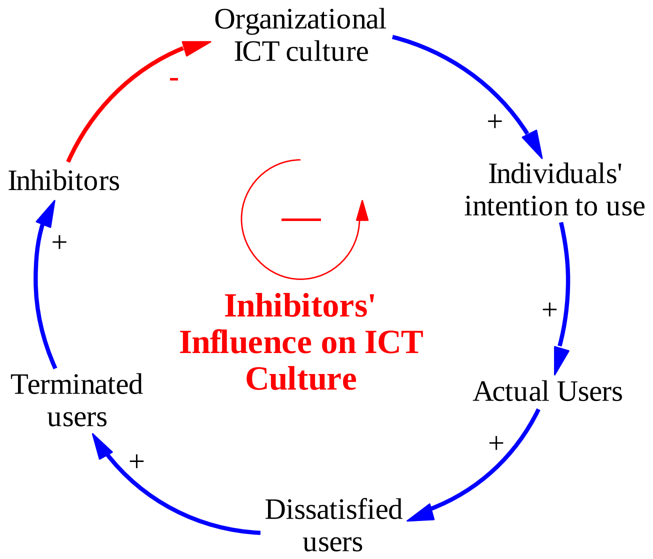


Figure 6.5 Influence of inhibitors' on the culture of information and technology use.

Both the FMOH and the FMOH partner's focus group teams indicated the growing culture of technology and information use within the healthcare organizations in Ethiopia. But the focus group discussion with the FMOH highlighted an increasing resistance in using technology for organizational purpose compared to personal use. The focus group discussion with the FMOH partner indicated that the culture of information dissemination was lagging compared to use of information to make informed decisions (Appendix 4.4, Code: Org_ICT culture). The focus group members further showed that the culture of technology and information use varied based on the age group and motivation level of the people within the organization.

The following section discusses the system dynamics model of techno-organizational factors. The SFD of techno-organizational model of technology acceptance is expanded from the socio-technical model of technology acceptance addressed in Chapter 5. It shows the dynamic interaction of techno-organizational factors in the ecosystem of sustainable eHealth implementation.

6.4. A system dynamics model of techno-organizational factors of eHealth Implementation

The parameters used in the CLD of a techno-organizational model of eHealth acceptance (Figure 6.1) are used to develop the SFD of a techno-organizational model of technology acceptance depicted in Figure 6.6. The SFD of the socio-technical model of technology acceptance (Figure 5.6) is used as a basis. The workforce and infrastructure resources readiness, management support, organizational ICT culture and organizational structure are some of the key additions to the SFD of the socio-technical model of technology acceptance in the process of developing the system dynamics model of the techno-organizational factors. The focus group data and the simulation results are discussed in an integrated way to explain the SFD of a techno-organizational model of technology acceptance shown in Figure 6.1.

The social factors in the implementation of the eHealth system operate within the organizational environment. Technology and social factors are embedded within an organizational environment of technology implementing institute (Musango and Brent, 2010). The system dynamic model of techno-organizational factors incorporated key parameters to the sustainability of eHealth systems that were not included in the socio-technical system dynamics model.

Stocks can accumulate or deplete, on the other hand, flows make stock increase or decrease (Sterman, 2000). Flows are variables that can change stocks. Time can be an important element in differentiating stocks and flows. Stocks continue to exist when time is stopped; however, flows will disappear with time as they are actions. Stock and flow variables, as well as the units of CLD variables, are identified in the process of converting the CLD into SFD. ‘Current workforce’ and ‘current infrastructure’ are identified as stocks with units of ‘Persons’ and Dimensionless’ respectively.

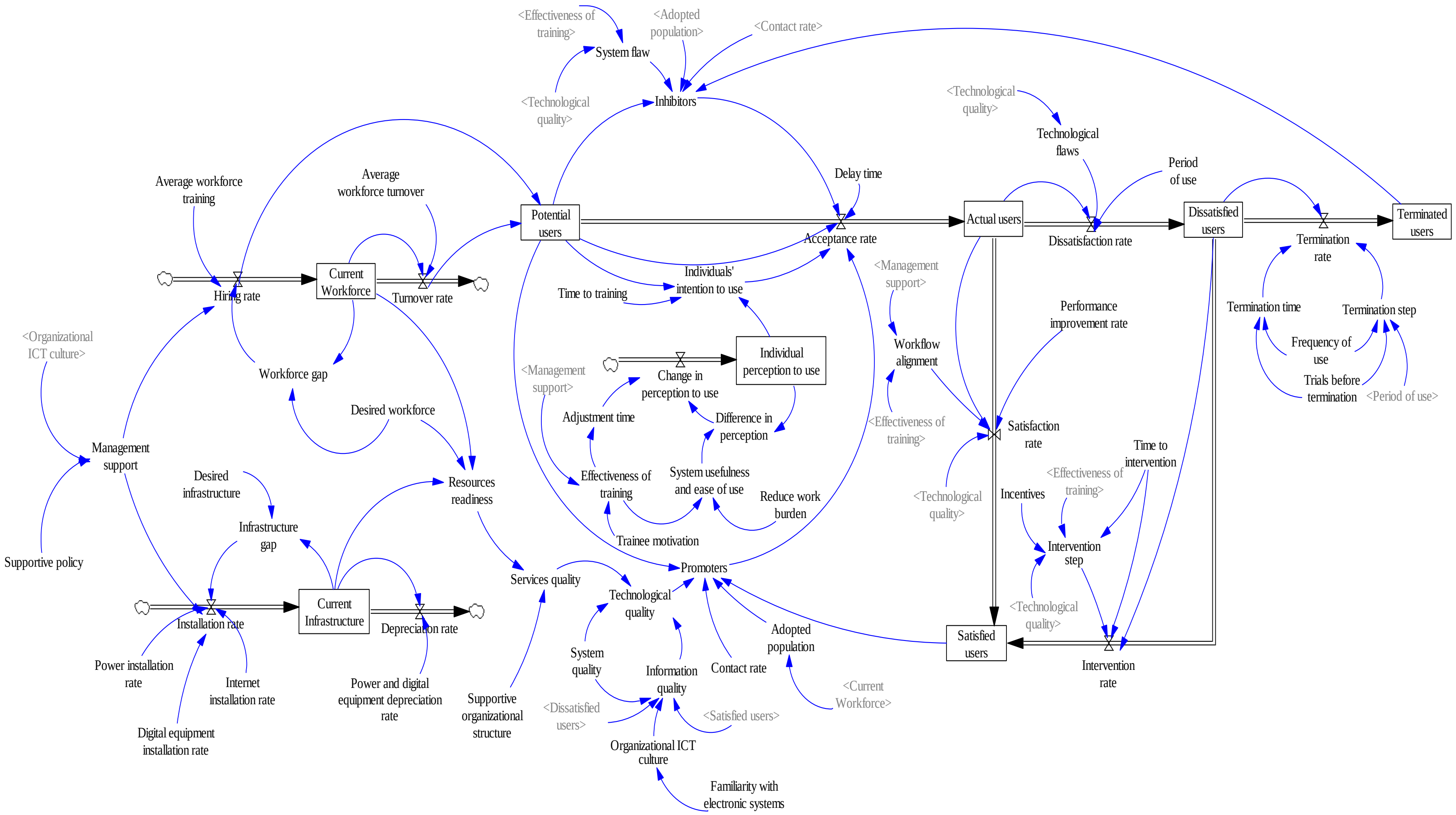


Figure 6.6 SFD for a techno-organizational model of technology acceptance.

The fifteen years' time horizon with TIME STEP of 1 year (See Chapter 5.5) is also applied here to simulate the SFD of a techno-organizational model of technology acceptance. Vensim DSS Version 6.3D software is used to develop, simulate and test the system dynamics model of techno-organizational factors (See Figure 6.6, Appendix 7.1 and 7.2). The model validation and verification with direct and indirect structural tests (See Chapter 5.7) are conducted using the case study, interview and focus group discussion data to ensure the system model robustness. The variables, values and equations of the model are shown in Appendix 6.1 and 6.2.

The dynamic interactions of techno-organizational factors are discussed under four key factors that describe the organizational dynamics of eHealth implementation. The impact of resources readiness, organizational ICT culture, and management support and workflow alignment on acceptance of eHealth is discussed by integrating the simulation results and empirical evidence of techno-organizational factors.

6.4.1. Resources readiness

'Resources readiness' assesses the adequacy of human resources and ICT infrastructure to implement successful eHealth system. The readiness of organizational resources is related to the availability of ICT infrastructure, electronic devices, connectivity, backup power supplies, and skilled human resources. The generators and UPS are important resources to back up unreliable commercial power supply even in the capital city of Ethiopia, Addis Ababa. Computers, printers, scanners, local area network (LAN), internet connectivity are IT infrastructure and electronic device resources used to evaluate the resource readiness within a healthcare organization (Appendix 4.4, Code: Org_Resources readiness). 'Resources readiness' is described with Equation 6.1 in this model. The 'Resources readiness' sub-model is depicted in Figure 6.7.

$$\text{Resources readiness} = \text{Current infrastructure} + \text{Current workforce}/\text{Desired workforce} \qquad \text{(Unit: Dimensionless)} \qquad (6.1)$$

The data collected from the FMOH documents, technical working group (TWG) reports, interviews, focus group discussions and EPHI survey data are used to validate the model and assign values to the parameters of human resource and ICT infrastructure readiness (Appendix 6.1 and 6.2).

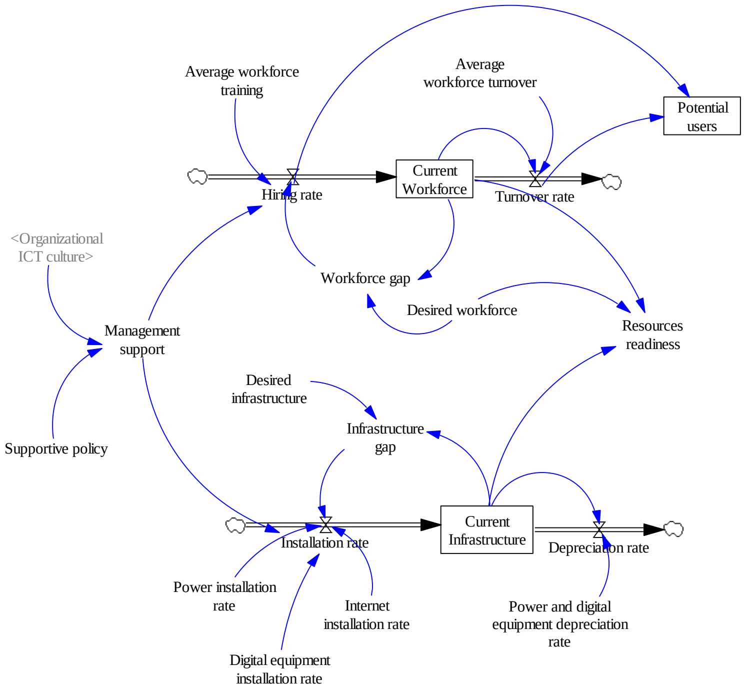


Figure 6.7 The health workforce and infrastructure readiness sub-model.

Human resources readiness

Clinical staffs were the main end-users of the SmartCare system in Gandhi Memorial Hospital and HIT personnel were the key users of eHMIS in Ethiopia. Therefore, the adequacy of clinical staffs was very critical to the use of electronic systems in the Gandhi hospital. The high workload of clinical staffs was one of the obstacles to the sustainable use of SmartCare in health facilities as indicated by the end-users and the focus group team (Appendix 4.4, Code: Use_Burden). The patient load in Gandhi Hospitals was very high that a physician might see an average of 30-40 patients a day. The second human resource factor was associated with the adequacy of IT staffs to give timely technical support to all users (Appendix 4.4, Code: Service Qlty_Resource availability). SmartCare users in the Gandhi hospital and eHMIS users in several health facilities indicated that the speed of technical support to fix SmartCare and eHMIS problems was a big concern (Appendix 4.4, Code Groups: Service Qlty). Therefore, adequacy of clinical and IT staffs are assessed to ensure the human resources readiness in using the SmartCare and eHMIS.

The 'Current workforce' is compared to the 'Desired workforce' to measure the 'Workforce gap' in per cent as shown in Figure 6.7. 'Current workforce' refers to the total number of health workers in the facility at any given time that are the current users or potential users of eHealth systems. Workforce addresses the readiness of skilled human resources that can use technology and provide technical support (Rippen *et al.*, 2013; Bilbao-Osorio, Dutta and Bruno

Lanvin, 2014). ‘Current workforce’ is the function of the initial workforce and the integral of the difference between the ‘Hiring rate’ and the ‘Turnover rate’ overtime (See Equation 6.2).

$$\text{Current workforce} = \text{INTEG}(\text{Hiring rate} - \text{Turnover rate}, \text{Current Workforce}_0) \quad (\text{Unit: Persons}) \tag{6.2}$$

‘Current workforce$_0$’ is the value of ‘Current workforce’ at the start of the simulation. ‘Current workforce$_0$’ is 26000 for eHMIS and 320 for SmartCare (See Chapter 5.5.1 and 5.5.2).

‘Desired workforce’ refers to the number of health works required by the health facilities to offer quality healthcare service and reduce the workload of the clinical workforce to facilitate the use of eHealth systems. ‘Workforce gap’ measures the current shortage of health workers to offer quality healthcare services. ‘Workforce gap’ is expressed with Equation 6.3 in this model.

$$\text{Workforce gap} = \text{Desired workforce} - \text{Current workforce} \quad (\text{Unit: Persons}) \tag{6.3}$$

‘Hiring rate’ refers to the rate at which workforces from external sources are added to the current workforce. The model equation of ‘Hiring rate’ is described in Equation 6.4.

$$\text{Hiring rate} = \text{Management support} * \text{Average workforce training} * \text{Workforce gap} \quad (\text{Persons/ Year}) \tag{6.4}$$

‘Management support’ addresses the willingness of top management to deploy and use eHealth, and allocate necessary resources for the successful implementation (See Chapter 6.4.2). ‘Average workforce training’ represents the percentage of trained health workforces available to join the ‘Current workforce’. With ever-increasing population, Ethiopia needs to produce over 30,000 health workers (Medical Doctors, Health Officers, Nurses and Midwives) per year for the next twelve years to achieve universal health coverage by 2030, i.e., 4.45 health workers per 1000 population (Haileamlak, 2018). However, the current production of the health workforce is not more than 10,000 per annum (Haileamlak, 2018). This indicates that the ‘rate of available trained workforce’ per annum is 33% (i.e., 10,000 / 30,000).

Ethiopia is one of the countries with a very low density of health workers (0.96 health workers per 1000 population) which is much lower than the minimum threshold of 4.45 per 1000 population set by the World Health Organization to meet the Sustainable Development Goal (SDG) (Haileamlak, 2018).

The current workforce in the Gandhi Memorial hospital is 320 people of which 189 are clinical staffs and 121 support staffs. The desired clinical workforce is 4.6 times the current clinical workforce (i.e., 869 clinical staffs). The focus group team estimated one IT personnel should be appointed to serve 100 end-users (Appendix 4.4, Code: Services Qlty_Resource availability). For a total of 990 workforces, a minimum of ten IT staffs are needed to offer satisfactory technical support. Therefore, the total 'desired workforce' for proper operation of SmartCare in Gandhi Memorial hospital is 879, which is the sum of 869 clinical staffs and ten (10) IT staffs.

For the proper operations of eHMIS, two HITs are needed in each health facilities as proposed by the focus group team (Appendix 4.4, Code: Services Qlty_Resource availability). Hence, the 'desired workforce' for 6500 eHMIS using facilities is 13000 HIT personnel.

'Turnover rate' represents the percentage of health workforces leaving a health facility within a certain period. Equation 6.5 depicts the equation of 'Turnover rate' used in the techno-organizational system dynamics model of eHealth acceptance.

$$\text{Turnover rate} = \text{Average turnover rate} * \text{Current workforce} \quad (\text{Persons/Year}) \qquad (6.5)$$

According to the recent study in Southwest Ethiopian health institutions, the turnover in five years period (September 2009 to August 2014) was 45.9% (Gesesew *et al.*, 2016). This shows the average turnover rate of the health workforce in Ethiopia is 9.2% per annum (i.e., 45.9/5year).

Infrastructure readiness

Infrastructure represents the internal capability of a healthcare organization to support the implementation of sustainable eHealth systems (Bilbao-Osorio, Dutta and Bruno Lanvin, 2014). These capabilities include electric power, computers, local area networks, internet connection, printer, and scanner that support the implementation of the eHealth (Rippen *et al.*, 2013). Infrastructure readiness refers to the availability of electronic device, electric power, and internet network infrastructures within the health facilities to implement successful eHealth systems. The availability of commercial power and other backup power sources such as generator and UPS are evaluated for sustained supply of electric power. Internet and LAN are very important elements of ICT infrastructure for the successful implementation of the eHealth systems. Lack of ICT infrastructure is one of the key problems of eHealth implementation in developing countries (Bilbao-Osorio, Dutta and Bruno Lanvin, 2014).

‘Current infrastructure’ measures the adequacy (in percent) of electronic device, electric power supply, internet and LAN to the successful implementation of SmartCare and eHMIS. ‘Current infrastructure’ is the function of initial infrastructure and the integral of the difference between the ‘Installation rate’ and ‘Depreciation rate’ overtime (See Equation 6.6).

Current infrastructure = INTEG (Installation rate-Depreciation rate, Initial Infrastructure, Current infrastructure$_0$) (Units: Dimensionless) (6.6)

‘Current infrastructure$_0$’ is the initial level of ‘Current infrastructure’ at the start of the simulation. The ‘current infrastructure’ is the average of power sources, digital equipment and internet. ‘Current infrastructure$_0$’ of SmartCare in Addis Ababa is 67% and eHMIS in Addis Ababa and SNNPR is 39% (See Table 6.2).

Table 6.2 Current infrastructure readiness level in Ethiopian health facilities in 2018 (EPHI and FMOH, 2018).

Regions	**Power Sources**	**Communication Equipment**	**Computers with Internet**	**Average Infrastructure**
Addis Ababa	79%	89%	33%	67%
SNNPR	11%	20%	1%	11%
Addis Ababa and SNNPR	45%	54.50%	17%	39%
National	15%	29%	2%	15%

‘Installation rate’ represents the rate at which new power supply and ICT infrastructure is built to facilitate the implementation of successful electronic health system. It is influenced by the level of management support and the average rate of electronic device, internet and power supply installation as shown in Equation 6.7 (Appendix 4.4, Code: Org_Resources readiness).

*Installation rate = Management support * (Power installation rate + Internet installation rate + Digital equipment installation rate) / 3 (Unit: 1/Year) (6.7)*

‘Power installation rate’ refers to the rate at which primary energy is supplied to new areas. According to the International Energy Agency (IEA) data, the average primary energy supply rate in Ethiopia is four percent (4%) per year (International Energy Agency, 2019).

‘Internet installation rate’ refers to the rate at which the internet is available to individuals. The International Telecommunications Unit (ITU) data between 2010 and 2016 shows that the average rate of individuals using the internet in Ethiopia is 2.4% per annum (ITU, 2019).

‘Digital equipment installation rate’ represents the rate at which electronic devices such as computers, scanners, printers, etc. are made available to health facilities. According to EPHI survey data, the percent of facilities that had access to computers with internet in 2016 and 2018 was only 0% and 1% in SNNPR respectively (EPHI, FMOH and WHO, 2017; EPHI and FMOH, 2018). As shown in Table 6.2, in Addis Ababa, 27% of facilities in 2016 and 33% of facilities in 2018 had access to computers with internet. Therefore, the ‘Digital equipment installation rate’ in Addis Ababa is 6% (33%-27%) in two years (3% per annum) and in SNNPR is 1% (1%-0%) in two years (0.5 per annum) (See Table 6.3).

Table 6.3 The installation rate of computers with internet (EPHI, FMOH and WHO, 2017; EPHI and FMOH, 2018).

	Computers with Internet	
Region	**2016**	**2018**
Addis Ababa	27%	33%
SNNPR	0%	1%

‘Depreciation rate’ the rate at which the ‘current infrastructure’ degrades. Equation 6.8 shows the ‘Depreciation rate’ as defined in the model.

$$\textit{Depreciation rate} = \textit{Current infrastructure} * \textit{Power and digital equipment depreciation rate} \quad \textit{(Unit: 1/Year)} \qquad (6.8)$$

‘Power and digital equipment depreciation rate’ refers to the rate at which power and electronic devices are depreciated. The Ethiopian Ministry of Revenue estimated the depreciation of computers, software, and data storage equipment is estimated at 20% per annum (Ethiopian Ministry of Revenues, 2018). The model variables, values and equations are available in Appendix 6.1 and 6.2.

6.4.2. Organizational ICT culture

‘Organizational ICT culture’ refers to the culture of using ICT systems within an organization to support the day-to-day activities. In this research study, the culture of information and technology use is measured by the number of available electronic systems in the health facilities. The focus group team believed that the more electronic systems available, the higher was the level of information culture within the healthcare organization (Appendix 4.4, Code: Org_ICT culture). ‘Effectiveness of training’ influences the ‘Organizational ICT culture’ as shown in Equation 6.10.

Organizational ICT culture = (Effectiveness of training + Familiarity with electronic systems) / 2 *(Unit: Dimensionless)* *(6.10)*

The national health information system (HIS) in Ethiopia includes eHRIS eHMIS, eRIS, eLMIS, eCHIS, eIFMIS, eLIS, HGIS, EHR, mHealth and Telehealth (FMOH, 2016). The 'Familiarity with electronic systems' represents the percentatge of electronic health systems available in the health facilities. As the focus group team indicated, the number of available electronic systems in the hospital could measure the culture of information and technology use (Appendix 4.4, Code: Org_ICT culture). 'Familiarity with electronic systems' was measured by calculating the ratio of the number of available electronic system by the total number of HIT systems (i.e., ten) indicated in the Ethiopia National Health Information Enterprise Architecture (FMOH, 2016).

There were three electronic health systems in the Gandhi Memorial Hospital, namely Health Commodities Management Information System (HCMIS), SmartCare and eHMIS. The ratio of present electronic systems in Gandhi hospital (three) and the total national health information system (ten) are used to determine the 'Familiarity with the electronic system' of SmartCare, 30% (3/10). As observed during the interview with the end-users at the health facilities, the average number of eHealth systems available in the health facilities was 2, so the overall 'Familiarity with electronic systems' of eHMIS was calculated to be 20% (2/10) (Appendix 4.3 and 4.4).

6.4.3. Management support

'Management support' addresses the willingness of top management to deploy and use eHealth, and allocate necessary resources for the successful implementation. It also evaluates the commitment of top management in accepting SmartCare and eHMIS as an important tool, set goal and plan for the implementation and use within the hospital. The level of organizational policy to support the implementation of eHealth systems, known as 'Supportive policy' and 'Organizational ICT culture' influenced the level of management support as indicated in Equation 6.10 (Appendix 4.4, Code: Org_Management support).

Management support = (Supportive policy + Organizational ICT culture)/2
(Unit: Dimensionless) *(6.9)*

'Supportive policy' refers to the availability of organizational roadmap and guideline to accommodate electronic health systems within a healthcare organization to facilitate the healthcare services provision. The focus group team of the FMOH and the FMOH partners indicated that the government of Ethiopia had a very supportive policy towards the use of electronic systems to strengthen the use of information for decision-making. The government policy encouraged the use of electronic systems in the health sectors. Moreover, the focus group discussion with the project team of the FMOH partner highlighted that the official launch of “information revolution” document could be an indication of strong commitment from the FMOH executives to use the electronic health system for data collection and presentation to support decision making (Appendix 4.4, Code Groups: Organization). The “Information revolution” document showed the government supportive roadmap towards using ICT in the health sector to improve quality of data, use of information, and informed decision making (FMOH, 2016).

The level of support from top management to the implementation of electronic health systems within the organization is influenced by the national and organizational policy towards using an electronic system. ‘Supportive policy’ and ‘culture of ICT’ lead to better management support towards the implementation of eHealth, whereas the lack of supportive policy and ICT culture limits support from the top management .

6.4.4. Workflow processes

The workflow processes alignment focuses on understanding the current workflow processes in the service units of the healthcare facilitity, identifying service units where eHealth will be implemented, and determining the possible changes of workflow processes to align the technology with existing workflow processes (Lluch, 2011). Equation 6.11 expresses the ‘Workflow alignment’ in terms of ‘Management support’, ‘Resources readiness’ and ‘Supportive organizational structure’.

Workflow alignment = (Management support + Resources readiness + Supportive organizational structure)/3 (Unit: Dimensionless) (6.11)

‘Supportive organizational structure’ represents the availability of organizational units such as the IT department and project management unit to support the successful implementation of SmartCare and eHMIS. The IT structural units were not available in most of the health facilities in Ethiopia. The focus group discussion indicated that the IT structure was only available at the Federal and Regional Health Bureau levels (Appendix 4.4, Code: Org_Organizational structure). Therefore, most of the technical support to facility level offered by a technical team in the Federal and Regional Health Bureau. Moreover, the hospital readiness assessment to implement SmartCare in Addis Ababa conducted by the FMOH technical working group showed that only four of ten (40%) hospitals in Addis Ababa had IT structure in-place in their organizational structure. Therefore, the ‘supportive organizational structure’ was set to 40% for SmartCare implementation in Gandhi hospital. For eHMIS, the interview data shows that only five of twenty-four health facilities (20%) had incorporated the IT department in their organizational structure (Appendix 4.3 and 4.4).

Leadership commitment, strategic plan to integrate SmartCare in the health facilities, understanding of eHealth benefits, identifying possible implementation risks, and willingness to invest in the system are some of leadership and policy readiness assessment points as indicated by the focus group members (Appendix 4.4, Code Groups: Organization).

The focus group discussion of techno-organizational factors of eHMIS and SmartCare implementation is summarised in the following section. The codes and code groups generated in the qualitative data analysis of techno-organizational factors are discussed in detail in the next section. ATLAS.ti software was used to analyse the transcribed interview and focus group discussion data under management support, organizational culture, availability of resources (infrastructure and human resources), the readiness of workflow processes, and convenience of organizational structures.

6.5. Discussions of techno-organizational factors

The focus group discussion of techno-organizational factors of eHMIS and SmartCare implementation is described in details in this section. A rigorous coding process was used to analyse the transcripts of raw data using ATLAS.ti (See Chapter 4.8.3). The codebook generated from ATLAS.ti is attached in Appendix 4.4. Figure 6.8 is the summary of organizational factors that influence the acceptance of eHealth. The variables are captured from literature and focus group discussions (Appendix 4.4, Code Groups: Organization).

The techno-organizational factors in Figure 6.8 were developed in ATLAS.ti by analysing the qualitative data gathered for this research study. The details are discussed under management support, organizational ICT culture, organizational structure, resources readiness and workflow processes.

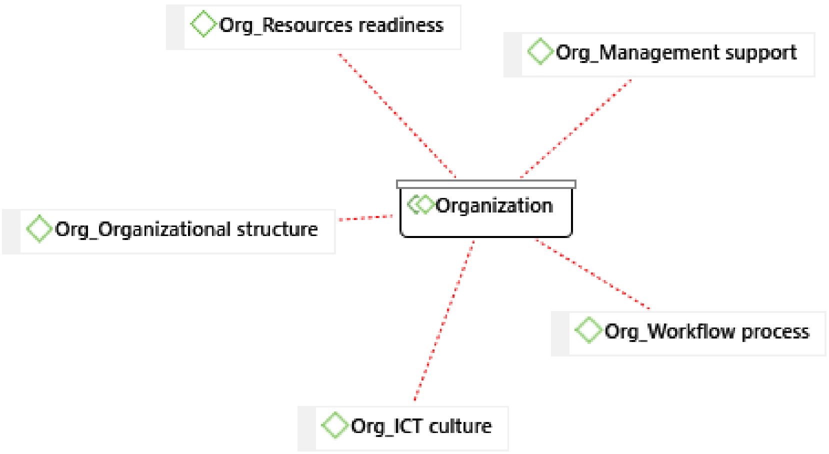


Figure 6.8 Organizational factors that influence eHealth acceptance (Appendix 4.4, Code Groups: Organization).

6.5.1. Management support

A focus group discussion with the project team of the FMOH partners highlighted that the official launch of "information revolution" document could be an indication of firm commitment from top managers to use the electronic health system for informed decision making. The "information revolution" document focused on the government roadmap towards the use of ICT in the health sector to improve quality of data, use of information, and informed decision making (FMOH, 2016). The government of Ethiopia had a very supportive policy towards the use of electronic systems to strengthen the use of information for decisions. The management support increased the quality of data, use of information, and informed decision making (Appendix 4.4, Code: Org_Management support).

A focus group discussion with the FMOH also revealed that the top management was committed to the implementation of successful eHMIS in Ethiopia. When one system failed, the top management was determined to trying another electronic health system as explained during the focus group discussion. The management supported the training of trainers (TOT) on eHMIS together with the two implementing partners (Appendix 4.4, Code: Org_Management support). The top management was strongly committed to plan and implement eHMIS nationally.

The top management showed support to the implementation of eHMIS by conducting supervision and a regular data quality assessment as indicated by the FMOH focus group team (Appendix 4.4, Code Groups: Information quality). Moreover, the top management supported eHMIS implementation by supplying necessary resources such as CDs and printed HMIS paper forms (Appendix 4.4, Code: Org_Resources readiness). The FMOH focus group team indicated that top management influenced the selection of electronic systems, resource and budget allocation, and provision of expert support. The focus group members of the FMOH highlighted the top management was willing to try new technology solutions that could improve data management and healthcare services (Appendix 4.4, Code: Org_Management support).

The FMOH focus group team indicated that better ICT skills and understanding of its benefits among the top managers led to improved support from the top management towards the implementation of eHMIS. In general, the top management support and commitment towards the successful implementation of electronic health systems had increased significantly. Previously, the top management had a limited understanding of an electronic system, as a result, the support level was low. But now they developed a very good understanding of the potential benefits of electronic systems to improve healthcare services leading to a greater support level (Appendix 4.4, Code: Org_Management support).

A focus group discussion with the FMOH partners indicated that most of the top management were supportive to the implementation of electronic health systems. Yet the level of support varied with the personality of the managers. There were some very supportive managers who closely followed-up the system use and data collection processes and actively used the information for decision makings. For example, the head of the Gurage zone was a strong supporter of eHMIS implementation in the Gurage zone, SNNPR. Even though the majority of the managers were supportive, some did not even know the existence of the electronic system in their organization (Appendix 4.4, Code: Org_Management support).

The focus group discussion further highlighted the possible influence of the top manager’s personality on the level of management support. Some of the managers had a culture of information use. Despite the technical difficulties of the electronic health system, these managers tried to get technical support and demanded information even if it was not good enough to make accurate decisions. For example, a hospital Chief Executive Officer (CEO) drove two days to collect computers and initiate eHMIS implementation in his hospital. On the other hand, some managers did not even use readily available information. Some managers had a big commitment while others had a low drive towards electronic systems due to a difference in the personality of the top managers (Appendix 4.4, Code: Org_Management support).

The level of support from top management towards the use of an electronic health system depended on the level of the manager’s commitment and culture of using the information to make decision. The manager who understood the benefits of the electronic system showed high intention to use the information generated from the system to make decisions. These type of managers provided all necessary support to get technical problems fixed and ensure the availability of resources for the proper operations of the technology. The electronic system success was considerably influenced by the level of top managers support. The managers were classified as strong supporters, neutral or opposers based on their support to the implementation of eHealth systems. In general, managers who have a culture of technology use were supportive of the implementation of technology. The support from top management increased the quality of data, use of information, informed decision making as indicated by the focus group team (Appendix 4.4, Code: Org_Management support).

6.5.2. Organizational ICT culture

It is apparent that people recognized the importance of technology to support or facilitate day-to-day activities. The routine use of the mobile application was evidence of the growing culture of technology within society. Cell phones became an integral part of society as described by the FMOH focus group team. Similarly, people within organizations developed the culture of technology use in the work environment. The fear factors to use ICT declined as people actively used computers, tablets, and phones for personal needs. The FMOH partner focus group team believed that ICT culture grew not only in the health sectors but also within the society due to high penetration of electronic devices (Appendix 4.4, Code: Org_ICT culture).

The FMOH focus group team described that the culture of information use within the healthcare organization contributed to the data quality improvement. Furthermore, the culture of technology and information use was highly dependent on individual experts. The ICT culture within health facilities in Ethiopian was not well developed when the electronic health technology was introduced. The FMOH focus group members indicated the confidence of the people increased and the culture of ICT grew over time. The users developed skills to evaluate technology and express their disappointment when technology failed to meet their requirements. When the system was running slow, an end-user said: “This technology is not better than the manual system”. This showed the impact of digital systems in speeding up end-users tasks. However, the culture of technology use for a personal reason developed more than the use of technology for organizational purpose. People still resisted using technology for organizational benefits compared to personal use as described by the focus group team (Appendix 4.4, Code: Org_ICT culture).

The focus group discussion with the FMOH further indicated that top managers proudly communicated to the public via media about the technologies they used within their organization to facilitate the service provision. The view of using technology as a competitive advantage was described as an indication of a growing culture of technology use within the organization team (Appendix 4.4, Code: Org_ICT culture). In summary, there was progress in the culture of technology use for personal and organizational purposes, but the resistance was high when the technology was used for organizational purpose compared to personal benefits.

The focus group discussion with the FMOH partners highlighted that the different ICT culture in various departments of a healthcare facility depends on the age of users and the type of software application they use. For example, the staffs in the MRU were old aged, less motivated, without technological capability and skill to use an electronic system. When younger HIT staffs were introduced to bridge the skills gaps, the ICT culture at the MRU improved. Generally, the culture of technology use by the younger generation was higher than that of the older generations. The young HIT professionals learnt faster and understood technology easily (Appendix 4.4, Code: Org_ICT culture).

The focus group discussion with the FMOH partners highlighted that information was not valued before the implementation of eHMIS but the introduction of electronic systems in the health facilities improved the culture of information use. One of the reasons for changes in information culture was associated with the mandatory requirements of reporting HMIS data every month through computer systems. Furthermore, the needs of information to make management and budget decisions forced end-users to develop information culture.

The overall ICT culture improved throughout a healthcare organization in Ethiopia; although the culture of information dissemination was weak. The focus group team of the FMOH partners indicated that relevant and quality information available in healthcare organizations were not shared enough to make a decision. Even though eHMIS end-users created charts and displayed reports in their office as part of the information dissemination effort, the skills to interpret the charts was lacking. Besides, poor infrastructure such as lack of internet connectivity influenced information dissemination effort. For example, due to lack of internet connection, the head of the woreda health office could not use email to send out information or feedback to all health facilities under his administration. Moreover, disseminating information through publications was weak in government health sectors (Appendix 4.4, Code: Impl_Data management).

In summary, the information culture improved as the end-users understood the value of technology and its information product. Yet the improvement in the culture of technology use for the work yields was weaker than that of personal benefits. Generally, as more users become familiar with electronic systems, the culture of technology use grew and the quality and use of information improved. However, the culture of information dissemination was lagging in the healthcare sector of Ethiopia.

6.5.3. Organizational structure

The lack of ICT support structure from the Federal to health facilities level was one of the main reasons for poor technical services and slow response time as described by the FMOH_HITD focus group team. The local ICT support team at health facility level was missing in the organizational structure. The staffs assigned for a technical support role at health facilities were involved in data entry instead of providing technical support services. The organization did not have a structure that accommodates the technical support team at health facilities so the local ICT team reported to the PPD instead of HITD (Appendix 4.4, Code: Org_Organizational structure).

The focus group discussion with the FMOH highlighted that the laboratory information system (LIS) in Ayder hospital was not part of the SmartCare system. The LIS module was developed and implemented by a different organization and it was not interoperable with the EMR (SmartCare) system. Hence the technical support services of the LIS and SmartCare were carried out by two separate teams. The fragmented technical support structure in health facilities caused end-users to call different teams to get support. As a result, the end-users described the technical support service as weak and slow (Appendix 4.4, Code: Org_Organizational structure, Code Groups: Services quality).

The FMOH partner’s focus group team indicated that the implementation of the eHMIS was led by PPD in the FMOH in the past; however, all ICT-related activities were moved under the HITD after a recent organizational restructuring exercise. The HITD involvement in the selection, design and implementation of electronic health systems were very limited. However, the current structure empowered HITD to lead the implementation and improvement of electronic systems in the FMOH. The top management valued the input from HITD experts to make technology-related decisions which were lacking previously. The focus group discussion with the FMOH partner further highlighted that the lack of proper IT structure also affected the speed of technical support and the use of eHealth technology (Appendix 4.4, Code: Org_Organizational structure, Code Groups: Services quality).

6.5.4. Resources readiness

The FMOH focus group team indicated that the top management supported eHMIS implementation by supplying necessary ICT resources such as CDs, printers, HMIS paper forms and computers, and skilled human resources. The focus group team acknowledged the improvement in top managements' understanding of ICT systems benefits improved the allocation of resources in terms of hiring and training IT personals and installing ICT infrastructure. The top management influenced the allocation of necessary resources to support the implementation of electronic health systems (Appendix 4.4, Code: Org_Resources readiness).

The focus group discussion with the FMOH partner organizations indicated that the readiness of ICT infrastructure (computers, LAN, internet, printer, scanners, etc.) and electric power within the organization were key to the successful implementation of eHealth technology. The focus group team discussed that the commercial electric power supply was not reliable, yet the alternative electric power was used at the regional and zonal administrative level. The generators were used as an alternative power source in the hospitals. However, these low-range generators were only able to supply power to critical life-saving service wards. Unfortunately, electronic health systems were not considered as critical services to be supplied with electric power supply from generators (Appendix 4.4, Code: Org_Resources readiness).

Access to the internet was another ICT infrastructure challenge highlighted by the focus group members of the FMOH partners. Internet connectivity was very limited or unavailable below zonal administrative level. Especially, the health facility hardly had access to the internet. The limitation of ICT infrastructure mainly, internet connectivity influenced the process of data submission. Therefore, instead of transferring data online via the internet, the facilities were forced to submit reports through CD, flash memory or paper. As a result, the design of the electronic system changed from a web-based system to a desktop system. The lack of ICT infrastructure at health facilities deterred the eHMIS implementation in the SNNPR with only a quarter of health facilities had access to eHMIS, mainly due to lack of electric power (Appendix 4.4, Code: Org_Resources readiness).

The low reporting frequent (monthly) of HMIS gave the flexibility to send reports using CDs or flash drives. Even in the absence of an internet connection, all health facilities could have implemented eHMIS; however, the lack of electric power hindered the implementation effort in some health facility as highlighted by the focus group team of the FMOH partners. As a result, health facilities with access to electric power were given priority in the implementation of eHMIS (Appendix 4.4, Code: Org_Resources readiness).

The FMOH focus group team indicated that most of the health facilities did not put electronic systems into consideration during the construction phase. The readiness assessment conducted by the FMOH focus group members covered the availability of commercial power and backup powers (such as a generator, UPS and solar), availability of the LAN, the internet, paper, computers and accessories in addition to the capability of a technical support team. The assessment showed that more than 90% of the facilities did not have enough ICT infrastructure necessary to implement SmartCare. Recently there was a new initiative by the FMOH to put ICT infrastructure during the construction of a new health facility. Most health facilities did not have internet connectivity, and infrastructure readiness was low to implement a robust electronic health system (Appendix 4.4, Code: Org_Resources readiness).

The ICT infrastructure of health facilities in Ethiopia was described as unprepared to the successful implementation of eHMIS and SmartCare systems. According to EPHI, FMOH, & WHO (2017) survey data, only two percent (2%) of facilities in Ethiopia have a computer with internet. The commercial electronic power interruption frequently is high; however, some facilities have a backup generator, solar or UPS. Approximately one-fourth of the facilities (23%) have a power source (e.g. electricity grid, generator, solar, or other) with less than two hours interruption per day (EPHI et al., 2017). In addition to other technical challenges in the implementation of electronic health systems, poor infrastructure also influenced information dissemination efforts. A single point of failure, lack of backup servers, and shortage of servers' capacity to accommodate an increasing amount of data were some of ICT infrastructure problems in the implementation of eHMIS and SmartCare systems (Appendix 4.4, Code: Org_Resources readiness). The implementation of eHMIS and SmartCare were deferred in some health facilities due to ICT infrastructure challenges.

One of the major problems to implement successful eHealth systems in the health facilities was the shortage of skilled manpower and high turn-over of staffs as indicated by the FMOH focus group team. A high turnover of both ICT and clinical staffs after acquiring skills on the electronic systems resulted in skill gaps in the successful operation of eHMIS and SmartCare. Due to the resignation of ICT experts, the entire information system collapsed in some health facilities. The process of hiring and training a new data manager usually took approximately six months disrupting the use of technology and information in the health facilities. Similarly, high physicians' turnover affected the use of information systems (Appendix 4.4, Code: Org_Resources readiness).

In the implementation of eHMIS, the original plan was to receive HMIS report electronically from all facilities through the internet and store the data in the TENA MAIL server installed at the FMOH data centre. But the lack of internet connection at health facilities level forced the use of alternative means such as CDs, flash disks or papers to submit monthly HMIS reports as indicated by the focus group of the FMOH partners. The focus group team further explained that health facilities did not have enough budget for the electronic system, hence they relied on the FMOH donations for computers, printers and other digital equipment. As a result, the implementation of SmartCare was delayed due to a lack of ICT infrastructure to deploy the application (Appendix 4.4, Code: Org_Resources readiness). In general, the health facilities in Ethiopia were described as not ready in terms of ICT infrastructure to the implementation of eHMIS and EMR systems during the focus group discussion with the FMOH. However, management support to implement successful electronic health technologies was very strong.

6.5.5. Workflow processes

The FMOH focus group discussion indicated that an electronic health system should follow the manual workflow processes. A minor deviation in the workflow processes from the existing manual workflow processes caused confusions to users. The eHealth was relatively a new technology so it was too early to ask clinicians to adjust themselves towards the electronic system. SmartCare system was not comprehensive to address all workflow processes in the health facility. The system supported the work processes of some departments, but it failed to consider other departments as indicated by the focus group team. Both eHMIS and SmartCare systems followed the existing paper-based workflow processes (Appendix 4.4, Code: Impl_Change management).

Although SmartCare did not cover the entire workflow processes of the facilities, the system followed the existing standard procedures and workflow processes of the health facilities from patient admission to discharge stages as indicated by the FMOH focus group discussion. SmartCare did not disrupt the workflow processes, rather it was a replication of the manual processes. In general, the system mapped to the workflow processes of the health facility such as patient admission, diagnosis results, laboratory results, medicine prescriptions, etc. The introduction of SmartCare systems did not force the facilities to adopt a new workflow process. Similarly, the focus group discussion with the FMOH partners indicated that the implementation of eHMIS followed the existing paper-based HMIS workflow without any significant change to the existing workflow processes (Appendix 4.4, Code Org_Workflow process).

The clinicians were the originators of HMIS data by recording the information on the paper registry. The HMIS focal person collected the paper forms from each department and entered the information into eHMIS. The HMIS data was first captured on paper at each ward or service unit before transferred into the electronic system as described by the FMOH focus group team. In summary, the implementation of the electronic health system in Ethiopia followed the manual workflow processes that made it easy to use. The eHMIS was implemented following the workflow process of paper-based HMIS. The focus group discussion with the FMOH partners highlighted that the end-users resistance to using electronic systems significantly reduced by aligning the electronic systems with an existing workflow process.

The initial values of exogenous variables used in the simulation model of the techno-organizational factors of eHMIS and SmartCare acceptance are discussed in the following section. The parameters and values of the system dynamics model are obtained from the qualitative data discussed in this section.

6.6. Simulation of techno-organization model of eHealth acceptance

The initial values of exogenous model variables of techno-organizational factors are depicted in Tables 6.1 and 6.2. The simulation results of the techno-organizational model of eHMIS and SmartCare acceptance uses these initial variables obtained from the qualitative data analysed in the previous section. Appendix 6.1 and 6.2 show a comprehensive list of techno-organizational model variables and equations for eHMIS and SmartCare respectively. The eHMIS and SmartCare cases in Ethiopia are simulated separately to study the behaviour of technology acceptance by the end-users. The techno-organizatioanl system model and equations were developed by the author originally in Vensim as an original contributions of this simulation research study. Vensim is flexible, fast and powerful software package for model building, simulation and sensitivity analysis (Ventana Systems, 2015).

6.6.1. The initial values of techno-organizational variables of eHMIS acceptance

The initial values of exogenous techno-organizational variables of eHMIS depicted in Table 6.4 are used in addition to the socio-technical variables of eHMIS shown in Table 5.3, Chapter 5.5.1. The techno-organizational model of eHMIS acceptance uses these initial variables for simulation. The comprehensive lists of system model parameters, values and equations are shown in Appendix 6.1.

Table 6.4 The initial values of techno-organizational variables of eHMIS.

Variable	Initial Value	Unit
Average workforce training	0.33	Dimensionless
Desired labour	13000	People
Average workforce turnover	0.092	Dimensionless
Supportive policy	1.0	Dimensionless
Power installation rate	0.04	Dimensionless
Internet installation rate	0.024	Dimensionless
Digital equipment installation rate	0.005	Dimensionless
Power and digital equipment depreciation rate	0.2	Dimensionless
Trainee motivation	0.6	Dimensionless
Familiarity with electronic systems	0.2	Dimensionless
Supportive organizational structure	0.2	Dimensionless

6.6.2. The initial values of techno-organizational variables of SmartCare acceptance

The initial values of exogenous techno-organizational variables of SmartCare depicted in Table 6.5 is used in addition to the socio-technical variables of SmartCare shown in Table 5.4, Chapter 5.5.2 The techno-organizational model of SmartCare acceptance uses these initial variables for simulation. The detail lists of system model variables, values and equations are shown in Appendix 6.2.

Table 6.5 The initial values of techno-organizational variables of SmartCare.

Variable	Initial Value	Unit
Average workforce training	0.33	Dimensionless
Desired labour	1000	Persons
Average workforce turnover	0.092	Dimensionless
Supportive policy	1.0	Dimensionless
Power installation rate	0.04	Dimensionless
Internet installation rate	0.024	Dimensionless
Digital equipment installation rate	0.03	Dimensionless
Power and digital equipment depreciation rate	0.2	Dimensionless
Trainee motivation	0.15	Dimensionless
Familiarity with electronic systems	0.3	Dimensionless
Supportive organizational structure	0.4	Dimensionless

'Effectiveness of training' measures the success level of training provided to the end-users to create awareness and facilitate the learning processes of a technology (Al-Mamary, Shamsuddin and Aziati, 2014). Trainee motivation refers to trainees desire to learn the content of a training program and to use the content of the training for their job (Saeed *et al.*, 2012; Chung, 2016). Based on the empirical evidence, the motivation of eHMIS users was high compared to that of SmartCare users. The desire of eHMIS users was estimated to be 60% and that of SmartCafre users is estimated at 15% (Appendix 4.4, Code: Impl_Training). The

low motivation level of users to the SmartCare training program was mainly due to low system fit to their job.

The next section discusses the simulation results of the techno-organizational model of eHMIS and SmartCare acceptance. The influence of organizational factors such as management support, organizational culture, availability of resources (infrastructure and human resources) and workflow processes alignment on eHMIS and SmartCare acceptance is discussed in the next section.

6.7. The influence of organizational factors on the rate of eHMIS and SmartCare acceptance

The simulation results depict the influence of management support, organizational culture, availability of resources (infrastructure and human resources) and workflow processes on eHMIS and SmartCare acceptance. As discussed in Chapter 5.3.1 and 5.8.1, 'individuals' intention to use', 'promoters' and 'inhibitors' are the key factors that influence 'acceptance rate'. The influences of organizational variables on the 'acceptance rate' through 'individuals' intention to use' is discussed below.

Management support on individuals' intention to use

The 'individuals' intention to use' developed from the effectiveness of training and communication about the technology to the 'potential users' (See Chapter 5.10). The simulation results of socio-technical model confirmed that 'effectiveness of training' was a dominant factor in the early years of implementation to improve the 'acceptance rate' of eHMIS and SmartCare through 'individuals' intention to use' (See Chapter 5.5). The 'management support' influences the 'individuals' intention to use' through the 'effectiveness of training'.

The causes tree depicts the influence of organizational factors on 'effectiveness of training' (See Figure 6.9). It is uniquely developed in systems thinking as part of a Vensim model to show the dynamic influence management support on 'effectiveness of training'. The qualitative analysis of focus groups (Appendix 4.4) was a key input in the systems thinking processes.

'Effectiveness of training' was an exogenous variable in the socio-technical model of technology acceptance (Chapter 5). But the techno-organizational model of technology acceptance depicted the dynamic influence of 'management support' on 'effectiveness of training'. The FMOH management supported the training effort during eHMIS implementation together with the two partner organizations (Appendix 4.4, Code: Org_Management support).

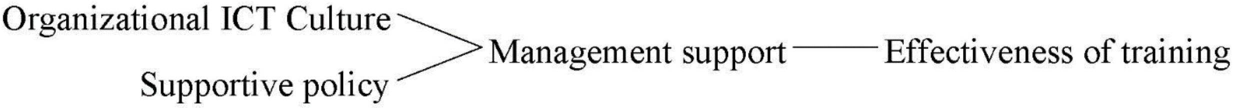
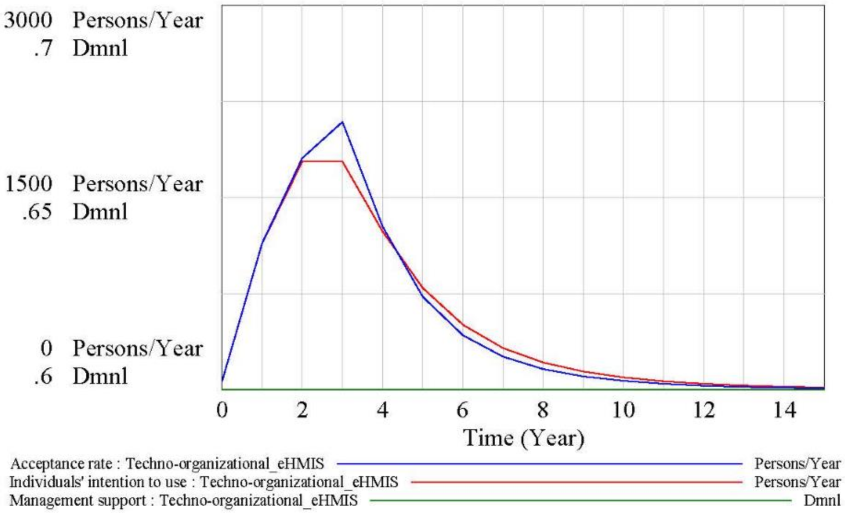


Figure 6.9 The influence of management support on 'effectiveness of training'.

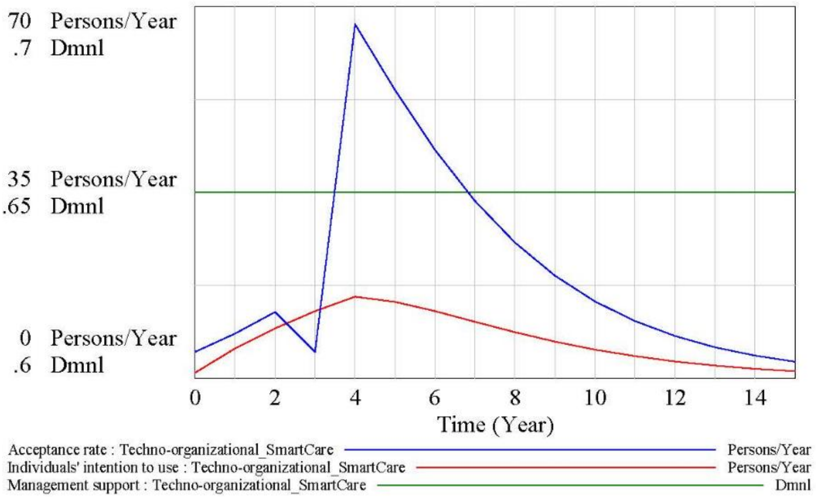
'Management support' was an important organizational factor to improve 'individuals' intention to use' through effective training and communication. High 'management support' helped to improve the 'effectiveness of training' which led to better 'individuals' intention to use' (Appendix 4.4, Code: Org_Management support). 'Individuals' intention to use' was a dominant factor to influence 'acceptance rate' in the early years of technology acceptance of eHMIS in the socio-technical model (See Figure 5.17 (a)). Figure 6.10 (a) also confirmed the dominant influence of 'individuals' intention to use' (red colour) on the 'acceptance rate' of eHMIS (blue colour).

The dominance of 'individuals intention to use' on 'acceptance rate' was affected by increasing number of 'inhibitors' starting from year three and two in eHMIS and SmartCare respectively (See Figure 6.10 (a) and (b)).

The next section shows the simulation results and discusses the influence of organizational factors on eHMIS and SmartCare users' satisfaction.



(a)



(b)

Figure 6.10 Comparison of 'management support', 'individuals' intention to use' and 'acceptance rate' (a) eHMIS. (b) SmartCare.

6.8. The influence of organizational factors on the eHMIS and SmartCare users' satisfaction

Figure 6.11 is developed in systems thinking as part of a Vensim model to show factors that influence 'satisfaction rate'. 'Workflow alignment' is a techno-organizational factor that influenced the 'satisfaction rate' (Figure 6.11). Other variables that impacted 'satisfaction rate' were discussed in Chapter 5 under socio-technical factors that influenced users' satisfaction. 'Workflow alignment' is influenced by 'management support' and 'effectiveness of training' as shown in the causes tree diagram below (See Figure 6.11).

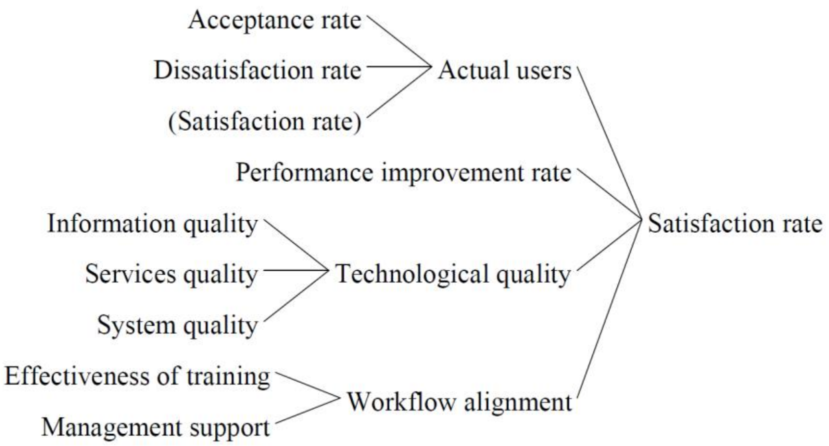
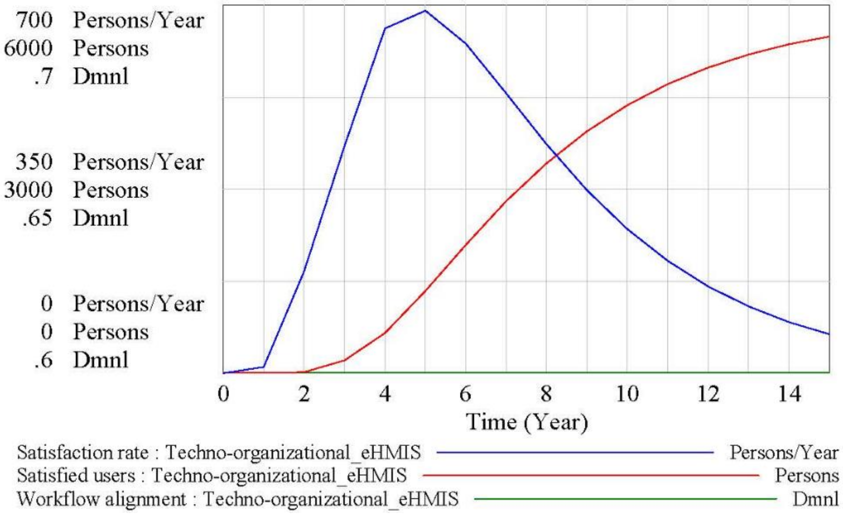


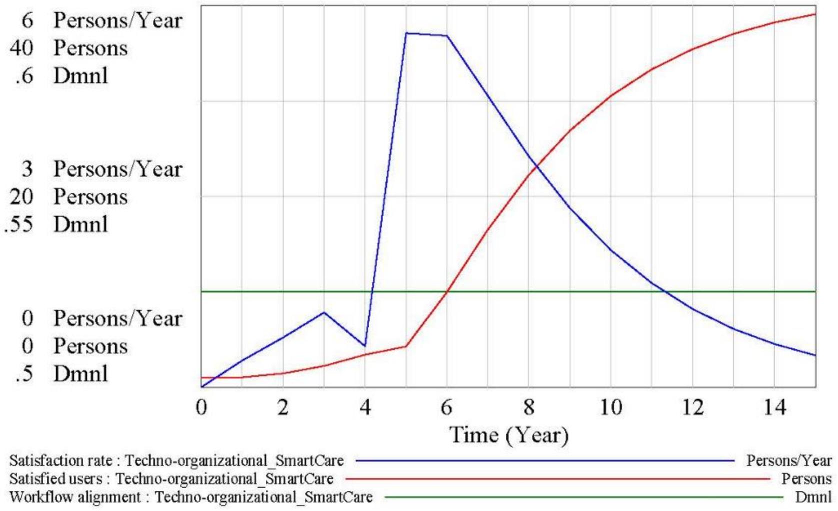
Figure 6.11 Organizational factors influence on 'satisfaction rate'.

Minor changes in the workflow processes of new technology from the existing manual workflow processes caused confusions and dissatisfaction to the end-users (Appendix 4.4, Code: Impl_Change management). Parkes (2002) described management commitment to implement workflow processes was accompanied by training, communication, and involvement of end-users. A good ‘workflow alignment’ is achieved by the high level ‘management support’, effective communications and effective training. The end-users’ satisfaction is influenced by the ‘workflow alignment’ (Appendix 4.4, Code Org_Workflow process).

The simulation graph (Figure 6.12 (a) and (b)) compared ‘workflow alignment’, ‘satisfaction rate’ and ‘satisfied users’. The ‘satisfaction rate’ of eHMIS was high after year one (Figure 6.12 (a) in blue colour), whereas SmartCare ‘satisfaction rate’ began to rise only after year four (Figure 6.12 (b) in blue colour). The ‘satisfaction rate’ increased with a good alignment of the technology with existing workflow processes. eHMIS had a better level of workflow alignment’ than SmartCare (Figure 6.12 (a) and (b) in green colour) and resulted in higher level of end-users’ satisfaction (Figure 6.12 (a) and (b) in blue colour).



(a)



(b)

Figure 6.12 Comparisons of ‘workflow alignment’ with ‘satisfaction rate’ and ‘satisfied users’ (a) eHMIS. (b) SmartCare.

The next section discusses the simulation results that depict the influence of organizational factors on 'information quality' of eHMIS and SmartCare.

6.9. The influence of organizational factors on 'information quality' of eHMIS and SmartCare

'Organization ICT culture' was one of the organizational factors that influenced the 'information quality' as shows in the causes tree (See Figure 6.13). The other socio-technical factors such as satisfaction level and system quality that influenced 'information quality' are discussed in Chapter 5.5.2 and 5.10. Researches showed that organizations that have developed a decision-making culture based on clear data insight rather than on intuition have managed to be more productive and profitable than their competitors (Bilbao-Osorio, Dutta and Bruno Lanvin, 2014). As the end-users understood the value of technology and became familiar with the technology, the ICT culture improved so do the quality of information product (See Chapter 6.5.2).

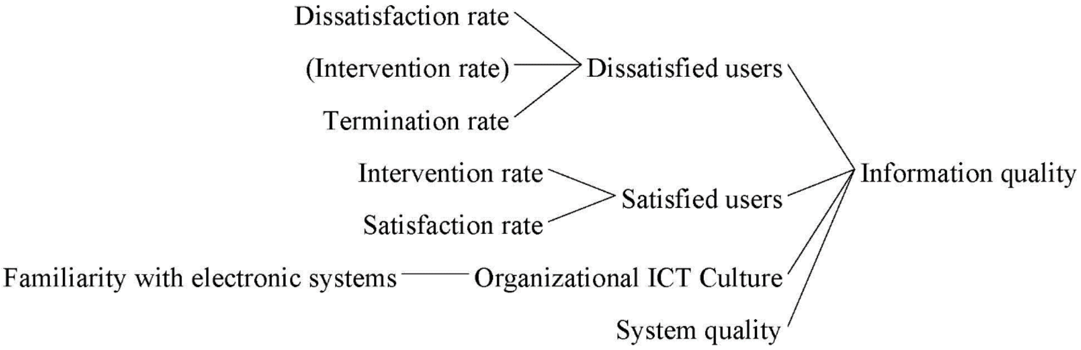
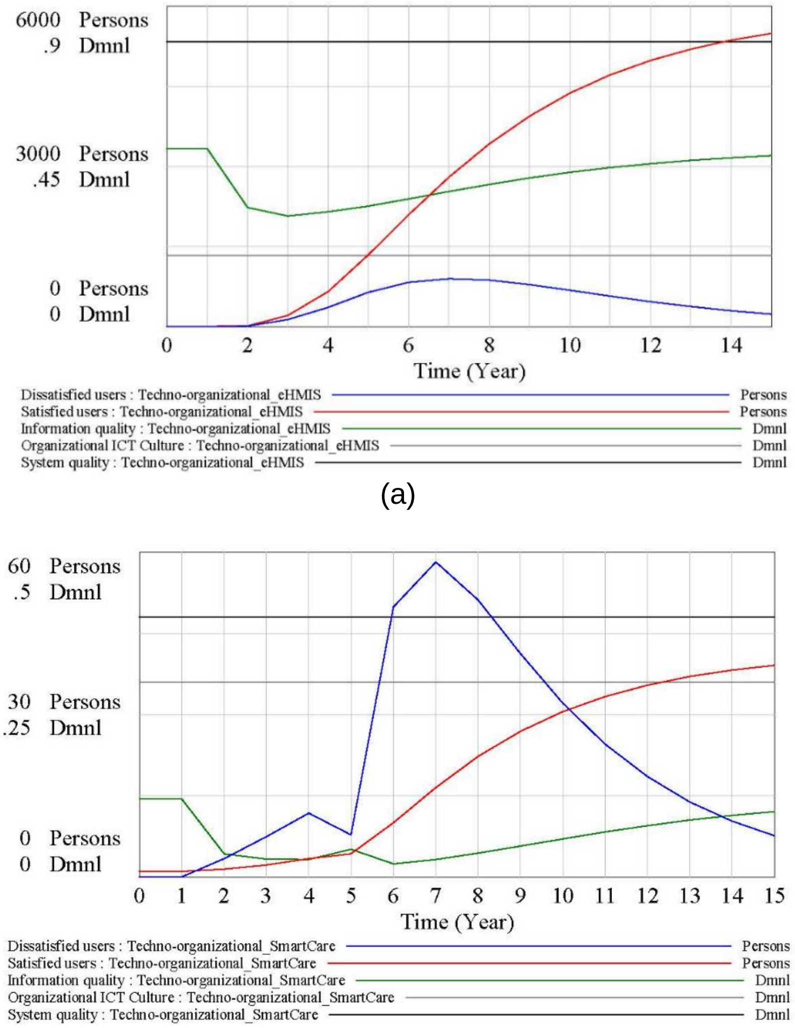


Figure 6.13 "Organizational ICT culture' on 'information quality'.

An increase in the 'organizational ICT culture' helped to improve 'information quality' (Appendix 4.4, Code Groups: Information quality and Code: Org_ICT culture). As end-users used electronic systems for personal and work reasons, the workforce became familiar with electronic systems and the culture of ICT grew within the organization (See Chapter 6.5.2). Organizations that promoted a culture of information perform better in the implementation of eHealth technology and use of information (Aqil, Lippeveld and Hozumi, 2009). Figure 6.14 (a) and (b) showed the influence of 'organizational ICT culture' (in grey colour) on the 'Information quality' of eHMIS and SmartCare (green colour) respectively.

'Information quality' was influenced by 'system quality', end-users' satisfaction and culture of ICT within the organization as shown in Figure 6.13. The simulation graph showed that SmartCare exhibited high dissatisfaction and low system quality although the organizational

ICT culture was good compared to eHMIS in Figure 6.14 (a) and (b). Despite higher organizational ICT culture of SmartCare facility (0.3) than that of eHMIS facilities (0.2), the information quality of SmartCare was lower than that of eHMIS due to low system quality and a high number of dissatisfied users of SamrtCare (See Figure 6.14 (a) and (b)). Organizational ICT culture was an important organizational factor to influence information quality as indicated by the focus group team (Appendix 4.4, Code: Org_ICT culture) and (Aqil et al., 2009); however, system quality and user satisfaction were dominant factors in impacting information quality (See Chapter 5.7).



(a)

(b)

Figure 6.14 The influence of 'organizational ICT culture' on the 'Information quality' of (a) eHMIS. (b) SmartCare.

The validation and verification tests of the techno-organizational model of eHealth acceptance are discussed in the next section of the report. The focus group discussions, interview data, eHMIS and SmartCare implementation documents obtained from the FMOH are used in the direct and indirect structure tests of the system dynamics model of techno-organizational factors (Barlas, 2016).

6.10. The verification and validation of techno-organizational model

The structural and behavioural validity of the model is tested to establish confidence in the model structure. The direct and indirect structure testing of the techno-organizational model of eHealth acceptance is discussed in this section. The model validation and verification processes outlined in Chapter 4.6 are followed and Vensim software package is used in the model testing processes. The credibility of the model to represent the real world is judged against the purpose of the model through direct and indirect structure tests. The qualitative case study data obtained through focus group discussions, interview and document reviews are used in the system dynamics model validation and verification processes.

6.10.1. Direct structure tests

Structure confirmation test

Structure confirmation procedures discussed in 5.12.1 are followed to assess the validity of the techno-organizational model of eHealth acceptance. The model variables are presented in two focus group discussion sessions to evaluate the structural validity of the model against the eHMIS and SmartCare projects in Ethiopia. The focus group members from the FMOH and the FMOH partners confirmed that the model variables capture the reality in the two eHealth projects, SmartCare and eHMIS (Appendix 4.4). The details of system dynamics model structure and the equations used in the model are supported by the literature study and the focus group members involved in the design, implementation and operation of the eHMIS and SmartCare systems in Ethiopia (See Chapter 6.6). The detail lists of the model variables, equations and values are depicted in Appendix 6.1 and 6.2.

Dimensional consistency test

The dimensional consistency checks the left and right sides of the equations for dimensional consistency and the real-life meaning of the parameters. Each techno-organizational model equations are made to pass the dimensional consistency test. The model variables, values and equations are discussed in Appendix 6.1 sn 6.2. The ‘unit check’ functionality of Vensim DSS 6.3D is used to ensure the consistency of all variable units across the model (Appendix 7.1 and 7.2).

Parameter confirmation test

The parameter confirmation test followed in this section is similar to the one discussed in Chapter 5.8.1. The exogenous parameter values of the two cases (eHMIS and SmatrtCare) in this PhD research project are judged from the focus group discussions, the interview data, the FMOH documents, eHMIS database and experts opinion (See Appendix 4.3 and 4.4). The parameter values reflect the real-life condition of both eHMIS and SmartCare projects in Ethiopia.

The following section discusses indirect structure tests. The test includes extreme-condition test, behaviour sensitivity test and boundary adequacy test.

6.10.2. Indirect structure tests

This section addresses indirect structure tests of techno-organizational system dynamics model which includes the boundary adequacy, extreme condition, and sensitivity tests.

Boundary adequacy tests

All important techno-organizational factors necessary for the implementation of eHealth systems in Ethiopia are addressed in the techno-organizational model of eHealth acceptance. The model boundary chart showing the endogenous, exogenous and excluded model variables are indicated in Table 6.1. The techno-organizational model of eHealth acceptance is limited to healthcare organization’s settings. Hence the boundaries are adequately and appropriately set within the context of healthcare institutions (Appendix 4.4, Code Groups: Organization).

Extreme conditions test

The response of the model to extreme input values is assessed in the extreme condition tests as outlined in Chapter 5.8.2.

Extreme conditions of ‘supportive policy’

The extreme condition tests are carried out by assigning the maximum value (one) and the minimum value (zero) to ‘supportive policy’ to assess the behavior of simulated ‘resource readiness’, ‘services quality’ and ‘acceptance rate’.

i. Extreme conditions of 'supportive policy' on 'resources readiness'

'Supportive policy' influenced 'management support' to impact 'resources readiness' level. High 'management support' improved workforce and infrastructure readiness level. Figure 6.15 indicates that high 'supportive policy' maximized the level of simulated 'resources readiness' as discussed in the focus group sessions (Appendix 4.4).

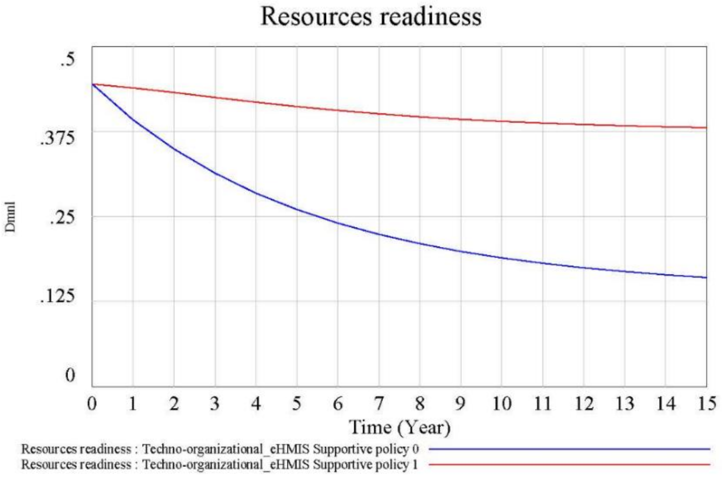


Figure 6.15 Extreme conditions of 'supportive policy' on 'resources readiness'.

ii. Extreme conditions of 'supportive policy' on 'services quality'

This test confirmed that 'supportive policy' improved simulated 'services quality' by increasing 'resources readiness'. High 'supportive policy' increased the simulated 'services quality' whereas low 'supportive policy' reduced simulated 'service quality' (See Figure 6.16). The focus group discussion indicated that a low level of 'supportive policy' resulted in low 'resources readiness' to affect the level of 'service quality' (Appendix 4.4, Code Groups: Organization).

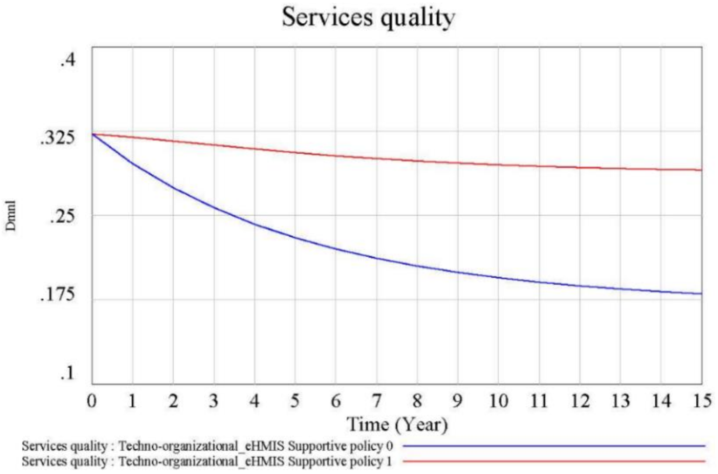


Figure 6.16 Extreme conditions of 'supportive policy' on 'services quality'.

iii. Extreme conditions of ‘supportive policy’ on ‘acceptance rate’

As indicated in the IS success model, ‘services quality’ influenced the level of technology acceptance (DeLone and McLean, 1992, 2003). Figure 6.17 depicts the behaviour of simulated ‘acceptance rate’ to extreme values of ‘supportive policy’. Low ‘supportive policy’ resulted in poor the simulated ‘acceptance rate’ and vice versa (Appendix 4.4).

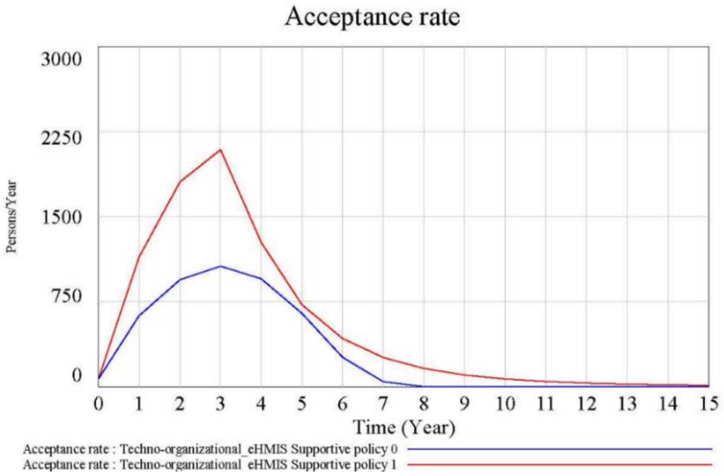


Figure 6.17 Extreme conditions of ‘supportive policy’ on ‘services quality’.

In general, ‘supportive policy’ influenced ‘acceptance rate’ through ‘management support’, ‘resources readiness’, ‘services quality ’and ‘promoters’. The extreme conditions tests of ‘supportive policy’ confirmed that the model response of the simulated ‘resources readiness’, ‘services quality’ and ‘acceptance rate’ was in line with the anticipated model behaviour.

Extreme conditions of ‘familiarity with electronic systems’

i. Extreme condition of ‘familiarity with electronic systems’ on ‘information quality’

One of the important factors that affected ‘information quality’ was ‘organizational ICT culture’ which was directly influenced by the familiarity of the workforce with electronic systems. Focus group discussion indicated that ICT culture of an organization grew as more staffs became familiar with using electronic systems for personal or work-related purposes (Appendix 4.4, Code: Org_ICT culture).

The ‘familiarity with electronic systems’ built the digital culture of an organization to impact ‘information quality’. When more end-users of eHMIS became familiar with electronic systems, the ‘information quality’ improved to facilitate decision makings (Appendix 4.4, Code: Org_ICT culture). Figure 6.18 shows the simulated ‘information quality’ response to the extreme values of 'familiarity with the electronic system'. The simulation results agree with the qualitative data analysed in this PhD research project.

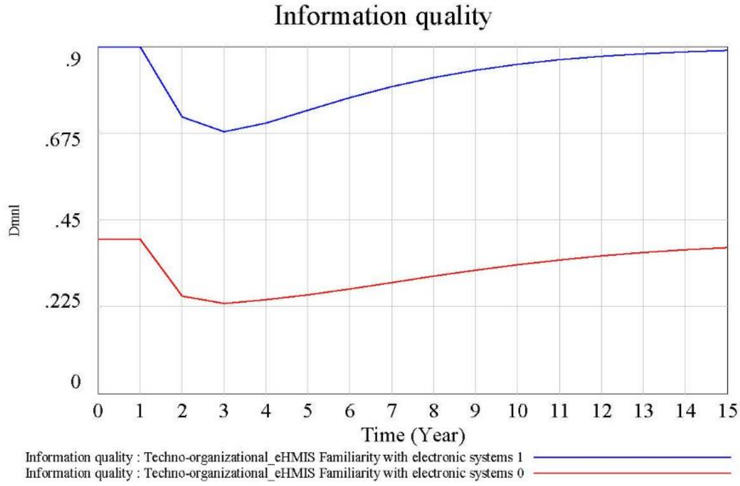


Figure 6.18 Extreme conditions of 'familiarity with electronic systems' on 'information quality'.

ii. Extreme conditions of 'familiarity with electronic systems' on 'acceptance rate'

As discussed in the IS success model, information quality influences technology acceptance (DeLone and McLean, 1992, 2003). Figure 6.19 showed the impact of 'familiarity with electronic systems' on the simulated 'acceptance rate'. The familiarity of end-users' with eHMIS systems improved 'information quality' and finally resulted in good 'acceptance rate' (See Figure 6.19 in blue colour). The simulated results of 'acceptance rate' to the extreme values of 'familiarity with electronic systems' agreed with the focus group data summarised in Appendix 4.4.

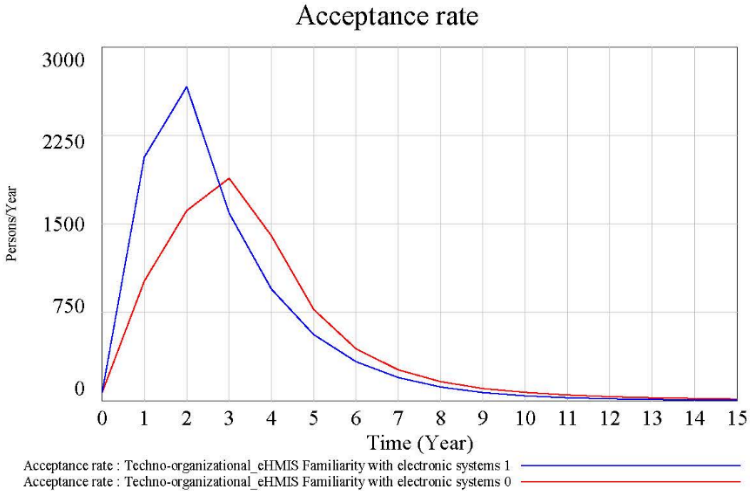


Figure 6.19 Extreme conditions of 'familiarity with electronic systems' on 'acceptance rate'.

The response of the techno-organizational model to the extreme conditions of 'familiarity with electronic systems' confirmed that the simulated results of 'information quality' and 'acceptance rate' behaved as anticipated in the real world. High familiarity level of end-users with electronic systems increased both ‘information quality’ and ‘acceptance rate’. Conversely, low familiarity with electronic systems reduced ‘information quality’ and ‘acceptance rate’.

Extreme conditions of ‘current workforce’

The extreme conditions of ‘current workforce’ was tested under two cases. Case 1 represented the worst condition of ‘current workforce’, i.e, no hiring but the maximum ‘turnover rate’. Whereas, case 2 represented the opposite, i.e., the maximum ‘hiring rate’ without workforce turnover (See Table 6.6).

Table 6.6 Cases of ‘current workforce’ extreme conditions.

	Average workforce training	Average workforce turnover
Case 1	0	1
Case 2	1	0

i. Extreme conditions of ‘current workforce’ on ‘resources readiness’

The readiness of the workforce was one of the key resources readiness factors to the successful implementation of eHealth systems in the techno-organizational dimension (Appendix 4.4., Code: Org_Resources readiness). Figure 6.20 in the blue colour showed that the simulated ‘resources readiness’ dropped exponentially with high ‘turnover rate’ and low ‘hiring rate’ of the workforce (Case 1) as anticipated in the real world.

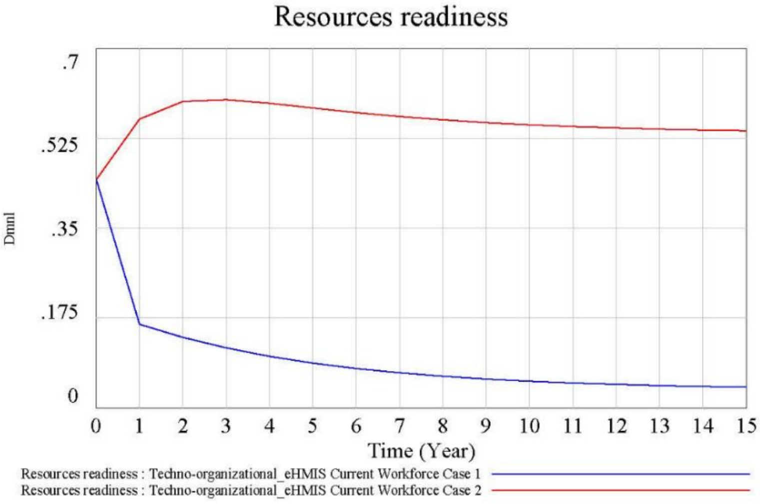


Figure 6.20 Extreme condition tests of ‘current workforce’ on ‘resources readiness’.

ii. Extreme condition tests of ‘current workforce’ on ‘services quality’

The ‘resources readiness’ influenced ‘services quality’ (Appendix 4.4., Code: Services Qlty_Resource availability) and Figure 6.21 confirmed that high ‘turnover rate’ and low ‘hiring rate’ of workforce reduced the simulated ‘services quality’.

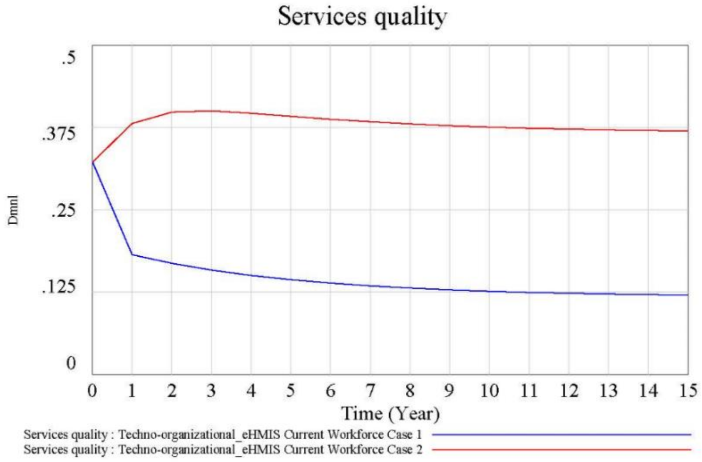


Figure 6.21 Extreme condition tests of ‘current workforce’ on ‘services quality’.

iii. Extreme conditions of ‘current workforce’ on ‘acceptance rate’

Technology acceptance was influenced by ‘services quality’ (DeLone & McLean, 1992, 2003). The influence of workforces readiness on the simulated ‘acceptance rate’ showed in Figure 6.22 happened through ‘services quality’. In the first extreme case (Case 1), no hiring but maximum turnover rate, the simulated ‘acceptance rate’ quickly dropped to zero as anticipated because all the ‘potential users’ resigned from the organization (See Figure 6.22 in blue colour).

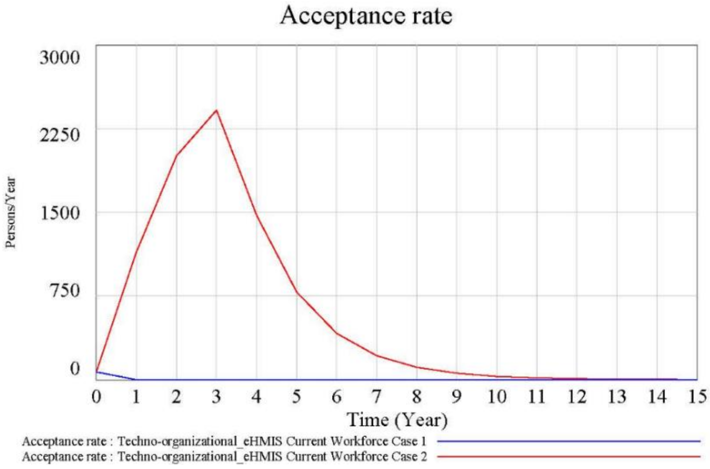


Figure 6.22 Extreme conditions of ‘current workforce’ on ‘acceptance rate’.

The behavioural responses of the simulated ‘resources readiness’, ‘services quality’ and ‘acceptance rate’ to the extreme conditions of ‘current workforce’ was in agreement with the expected behaviour of the model variables in the real world.

Extreme conditions of ‘current infrastructure’

Case 1 in Table 6.7 showed the extreme condition of maximum depreciation rate without the installation of new infrastructure that represented the worst-case scenario in infrastructure readiness. Conversely, Case 2 represented the maximum infrastructure installation rate without depreciation of the current infrastructure that represented the best-case scenario in terms of infrastructure readiness (Table 6.7).

Table 6.7 Cases of 'current infrastructure' extreme conditions.

	Power installation rate	Internet instsllation rate	Digital equipment installation rate	Power and digital equipment depriciation rate
Case 1	0	0	0	1
Case 2	1	1	1	0

i. Extreme conditions of 'current infrastructure' on 'resources readiness'

Infrastructure readiness such as power, internet and digital equipment played a critical role in the 'resources readiness' in the implementation of eHealth systems (Appendix 4.4, Code: Org_Resources readiness). The model showed that a low level of infrastructure installation rate and high level of infrastructure depreciation rate resulted in a low level of simulated 'resources readiness' (See Figure 6.23, Case 1 in red colour). This test discovered a model structural problem with the techno-organization model of technology acceptance which was later fixed by introducing a new model variable called 'infrastructure gap'.

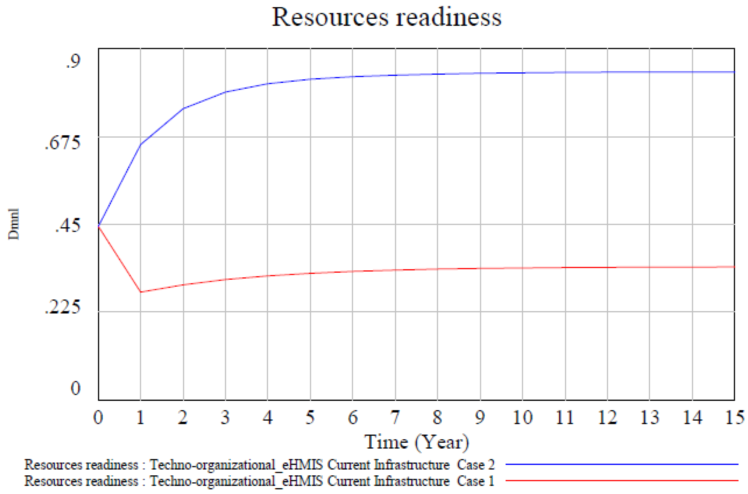


Figure 6.23 Extreme conditions of 'current infrastructure' on 'resources readiness'.

ii. Extreme conditions of 'current infrastructure' on 'services quality'

The influence of 'infrastructure readiness' on the simulation behaviour of 'services quality' was depicted in Figure 6.24. Low readiness in the 'current infrastructure' resulted in low 'services quality' due to low infrastructure readiness (See Figure 6.24, Case 1 in red colour). This simulation response of 'services quality' to the extreme condition of infrastructure agreed with the qualitative data showed in Appendix 4.4.

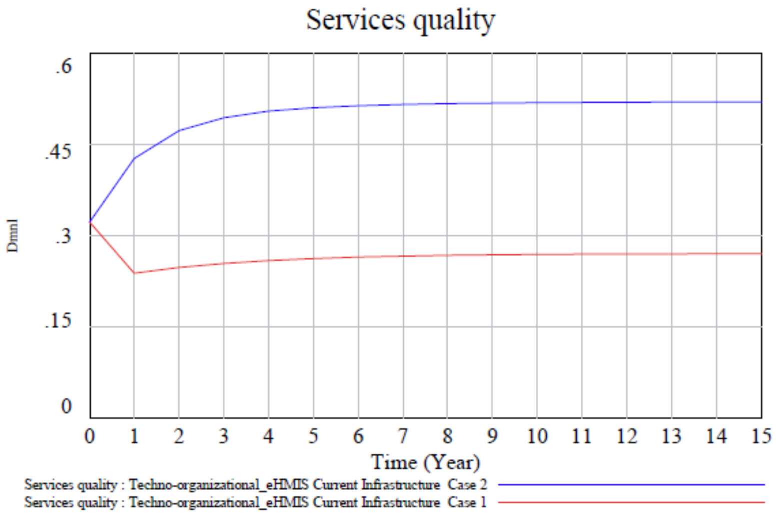


Figure 6.24 Extreme conditions of 'current infrastructure' on 'services quality'.

iii. Extreme conditions of 'current infrastructure' on 'acceptance rate'

Figure 6.25 showed that the simulated 'acceptance rate' slightly dropped with low readiness level of the 'current infrastructure' (Case 1 in red colour) as anticipated in the real world.

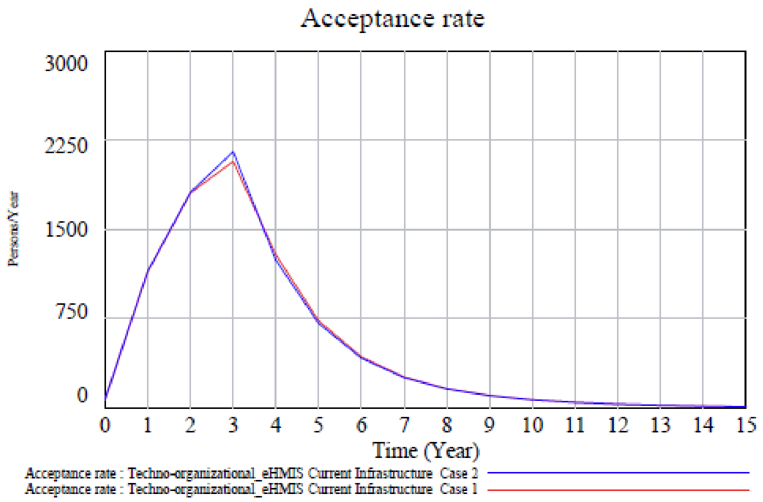


Figure 6.25 Extreme conditions of 'current infrastructure' on 'services quality'.

In summary, the response of techno-organizational model of eHealth acceptance to the extreme conditions of 'current infrastructure' agrees with the anticipated behaviour of 'resources readiness', 'services quality' and 'acceptance rate'.

Extreme conditions of 'supportive organizational structure'

The extreme condition tests are carried out by assigning the maximum value (one) and the minimum value (zero) to 'supportive organizational structure' to assess the behaviour of simulated 'services quality' and 'acceptance rate'.

i. Extreme conditions of 'supportive organizational structure' on 'services quality'

The lack of proper IT structure affected the speed of technical support and the use of eHealth technology (Appendix 4.4, Code: Org_Organizational structure, Code Groups: Services quality). Figure 6.26 confirmed that good 'supportive organizational structure' improved the simulated 'services quality' (in blue colour) while poor 'supportive organizational structure' reduced the simulated 'service quality' (in red colour) as explained in the qualitative data in this PhD research study.

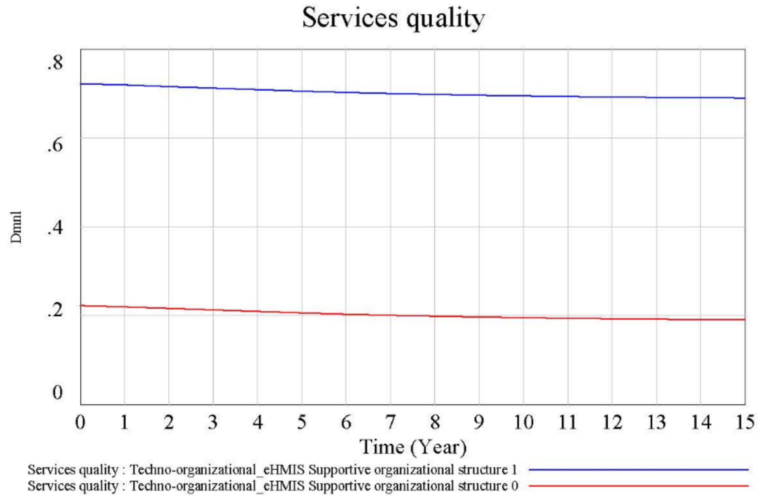


Figure 6.26 Extreme condition of 'supportive organizational structure' on 'services quality'.

ii. Extreme conditions of 'supportive organizational structure' on 'acceptance rate'

Figure 6.27 showed a slight drop in the simulated 'acceptance rate' to the poor 'supportive organizational structure' (in red colour). Whereas a good 'supportive organizational structure' improved the simulated 'acceptance rate' (in blue colour) as indicated by the focus group team (See Appendix 4.4).

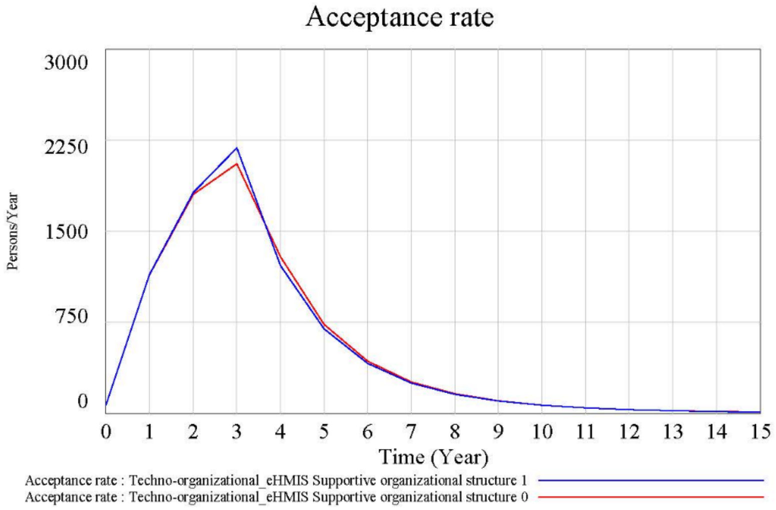


Figure 6.27 Extreme conditions of 'supportive organizational structure' on 'acceptance rate'.

The extreme condition tests of ‘supportive policy’, ‘familiarity with electronic systems’, ‘current workforce’, current infrastructure’ and ‘supportive organizational structure’ confirmed that the model behaviour was plausible to the extreme values. The following section addresses a univariate and multivariate sensitivity analysis of a techno-organizational model of eHealth acceptance.

6.11. Sensitivity analysis of techno-organizational model

Sensitivity analysis studies the effect of changes in input parameters on the outputs (Sterman, 2000; Pruyt, 2013; Hekimo and Barlas, 2017). Sensitivity analysis concept discussed in Chapter 5.9 is also followed in this section. A univariate and multivariate sensitivity analysis using the random uniform distribution with 200 number of simulation is used to run the simulation model as discussed in Chapter 5.9. As suggested by Sterman (2000), the minimum and maximum parameter values are chosen in the distribution range of 20% of the actual model value. Table 6.8 shows the proposed minimum and maximum parameter values of selected exogenous variables for sensitivity analysis of techno-organizatioanl model of eHealth accpetance.

Table 6.8 Exogenous variables used in the sensitivity analysis of techno-organization model of eHealth acceptance.

Exogenous variables	**eHealth Applications**	**Estimated Value in basic model**	**Proposed minimum value of variable**	**Proposed Maximum value of variable**
Supportive policy	eHMIS	1.0 (dimensionless)	0.8	1
	SmartCare	1.0 (dimensionless)	0.8	1
Familiarity with electronic systems	eHMIS	0.2 (dimensionless)	0	0.4
	SmartCare	0.3 (dimensionless)	0.1	0.5
Supportive organizational structure	eHMIS	0.2 (dimensionless)	0	0.4
	SmartCare	0.4 (dimensionless)	0.2	0.6
Average workforce turnover	eHMIS	0.092 (dimensionless)	0	0.292
	SmartCare	0.092 (dimensionless)	0	0.292
Digital equipment installation rate	eHMIS	0.005 (dimensionless)	0	0.205
	SmartCare	0.03 (dimensionless)	0	0.23

6.11.1. A univariate sensitivity analysis of eHMIS and SmartCare

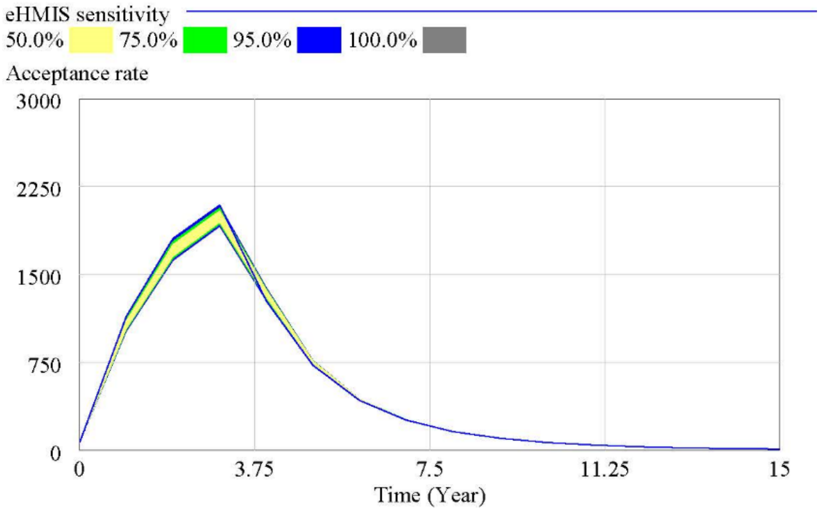
Sensitivity testing is the process of changing your assumptions about the value of constants in the model and examining the resulting output for a change in values (Ventana Systems, 2012a; Hekimo and Barlas, 2017). The simulation results of sensitivity analysis are the result of univariate sensitivity analysis with 200 simulation runs by assigning parameter values using the random uniform distribution. The minimum and maximum parameter values are shown in Table 6.8. In each simulation run, a parameter value is randomly selected between the minimum and maximum. A random uniform distribution is assigned for all variables to perform univariate sensitivity analysis using Vensim.

The 'acceptance rate' of eHMIS and SmartCare (univariate sensitivity analysis)

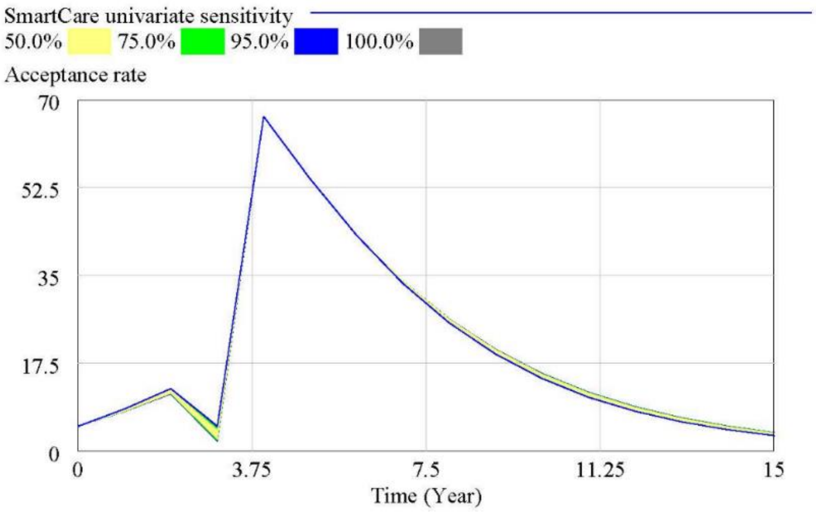
The simulated behaviour pattern of 'acceptance rate' of eHMIS and SmartCare due to changes in the 'supportive policy', 'familiarity with electronic systems', 'supportive organizational structure', 'average workforce turnover', and 'digital equipment installation rate' is discussed below.

i. The 'acceptance rate' of eHMIS and SmartCare under uncertainty in 'supportive policy'

Uncertainty in 'supportive policy' did not bring substantial change to the essential original behaviour pattern of simulated 'acceptance rate' of eHMIS. The random changes in 'supportive policy' (0.8,1) resulted in minimal numerical variations in the 'acceptance rate' of both eHMIS and SmartCare (See Figure 6.28 (a) and (b)).



(a)

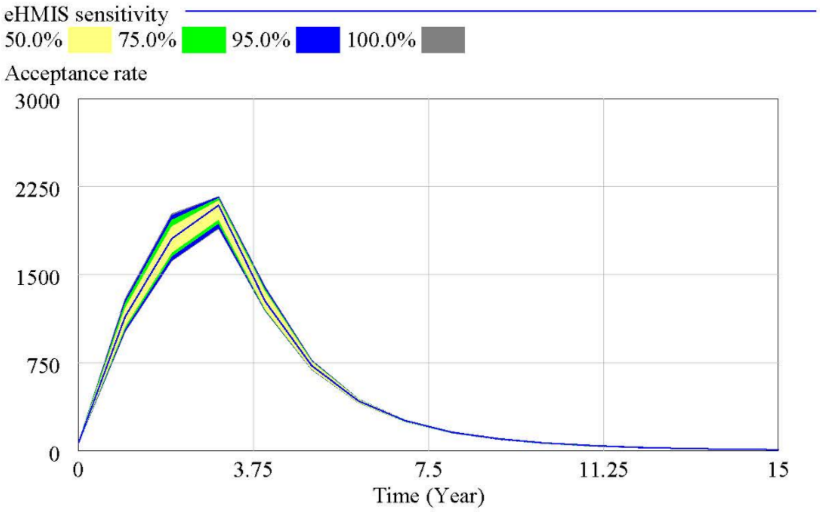


(b)

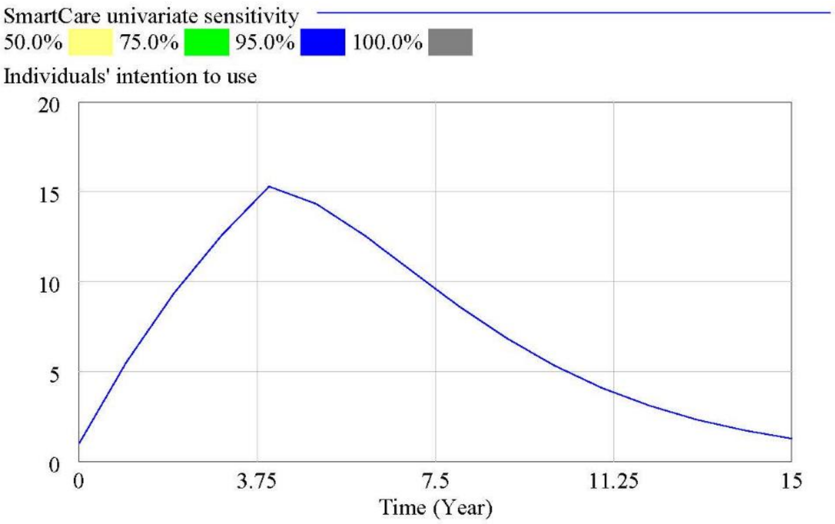
Figure 6.28 (a) eHMIS 'acceptance rate' under uncertainty in 'supportive policy' for interval (0.8,1). (b) SmartCare 'acceptance rate' under uncertainty in 'supportive policy' for interval (0.8,1).

ii. *The 'acceptance rate' of eHMIS and SmartCare under uncertainty in 'familiarity with electronic systems'*

Figure 6.29 (a) showed randomly changing 'familiarity with electronic systems' (0,0.4) resulted in a small numerical variation of eHMIS 'acceptance rate'. Figure 6.29 (b) showed that uncertainty in 'familiarity with electronic systems' (0.1,0.5) did not produce substantial change to the main essential behaviour pattern and hardly showed a numerical variation on SmartCare 'acceptance rate'. The essential original behaviour response of the model remained unchanged in both cases.



(a)

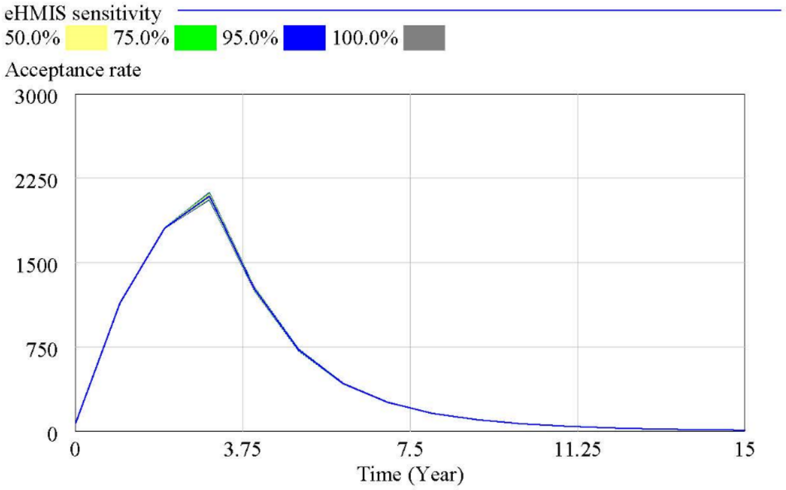


(b)

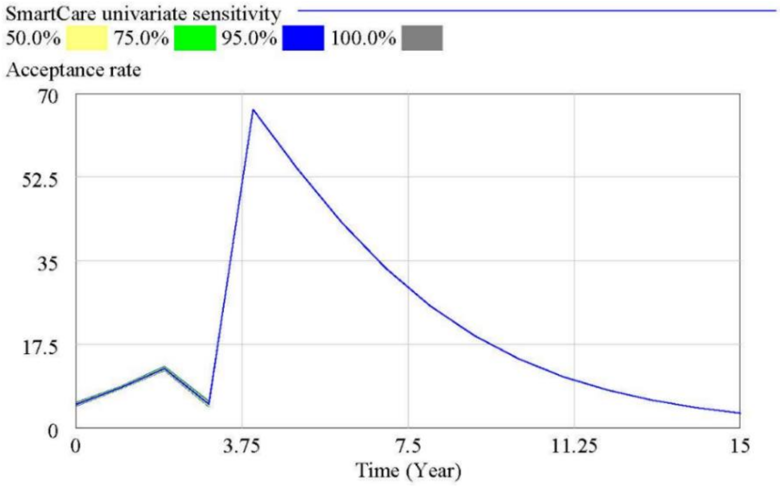
Figure 6.29 (a) eHMIS 'acceptance rate' under uncertainty in 'familiarity with electronic systems' for interval (0,0.4). (b) SmartCare 'acceptance rate' under uncertainty in 'familiarity with electronic systems' for interval (0.1,0.5).

iii. *The 'acceptance rate' of eHMIS and SmartCare with uncertainty in 'supportive organizational structure systems'*

Figure 6.30 (a) and (b) showed that the main essential behaviour of the model remained unchanged in both cases. Besides, uncertainty in 'supportive organizational structure systems' resulted in almost no fundamental change in the numerical values of the simulated 'acceptance rate' of both eHMIS and SmartCare systems.



(a)

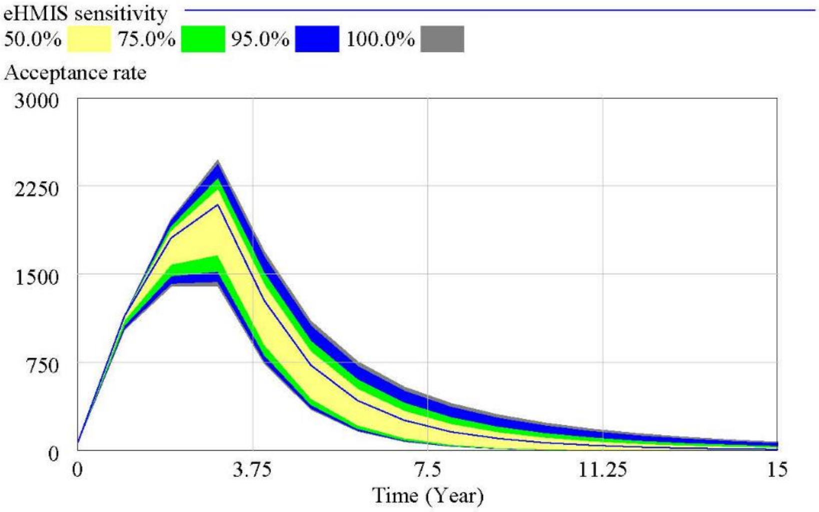


(b)

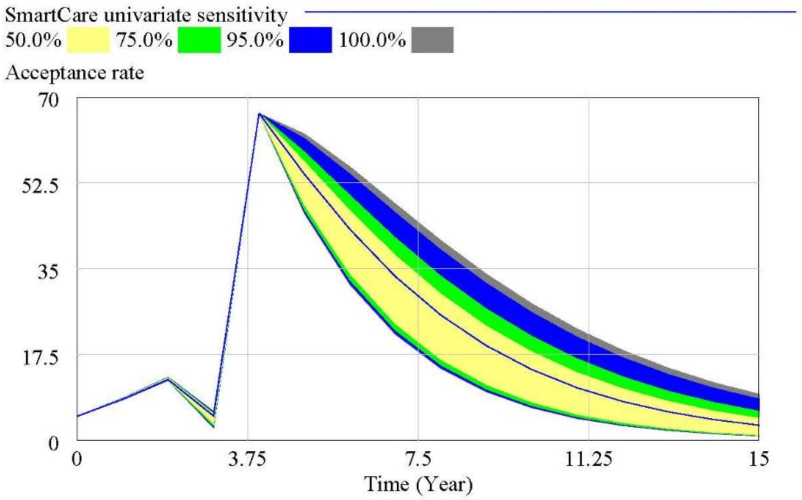
Figure 6.30 (a) eHMIS 'acceptance rate' under uncertainty in 'supportive organizational structure' systems for interval (0,0.4). (b) SmartCare 'acceptance rate' under uncertainty in 'supportive organizational structure' for interval (0.2,0.6).

iv. The 'acceptance rate' of eHMIS and SmartCare with uncertainty in 'average workforce turnover'

The simulated behaviour pattern of 'acceptance rate' of eHMIS and SmartCare remained unchanged under uncertainty in the 'average workforce turnover' (See Figure 6.31 (a) and (b)). However, significant numerical variations were observed in both eHMIS and SmartCare. Since a healthcare organization can have control over 'average workforce turnover' to maximize the 'acceptance rate' of both eHMIS and SmartCare systems, the variable can be a good candidate for policy analysis.



(a)

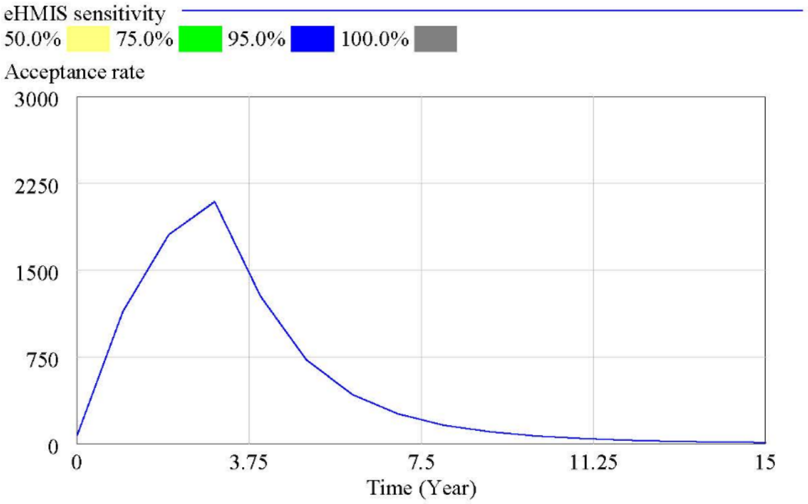


(b)

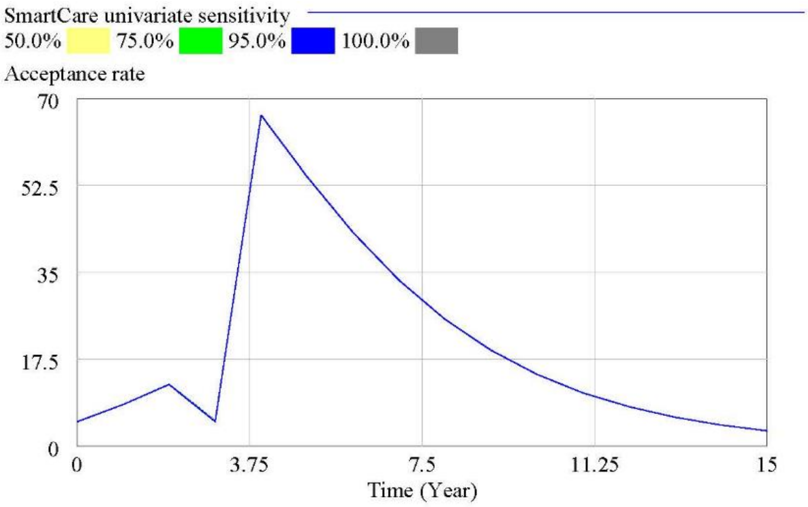
Figure 6.31 (a) eHMIS 'acceptance rate' under uncertainty in 'average workforce turnover' for interval (0,0.292). (b) SmartCare 'acceptance rate' under uncertainty in 'average workforce turnover' for interval (0,0.292).

v. The 'acceptance rate' of eHMIS and SmartCare with uncertainty in 'digital equipment installation rate'

Figure 6.32 (a) and (b) showed that the main essential behaviour of the model remained unchanged in both eHMIS and SmartCare cases. Besides, uncertainty in 'digital equipment installation rate' resulted in almost no substantial changes in the simulated 'acceptance rate' in both eHMIS and SmartCare systems.



(a)



(b)

Figure 6.32 (a) eHMIS 'acceptance rate' under uncertainty in 'digital equipment installation rate' for interval (0,0.205). (b) SmartCare 'acceptance rate' under uncertainty in 'digital equipment installation rate' for interval (0,0.23).

In summary, the sensitivity analysis with random variation in the 'supportive policy', 'familiarity with electronic systems', 'supportive organizational structure', 'average workforce turnover', and 'digital equipment installation rate' produced no fundamental change in the simulated behaviour pattern of 'acceptance rate' of both eHMIS and SmartCare. However, uncertainty in these exogenous variables produced from very minimal to significant numerical variations in the simulated 'acceptance rate' of both systems.

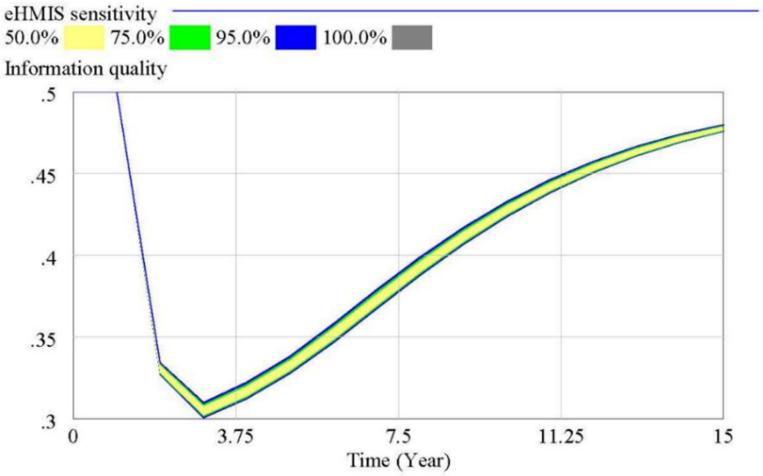
The change in 'average workforce turnover' produced significant numerical variations in the simulated 'acceptance rate' of eHMIS and SmartCare. Since healthcare organizations can have control over 'average workforce turnover', the variable can be a good candidate for policy analysis to maximize the 'acceptance rate' of both eHMIS and SmartCare. The pattern of the model behaviour of simulated 'acceptance rate' fundamentally remained unchanged for both eHMIS and SmartCare.

<u>The 'information quality' of eHMIS and SmartCare (univariate sensitivity analysis)</u>

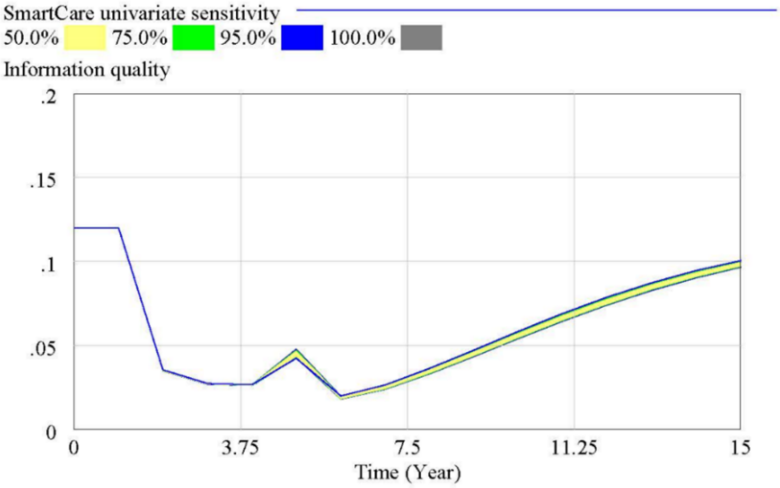
The simulated behaviour pattern response of 'information quality' of eHMIS and SmartCare due to changes in the 'supportive policy', 'familiarity with electronic systems', 'supportive organizational structure', 'average workforce turnover', and 'digital equipment installation rate' is discussed.

i. *The 'information quality' of eHMIS and SmartCare with uncertainty in 'supportive policy'*

Figure 6.33 (a) and (b) showed the impact of uncertainty in 'supportive policy' on the simulated 'information quality' of eHMIS and SmartCare respectively. A minor numerical variation in the 'information quality' of eHMIS began approximately at year two (Figure 6.33 (a)); whereas the numerical variation for the 'information quality' of SmartCare (Figure 6.33 (b)) began approximately at year four under uncertainty in the 'supportive policy'.



(a)

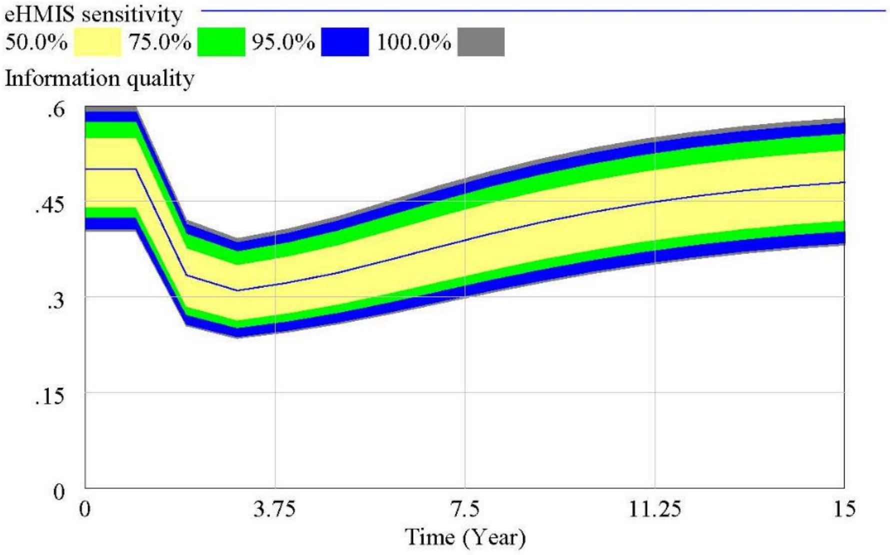


(b)

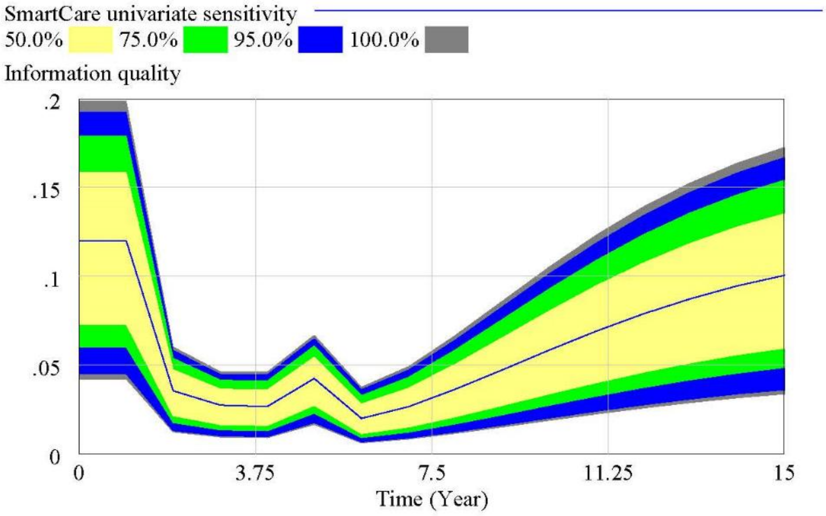
Figure 6.33 (a) eHMIS 'information quality' under uncertainty in 'supportive policy' for interval (0.8,1). (b) SmartCare 'information quality' under uncertainty in 'supportive policy' for interval (0.8,1).

ii. *The 'information quality' of eHMIS and SmartCare with uncertainty in 'familiarity with electronic systems'*

Figure 6.34 (a) and (b) showed significant numerical variations in the simulated 'information quality' of eHMIS and SmartCare right from the beginning under uncertainty in 'familiarity with electronic'. However, the essential original behaviour pattern was maintained in both cases. 'Familiarity with electronic' can be a good candidate for policy analysis to improve 'information quality'.



(a)

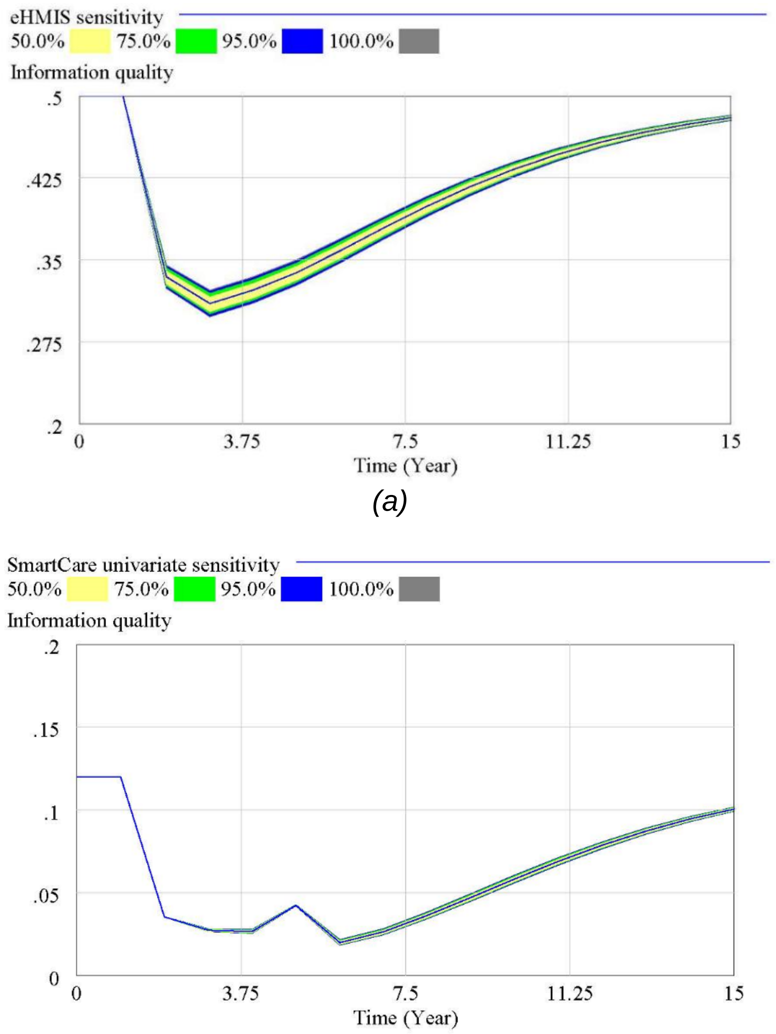


(b)

Figure 6.34 (a) eHMIS 'information quality' under uncertainty in 'familiarity with electronic systems' for interval (0,0.4). (b) SmartCare 'information quality' under uncertainty in 'familiarity with electronic systems' for interval (0.1,0.5).

iii. The 'information quality' of eHMIS and SmartCare with uncertainty in 'supportive organizational structure systems'

Figure 6.35 (a) and (b) showed the simulated behaviour pattern of 'information quality' of eHMIS and SmartCare respectively under uncertainty in 'supportive organizational structure systems' as defined in Table 6.8. There was a minimal numerical variation but the essential original behaviour pattern was maintained in both cases.



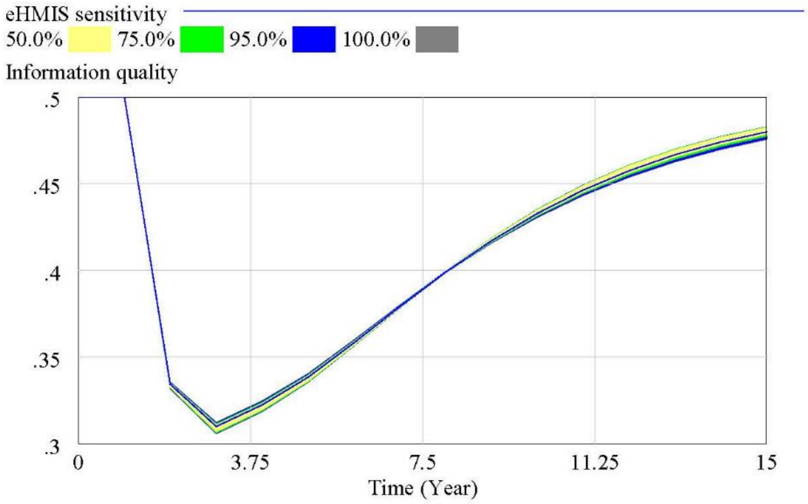
(a)

(b)

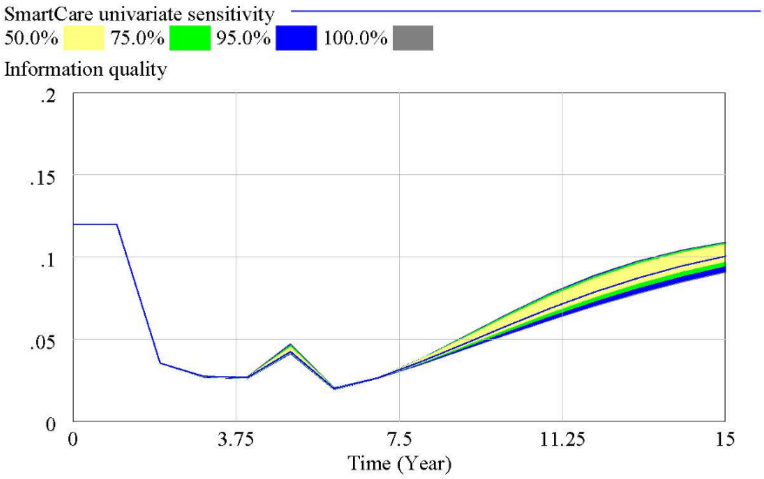
Figure 6.35 (a) eHMIS 'information quality' under uncertainty in 'supportive organizational structure' systems for interval (0,0.4). (b) SmartCare 'information quality' under uncertainty in 'supportive organizational structure' for interval (0.2,0.6).

iv. The 'information quality' of eHMIS and SmartCare with uncertainty in 'average workforce turnover'

Figure 6.36 (a) and (b) showed the impact of uncertainty in 'average workforce turnover' (0,0.292) on the simulated 'information quality' of eHMIS and SmartCare respectively. A minimal numerical variation was observed in both cases without changing the main essential behaviour pattern.



(a)

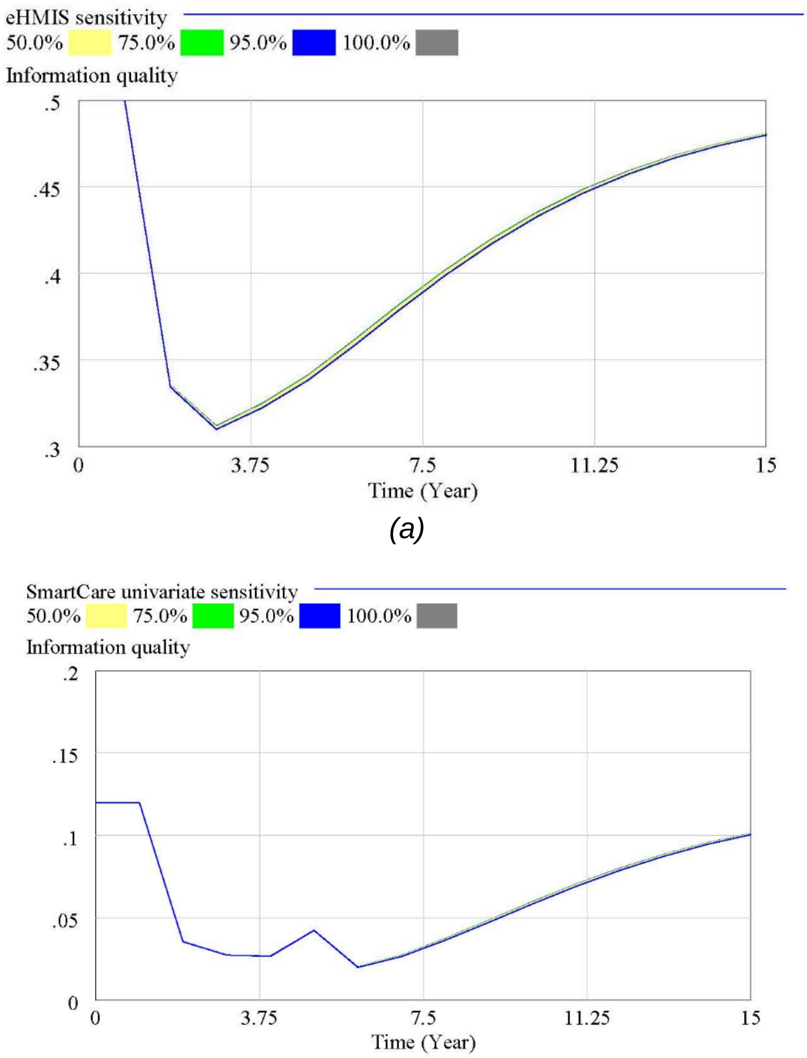


(b)

Figure 6.36 (a) eHMIS 'information quality' under uncertainty in 'average workforce turnover' for interval (0,0.292). (b) SmartCare 'information quality' under uncertainty in 'average workforce turnover' for interval (0,0.292).

v. *The 'information quality' of eHMIS and SmartCare with uncertainty in 'digital equipment installation rate'*

Uncertainty in the 'digital equipment installation rate' hardly produced a numerical variation in the simulated 'information quality' of eHMIS and SmartCare (See Figure 6.37 (a) and (b)). Moreover, the original behaviour pattern was maintained in both cases.



(a)

(b)

Figure 6.37 (a) eHMIS 'information quality' under uncertainty in 'digital equipment installation rate' for interval (0,0.205). (b) SmartCare 'information quality' under uncertainty in 'digital equipment installation rate' for interval (0,0.23).

The general pattern of essential behaviour of the simulated 'information quality' of both eHMIS and SmartCare was maintained under uncertainties in the 'supportive policy', 'familiarity with electronic systems', 'supportive organizational structure', 'average workforce turnover', and 'digital equipment installation rate'. However, uncertainty in these variables produced minor to major numerical variations at different years.

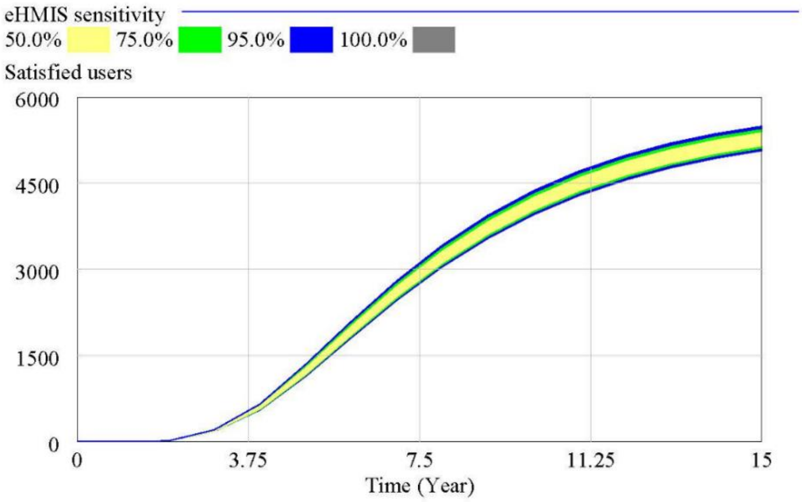
The simulated 'information quality' was sensitive to changes in the 'familiarity with electronic systems' which was strongly linked to ICT culture of the organization. 'Familiarity with electronic systems' can be a good candidate for policy analysis to improve 'information quality' which is one of the important factors to drive the satisfaction of end-users and improve the accuracy of decision making.

‘Satisfied users’ of eHMIS and SmartCare (univariate sensitivity analysis)

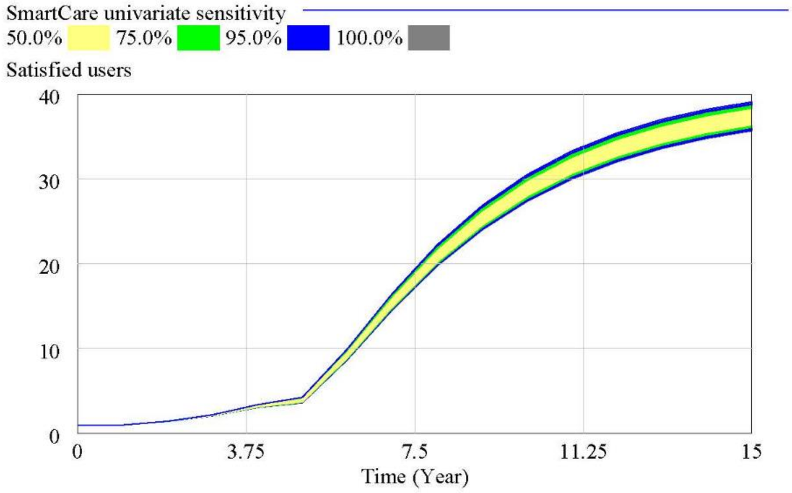
The simulated behaviour pattern of ‘satisfied users’ of eHMIS and SmartCare to changes in the ‘supportive policy’, ‘familiarity with electronic systems’, ‘supportive organizational structure’, ‘average workforce turnover’, and ‘digital equipment installation rate’ is discussed below.

i. The ‘satisfied users’ of eHMIS and SmartCare with uncertainty in ‘supportive policy’

Uncertainty in ‘supportive policy’ (0.8,1) showed some numerical variations on the simulated ‘satisfied users’ of eHMIS and SmartCare in the later years of implementation (See Figure 6.38 (a) and (b)). However, the essential original behaviour pattern remained unchanged in both cases.



(a)

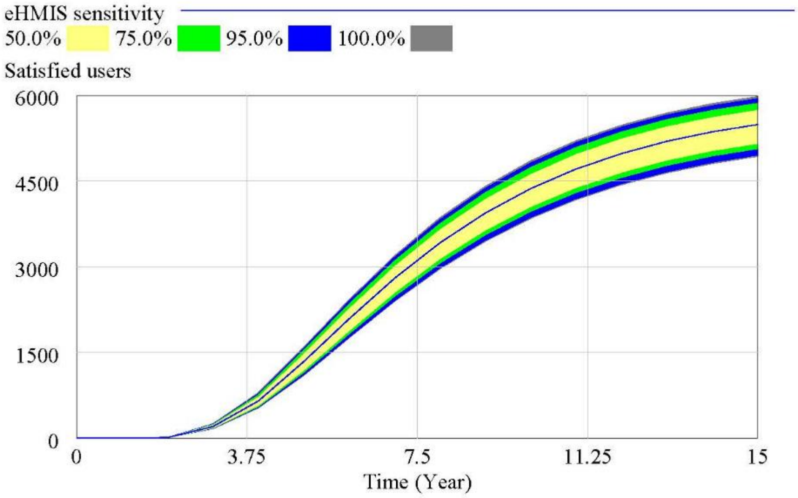


(b)

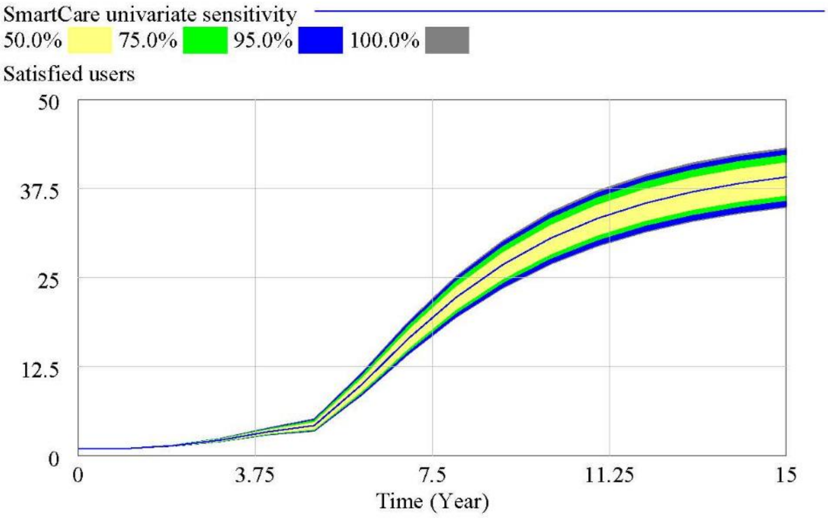
Figure 6.38 (a) ‘Satisfied users’ of eHMIS under uncertainty in ‘supportive policy’ for interval (0.8,1). (b) ‘Satisfied users’ of SmartCare under uncertainty in ‘supportive policy’ for interval (0.8,1).

ii. The ‘satisfied users’ of eHMIS and SmartCare with uncertainty in ‘familiarity with electronic systems’

Figure 6.39 (a) and (b) showed the impact of uncertainty in ‘familiarity with electronic systems’ on the simulated ‘satisfied users’ of eHMIS and SmartCare respectively. Important numerical variations in the simulated ‘satisfied users’ of eHMIS and SmartCare was observed yet the main essential behaviour pattern was maintained.



(a)

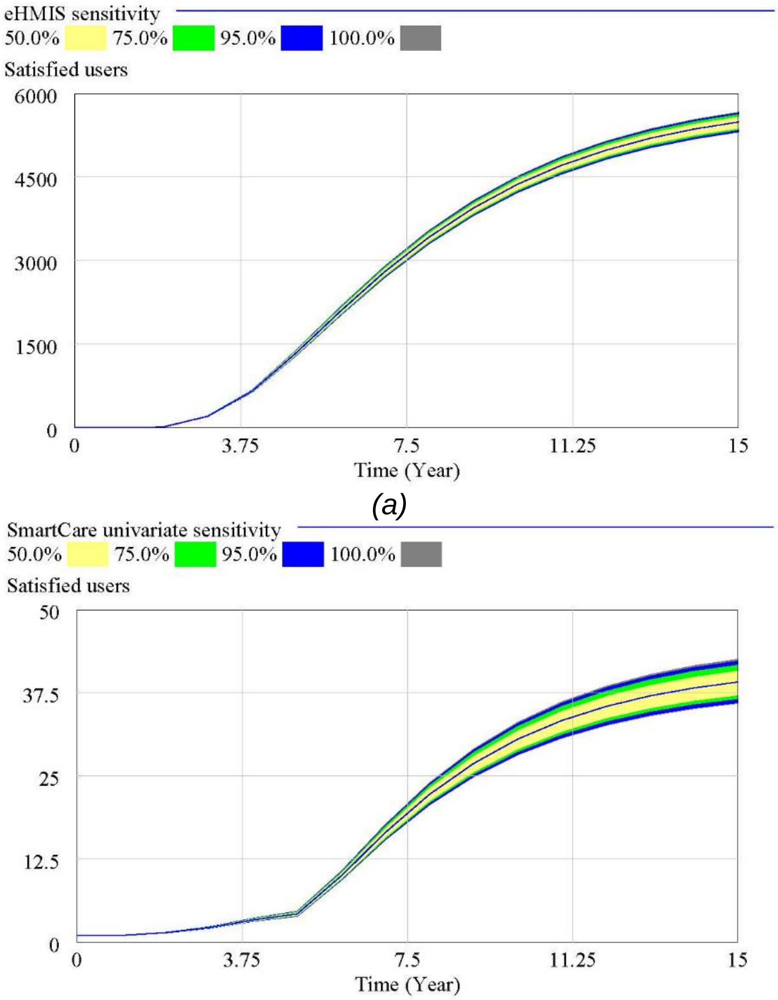


(b)

Figure 6.39 (a) ‘Satisfied users’ of eHMIS under uncertainty in ‘familiarity with electronic systems’ for interval (0,0.4). (b) ‘Satisfied users’ of SmartCare under uncertainty in ‘familiarity with electronic systems’ for interval (0.1,0.5).

iii. *The ‘satisfied users’ of eHMIS and SmartCare with uncertainty in ‘supportive organizational structure systems’*

Figure 6.40 (a) and (b) showed the impact of uncertainty in ‘supportive policy’ on the simulated ‘satisfied users’ of eHMIS and SmartCare respectively. A numerical variation in the simulated ‘satisfied users’ of eHMIS and SmartCare was observed in both cases without changing the essential original behaviour pattern.



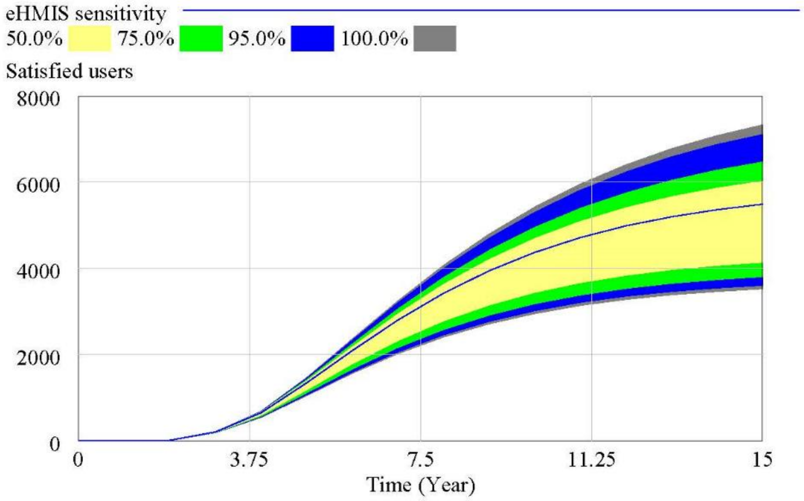
(a)

(b)

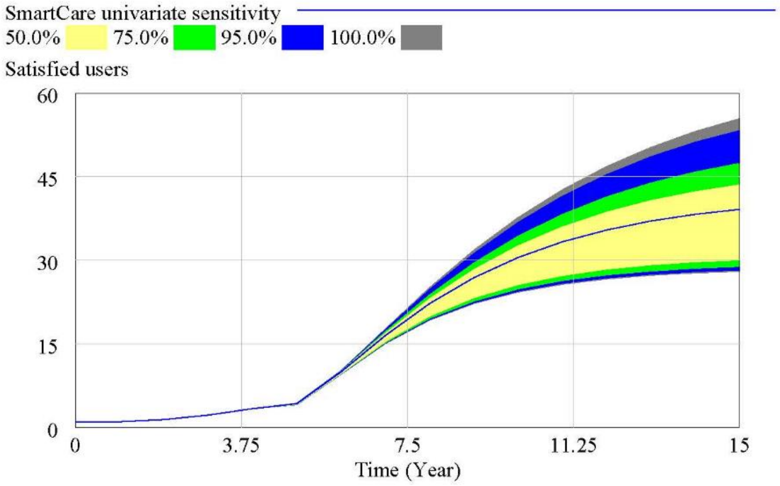
Figure 6.40 (a) ‘Satisfied users’ of eHMIS under uncertainty in ‘supportive organizational structure’ systems for interval (0,0.4). (b) ‘Satisfied users’ of SmartCare under uncertainty in ‘supportive organizational structure’ for interval (0.2,0.6).

iv. *The ‘satisfied users’ of eHMIS and SmartCare with uncertainty in ‘average workforce turnover’*

Figure 6.41 (a) and (b) showed significant numerical variations in the simulated ‘satisfied users’ of eHMIS and SmartCare under uncertainty in ‘average workforce turnover’ in the later years of implementation. However, the main essential behaviour pattern was maintained in both cases. ‘Average workforce turnover’ can be a good candidate for policy analysis to improve ‘satisfied users’.



(a)

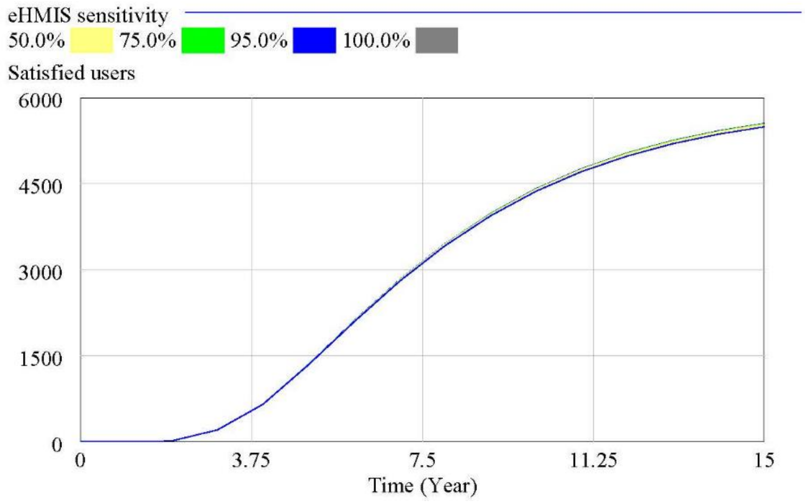


(b)

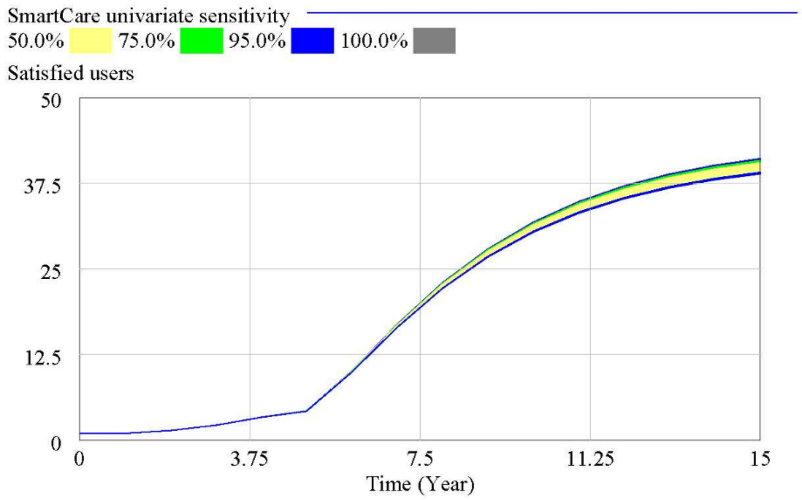
Figure 6.41 (a) ‘Satisfied users’ of eHMIS under uncertainty in ‘average workforce turnover’ for interval (0,0.292). (b) ‘Satisfied users’ of SmartCare under uncertainty in ‘average workforce turnover’ for interval (0,0.292).

v. The ‘satisfied users’ of eHMIS and SmartCare with uncertainty in ‘digital equipment installation rate’

Uncertainty in the ‘digital equipment installation rate’ hardly produced numerical variations in the simulated ‘satisfied users’ of eHMIS (Figure 6.42 (a)) but demonstrated minor numerical variation in SmartCare in the later years (Figure 6.42 (a)). The essential original behaviour pattern was maintained in both cases.



(a)



(b)

Figure 6.42 (a) 'Satisfied users' of eHMIS under uncertainty in 'digital equipment installation rate' for interval (0,0.205). (b) 'Satisfied users' of SmartCare under uncertainty in 'digital equipment installation rate' for interval (0,0.23).

The general simulated behaviour pattern of 'satisfied users' was maintained with S-shaped growth under uncertainty in the selected exogenous variables, i.e., 'supportive policy', 'familiarity with electronic systems', 'supportive organizational structure', 'average workforce turnover', and 'digital equipment installation rate'. The simulated 'satisfied users' of eHMIS and SmartCare showed significant numerical sensitivity to changes in the 'average workforce turnover' and 'familiarity with electronic systems'. The first was related to the work burden while the latter was associated with organizational ICT culture.

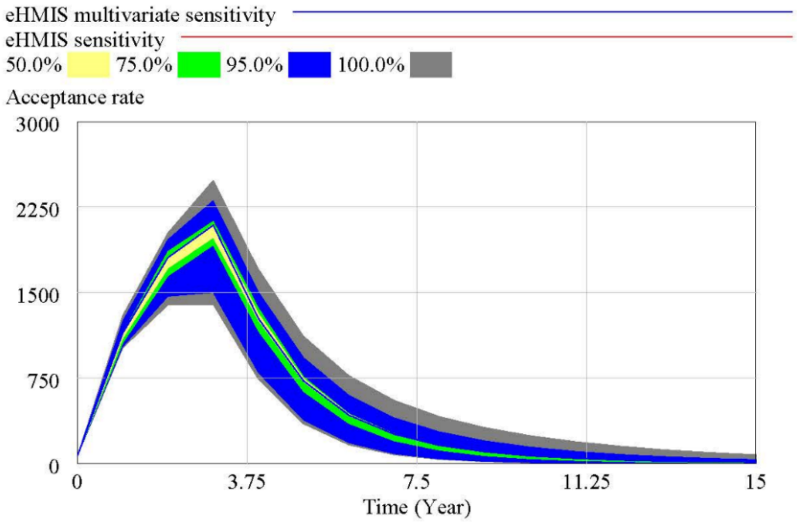
In summary, the behaviour mode sensitivity test revealed the model was essentially robust. The numerical variations indicated the possible policy interventions to improve 'acceptance rate', 'information quality' and the satisfaction of eHMIS and SmartCare users. 'Average workforce turnover' and 'familiarity with electronic systems' were the two variables with significant influence on 'acceptance rate', 'information quality' and 'satisfied users' in the techno-organizational dimension of eHealth implementation. The next section discusses multivariate sensitivity analysis by varying all five exogenous parameters together.

6.11.2. Multivariate sensitivity analysis of eHMIS and SmartCare

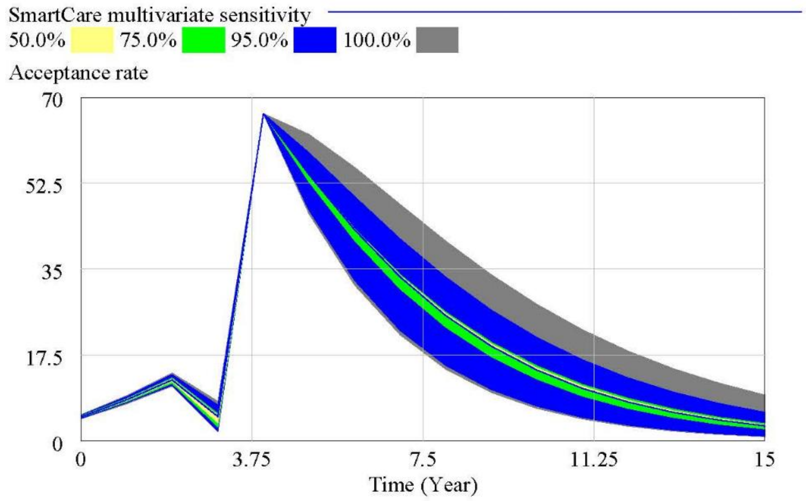
All five exogenous parameters namely 'supportive policy', 'familiarity with electronic systems', 'supportive organizational structure', 'average workforce turnover' and 'digital equipment installation rate' (See Table 6.8) were changed together to perform a multivariate sensitivity analysis. The number of simulations was set at 200 and a random uniform distribution was selected in Vensim to examine the simulation results. The simulation results of multivariate sensitivity analysis are presented below.

'Acceptance rate' of eHMIS and SmartCare (multivariate sensitivity analysis)

The multivariate sensitivity analysis of the simulated 'acceptance rate' of eHMIS and SmartCare showed that the essential behaviour pattern remained unchanged throughout the entire simulation under a random uniform distribution (Figure 6.43 (a) and (b)). However, significant numerical variations observed in simulated 'acceptance rate' of both eHMIS and SmartCare showed the possibility of policy interventions to improve 'acceptance rate'.



(a)

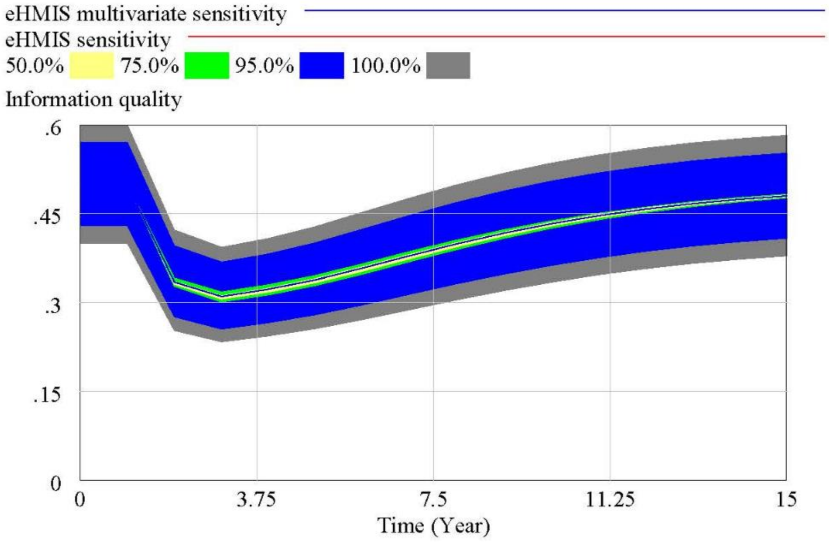


(b)

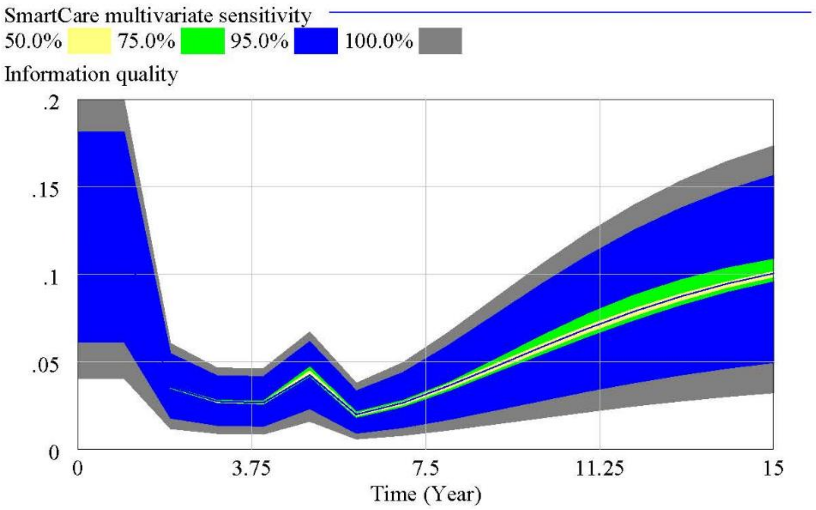
Figure 6.43 (a) A multivariate analysis of eHMIS 'acceptance rate'. (b) A multivariate analysis of SmartCare 'acceptance rate'.

<u>'Information quality' of eHMIS and SmartCare (multivariate sensitivity analysis)</u>

The simulation of 'information quality' essential behaviour pattern of both eHMIS and SmartCare remained unchanged under the uncertainty of multiple exogenous variables in the multivariate sensitivity analysis (Figure 5.44 (a) and (b)). The multivariate analysis demonstrated significant numerical variations in the simulated 'information quality' of both eHMIS and SmartCare. This shows the possibility of policy interventions to improve 'information quality'.



(a)

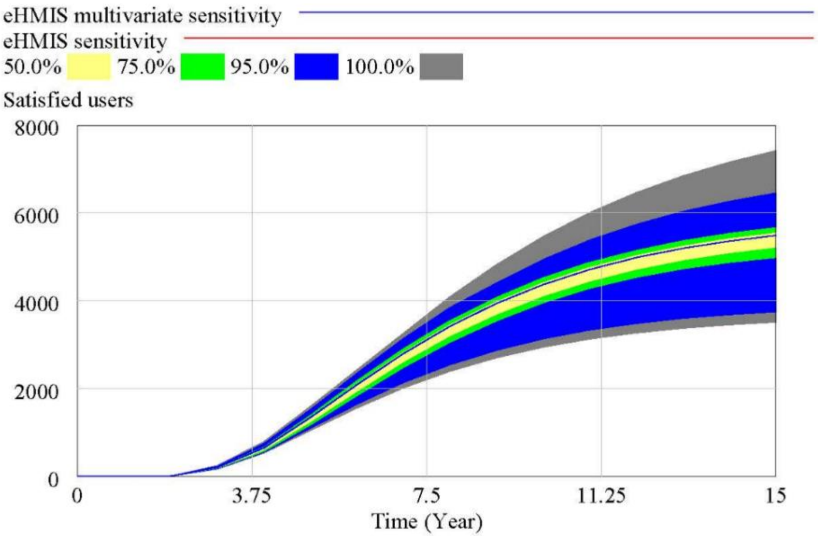


(b)

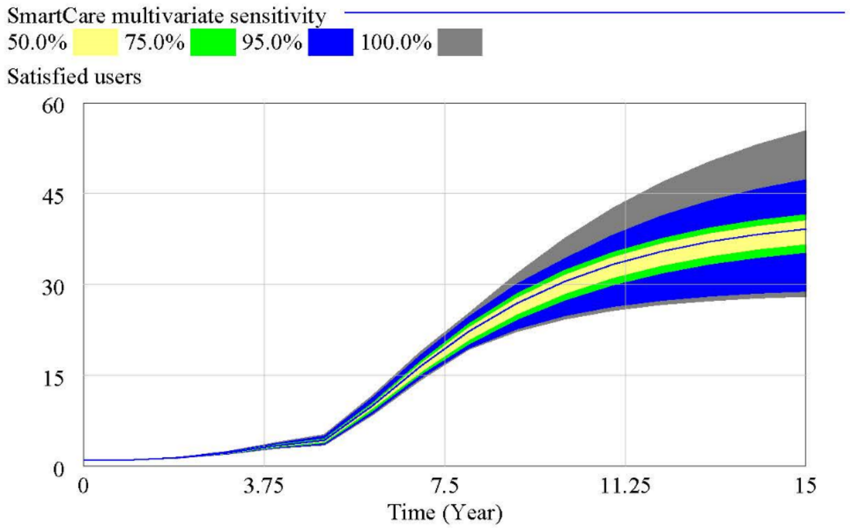
Figure 6.44 (a) A multivariate analysis of 'information quality' of eHMIS. (b) A multivariate analysis of 'information quality' of SmartCare.

'Satisfied users' of eHMIS and SmartCare (multivariate sensitivity analysis)

Figure 5.45 (a) and (b) showed the simulated behaviour pattern of 'satisfied users' of eHMIS and SmartCare followed the popular S-shaped growth without showing essential behaviour variation to the multivariate sensitivity analysis. However, the numerical variations of the simulated 'satisfied users' were significantly high to the random changes of the exogenous parameters.



(a)



(b)

Figure 6.45 (a) A multivariate analysis of 'satisfied users' of eHMIS. (b) A multivariate analysis of 'satisfied users' of SmartCare.

The multivariate analysis confirmed that the model was fundamentally robust in maintaining the essential behaviour pattern of the simulated 'acceptance rate', 'information quality', and 'satisfied users'. The numerical variations to the uncertainty of exogenous variables indicated the possibility of alternative policy designs to improve technology acceptance, the quality of information and end-users' satisfaction. The next section focuses on the policy analysis and what-if scenario for alternative policies design.

6.12. Policy analysis of techno-organizational model

The policy analysis focused on improving the performance of 'acceptance rate', 'information quality' and 'satisfied users' by varying selected exogenous parameters. These three factors indicated to be important factors to ensure sustainable use of eHMIS and SmartCare technologies to improve healthcare services through informed decisions. As seen in the univariate and multivariate sensitivity analysis, 'average workforce turnover' and 'familiarity with electronic systems' were candidates for policy analysis due to a significant numerical influence on the simulated 'acceptance rate', 'information quality' and 'satisfied users'. Therefore, these variables of the techno-organizatioanl model of eHealth acceptance were varied in the what-if simulation analysis to test alternative policies.

6.12.1. What-if scenario analysis

The purpose of "what-if" simulation experiment is to examine the impact of candidate exogenous variables ('average workforce turnover' and 'familiarity with electronic systems') on the simulated 'acceptance rate', 'information quality' and 'satisfied users'. The values of 'average workforce turnover' and 'familiarity with electronic systems' were varied and tested under different scenarios for alternative policies. The what-if experiment analysis of base scenario for the ‘average workforce turnover’ was represented in scenario 0. Scenario 1 denoted 20% lower values of ‘average workforce turnover’ for eHMIS and SmartCare from scenario 0 (base) values. Whereas Scenario 2 described a 20% higher values of ‘average workforce turnover’ for eHMIS and SmartCare from scenario 0 (See Table 6.9).

Table 6.9 What-if experiments for ‘average workforce turnover’.

Scenario	eHealth application	Average workforce turnover’
0 (Base)	eHMIS	0.092 (Base)
	SmartCare	0.092 (Base)
1	eHMIS	0 (low)
	SmartCare	0 (low)
2	eHMIS	0.292 (high)
	SmartCare	0.292 (high)

Table 6.10 summarises the parameter values of ‘familiarity with electronic systems’ used in the what-if analysis scenario analysis of eHMIS and SmartCare. Scenario 0 represented the base scenario; whereas scenario 1 and 2 respectively represented 20% lower and higher values from the base scenario for the users’ ‘familiarity with electronic systems’ (See Table 6.10).

Table 6.10 What-if experiments for ‘familiarity with electronic systems’.

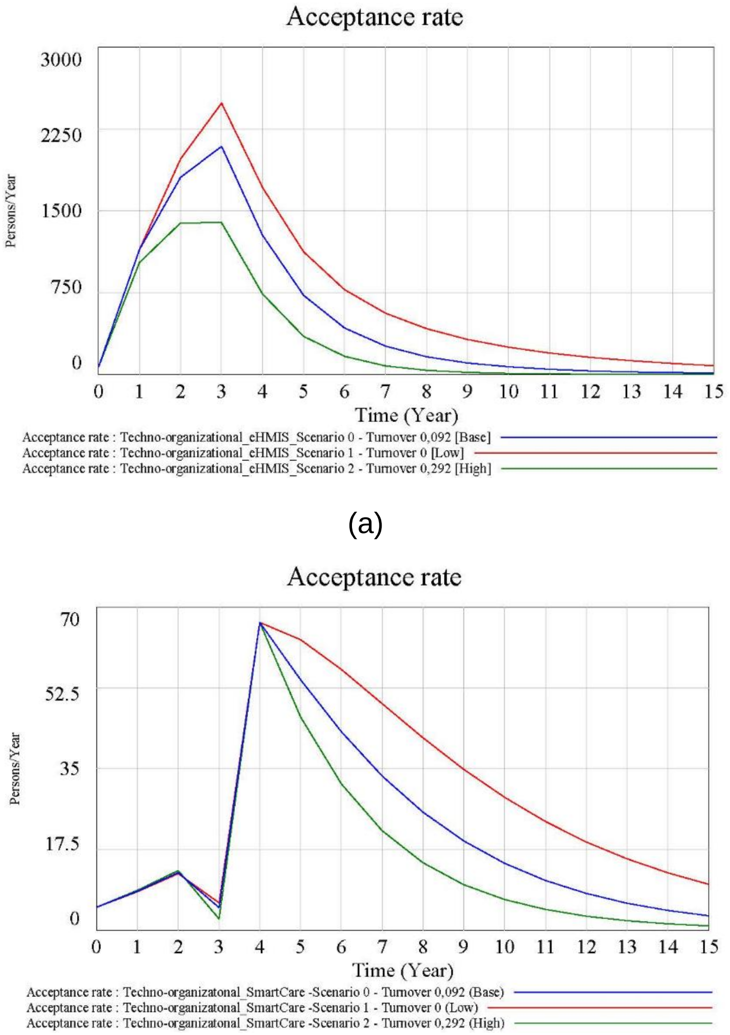
Scenario	eHealth application	Familiarity with electronic systems
0 (Base)	eHMIS	0.2 (Base)
	SmartCare	0.3 (Base)
1	eHMIS	0 (low)
	SmartCare	0.1 (low)
2	eHMIS	0.4 (high)
	SmartCare	0.5 (high)

The what-if analysis for the simulated behaviour pattern of ‘acceptance rate’, ‘information quality’, and ‘satisfied users’ was carried out by increasing and reducing the values of the base scenario for selected exogenous variables by 0.2 (20%) for both eHMIS and SmartCare. In-depth discussion of what-if simulation experiments of the simulation results are presented in the following section.

<u>Improving the ‘acceptance rate’ of eHMIS and SmartCare</u>

Improving ‘acceptance rate’ through ‘average workforce turnover’

The influence of ‘average workforce turnover’ was significant in terms of changing the peak values of the simulated ‘acceptance rate’ of eHMIS (See Figure 6.46 (a)). On the third year, the biggest gaps and the peak values of the different scenarios of simulated ‘acceptance rate’ of eHMIS were observed (See Figure 6.46 (a)). A 0.2 (20%) increase in the 'average workforce turnover' reduced the simulated 'acceptance rate' of eHMIS from 2089 to 1390 Persons/Year (699 Persons/Year) on year three (See Figure 6.46 (a) in blue and green). Conversely, a 0.2 (20%) reduction in the 'average workforce turnover' improved the simulated 'acceptance rate' of eHMIS from 2089 to 2488 Persons/Year (399 Persons/Year) on the third year (See Figure 6.46 (a) in blue and red).



(a)

(b)

Figure 6.46 (a) A what-if analysis of 'acceptance rate' of eHMIS with respect to changes in 'average workforce turnover'. (b) A what-if analysis of 'acceptance rate' of SmartCare with respect to changes in 'average workforce turnover'.

The impact of different scenarios of 'average workforce turnover' on the simulated 'acceptance rate' of SmartCare was significant after year four (Figure 6.46 (b)). In year seven, the 'acceptance rate' of SmartCare was 21 Persons/Year (in green colour) and 49 Persons/Year (in red colour) (See Figure 6.46 (b)). As shown in Figure 6.46 (b), a 0.2 (20%) increase in the 'average workforce turnover' reduced the 'acceptance rate' of SmartCare by 12 Persons/Year, from 33 Persons/Year (in blue colour) to 21 Persons/Year (in green colour). On year seven, a 0.2 (20%) decrease in the 'average workforce turnover' produced an increase 16

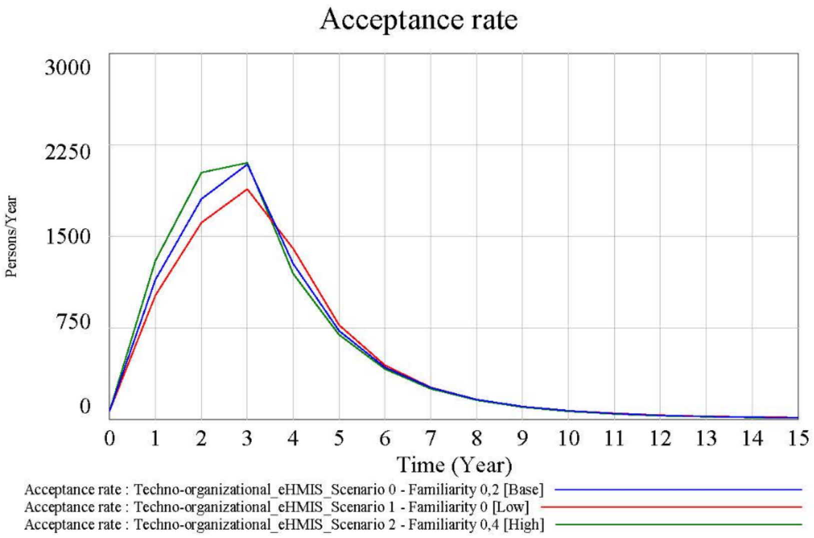
Persons/Year, from 33 Persons/Year (in blue colour) to 49 Persons/Year (in green colour). The impact of ‘average workforce turnover’ on the ‘acceptance rate’ of SmartCare was more significant in the later years of implementation (See Figure 6.46(b)).

Improving ‘acceptance rate’ through ‘familiarity with electronic systems’

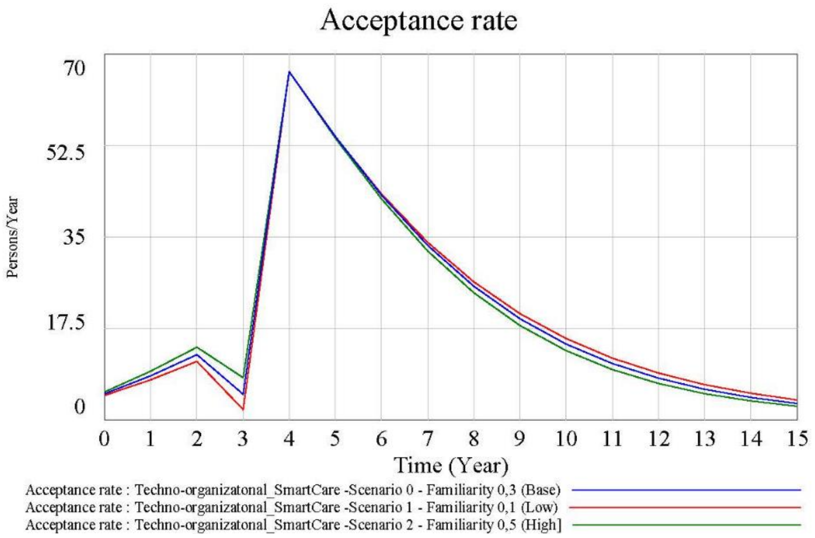
Figure 6.47 (a) and (b) depicts the impact of different scenarios of ‘familiarity with electronic systems’ on the simulated ‘acceptance rate’ of eHMIS and SmartCare. A 0.2 (20%) increase in the ‘familiarity with electronic systems’ showed a small increase in simulated ‘acceptance rate’ of eHMIS until three and a half years (See Figure 6.47 (a) in green colour). However, after three and a half years, the influence of ‘familiarity with electronic systems’ on the simulated ‘acceptance rate’ of eHMIS reduced (See Figure 6.47 (a)). This was perhaps related to the dominant influence of other factors such as ‘average workforce turnover’ (See Figure 6.47 (a)).

Similarly, A 0.2 (20%) increase in the ‘familiarity with electronic systems’ had a minor positive influence on the simulated ‘acceptance rate’ of SmartCare until year four (Figure 6.47 (b) in green colour). However, the influence of ‘familiarity with electronic systems’ on simulated ‘acceptance rate’ of SmartCare disappeared after year four (Figure 6.47 (b)) due to the stronger influence of other factors like ‘average workforce turnover’.

In summary, the improvement of ‘familiarity with electronic systems’ by 0.2 (20%) had a minor influence on the simulated ‘acceptance rate’ of eHMIS and SmartCare. Moreover, the small influence of ‘familiarity with electronic systems’ on the simulated ‘acceptance rate’ disappeared after three and a half years for eHMIS and four years for SmartCare. On the other hand, ‘average workforce turnover’ demonstrated a significant influence on the simulated ‘acceptance rate’ of eHMIS and SmartCare.



(a)



(b)

Figure 6.47 (a) A what-if analysis of 'acceptance rate' of eHMIS with respect to changes in 'familiarity with electronic systems'. (b) A what-if analysis of 'acceptance rate' of SmartCare with respect to changes in 'familiarity with electronic systems'.

The 'average workforce turnover' showed a significant influence on the simulated 'acceptance rate' of both systems. Hence retaining trained workforces in the healthcare organization could increase the 'acceptance rate' of eHMIS and SmartCare in Ethiopia. The top management should implement a policy to minimize the workforce turnover rate by addressing staffs' concerns captured during the employees' exit interviews.

Improving the 'information quality' of eHMIS and SmartCare

Improving 'information quality' through 'average workforce turnover'

Figure 6.48 (a) and (b) depicted the impact of different scenarios of 'average workforce turnover' on the simulated 'information quality' of eHMIS and SmartCare. 'Average workforce turnover' hardly influenced the simulated 'information quality' of eHMIS and SmartCare (See Figure 6.48 (a) and (b)). 'Average workforce turnover' did not show a uniform influence on the simulated 'information quality' of eHMIS (Figure 6.48 (a)). Between year two and year eight, an increase in the 'average workforce turnover' reduced the 'information quality' of eHMIS. However, beyond year eight, an increase in the 'average workforce turnover' improved information quality of eHMIS (Figure 6.48 (a) in green colour).

Similar to the simulated 'information quality' of eHMIS after year eight (Figure 6.48 (a) in green colour), high 'average workforce turnover' increased 'information quality' of SmartCare after year four (See Figure 6.48 (b) in green colour). The focus group team reported that dissatisfied users could be sources of data quality problems (Appendix 4.4, Code group: Information Quality). A high turnover led to a reduction in the number of dissatisfied users who might supply low-quality data. This reduced low-quality data reporting and resulted in improved data quality.

However, the overall impact of ‘average workforce turnover’ on the simulated ‘information quality’ of eHMIS and SmartCare was insignificant.

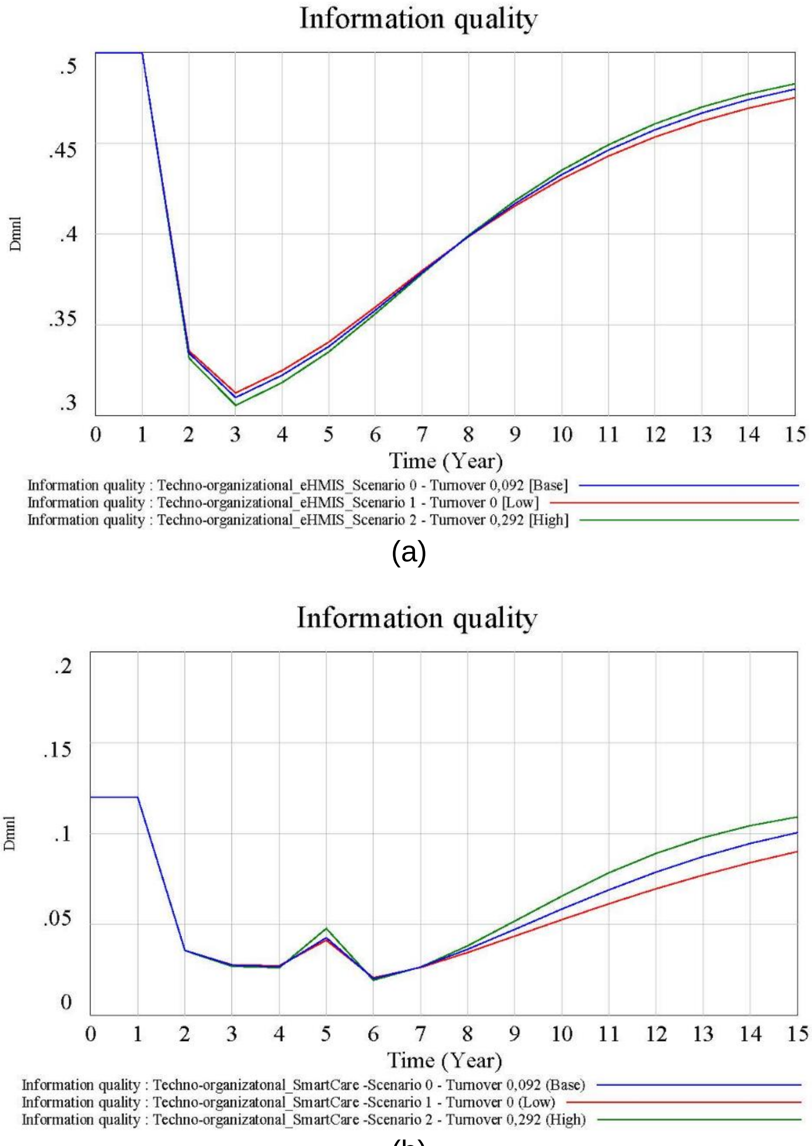
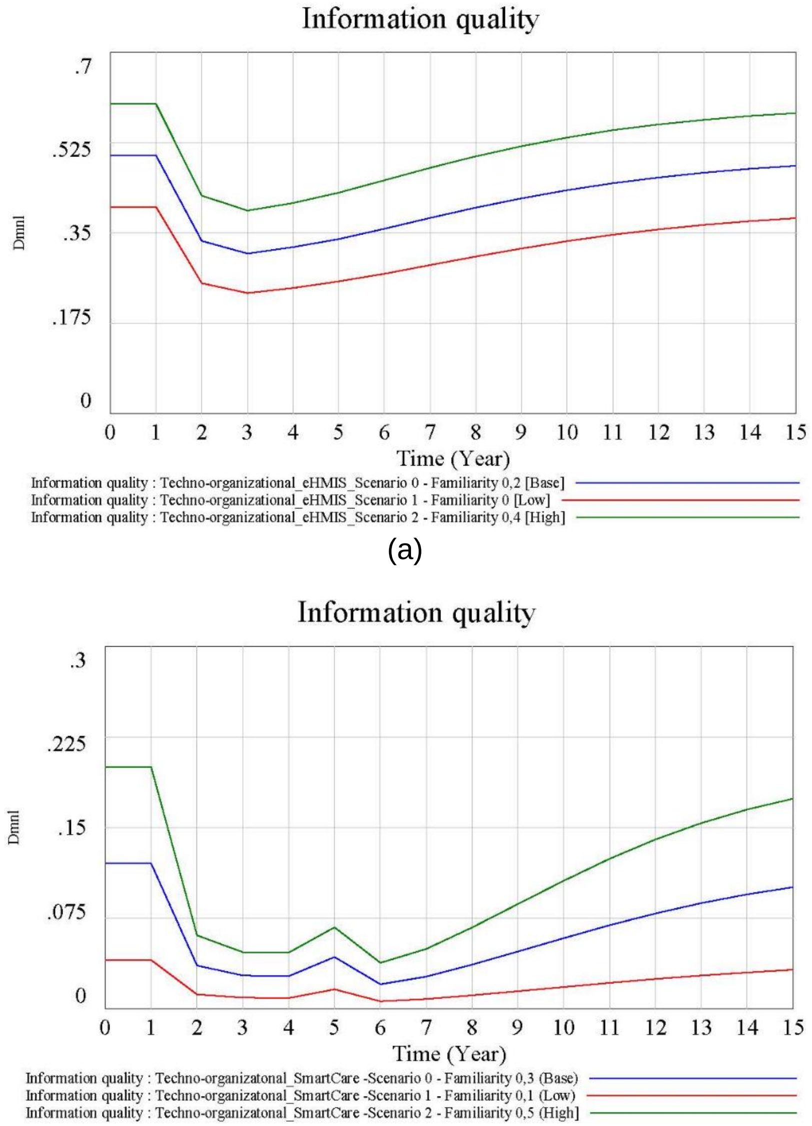


Figure 6.48 (a) A what-if analysis of ‘information quality’ of eHMIS with respect to changes in the ‘average workforce turnover’. (b) A what-if analysis of ‘information quality’ of SmartCare with respect to changes in the ‘average workforce turnover’.

Improving ‘information quality’ through ‘familiarity with electronic systems’

‘Familiarity with electronic systems’ was increased by 0.2 (20%) to test alternative policies to improve simulated ‘information quality’ (See Figure 6.49 (a) and (b)) in green colour). On year four, a 0.2 (20%) increase in the ‘familiarity with electronic systems’ produced a 26% and 73% increase in the simulated 'information quality’ of eHMIS and SmartCare respectively (See Figure 6.49 (a) and (b) in green colour). Conversely, a 0.2 (20%) reduction in the ‘familiarity with electronic systems’ produced a 24% and 68% decrease in the simulated ‘information quality’ of eHMIS and SmartCare on year four respectively (See Figure 6.49 (a) and (b) in red colour).



(a)

(b)

Figure 6.49 (a) A what-if analysis of 'information quality' of eHMIS with respect to changes in 'familiarity with electronic systems'. (b) A what-if analysis of 'information quality' of SmartCare with respect to changes in 'familiarity with electronic systems'.

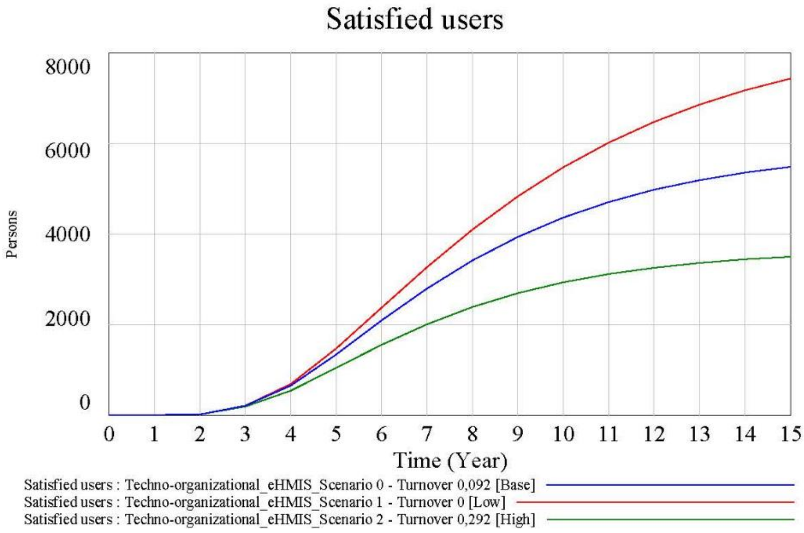
The impact of 'familiarity with electronic systems' on the simulated 'information quality' of eHMIS and SmartCare was stronger than that of 'average workforce turnover'. The influence of 'familiarity with electronic systems' on the simulated 'information quality' of eHMIS and SmartCare was uniform and significant right from the beginning; whereas 'average workforce turnover' had a minor and mixed influence on the 'information quality'. The focus of top leadership should be creating opportunities for end-users to become familiar with electronic systems through on the job training and by preparing an ample trial period before the introduction of technology. A slow introduction of electronic systems improved end-users' familiarity with systems over time.

Improving the ‘satisfied users’ of eHMIS and SmartCare

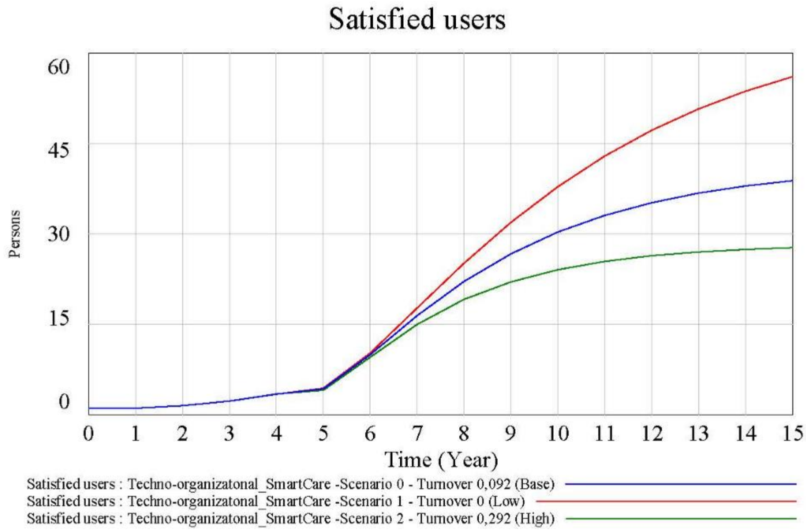
Improving ‘satisfied users’ through ‘average workforce turnover’

The influence of ‘average workforce turnover’ on the simulated ‘satisfied users’ of eHMIS significantly increased after year three (Figure 6.50 (a)). On year six, an increase in the ‘average workforce turnover’ by 0.2 (20%) demonstrated a reduction in the simulated ‘satisfied users’ of eHMIS from 2090 to 1551 Persons (25%) (See Figure 6.50 (a) in blue and green colour). Likewise, a reduction in the ‘average workforce turnover’ by 0.2 (20%) improved the number of the simulated ‘satisfied users’ of eHMIS from 2090 to 2372 (13%) (See Figure 6.50 (a) in red colour). The influence of ‘average workforce turnover’ grew strongly as the year progressed.

Similarly, the impact of ‘average workforce turnover’ on the simulated ‘satisfied users’ of SmartCare increased significantly from year five onward (Figure 6.50 (b)). On year seven, the simulated ‘satisfied users’ of SmartCare increased from 16 to 17 Persons (6%) due to the reduction of ‘average workforce turnover’ by 0.2 (20%) (Figure 6.50 (b) in blue and red). Whereas a 0.2 (20%) increase in the ‘average workforce turnover’ reduced the simulated ‘satisfied users’ of SmartCare from 16 to 14 (13%). The influence of workforce turnover on the simulated ‘satisfied users’ even grew bigger as the year progressed. The simulation results showed the growing impact of ‘average workforce turnover’ on the simulated ‘satisfied users’ of eHMIS and SmartCare (Figure 6.50 (a) and (b)).



(a)

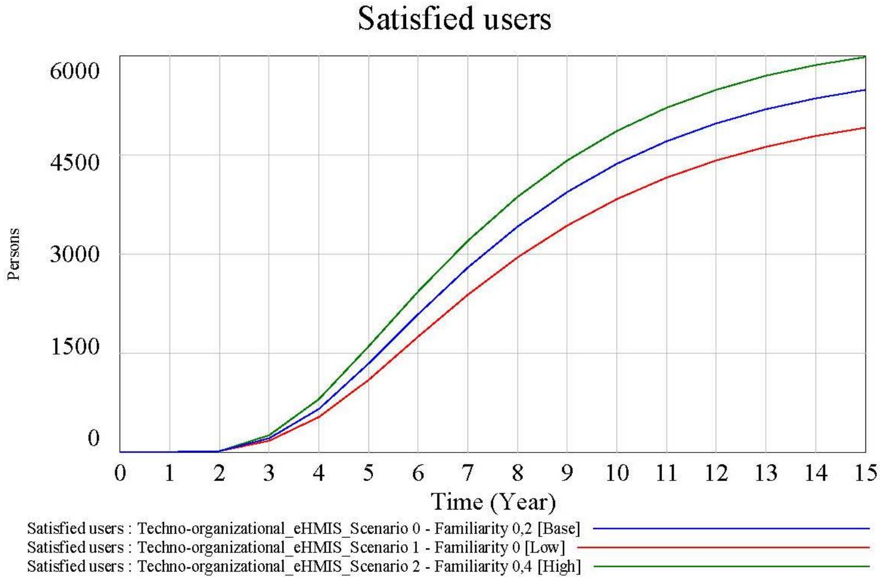


(b)

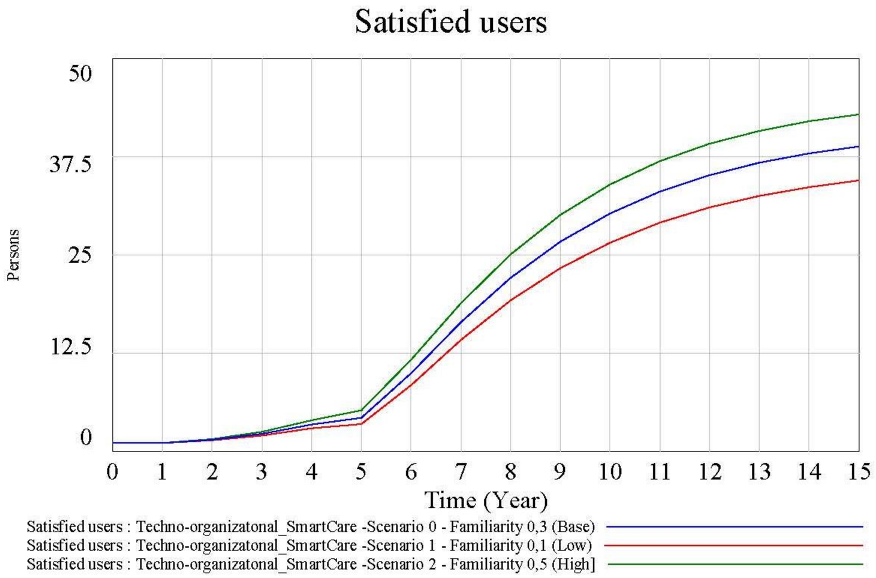
Figure 6.50 (a) A what-if analysis of 'satisfied users' of eHMIS with respect to changes in 'average workforce turnover'. (b) A what-if analysis of 'satisfied users' of SmartCare with respect to changes in 'average workforce turnover'.

Improving 'satisfied users' through 'familiarity with electronic systems'

Figure 6.51 (a) and (b) showed the simulated 'satisfied users' of eHMIS and SmartCare in response to changes in the 'familiarity with electronic systems' by 0.2 (20%) from the base scenario (in blue colour). On the fifth year, an improvement in the 'familiarity with electronic systems' by 0.2 (20%) increased the simulated 'satisfied users' of eHMIS from 2090 to 2433 Persons (16%) (Figure 6.51 (a) in blue and green colour). On the other hand, a decline of 'familiarity with electronic systems' by 0.2 (20%) reduced the simulated 'satisfied users' of eHMIS from 2090 to 1727 Persons (17%) (Figure 6.51 (a) in blue and red colour).



(a)



(b)

Figure 6.51 (a) A what-if analysis of 'satisfied users' of eHMIS with respect to changes 'average workforce turnover'. (b) A what-if analysis of 'satisfied users' of SmartCare with respect to changes in 'average workforce turnover'.

Similarly, the simulated 'satisfied users' of SmartCare grew from 4 to 5 Persons (20 %) on the fifth year due to increase in the 'familiarity with electronic systems' by 0.2 (20%) (Figure 6.51 (b) in blue and green colour). A decline in the 'familiarity with electronic systems' by 0.2 (20%) reduced the simulated 'satisfied users' of SmartCare from 4 to 3 Persons (20 %).

In summary, both 'average workforce turnover' and 'familiarity with electronic systems' demonstrated significant and growing influence on the simulated 'satisfied users' of eHMIS and SmartCare. An increase in the 'familiarity with electronic systems' increased the simulated 'satisfied users' of eHMIS and SmartCare while high 'average workforce turnover' reduced the simulated 'satisfied users' of eHMIS and SmartCare. 'Familiarity with electronic systems' led to ease of use of eHMIS and SmartCare systems. Whereas high 'workforce turnover' reduced the number of 'potential users' adding too much work burden on the remaining workforces resulting in dissatisfaction. Generally, 'workforce turnover' is often an indication of dissatisfaction.

6.13. Conclusions

The sustainability of eHealth systems from a socio-technical perspective was discussed in Chapter 5. However, the interplay of eHealth technology goes beyond social factors to create dynamic interaction with organizational factors. The implementation of eHealth technology in healthcare setting is complex and dynamic in nature. The workflow processes, resource availability, leadership support, and the environmental appropriateness were the reasons for the success of one eHealth application over another application (Rippen et al., 2013). The conceptual framework for organizational dynamics of eHealth implementation addresses the techno-organizational factors and explains the key interplay between these factors to achieve sustainable eHealth systems.

This section answered the second research question discussed in Chapter 1.5.1, i.e., "How do the techno-organizational factors of resource-constrained settings affect the long-term sustainability of eHealth use?" Based on focus group data (Appendix 4.4) and literature findings (Chapter 2.8), the key techno-organizational factors of sustainable eHealth implementation are addressed under resources readiness, management support, workflow alignment and organizational ICT culture. This is the original contribution of this research study to the knowledge base in the techno-organizational study of sustainable eHealth implementation in resources-constrained settings. These factors are code groups generated through the qualitative data analysis in ATLAS.ti (Appendix 4.4).

The interplay between the techno-organizational factors of eHealth success factors was captured by three reinforcing loops and one balancing loop of the CLD through the systems thinking approach. The influence of management support and change management on technology acceptance and resources readiness on users satisfaction were addressed in the reinforcing loops while the balancing loop highlighted the impact of inhibitors on ICT culture within an organization (See Chapter 6.3). The techno-organizational dimension plays a key role in the sustainability of eHealth systems in resource-constrained settings.

The SFD of the techno-organizational model of technology acceptance incorporated resources readiness, organizational ICT culture, management support, and workflow processes in addition to socio-technical factors discussed in Chapter 5. 'Resources readiness' addressed the adequacy of human resources and ICT infrastructure to implement successful eHealth system. The culture of using ICT and information to make decisions and the level of management support to the use of eHealth within the organization were identified as other key factors that influence eHealth acceptance. The alignment of technology workflow with an existing workflow process was also identified as the focus area in the techno-organizational dynamics of sustainable eHealth implementation.

The electronic system success was strongly influenced by the level of top management support (Al-Mamary, Shamsuddin and Aziati, 2014). The support from management increased the quality of data and the use of information to make informed decision as indicated by the focus group team (Appendix 4.4, Code: Org_Management support). Al-Mamary, Shamsuddin and Aziati (2014) indicated that the top management support influenced the perceived usefulness and user satisfaction. However, this simulation case study showed an indirect impact of management support on users' satisfaction was through resources allocation and improved effectiveness of training.

The culture of ICT within healthcare organizations improved as the end-users became familiar with technology and understood the value of its information product. Despite the weak culture of information dissemination, the quality and use of information improved due to the growing culture of ICT within health facilities (Appendix 4.4, Code: Impl_Data management). Organizational ICT culture was an important factor to influence information quality (Aqil et al., 2009). Besides, the weak culture of teamwork in the process of HMIS data management contributed to the data quality problems at the health facility level. Lluch (2011) indicated that the traditions of healthcare structures are strongly hierarchical which does not support teamwork; besides healthcare professionals have autonomy.

The ICT structure was only available at the Federal and Regional Health Bureau levels of the healthcare organization in Ethiopia (Appendix 4.4, Code: Org_Organizational structure). Besides the lack of ICT departments in most of the healthcare organizational structure, the few available ICT departments were not adequately empowered to give technical inputs during eHealth systems selection and implementation. The lack of proper organizational structure to address ICT within the healthcare tier in Ethiopia also affected the speed of technical support and the use of eHealth technology (Appendix 4.4, Code: Org_Organizational structure, Code Groups: Services quality).

Human resources and ICT infrastructure are important resource factors for the implementation of successful eHealth systems. The weak ICT infrastructure delayed the implementation of SmartCare. Moreover, the lack of internet connection at facility level forced the use of alternative options such as CDs, flash disks or papers to submit monthly HMIS reports instead of online application. In general, the focus group team and the FMOH TWG assessment document indicated that ICT infrastructure readiness of health facilities in Ethiopia was weak to support the implementation of successful eHMIS and SmartCare systems. Besides, the high turnover of physicians and ICT experts affected the use of information systems (Appendix 4.4, Code: Org_Resources readiness). However, the management support to implement successful electronic health technologies was strong which could contribute to improved resources readiness (Appendix 4.4, Code: Org_Resources readiness).

The workflow processes of SmartCare followed the existing standard workflow processes starting from patient admission to discharge in the health facilities. However, SmartCare could not cover the entire workflow processes in the facilities. In some cases, the pharmacy stores were not included in the workflow processes of SmartCare or not integrated with existing pharmacy management systems. eHMIS was also implemented following the workflow processes of paper-based HMIS. The implementation of the electronic health system in Ethiopia was good in following the manual workflow processes that made the electronic systems easy to use. The end-users resistance that might arise due to the disparity of workflow processes could be reduced significantly by aligning the electronic systems with the existing workflow processes (Appendix 4.4, Code: Org_Workflow process).

The simulation model results are discussed together with the empirical evidence of focus group discussion data to answer the research question. The sustainability of eHealth system is studied from the perspective of technology acceptance, information quality and end-users satisfaction in this simulation study. The acceptance rate of eHealth was the results of 'individuals' intention to use' the technology as indicated in the TAM (See Chapter 2.4.1). Besides, social promoters and inhibitors influenced technology acceptance (See UTAUT in Chapter 2.4.2).

'Individuals' intention to use' was a dominant factor to influence 'acceptance rate' in the early years of technology acceptance of eHMIS in the socio-technical model (See Figure 5.17 (a)). Strong 'management support' helped to improve the 'effectiveness of training' which led to better 'individuals' intention to use' the technology (Appendix 4.4, Code: Org_Management support). Similarly, the techno-organizational model also confirmed the dominant influence of 'individuals' intention to use' on the simulated 'acceptance rate' of eHMIS. The management support should focus on improving the effectiveness of training to facilitate technology acceptance in the early phases of implementation. The effectiveness of training and communication enhanced end-users ICT skill to ensure ease of use and created awareness about the usefulness of the technology (See Chapter 5.10).

The 'satisfaction rate' of eHMIS and SmartCare increased with a good alignment of the technology with existing workflow processes. The eHMIS had a better level of workflow alignment than SmartCare and resulted in a higher level of end-users' satisfaction. The 'organizational ICT culture' was an organizational factor that influenced the simulated 'information quality' of eHMIS and SmartCare (Appendix 4.4, Code: Org_ICT culture). However, the influence of technological factor (system quality) and social factor (users' satisfaction) on the simulated ‘information quality’ was stronger than that of the organizational factor (‘organizational ICT culture’).

The direct and indirect structure tests were used in the validation and verification tests of the techno-organizational model of eHealth acceptance through the qualitative data in this research study. The structural validly of the model was confirmed through the literature findings and evidence from the qualitative data analysis. Each model equation was made to pass the dimensional consistency test using Vensim. The model parameter values of eHMIS and SmartCare were judged from the focus group discussions, the interview data, the FMOH documents, eHMIS database and experts opinion (Appendix 4.3, 4.4, 6.1 and 6.2).

The boundary adequacy test explained the validity of endogenous, exogenous and excluded model variables for this study. The extreme condition tests of ‘supportive policy’, ‘familiarity with electronic systems’, ‘current workforce’, current infrastructure’ and ‘supportive organizational structure’ confirmed that the model behaviour was plausible to the extreme values. The simulated behaviour of the model to the extreme values were in harmony with the expected outputs. The univariate and multivariate sensitivity analysis demonstrated that the model was essentially robust in maintaining the simulated behaviour pattern of ‘acceptance rate’, ‘information quality’, and ‘satisfied users’ under uncertainties in the ‘supportive policy’, ‘familiarity with electronic systems’, ‘supportive organizational structure’, ‘average workforce turnover’, and ‘digital equipment installation rate’. Yet a minor to major numerical variations at different years were observed.

The univariate sensitivity analysis of a techno-organizational model of technology acceptance produced no substantial change in the simulated behaviour pattern of ‘acceptance rate’ of both eHMIS and SmartCare. But the change in ‘average workforce turnover’ produced significant numerical variations in the eHMIS and SmartCare ‘acceptance rate’. Similarly, the univariate sensitivity analysis showed that the simulated behaviour pattern of ‘information quality’ of both eHMIS and SmartCare was maintained. The analysis further uncovered that the simulated 'information quality’ was numerically sensitive to changes in the ‘familiarity with electronic systems’ which was strongly linked to ICT culture of the organization.

The influence of ‘familiarity with electronic systems’ on the simulated ‘acceptance rate’ was not strong and consistent over time. This showed the impact of other factors such as ‘average workforce turnover’ on the simulated ‘acceptance rate’ was stronger than the ‘familiarity with electronic systems’. On the other hand, ‘average workforce turnover’ demonstrated a significant influence on the simulated ‘acceptance rate’ of eHMIS and SmartCare. Hence, to increase the ‘acceptance rate’ of eHMIS and SmartCare in Ethiopia, the focus of the leadership in the organizational dimension should be in retaining skilled workforces within the healthcare organization. The top management should implement a policy to minimize the workforce turnover rate by addressing staffs' concerns to increase workforce satisfaction.

The ‘average workforce turnover’ and ‘familiarity with electronic systems’ were the two variables with a significant influence on the simulated ‘acceptance rate’, ‘information quality’ and ‘satisfied users’ in the techno-organizational mode of sustainable eHealth implementation.

The policy analysis of the two candidate variables of techno-organizational factors, i.e., ‘average workforce turnover’ and ‘familiarity with electronic systems’, indicated that the ‘average workforce turnover’ significantly influenced the simulated ‘acceptance rate’ of both eHMIS and SmartCare systems. On the third year, a 0.2 (20%) increase in the ‘average workforce turnover’ reduced the simulated ‘acceptance rate’ of eHMIS from 2089 to 1390 Persons/Year (33% per year). Conversely, decrease by 0.2 (20%) in the ‘average workforce turnover’ improved the simulated ‘acceptance rate’ of eHMIS from 2089 to 2488 Persons/Year (19% per year). Similarly, a 0.2 (20%) increase in the ‘average workforce turnover’ reduced the simulated ‘acceptance rate’ of SmartCare by from 33 to 21 Persons/Year (36% per year) in year seven. Whereas, a 0.2 (20%) decrease produced an increase from 33 to 49 Persons/Year (48% per year) in the simulated ‘acceptance rate’ of SmartCare in the same year. The impact of ‘average workforce turnover’ on the ‘acceptance rate’ of eHMIS and SmartCare were more significant in the later years of implementation.

The overall impact of ‘average workforce turnover’ on the simulated ‘information quality’ of eHMIS and SmartCare was insignificant compared to ‘familiarity with electronic systems’. On year four, a 0.2 (20%) increase in the ‘familiarity with electronic systems’ produced a 26% and 73% increase in the simulated ‘information quality’ of eHMIS and SmartCare respectively (See Figure 6.49 (a) and (b) in green colour). Conversely, a 0.2 (20%) reduction in the ‘familiarity with electronic systems’ produced a 24% and 68% decrease in the simulated ‘information quality’ of eHMIS and SmartCare on year four respectively (See Figure 6.49 (a) and (b) in red colour). Therefore, the management should focus on increasing end-users familiarity with electronic systems by preparing trial period before technology implementation, through on the job training and slow introduction of electronic systems.

The simulated behaviour pattern of ‘satisfied users’ of eHMIS and SmartCare showed significant numerical sensitivity to changes in the ‘average workforce turnover’ and ‘familiarity with electronic systems’. On year seven, the simulated ‘satisfied users’ of SmartCare increased by 6% for the reduction of ‘average workforce turnover’ by 0.2 (20%). Whereas, a 0.2 (20%) increase in the ‘average workforce turnover’ produced a 13% reduction in the simulated ‘satisfied users’ of SmartCare. An improvement in the ‘familiarity with electronic systems’ by 0.2 (20%) produced a 16% increase in the ‘satisfied users’ of eHMIS in the fifth year. On the other hand, a decline of ‘familiarity with electronic systems’ by 0.2 (20%) reduced the simulated ‘satisfied users’ of eHMIS by 17%. The satisfaction of users increased with low workforce turnover due to reduced work burden; besides familiarity with digital systems improved ease of use to enhance satisfaction.

The two variables of techno-organizational factors, i.e., ‘average workforce turnover’ and ‘familiarity with electronic systems’, showed significant influence on the simulated ‘acceptance rate’, ‘information quality’ and ‘satisfied users’. The ‘average workforce turnover’ considerably influenced the simulated ‘acceptance rate’ of both eHMIS and SmartCare systems. The policy analysis also showed that the impact of ‘familiarity with electronic systems’ on the simulated ‘information quality’ of eHMIS and SmartCare was stronger than that of ‘average workforce turnover’. Moreover, both ‘average workforce turnover’ and ‘familiarity with electronic systems’ demonstrated significant and growing influence on the simulated ‘satisfied users’ of eHMIS and SmartCare. This is an original contribution to the study of technology acceptance dynamics to the sustainable implementation of eHealth systems in the techno-organizational dimension. These findings are significant to eHealth implementations in guiding which techno-organizational factors must be considered to improve technology acceptance, information quality and users satisfaction for sustainable use of eHealth systems in resource-constrained settings.

The next chapter continues the discussion on the results section of this research report focusing on techno-economic factors of sustainable eHealth implementation. It addresses the third objective of the research, which is to determine the techno-economic features of sustainable eHealth use in a resource-constrained environment. The techno-organizational factors such as resources readiness depend on financial factors. Hence the techno-economic study can describe the other dimension of sustainable eHealth implementation. A systematic literature review result of eHealth economics and systems thinking approach are used to understand the dynamics of techno-economic factors in the implementation of sustainable eHealth systems in resource-constrained settings. The system dynamics simulation model could not be tested, validated and verified due to lack of access to primary and inadequate secondary techno-economic data. Yet the possible model parameters are identified from secondary data sources through a systematic literature review of techno-economic factors of eHealth systems to future studies.

7. RESULTS OF TECHNO-ECONOMIC FACTORS OF SUSTAINABLE EHEALTH IMPLEMENTATION

> “Limited financial resources within Ministries of Health was one of the major problems prevented the long-term sustainability and scaling up of e-health projects in the LMIC” (Quaglio *et al.*, 2016)

7.1. Introduction

The economic strategies are described as one of the key factors for a long-term sustainability of eHealth implementation (De Rosis and Nuti, 2018). In this research study, the sustainability of eHealth systems are studied under three pillars of sustainability – social, organizational and economic factors. The previous two chapters of the research study addressed the results of socio-technical and techno-organizational factors of sustainable eHealth implementation. In this chapter, the third factor of sustainable eHealth implementation, i.e., techno-economic factors, are addressed.

The financial model of eHealth implementations in the developing countries differ from the developed world in terms of the amount, source and period of funding. The implementation of eHealth in developing countries is typically driven by the non-governmental organizations (NGOs) and private players (Jahangirian and Taylor, 2015; Quaglio *et al.*, 2016). However, donor-funded projects pose a strong hindrance to interoperability and standardization of eHealth system pushing high the overall cost of eHealth implementation (Schweitzer and Synowiec, 2012). The limited amount of budget and the short-term project duration of donor organizations presented a threat to the long-term sustainability and large-scale implementation of eHealth (Quaglio et al., 2016). The purpose of this chapter is to evaluate the implication of techno-economic features on sustainable eHealth use in a resource-constrained environment as indicated in the third objective of the research (See Chapter 1.5.2).

The implementation of eHealth was anticipated to reduce the healthcare costs; however, evidence showed that technological innovations tended to drive the healthcare unit cost upwards in the developed world (Da´valos *et al.*, 2009; Schweitzer and Synowiec, 2012). The 25.9 billion dollars of financial incentives launched in the USA to support the “meaningful use” of electronic health systems accelerated the broad use of EHRs by the hospitals (Stroetmann, Motti and Kalra, 2015). Stroetmann et al. (2015) concluded that financial incentives can facilitate the use of EHR but it does not ensure sustainable use of EHRs. The high investment and incentive costs are hardly affordable by the developing countries to facilitate the adoption of eHealth.

The eHealth implementation success significantly differs between developed and developing countries as a result of resource availability which is linked to economic factors and efficiency of existing paper-based workflows (Driessen *et al.*, 2013). The financial category was one of the eight major barriers of eHealth implementations as discussed in the systematic review study of electronic medical records acceptance by physicians (Boonstra & Broekhuis 2010). Financial issues of eHealth implementation refer to initial investment costs, ongoing maintenance costs, uncertainty over return on investment (ROI), cost-effectiveness, cost-minimization, and availability of financial resources (Boonstra & Broekhuis 2010; Stroetmann et al. 2015).

The shortage of funding and health professionals' willingness to use eHealth is often referred to as the main challenge to sustaining and increasing the uptake of eHealth services (Bergmo, 2015). Two of the major problems preventing the scaling up of eHealth projects were the limited financial resources within Ministries of Health and the lack of policy and regulatory frameworks (Quaglio et al., 2016). To ensure the cost-effectiveness of eHealth interventions, Naversnik & Mrhar (2014) proposed a cost-sharing scheme between the payer and provider that helps to avoid a potential loss to the provider and high treatment cost to the payer. This chapter of the research study aims at answering how the sustainable implementation of eHealth is influenced by the economic factors in developing countries through a systematic review.

Several NGOs were involved in the implementation of different eHealth systems in Ethiopia. Moreover, there was no centralized project management office in the FMOH to integrate and create synergy the implementation of eHealth. Therefore, the efforts of gathering techno-economic data for eHMIS and SmartCare systems in Ethiopia was costly and time-consuming. In principle, it is possible to conduct and develop a system dynamic model for this techno-economic part of this eHealth study; however due to the constraint on the immediate availability of techno-economic data to the candidate in Ethiopia, it was decided to limit the study at this stage to a more detailed systematic literature review in an attempt to gather more appropriate techno-economic data for a developing country context. The result may in future be used in the study of a more detailed system dynamics modelling of a techno-economic dimension of eHealth implementations (See future researches in Chapter 8.5).

The techno-economic literature evidence was already covered in the detailed literature review section of this thesis (Chapter 2.9). A comprehensive systematic literature review conducted in this chapter aims at finding techno-economic evidence that can support the development, testing, validation and verification of the techno-economic systems dynamic model to support the future detailed research studies (See future researches in section 8.5). This literature search followed a comprehensive systematic review of three databases (ScienceDirect, PubMed, SAGE journal). The search terms e-Health, eHealth, econom*, finance* and fund* were used to identify studies published between 2007 and 2017. PRISMA approach was followed for the systematic review study. This chapter answers the third research question, i.e., “What is the implication of techno-economic factors on the sustainable use of eHealth systems by end-users in resource-constrained settings?”

A systematic review of techno-economic analysis of eHealth systems in developing countries was published in the IAMOT proceedings and presented in the IAMOT conference in 2018, Birmingham, UK.

Fanta, G. B., Pretorius, L. and Erasmus, L. (2018) ‘Economic analysis of sustainable ehealth implementation in developing countries : A systematic review’, in IAMOT 2018. Birmingham, pp. 1–16.

The successive sections present the selection processes of relevant studies, analysis and discussion of selected articles. The findings of the study are presented under three sub-categories, i.e., promising, inconclusive and unfavourable outcome reports. The findings of techno-economic factors discussed in this chapter contribute to the knowledge of sustainable eHealth implementation by showing the influence of funding amount, funding duration, funding sources and economic incentives to meaningful use, scaling-up of eHealth implementation and financial benefits (ROI).

7.2. Selection of relevant studies

The full period search (1976-2017) for studies of eHealth economics published in ScienceDirect, PubMed, and SAGE journal showed that 90%, 80% and 82% of the total studies were published in the past decade respectively. The majority (83%) of eHealth economic studies available in these three databases were published in the past 10 years, hence the literature review focused on studies published between 2007 and 2017.

The search on the three databases (ScienceDirect, PubMed, and SAGE journal) returned with a total of 527 articles that met the search criteria discussed in Chapter 4.3.4. After removing duplications, 453 distinct articles remained. Further 22 articles that were non-English text and did not have full-text were excluded. After reviewing the abstracts of all remaining 411 selected studies, 70 studies were identified for full-text analysis and 15 articles met the inclusion criteria.

The majority 335 (81.5%) of 411 articles were excluded because they failed to address the economic evaluation aspects of eHealth. Whereas 61 (14.8%) did not discuss eHealth technologies. Only 15 (3.7%) articles met the inclusion criteria for further analysis. The flow diagram in Figure 7.1 depicts the selection process of eligible studies in this research.

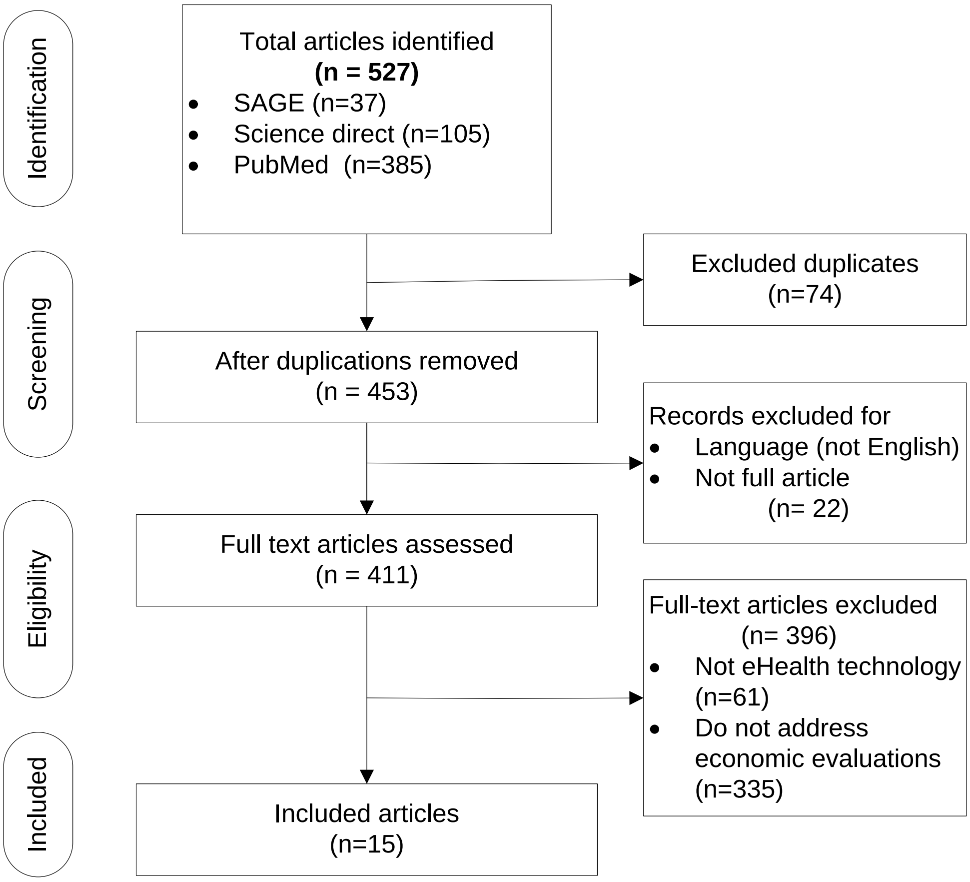


Figure 7.1 Flow chart for the identification of relevant studies.

The selected 411 studies were published in a total of 183 journals. Five journals published 126 (31%) of the total studies selected for further analysis (Table 7.1). One journal, studies in health technology and informatics, contributed to 12% of the selected articles (Table 7.1).

Table 7.1 The journal representation of selected studies.

No	Name of Journals	Total Studies	Percent
1	Studies in health technology and informatics	50	12%
2	Journal of medical Internet research	24	6%
3	Telemedicine journal and e-health : the official journal of the American Telemedicine Association	21	5%
4	JMIR research protocols	16	4%
5	International journal of medical informatics	15	4%

The publication trend of selected 411 studies showed an increase in the number of eHealth economic articles in the past 10 years. These studies met the search criteria for further assessment for inclusion criteria. The number of eHealth studies that address economic factors has grown from 3 studies in 2007 to 79 studies in 2017 (See Figure 7.2). This is an indication of growing research interest in the area of eHealth and economic implications.

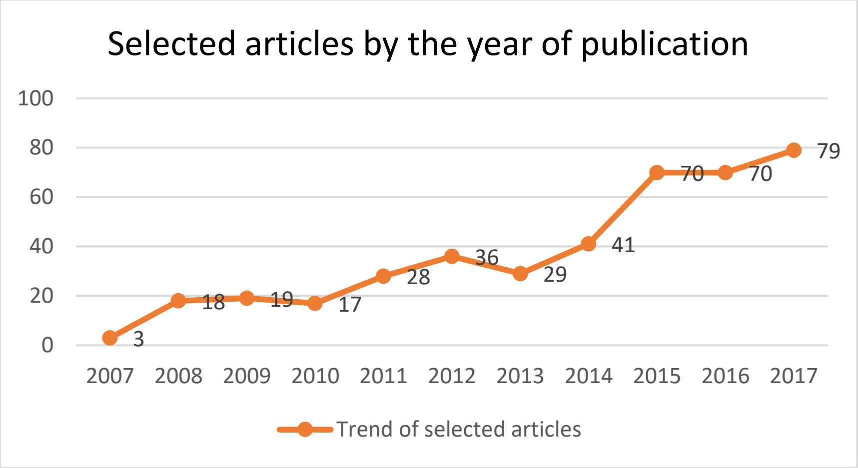


Figure 7.2 Trend of selected articles that fulfiled search criteria.

Seventy (70) studies were identified for full-text analysis after a review of the abstracts of all 411 selected studies. Finally, the 15 articles included articles address both the eHealth and economic factors of the electronic system. Four of 15 included articles were systematic review studies, whereas the rest (11) of included studies were non-systematic studies.

7.3. Discussions on selected articles

Discussions on the included studies addressed the economic as well the health technology findings of the articles. The analysis on the fifteen included articles focused on the following key areas.

- The health economic evaluation techniques used, like CBA, CEA, CUA, and CUA.
- The type of eHealth application such as EMR, EHR, mHealth, telemedicine, and web-application.
- The area of intervention addressed by the eHealth like dermatology, depression disorder, diabetes, health record digitalization, or others.
- The place or country of study.
- The number of participants.
- Period of study.
- Research methodology.
- The outcomes of economic evaluation studies.

7.3.1. Domains of eHealth interventions

eHealth systems were used to improve healthcare service delivery in different domains of healthcare. mHealth was used for appointment reminders, treatment reminders, medication reminder, health promotion, emergency notifications, surveillance, community mobilisation, patient diagnostics (Leon, Schneider and Daviaud, 2012; Marshall, Lewis and Whittaker, 2013). Telemedicine has been used in the cardiology (telecardiology), radiology (teleradiology), pathology (telepathology), dermatology (teledermatology), obstetrics (teleultrasonography), psychiatry (telepsychiatry) and ophthalmology (teleophthalmology) (Mars, 2013).

In this systematic review study, the selected studies addressed eHealth interventions in the following healthcare domains: dermatology (psoriasis), depression disorder, eating disorder, patients at emergency care, type II diabetes patients, digitize paper documents, discharge process facilitation, migraine prediction, and prevention recurring ankle sprain.

7.3.2. Types of eHealth applications

There are a number of eHealth applications that are implemented in healthcare sectors globally. Examples of popular eHealth applications include, EMR, EHR , PHR, Teemedicine, and mHealth. The types of eHealth applications are disussed in Chapter 2.2.2.

The eHealth applications addressed in the selected studies included mHealth (4), telemedicine (1), EHR (6), and three studies addressed a combination of different eHealth applications; but one study (De Rosis and Nuti, 2018) failed to specify the type of eHealth application. The six EHR systems supported financial systems (Akematsu and Tsuji, 2010), emergency care summary (Jones *et al.*, 2009), discharge communications (Sevick *et al.*, 2017), general health record (Buccoliero, Calciolari and Marsilio, 2008; Parv *et al.*, 2012), and disability health information (Noben *et al.*, 2017). The EHR was dominant eHealth application followed by the mHealth in the included articles.

7.3.3. Health economic evaluation techniques

The economic evaluation in healthcare aims at comparing the costs and outcomes of two or more health interventions. The popular economic evaluation techniques in healthcare include cost-benefit analysis (CBA), cost-effectiveness analysis (CEA) and cost-utility analysis (CUA). This economic evaluation in healthcare differs in their approach to measuring outcomes (McCabe, 2009). The economic evaluation techniques in healthcare are discussed in Chapter 2.9.1.

Three of the fifteen studies used Randomized Control Trial (RCT), with two studies reporting the cost-effectiveness of eHealth interventions; whereas the evidence from one study was not conclusive (Parsi, Chambers and Armstrong, 2012; Aardoom *et al.*, 2016; Van Reijen *et al.*, 2017). RCT is a trial in which subjects are randomly assigned to one of two groups: one (the experimental group) receiving the intervention that is being tested, and the other (the comparison group or control) receiving an alternative (conventional) treatment. The two groups are then followed up to see if there are any differences between them in outcome. The results and subsequent analysis of the trial are used to assess the effectiveness of the intervention, which is the extent to which a treatment, procedure, or service does patients more good than harm. RCTs are the most stringent way of determining whether a cause-effect relation exists between the intervention and the outcome. (Kendall J M, 2003). The trail-based evaluation is the most appropriate method to evaluate the cost-effectiveness of a particular eHealth intervention in a specific setting (Bergmo, 2015).

Four studies used a systematic review without conclusive results on the cost-effectiveness of eHealth interventions. Three case studies (Buccoliero, Calciolari and Marsilio, 2008; De Rosis and Nuti, 2018; Pagán, Zapater and Ayala, 2018), two quantitative approach (Akematsu and Tsuji, 2010; Noben *et al.*, 2017), one cost-benefit analysis (Jones *et al.*, 2009), one pilot efficacy trial (Naversnik and Mrhar, 2013) and a qualitative study with a panel of experts (Parv *et al.*, 2012) were used to present the economic evaluation outcome of eHealth interventions.

7.3.4. Countries where the studies were conducted

Out of fifteen included articles, four of them were applied a systematic review study. From eleven non-systematic review studies, nine studies were from Europe, one study (Parsi, Chambers and Armstrong, 2012) from the USA and another study (Akematsu and Tsuji, 2010) from Japan. Three of four systematic review studies (Elbert *et al.*, 2014; Paganini *et al.*, 2017; Sevick *et al.*, 2017) reported the countries where the studies were executed except for one systematic review study (de la Torre-Diez *et al.*, 2015). Three studies indicated European countries in their reviews, two studies were from North America, and only one systematic review included studies from Latin America, Asia, and Oceania countries.

No studies were found on the economic evaluation of eHealth interventions from developing countries. According to the World Bank classification, developing countries refer to countries with GNI per capita $1,005 USD or less in 2016 (the World Bank, 2017). This highlighted the high demand for studies of economic evaluation of eHealth systems in developing countries. Bergmo (2015) discussed that the economic evaluation of eHealth systems depends on the type of services provided and the context of local settings, such as infrastructure and technologies investment needs. The cost-effectiveness study is affected by the economic condition of the country which is directly related to the stakeholders' willingness-to-pay (WTP)

(Paganini *et al.*, 2017). WTP estimates the maximum amount an individual is willing to pay for a program or health outcome (Da´valos *et al.*, 2009). Cost-effective eHealth interventions in developed countries may not be cost-effective in developing countries because of a big gap between the two settings in the value of stakeholders' WTP.

7.4. Discussion of the outcomes of economic evaluation studies

The majority of studies (nine of fifteen studies, 60%) reported promising evidence of eHealth economic benefits either in terms of cost-effectiveness, cost-savings or cost-minimization (Table 7.2 & Table 7.3). Five studies, of which four of them were systematic reviews, presented a mixed report without conclusive evidence on the cost-effectiveness of eHealth interventions (Table 7.4). One study concluded that the web-based employment intervention aimed at increasing the quality of life for disabled employees was not cost-effective. The outcome of the economic evaluation is discussed in more detail as promising, inconclusive and unfavourable outcome reports.

7.4.1. Promising outcome reports

The result of two studies that used the RCT method to evaluate the cost-utility and cost-effectiveness of eHealth intervention for eating disorder therapy and management of skin disease respectively, reported the cost-effectiveness of the interventions from the societal perspective (See Table 7.2). The first study investigated the cost-utility of fully automated Internet-based intervention "Featback" with different levels (i.e., none, once a week, and three times a week) of therapist support in comparison to a waiting list for individuals with eating disorder symptom (Aardoom *et al.*, 2016). Waiting list represents individuals who waited 5 months before receiving low-intensity therapist support with Featback (Aardoom *et al.*, 2016). The finding showed no clear preferences in the Internet-based intervention with or without therapist support from the economic viewpoint; however, the Internet-based intervention seemed to be cost-effective in comparison to a waiting list (Aardoom *et al.*, 2016).

The second study compared the cost-effectiveness of standard in-office care and an online patient-centred model for management of psoriasis, skin disease, from a societal perspective (Parsi, Chambers and Armstrong, 2012). The result showed that the patient-centred online model appeared to be a cost-effective healthcare service delivery. For an approximately similar effectiveness level, the online patient-centred intervention costs $241.10 USD less per patient than in-office visits from a societal perspective (Parsi, Chambers and Armstrong, 2012). The online patient-centred model empowered patients with psoriasis to capture and transmit skin images and medical history that reduce the time wasted through travel and waiting for face-to-face consultation of in-office care (Parsi, Chambers and Armstrong, 2012).

The CBA of an electronic Emergency Care Summary (ECS) system and the CEA of a Web- and Mobile-health system to treat depression disorder showed promising economic benefits (See Table 7.2). An electronic system of ECS in Scotland has improved patient safety by providing information about patients' medication, drug adverse reactions and allergies during patients' emergency care services (Jones *et al.*, 2009). The ECS served 1.3 million people (25% of Scotland's population) with live medication information (Jones *et al.*, 2009). The result of CBA indicated that it took seven years for a cumulative benefit to exceed the cumulative cost of ECS (Jones *et al.*, 2009).

Table 7.2: Promising economic benefits of eHealth based on CEA, CUA and CBA methods.

Author	Naversnik & Mrhar 2013	Aardoom et al. 2016	Parsi et al. 2012	Jones et al. 2009
Study perspective	Patient	Societal	Societal	Patients, Technology Providers, Health-care professionals
Evaluation techniques	CEA	CUA	CEA	CBA
eHealth type	Web- & Mobile-Health	Internet-based intervention (Featback)	Telemedince	Electronic Emergency Care Summary
Area of intervention	Depression disorder treatment	Eating disorder	Dermatology (psoriasis)	Patients at emergency care
Country	Slovenia	Netherlands	USA	Scotland
Participants	46 Patients	354 Participants	64 patients	1.3 million people
Study period	6 months	Not specified	24 weeks	2002 -2010
Methodology	Pilot Efficacy Trial/ Scenario analysis	RCT	RCT	Cost-benefit analysis
Results	Promising	Promising	Promising	Promising

Another study on the cost-effectiveness of Improvehealth.eu showed attractive economic benefits in Slovenia (Naversnik and Mrhar, 2013). Improvehealth.eu service is an eHealth system that supports the treatment of patients with a depression disorder through online- and phone-based care management performed by a trained psychologist (Naversnik and Mrhar, 2013). The cost-effectiveness scenario analyses of Improvehealth.eu produced ICER values ranging between 1,000 Euro/QALY and 5,000 Euro/QALY, which is lower than the average WTP value of Slovenians, 30,000-45,000 Euro/QALY (Naversnik and Mrhar, 2013). The high attrition rate (24 of 46 patients were not available at follow-up), use of cost data from the UK study and assumptions in the area of uncertainty can be viewed as the limitation of the study.

The promised economic gains of an electronic ECS system requires an increase in the number of system users which is very unpredictable especially in healthcare settings. Besides, the majority of ECS benefits (77%) were non-financial and 23% of the benefits came from deployed finance (Jones *et al.*, 2009). Similarly, the weak assumptions in the CBA and CEA of both ECS and a Web- and Mobile-health systems were the limitations of the studies.

Three studies reported the promissing benefits of eHealth intervention in terms of cost-minimization and cost-saving of medical expenditure (Table 7.3). A study comparing the medical expenditure of 199 eHealth users and 209 non-user groups in Nishi-aziru, Japan indicated that the eHealth users group spend $156.88 USD per year (21.2% of average annual medical expenditure) less than non-user groups (Akematsu and Tsuji, 2010). Furthermore, as the users utilize the system one more year, the medical expenditure of lifestyle-related illnesses reduced by $11.33 per year, which is about 1.5% of the average annual medical expenditures (Akematsu and Tsuji, 2010).

In a different study of Wireless Body Sensor Network that predicted a migraine headache, a simulation was carried out targeting 2% (1,393,649) of the 15% migraine patients in Europe for a period of 10 weeks (Pagán, Zapater and Ayala, 2018). The simulation result of a case study predicted 32.6% energy saving from low-power technique and workload balancing policies of the intervention which was translated into a cost saving of €288 million when applied to 2% of European migraine patients (Pagán, Zapater and Ayala, 2018). Additionally, €1,272 million Euro savings were expected to be achieved from the benefits of migraine prediction (Pagán, Zapater and Ayala, 2018).

The third study considered a wider stakeholder group to assess the economic value of ESCAPE project, an ICT system to digitalize the clinical and administrative paper documents (Buccoliero, Calciolari and Marsilio, 2008). The study evaluated the reputation and operational efficiency of the organization, the values created to the patients, and the level of approval by the wider community of the region as a result of ESCAPE project (Buccoliero, Calciolari and Marsilio, 2008). Assuming the production of 272 000 external health reports a year and targeting 40% of patients to use the electronic system, the net value of the project to the organization in 5 years span at a discounted rate of 3.5% demonstrated a slightly positive result (approximately €39,000 Euro gain) (Buccoliero, Calciolari and Marsilio, 2008). The reduction of mistakes, improvement in reporting, image improvement (hospital brand) and reduced waiting and service time were presented as intangible corporate benefits of the electronic system (Buccoliero, Calciolari and Marsilio, 2008). The evaluation of the social benefit of the electronic system showed a statistically significant reduction of the average waiting time for non-urgent reports from 23.4 to 17.1 hours (Buccoliero, Calciolari and Marsilio, 2008). The overall social benefit from the simplification of the document delivery, i.e., costs saved from the time required to pick up the report from the closest delivery office and travel expenses, was estimated to be approximately €4,072,826 Euro (Buccoliero, Calciolari and Marsilio, 2008).

Despite the potential of eHealth interventions to minimize health expenditure of patients, studies fail to address the cost implications of eHealth intervention to the healthcare organization. Healthcare providers bear two third of the overall costs of eHealth, but only sharing 6% of the benefits through improved efficiency (Parv *et al.*, 2012). The National Health Service board of Scotland and the patients regarded as the main beneficiaries of ECS, each sharing approximately 40% of the benefits. The health-care professionals accrue the reminder of the benefits (Jones *et al.*, 2009). Hence future studies need to follow a comprehensive economic evaluation of eHealth to address not only the economic benefits to the patient and society but also eHealth economic implication to the providers and healthcare professionals.

Table 7.3: Promising economic benefits of eHealth from the perspectives of key stakeholder groups.

Author	De Rosis & Nuti 2017	Buccoliero et al. 2008	Pagán et al. 2018	Akematsu & Tsuji 2010	Parv et al. 2012
Study perspective	Physicians, Patients, organizations, innovators, regulatory	Organizational, patient and society	Patients, Organizational	Patient	Societal
Evaluation techniques	Not specified	ROI and Cost-saving	Cost-saving	Cost-minimization/ Cost-saving	PENG evaluation
eHealth type	Not specified	EHR	Mobile cloud computing	EHR - Finance	EHR-
Area of intervention	Not specified	digitalize the clinical and administrative papers	Predicting migraine patients	Not specified	Type II diabetes
Country	Italy	Italy	European countries	Japan	Estonia
Participants	33 Participants	272,000 reports	2 migraine patients	412 Patients	Not specified
Study period	Sep 2014 - Mar 2015	2003- 2006 (Estimated)	10 weeks	1994-2006	Not specified
Methodology	Case study, Qualitative	Case study, Mixed	Simulation/ Case study	Quantitative	A panel of Expert
Results	Promising	Promising	Promising	Promising	Promising

Eventually, the Estonian EHR economic evaluation result showed that the estimated annual net benefit will surpass costs within three years (Parv *et al.*, 2012). Starting from the third year, the annual benefits of EHR continued to grow with the increasing number of users until it reached the steady state in the seventh year (Parv *et al.*, 2012). The main beneficiaries of the EHR system are society represented by the government who will contribute back through increased tax contribution as healthier workforces (Parv *et al.*, 2012). A panel of experts' analysis concluded that despite considerable costs of EHR in Estonia, its potential benefits are high (Parv *et al.*, 2012).

A case study involving 33 informants from key stakeholders as a group explored the possible strategies and financial mechanisms for successful long-term implementation of eHealth intervention in public health care (De Rosis and Nuti, 2018). The importance of considering the initial investment and long-term financial plan in the current economic crisis and budget constraints was highlighted by informants (De Rosis and Nuti, 2018). The study indicated that focusing on initial investment without considering ongoing costs, time-consuming public procurement process and short-term grant approach were challenges to sustain eHealth solution (De Rosis and Nuti, 2018). Since healthcare providers bear two third of the overall costs of eHealth interventions sharing only 6% of the benefits through improved efficiency (Parv *et al.*, 2012), the economic evaluation must consider the perspective of key stakeholder groups and both initial and ongoing costs (De Rosis and Nuti, 2018).

In summary, the majority (60%) of the studies reported attractive economic benefits of eHealth interventions. However, these studies are not without limitations. Five of nine selected studies that reported promising economic benefits evaluated the technologies from the perspective of only one stakeholder group. The RCT method which is described as the most appropriate method to evaluate the economic benefits of eHealth was applied by only two of the nine studies that reported promising economic outcomes. Furthermore, the diversity of eHealth applications in evaluation studies, the difference in the perspective of the studies, the difference in the settings of the study make it difficult to transfer the result to other settings. Some findings of positive benefits depend on the forecasted increasing utilization of eHealth intervention by end users, which may not be always true.

7.4.2. Inconclusive outcome reports

The result of four systematic reviews and one cost-effectiveness study presented a mixed report without conclusive evidence on the economic benefit of eHealth interventions (Table 7.4). The first systematic review identified four studies on the cost and cost-effectiveness of electronic discharge communication. Three of the four identified studies focused on the potential cost savings (Sevick *et al.*, 2017). Only one of the four studies addressed the cost-effectiveness in terms of cost per clinical benefit but the study failed to measure meaningful clinical outcomes (Sevick *et al.*, 2017). None of these studies reported on the costs of essential infrastructure, personnel, maintenance and network connectivity costs associated with the implementation and operation of electronic discharge communication tool (Sevick *et al.*, 2017). The result of a systematic review was not conclusive to make generalization to other settings or contexts (Sevick *et al.*, 2017).

Similarly, the second systematic review of 35 selected papers on cost-utilization and cost-effectiveness of eHealth concluded that the economic evaluation results were not conclusive because of some limitations in the studies (de la Torre-Diez *et al.*, 2015). Although the majority of the studies indicated the cost-effectiveness of telemedicine systems, few studies claimed that it is not explicitly conclusive (de la Torre-Diez *et al.*, 2015). Furthermore, the study indicated that there is very little evidence about the effectiveness of mHealth and other eHealth systems in the literature (de la Torre-Diez *et al.*, 2015).

Table 7.4 Inconclusive evidence of eHealth economic benefits.

Author	de la Torre-Diez et al. 2015	Elbert et al. 2014	Sevick et al. 2017	Paganini et al. 2017	Van Reijen et al. 2017
Study Perspective	Literature	Literature	Literature	Literature	Patients
Evaluation techniques	CEA/ CUA /Sustinable funding	CEA (effectiveness)	Cost-analysis/CEA/CBA	CEA/ CUA	CEA/ ICER
eHealth type	eHealth, mHealth, Telemedicine	Home telemonitoring, Structured telephone support, Video-teleconferencing, Education, Self-management programs, Telerehabilitation, Telemedicine	Electronic discharge communication	Internet- and mobile-based interventions	Mobile App (mHealth)
Area of intervention	Not specified	Not specified	Discharge communication process	Depression disorder	Ankle sprain
Country	Not specified	Europe, North America, Asia, Oceania, Latin America	Canada, Germany, Norway, USA	United Kingdom, Australia, Germany, and Netherlands	Netherlands
Participants	35 Papers	31 Papers	4 literature	12 literature	220 athletes
Study period	Up to Feb 2014	2009-2012	Up to Oct 2015	2010-2017	12 months
Methodology	A systematic review	A systematic review	A systematic review	A systematic review	RCT
Results	Not conclusive	Not conclusive	Not conclusive	Not conclusive	Not conclusive

The third systematic review study of the internet- and mobile-based interventions (IMIs) targeting depression classified interventions as cost-effective if the cost-effectiveness ratio was below a WTP value of €20, 000 – €30,000 per additional quality-adjusted life year (QALY) (Paganini *et al.*, 2017). Six of the twelve eligible studies, that reported an incremental cost-utility ratio (ICUR) between €3,088 and €22,609 were found to be cost-effective (Paganini *et al.*, 2017). Five studies were likely to be not cost effective (Paganini *et al.*, 2017).

In the fourth systematic reviews and meta-analyses study, 7 of 31 reviews (23%) indicated effectiveness in cost related or outcome measures, 13 reviews (42%) showed promising evidence, and 11 reviews (35%) concluded that there is no, limited, or inconsistent proof of evidence of cost-effectiveness (Elbert *et al.*, 2014).

The fifth study focussed on the prevention of recurring ankle sprains and recruited a total of 220 athletes to evaluate the cost-effectiveness of a neuromuscular training (NMT) program delivered via a mobile App vs. printed booklet. The result showed no significant difference in the cost-effectiveness of the interventions (Van Reijen *et al.*, 2017). The study indicated that the preventative ankle sprains intervention either through App or Booklet could potentially reduce the current high total societal costs associated with ankle sprains treatment without a significant difference in the cost-effectiveness between the two interventions (Van Reijen *et al.*, 2017).

Generally, five of fifteen selected studies could not produce conclusive evidence on the cost-effectiveness of eHealth interventions. The potential of eHealth interventions to be cost-effective depends on the economic condition of the country which is directly related to WTP and the variable costs associated with scale-up (Paganini *et al.*, 2017). The weak estimation methods, lack of RCT, lack of long-term evaluation studies, small sample sizes, and absence of quality data and appropriate methods were listed as the main limitations to the studies of eHealth economic evaluation (de la Torre-Diez *et al.*, 2015). Sevick et al. (2017) also presented that the studies were old compared to the short life cycle of ICT and the literature on the cost-effectiveness of electronic discharge communication tools were limited. Moreover, the detail costs associated with eHealth intervention such as infrastructure, maintenance, support and other on-going costs were not covered by the economic analysis (Jones *et al.*, 2009).

7.4.3. Unfavourable outcome report

One study reported that web-based employment intervention was not cost-effective in terms of increasing quality of life (Noben *et al.*, 2017). The study was conducted in Netherlands over the control group and the intervention group of 34 and 29 participants respectively on the web-based employment intervention that aimed at providing an easy access for interested people to ask questions about disability, health and work (Noben *et al.*, 2017). The four core elements of the web-based intervention included knowledge website, personal advice, feedback session and forum. Compared to the controlled group, the intervention group demonstrated lower score on the Work Ability Index (-0.51) and higher total costs (€483.8) (Noben *et al.*, 2017).

The next section summerises the techno-economic factors obtained from literature review effort that perhaps influence the sustainability of eHealth system in resource-constrained settings.

7.5. Techno-economic factors of sustainable eHealth implementation

The techno-economic factors that influence the sustainability of the eHealth system in resource-constrained settings are discussion under economic incentives, funding durations, funding amount, funding sources and economic benefits in this section. These variables can serve as a system dynamics model parameters in the development of a techno-economic model of technology acceptance in future research.

Funding duration

The duration of funding is an important economic factor to achieve financial benefit from eHealth interventions. A cumulative benefit exceeds the cumulative cost of eHealth systems after seven years with the increasing number of users (Jones et al., 2009; Parv et al., 2012). Therefore, the funding duration can be considered as a system dynamics model parameter for the study of techno-economic factors of eHealth acceptance for sustainable use. The short-term funding from donor organizations is a threat to the long-term sustainability and large-scale implementation of eHealth (Quaglio et al., 2016). The funding duration can influence the maintenance and technical support services of eHealth systems which affects the long-term sustainability of eHealth.

Funding amount

The amount of funding must consider not only the initial investment but also long-term financial plan to ensure the quality of technology and ongoing maintenance to ensure end-users' satisfaction (De Rosis and Nuti, 2018). Focusing on the initial investment without considering ongoing costs, the time-consuming public procurement process is one of the challenges to sustaining eHealth solution (De Rosis and Nuti, 2018). The adequacy of funding amount to cover both the initial and ongoing costs should be one of the parameters in the development of system dynamics model for techno-organizational factors of eHealth acceptance in future research. The amount of funding influences the technological quality, resources readiness and financial incentives that may affect technology acceptance, information quality and users satisfaction.

Economic incentives

The meaningful use of eHealth systems is influenced by the organizational pre-conditions to incentivize end-users (Mettler, 2015). The insufficient incentive was described as one of the challenges in the implementation of eHealth systems to ensure meaningful use by the end-users (Jarosławski and Saberwal, 2014; Mettler, 2015). The simulation study of eHealth adoption showed that financial incentives may affect the EHR adoption rate among hospitals and physicians but does not change the patients' use of EHR (Otto and Simon, 2009).

The economic incentives to the end-users of EHR increased the meaningful use of EHR systems in the USA (Adler-Milstein, Everson and Lee, 2015). The 25.9 billion dollars of financial incentives launched in the USA to support the "meaningful use" of EHR accelerated the broad use of EHRs by the hospitals (Stroetmann, Motti and Kalra, 2015). The large national investment in EHRs in the USA appears to improve performance and patient satisfaction, but not efficiency(Adler-Milstein, Everson and Lee, 2015). Efficiency is measured as the total expenditures per adjusted patient day (Adler-Milstein, Everson and Lee, 2015). Stroetmann et al. (2015) concluded that financial incentives can facilitate the use of EHR but it does not ensure sustainable use of EHRs.

The high investment and incentive costs are hardly affordable by the developing countries due to the low average health expenditure in developing countries besides the low GDP of these countries (The World Bank, 2017). The total health expenditure of LIC in 2014 was only 5.8% of GDP compared to the health expenditure of the HIC (12.3% of GDP) (The World Bank, 2017). The per capita total expenditure on health at average exchange rate was USD 37 for LIC which was significantly less than HIC (USD 5,266) in 2014 (The World Bank, 2017). In developing countries where economic resources are limited, driving eHealth acceptance and users' satisfaction through economic incentive is a challenge. Hence economic incentives should be a candidate parameter in the system dynamic model of techno-economic factors of eHealth acceptance. The economic incentive can facilitate the intervention process of improving users' satisfaction to increase the acceptance rate of eHealth systems.

Funding sources

The implementation of eHealth in developing countries is dominantly driven by the NGOs and international agency with minimum investment from the MOH (Jahangirian and Taylor, 2015; Quaglio et al., 2016). However, the short-term grants from donors and international aid agencies affect the sustainability and large-scale implementation of eHealth systems. Moreover, donor-funded eHealth project in developing countries are disease-specific and lack standardization to be interoperable with other eHealth systems (Schweitzer and Synowiec, 2012). As a result, donor-driven pushed the overall costs of eHealth implementation high (Schweitzer and Synowiec, 2012).

The limited amount of budget and the short-term project duration of donor organizations presented a threat to the long-term sustainability and large-scale implementation of eHealth (Quaglio et al., 2016). Therefore, the source of funding determines the duration of funding. The benefit from the implementation of eHMIS surpasses the total expense as more people begin to use the system (McCabe, 2009; Parv et al., 2012). Hence the funding source should not fully rely only on short-term grants from donor agencies to achieve sustainability in the implementation of eHealth.

The MOH needs to be a major funding source to ensure the economic sustainability of eHealth implementation. The funding source is critical in determining the duration of funding in the implementation of eHealth systems in developing countries. Hence the techno-economic model of eHealth acceptance should use funding source as one of the parameters in the system dynamics modelling of future research. The funding sources from the MoH may indicate the high level of support from the top management to implement electronic systems.

Economic benefits

The systematic literature review conducted in this chapter showed that the majority (60%) of the studies reported attractive economic benefits of eHealth interventions. Yet, the level of economic benefits varies between stakeholder groups. Although healthcare providers bear two-third of the overall costs of eHealth interventions, they share only 6% of the benefits through improved efficiency (Parv et al., 2012). Therefore, all key stakeholder groups should realize the economic benefits of the eHealth intervention to ensure sustainability (De Rosis and Nuti, 2018).

The economic benefits to the healthcare organizations include avoiding legal fees due to medical errors and missing patient medical files, minimize patient waiting time, improve branding through better medical effectiveness and quality of healthcare services (Byrne et al., 2010). The benefits of eHealth to healthcare workers include an increase in productivity and work satisfaction, collaboration with the healthcare team, access to comprehensive patient health record to avoid allergies or adverse reactions (Byrne *et al.*, 2010; Schweitzer and Synowiec, 2012; Michel-Verkerke, Robert A Stegwee and Spil, 2015).

The potential economic benefits of eHealth to patients include:

- Reduce money spent on travel (transportation, accommodation and other expenses) (Schweitzer and Synowiec, 2012).
- Reduced healthcare cost associated with redundant laboratory and radiology tests (Byrne et al., 2010).
- continuity of employment or income generation due to the better quality of healthcare services (Parv et al., 2012; Schweitzer and Synowiec, 2012).

The economic benefits impact policies towards the implementation of eHealth, the level of management support and users satisfaction as described in the CLD of the techno-organizational model of eHealth acceptance (Figure 6.1). The systematic literature review of the techno-economic factors of eHealth acceptance is concluded in the following section. Future research can use the findings of systematic review together with system dynamics models discussed in Chapter 5 and 6 to develop a techno-economic model of eHealth acceptance in future research once some more detailed data is established.

7.6. Conclusions

The limited financial resources within Ministries of Health was one of the major problems preventing the scaling up of e-health projects in developing countries (Quaglio et al., 2016). Nine of fifteen (60%) selected studies in this research indicated the economic attractiveness of eHealth interventions and the potential promise of eHealth to benefit a wider group of stakeholders. However, the results were from developed countries that could not be directly transferred to different settings in developing countries. Because, these outcomes of economic evaluation were influenced by the place where the studies were executed, the type of eHealth applications assessed, and the perspectives of the study. Moreover, the majority of selected studies were disease-specific which made it difficult to generalize to other areas of health problems.

Five studies, of which four of them were systematic reviews, presented a mixed report without conclusive evidence on the cost-effectiveness of eHealth interventions. One study concluded that the web-based employment intervention aimed at increasing the quality of life for disabled employees was not cost-effective. In this systematic review study, no economic evaluation studies of eHealth systems were found from the developing countries. Schweitzer and Synowiec (2012) indicated that a small number of eHealth projects and little reliable economic data for eHealth implementation in developing countries were the major concern to address the techno-economic factors of sustainable eHealth implementation. Despite the financial constraints in the developing world, the role of economic factors in the long-term sustainability of eHealth systems did not get enough research attention in developing countries.

The cost-effectiveness of eHealth intervention depends on the value of WTP, which is associated with the economic condition of the country. As a result, cost-effective eHealth intervention in the developed world may not replicate the same result in developing world settings. This suggests the greater need for the economic evaluation of eHealth interventions in developing countries. The availability of reliable economic evaluation of eHealth systems may improve the decision of providers and government bodies towards the implementation of sustainable and large-scale eHealth programs.

This study highlighted the importance of economic factors to the sustainable eHealth implementation in developing countries. Furthermore, the systematic review discovered the complexity of the economic evaluation of eHealth intervention. First, the economic evaluation technique should be able to address the fast-changing nature of eHealth technology in terms of the costs and benefits of technology. Second, the economic evaluation of eHealth system is specific to the economic settings of the country, the type of eHealth application, the type of health problems addressed by eHealth intervention, and the perspective of stakeholder groups. These factors added complexity to the economic analysis of eHealth interventions and made it unrealistic to extend the findings of a study from the developed world to different settings in the developing countries.

An economic incentive, funding duration, funding amount, funding source and economic benefit are identified as potential system dynamic model parameters in the development of a techno-economic model of eHealth acceptance in future research. The funding amount must support not only the initial eHealth investment but also the ongoing maintenance costs to ensure the quality of the systems and the satisfaction of end-users. Besides, the funding duration contributes to the sustainability of eHealth systems. The source of funding is usually associated with the duration of funding, especially in resource-constrained settings. In the case of developing countries where eHealth systems are dominantly donor-driven, the sustainability of eHealth is affected by the short-term grant of donors and international agencies. Therefore, financial commitment from the MOH impacts the duration and amount of funding to ensure the sustainability of eHealth.

The economic incentive to the end-users for the meaningful use of eHealth systems improves acceptance of eHealth technology and satisfaction of end-users. Moreover, the economic return of eHealth systems should not only benefit patients but also healthcare professionals (end-users) and healthcare organizations to sustain eHealth systems. In general, the implementation and use of eHealth systems should benefit all major stakeholders. Healthcare organizations who bear the majority of the cost should get attractive ROI to continue investing and maintaining the operation of eHealth systems to ensure sustainability.

Finally, not only the lack of primary data but also the absence of adequate secondary data on the techno-economic factors of eHealth implementation in developing countries made it difficult to develop, test, validate and verify a system dynamics simulation model for this techno-economic dimension of sustainable eHealth implementation. Yet, the systematic review confirmed the importance of techno-economic feature to the sustainable eHealth use in a resource-constrained environment. With the comprehensive information obtained from the systematic review and the system dynamics model of socio-technical and techno-organizational discussed in Chapter 5 and 6, a system dynamics model of techno-economic factors can now be developed in future research once some more detailed data has been established. The next chapter gives the overall conclusions to this research from the research objective perspective, discusses contributions to the knowledge, limitations and opportunities for future works in relation to this research study.

8. Conclusions and future works

"People do not like to think. If one thinks, one must reach conclusions. Conclusions are not always pleasant."
Helen Keller

8.1. Introduction

The use of ICT improved the service performance of a transportation, financial, communications and manufacturing sectors (Reid et al. 2005). Similarly, the use of ICT in the healthcare sector (eHealth system) is believed to improve the efficiency of healthcare delivery, advance patient record keeping and reduce healthcare costs. However, the healthcare has barely begun to take advantage of ICT mainly in a resource constrained-environment (van Gemert-Pijnen et al., 2011). Despite an increase in the implementation of eHealth systems globally, most of the implementations could not proceed beyond the pilot phase to demonstrate sustainability and a large-scale rollout (Djorlolo and Ellingsen, 2013). The challenges associated with sustainability and uptake of eHealth systems are still unresolved issues that require further analysis and intervention (Bergmo, 2015).

The study targeted at understanding the dynamic interaction between technical, social, economic and organizational factors of sustainable eHealth implementation. It provided an insight concerning the complex interaction of the socio-technical, techno-organizational, and techno-economic elements of eHealth implementation to ensure sustainable use of eHealth systems. This thesis focused on how factors of eHealth implementation interplay to influence technology and information use to ensure the long-term sustainability of eHealth in resource-constrained settings. The research study answered the following research questions asked in the first chapter.

- How do socio-technical factors influence the sustainable use of eHealth systems?
- How do the operating environments (organizational factors) of resource-constrained settings affect the long-term sustainability of eHealth use?
- What is the implication of techno-economic factors on the sustainable use of eHealth systems by end-users in resource-constrained settings?

The first two research questions are answered through a system dynamic simulation model of socio-technical and techno-organizational factors of eHealth acceptance. The third research question is addressed through systematic literature review of techno-economic factors of sustainable eHealth implementations. The system dynamic simulation model of techno-economic factors could not be developed due to the lack of access to primary data and insufficient secondary data. However, the systematic review identified potential system dynamics model parameters to develop the techno-economic model of eHealth acceptance in future research once some more detailed data can be established.

The sustainability of eHealth systems can be achieved when the technology is accepted by the end-users (Davis, 1989; Venkatesh and Davis, 2000), the quality of information product is good to make accurate decisions (Aqil, Lippeveld and Hozumi, 2009; FMOH, 2016), and the end-users are satisfied in using the systems and the information product (DeLone and McLean, 1992, 2003). Therefore, the rate of technology acceptance, information quality, and users' satisfaction were the three key focus areas in the simulation study of sustainability of eHealth technology.

An explanatory case study research of eHMIS and SmartCare implementation in Ethiopia was used to understand the dynamic interaction between the elements of technological, social, organizational and economic factors during the implementation of sustainable eHealth. A focus group discussions and a face-to-face interviews with the eHMIS and SmartCare end-users were used to collect research data. System dynamics modelling was used to capture the dynamic complexity of eHealth implementation. The basic model was verified, validated and tested to ensure the robustness of the socio-technical and techno-organizational model originally developed by the author in this research study. The simulation and systematic review results are presented under socio-technical, techno-organizational and techno-economic dimensions of sustainable eHealth systems.

8.2. Conclusions

The long-term sustainability of eHealth technology is associated with the fit between the technology, economic, social and organizational factors (Musango and Brent, 2010; Hay, Duffy and Whitfield, 2014). A technology is embedded within the three pillars of sustainability theory namely: economic, social and environmental (Musango and Brent, 2010). Sustainability theory and eHealth success factors (Appendix 1) were used to develop a conceptual framework for sustainable eHealth implementation through systems thinking process (Figure 3.2). A systems thinking was used to understand a set of interrelated elements of eHealth systems and system environment (Blanchard, 2008; Kossiakoff et al., 2011). The holistic worldview of systems thinking approach helps to ensure the long-term best interests of the system as a whole (Sterman, 2000). Technology acceptance, information quality and users satisfaction were identified as three key factors in the simulation study of sustainable eHealth implementation. The influence of socio-technical and techno-organisational factors are tested against acceptance rate, information quality and users satisfaction through a system dynamics modelling method.

The TAM and IS Success model were studied in connection to sustainable eHealth implementation in this research study. Literature studies showed that elements of these two models had been widely used to assess the success level of different healthcare technologies. The TAM focused on the processes and decision of technology acceptance, namely the implementation and confirmation stages of innovation diffusion model (Davis, 1989; Rogers, 1995). The individual perception and the social factors were the emphasis of the TAM to ensure acceptance of technology. The IS success model shared common success factors with TAM such as intention to use, technology use and satisfaction (DeLone and McLean, 1992, 2003). Moreover, the IS success addressed the technological factors under three quality groups, i.e. systems quality, information quality and services quality.

eHMIS and SmartCare systems in Ethiopia were the two eHealth cases selected for this research study. The large-scale implementation, relatively longer operational period and access to data were among the key factors for the inclusion of eHMIS and SmartCare for a case study in this research. Furthermore, eHMIS regarded as a successful system by the wide group of stakeholders relative to other eHealth systems. Compared to eHMIS, the diffusion of SmartCare was limited. The two systems had a long track record in Ethiopia since 2010 and believed to represent high and low diffusion scenarios of eHealth within healthcare facilities in Ethiopia. The selection of eHMIS and SmartCare for case study in this research gave a good emperical evidence to develop, verify and validate a system dynamic model of sustinable eHealth system.

The research addressed the dynamic complexity of sustainable eHealth implementation under three important sub-categories, i.e., socio-technical, techno-organizational and techno-economic. The research results were discussed to meet the objectives of this PhD research project. The related research objectives as indicated in Chapter 1.5.2 were:

- To assess the influence of socio-technical factors on the sustainable use eHealth systems.
- To determine the effect of techno-organizational factors on the successful implementation and sustainable use of eHealth technology.
- To evaluate the techno-economic features of sustainable eHealth use in a resource-constrained environment.

The conclusions were made in relation to the key objectives of the research shown above.

Objective 1: Influence of socio-technical factors on the sustainable use eHealth

A socio-technical system addresses dynamic and mutual influences among the social subsystems (people, tasks, and relationships), and technical subsystems (technologies, techniques, task performance methods, and work settings) (Harrison, Koppel and Bar-Lev, 2007). A systems thinking was applied to the technological dimension under the system, information, and services quality as indicated in the IS success model (See Appendix 2) and (DeLone and McLean, 2003); and to the constructs of TAM in the social dimension (See Appendix 3) and (Venkatesh et al., 2003; Venkatesh and Bala, 2008). Moreover, the TAM and IS success models were combined to develop the technology use dimension of the theoretical framework (See Figure 3.7 in Chapter 3). The interplay between the elements of eHealth success factors described in Appendix 1 and the feedback processes were captured by four feedback loops of the CLD through the systems thinking approach. The four feedback loops expressed with one balancing and three reinforcing loops represented the dynamic hypotheses of the socio-technical factors towards the sustainable use of eHealth systems.

The system dynamic model of socio-technical factors captured the nonlinear interaction of model parameters using SFD of the socio-technical model of technology acceptance (See 5.6). It began by showing the conversion of ‘potential users’ to ‘actual users’ at the rate of technology acceptance. The ‘actual users’ became either satisfied or dissatisfied users to influence the overall technology acceptance dynamics. The simulation model described the intervention processes to address end-users’ dissatisfaction by converting ‘dissatisfied users’ to ‘satisfied users’ before they became ‘terminated users’. The system dynamic simulation model depicted the feedbacks or nonlinear influences of socio-technical factors of technology acceptance. The direct and indirect structure tests confirmed the structural validly, dimensional consistency, the plausibility of the model to extreme input values and robustness in maintaining the behaviour pattern of simulation results. The rate of technology acceptance, information quality, and users’ satisfaction are used in the simulation study of sustainable eHealth implementation.

The acceptance rate of eHealth was the results of ‘individuals’ intention to use’ (See Appendix 3.1 and 3.2), social promotion, and social inhibitions (See Appendix 3.3). The end-users’ acceptance or the use of technology was described as the primary step of sustainable technology. The continue use of technology by the end-users produces quality information to make accurate decision. Hence, not only the acceptance of technology but also the level of information quality was critical for accurate decision-making. The quality of information product was affected not only by the ‘system quality’ but also by satisfaction of end-users. ‘Satisfied users’ improved the ‘information quality’ while ‘dissatisfied users’ reduced the quality of information product as indicated by the focus group (Appendix 4.4, Code Groups: Satisfaction).

The users' intention to use technology had developed from the end-users' ICT skills, technophobia, understanding of technology benefits, and the burden of technology use as perceived by end-users (Appendix 4.4, Code Groups: Benefits, Code: Ind_ICT use skill, and Code: Use_Burden). The main determinants of volunteer acceptance of technology appeared to develop from the high level of end-users ICT skills and understanding of the technology benefits. These findings correspond to the two determinates of technology acceptance (ease of use and usefulness) as postulated by Davis (1989) and confirmed by several other studies (Moores, 2012; Wallace and Sheetz, 2014; Fritz, Kebede and Tilahun, 2015). The ICT skills and work burden linked to the ease of use; whereas the understanding of the benefits related to the usefulness of technology as perceived by the end-users.

The simulation results and focus group discussions confirmed that the influence of 'individuals' intention to use' on the acceptance rate of eHMIS was high in the early years of the implementation. 'Effectiveness of training' improved ICT skill and created awareness about the benefits of technology resulting in better 'individuals' intention to use'. The simulation results confirmed that 'effectiveness of training' was a dominant factor to improve the 'acceptance rate' of eHMIS and SmartCare than 'system quality', 'services quality' or 'performance improvement rate'.

The simulation result showed that the dominant influence of 'individuals' perception to use' on technology acceptance shifted to the social factors over time. The social influence of 'promoters' and 'inhibitors' on acceptance of technology grew in the later years of implementation based on the 'actual users' level of satisfaction with the technology. The 'performance improvement rate' showed a stronger impact on the simulated 'satisfied users' compared to 'effectiveness of training', 'system quality' and 'services quality'. The ability of eHMIS and SmartCare to enhance the work performance of end-users strongly determined the level of users' satisfaction. In addition to the heavy workload of end-users due to the shortage of workforce, the use of paper in parallel to the digital system caused dissatisfaction among SmartCare users (Appendix 4.4, Code Groups: Satisfaction, and Code: Use_Burden). Involving all key stakeholder in setting system requirements as early as possible improved the technologies ability to improve work performance and reduce the work burden of end-users through digital systems. Wang and Liu (2005) indicated that training and communication efforts drive the perceived ease of use; whereas users' engagement influences the perception of technology usefulness.

This simulation study confirmed that 'system quality' had the strongest impact on 'information quality'. The influence of 'system quality' on 'information quality' was also reported in other studies (Gorla, Somers and Wong, 2010; Aggelidis and Chatzoglou, 2012). Furthermore, 'services quality' and 'performance improvement rate' had shown a moderate influence on the simulated 'information quality'. However, the influence of 'effectiveness of training' on the simulated 'information quality' was weak. 'Dissatisfied users' affected the accuracy, completeness and timeliness of data that in turn impacted the 'information quality'. The effort of improving 'information quality' should focus on developing reliability, easy to use, and capable system that meets end-users' requirements to keep users satisfied.

Objective 2: Effect of techno-organizational factors on the successful implementation and sustainable use of eHealth

The relationship between elements of sustainable eHealth technology goes beyond social factors to create dynamic interaction with organizational factors. The impact of organizational factors is evident to the successful implementation of eHealth technology in healthcare settings (Rippen et al., 2013). Based on the qualitative data analysis in ATLAS.ti, the key techno-organizational factors of sustainable eHealth implementation were discussed under resources readiness, management support, workflow alignment and organizational ICT culture.

The interplay between the techno-organizational factors of eHealth success factors were captured by three reinforcing loops and one balancing loop of the CLD through the systems thinking approach. The influence of resources readiness, management support, and change management on users' satisfaction and technology acceptance were addressed in the reinforcing loops while the balancing loop highlighted the impact of inhibitors on ICT culture within a healthcare organization. The socio-technical simulation model was expanded to incorporate these techno-organizational factors to develop, validate and verify the techno-organizational model of technology acceptance. The focus group data and the simulation results are discussed in an integrated way to explain the techno-organizational model of technology acceptance and system dynamics model validation tests.

'Resources readiness' addressed the adequacy of human resources and ICT infrastructure to implement successful eHealth system. The weak ICT infrastructure delayed the implementation of SmartCare and forced HMIS data to be transferred by CDs, flash disks or papers instead of an online system using an internet connection. The overall resources readiness was weak to the implementation of successful eHMIS and SmartCare systems in Ethiopia. However, management support was strong and executives showed a willingness to allocate human and ICT resources to the successful implementation of electronic health technologies. The electronic system success was influenced by the level of top management support (Al-Mamary, Shamsuddin and Aziati, 2014). The support from management increased the quality of data, use of information, informed decision making as indicated by the focus group team (Appendix 4.4, Code: Org_Management support).

Strong ‘management support’ helped to improve the ‘effectiveness of training’ which led to a better ‘individuals’ intention to use’ and high ‘acceptance rate’ of eHealth in the early years of implmentation (Appendix 4.4, Code: Org_Management support). Similar to the simulated socio-technical model results, the influence of ‘Individuals’ intention to use’ on the simulated ‘acceptance rate’ of eHMIS was a dominant factor in the techno-organizational model in the early years of eHealth implementation (See Figure 5.17 (a)). Hence ‘management support’ to increase the effectiveness of training could be an effective way of increasing technology acceptance in the early stage of eHealth implementation. The effectivenees of training and communication enhanced end-users ICT skill to improve ease of use and understanding of technology usefulness.

The culture of ICT within healthcare organizations improved as the end-users became familiar with technology and understood the value of its information product (Appendix 4.4, Core: Org_ICT culture). Aqil et al (2009) confirmed that information culture of a healthcare organization influenced the workflow process and affects the output of technology performance, i.e. the quality of data and continuous use of information. The growing culture of ICT within health facilities in Ethiopia improved the quality of data and the use of information of decision making; however, information dissemination culture was weak. The weak culture of teamwork in the process of HMIS data management contributed to poor data quality at the health facility level. Lluch (2011) indicated that the traditions of healthcare structures are strongly hierarchical which does not support teamwork, besides healthcare professionals have autonomy. The simulated ‘satisfaction rate’ of eHMIS and SmartCare increased with a good alignment of the technology with existing workflow processes.

The lack of ICT structure reduced the involvement of the ICT department in the selection of eHealth systems at the FMOH level. The IT structure was only available at the Federal and Regional Health Bureau levels in Ethiopia, yet it was not well staffed (Appendix 4.4, Code: Org_Organizational structure). Furthermore, end-users could not get access to speedy technical support in times of technical problems. Among organizational factors, the influence of ‘organizational ICT culture’ on the simulated ‘information quality’ of eHMIS and SmartCare was significant (Appendix 4.4, Code: Org_ICT culture). ‘System quality’ showed a greater impact on the simulated ‘information quality’ followed by users’ satisfaction factors than that of organizational factors (‘organizational ICT culture’). Generally, the socio-technical factors showed a higher influence on the simulated 'information quality' than the techno-organizational factors.

Both eHMIS and SmartCare systems implementation followed the existing manual workflow processes. However, the pharmacy stores were not included in the workflow processes of SmartCare or not integrated with existing electronic pharmacy management systems. The alignment of the technology workflow with existing workflow process reduced the end-users resistance. The FIIT framework emphasized the key contribution of the workflow process on the adoption of eHealth systems (Tsiknakis and Kouroubali, 2009). Rippen et al. (2013) also showed the fit between technology and clinician's workflow was one of the key reasons for the success of eHealth applications in the healthcare sectors.

The validity and robustness of techno-organizational model of eHealth acceptance was confirmed through direct and indirect structure tests. The focus group discussions, the interview data, the FMOH documents, eHMIS database and experts opinion were used to judge model parameter values. The boundary adequacy test, extreme condition tests and univariate and multivariate sensitivity analysis satisfied the validity of the model in maintaining the essential behaviour pattern described in the case study data.

The two organizational variables, 'average workforce turnover' and 'familiarity with electronic systems' produced significant numerical variations on the 'acceptance rate', 'information quality', and 'satisfied users'. The analysis further uncovered that 'information quality' was sensitive to changes in the 'familiarity with electronic systems' which was strong influencer of ICT culture of the organization. Both 'average workforce turnover' and 'familiarity with electronic systems' produced significant numerical variation on the 'satisfied users' of eHMIS and SmartCare.

The policy analysis on the two variables of techno-organizational factors, i.e., 'average workforce turnover' and 'familiarity with electronic systems', indicated that the 'average workforce turnover' influenced the simulated 'acceptance rate' of both eHMIS and SmartCare systems. Due to the growing influence of 'average workforce turnover', the influence of 'familiarity with electronic systems' on 'athe simulated cceptance rate' was not strong and consistent over time. The impact of 'average workforce turnover' on the simulated 'acceptance rate' of eHMIS and SmartCare was more significant in the later years of implementation. Therefore, retaining skilled workforces in the healthcare organization should be the focus in the techno-organizational dimension of sustainable eHealth implementation to increase the 'acceptance rate' of eHMIS and SmartCare in Ethiopia.

The overall impact of ‘average workforce turnover’ on the ‘information quality’ of eHMIS and SmartCare was insignificant compared to ‘familiarity with electronic systems’. On year four, a 0.2 (20%) increase in the ‘familiarity with electronic systems’ produced a 26% and 73% increase in the simulated ‘information quality’ of eHMIS and SmartCare respectively. Conversely, a 0.2 (20%) reduction in the ‘familiarity with electronic systems’ produced a 24% and 68% decrease in the simulated ‘information quality’ of eHMIS and SmartCare on the year four respectively. Therefore, the eHealth implementers should focus on increasing end-users familiarity with electronic systems to improve ICT culture of the organization. This can be achieved by preparing a trial period before the implementation of technology, offering on the job training and slow introduction of electronic systems.

Both ‘average workforce turnover’ and ‘familiarity with electronic systems’ demonstrated significant and growing influence on the simulated ‘satisfied users’ of eHMIS and SmartCare. The influence of these variables on ‘satisfied users’ grew stronger as the year progressed. The satisfaction of users increased with low workforce turnover due to reduced work burden on the end-users; moreover, familiarity with digital systems improved ease of use to enhance satisfaction.

Objective 3: Evaluation of the techno-economic features of sustainable eHealth use in a resource-constrained environment

The initial investment and long-term financial plan of ongoing costs are key economic factors that influence the long-term sustainability of eHealth implementation (De Rosis and Nuti, 2018). Several NGOs had been involved in the implementation of eHealth in Ethiopia but the coordinating role of the FMOH to create synergy was very weak. As a result, it was difficult to access the techno-economic data of eHMIS and SmartCare in Ethiopia. Schweitzer and Synowiec (2012) indicated that a small number of eHealth projects and little reliable economic data for eHealth implementation in developing countries were the major concern to address the techno-economic factors of sustainable eHealth implementation. The primary techno-economic data of eHMIS and SmartCare was not accessible to develop, test, verify and validate the system dynamics model of techno-economic factors. Therefore, three journal databases were searched for secondary data to aid the development and test of system dynamics model of techno-economic factors.

A comprehensive systematic review of three databases (ScienceDirect, PubMed, SAGE journal) was conducted looking for secondary data. The search terms e-Health, eHealth, econom*, finance* and fund* were used to identify studies published between 2007 and 2017. The majority (83%) of eHealth economic studies found in these three databases were published in the past 10 years. The publication trend of selected studies showed an increase in the number of eHealth economic articles from 3 studies in 2007 to 79 studies in 2017. This is an indication of increasing research interest in the economic side of eHealth implementation but the studies were dominantly from the developed world.

The three database search returned 527 articles that fulfilled the search criteria. The duplications, non-English and articles without full-text were removed. Of the remaining 411 articles, 335 (81.5%) failed to fundamentally address the economic factors and 61 (14.8%) did not discuss eHealth technologies. Finally, the included 15 articles addressed eHealth intervention in the domain of dermatology, depression disorder, eating disorder, emergency care, diabetes, discharge processes, migraine and ankle sprain. This showed that eHealth economic studies were tied to specific areas of health problems. The EHR was the dominant eHealth the application followed by the mHealth in the included articles.

Four of the included studies used a systematic review without conclusive results on the cost-effectiveness of eHealth interventions. These systematic review studies also indicated European countries and North America in their review with only one systematic review included studies from Latin America, Asia, and Oceania countries. The majority of non-systematic review studies (nine) were from Europe, one from the USA and another from Japan. There were no studies from the developing countries. The lack of primary and secondary data of the techno-economic factors of eHealth implementation made it difficult to build and test a system dynamics simulation model. However, the systematic review identified possible model parameters that can aid the development of a system dynamics model techno-economic factors in future research with the availability of some more data to validate the variables. The possible system dynamics parameters of techno-economic factors identified through a systematic review are economic incentives, funding durations, funding amount, funding sources and economic benefits.

The absence of eHealth economic studies in the developing countries suggested the need for techno-economic studies of eHealth systems in the developing world. The economic evaluation of eHealth systems depends on the type of services provided and the context of local settings, such as infrastructure and technologies investment needs (Bergmo, 2015). Besides, the stakeholders' willingness-to-pay (WTP) determines the economic attractiveness of eHealth (Paganini et al., 2017). Therefore, studies from the developed world cannot be transferred to developing countries. The availability of reliable economic evaluation of eHealth systems may improve the decision of providers and government bodies towards the implementation of sustainable and large-scale eHealth programs.

In this systematic review study, the majority of included studies (nine of fifteen studies, 60%) reported promising evidence of eHealth economic benefits either in terms of cost-effectiveness, cost-savings or cost-minimization. Five studies, of which four of them were systematic reviews, presented a mixed report without conclusive evidence on the cost-effectiveness of eHealth interventions. One study concluded that the web-based employment intervention aimed at increasing the quality of life for disabled employees was not cost-effective. However, these findings cannot be transferred to different settings due to the disease-specific nature of the studies and different economic settings of the study places.

The consideration of the financial factors associated with eHealth implementation as early as possible may significantly support the scale-up and long-term sustainability of technology in the later phase of implementation, especially in developing countries where there is a budget limitation. The financial support from international donors and NGOs only last the pilot or the initial phases of eHealth implementation. The responsibility of international donors and NGOs is significantly high in the early phases of eHealth implementation in developing countries which is believed to weaken over time (FMOH and MEASURE Evaluation, 2012). Hence the long-term sustainability of eHealth projects depends on the financial capacity and commitment of the FMOH.

8.3. Contributions to knowledge

The three pillars of sustainability, i.e. economic, social and organizational, are important sub-systems in which a technology is embedded (Musango and Brent, 2010). These factors play a key role in the success of eHealth implementation (Dodds and Venables, 2005). The long-term future of eHealth technology is associated with the fit between the technology, economic, social and organizational factors (Musango and Brent, 2010; Hay, Duffy and Whitfield, 2014). The key focus of models such as TAM and IS success is the acceptance of technology by the end-users to ensure the success of information technology implementations. However, the long-term sustainability of technology is affected by more factors than technology acceptance. The evaluation of sustainability of eHealth systems through acceptance of technology (Davis, 1989; Venkatesh and Davis, 2000), quality of information product (Aqil, Lippeveld and Hozumi, 2009; FMOH, 2016), and end-users satisfaction (DeLone and McLean, 1992, 2003) simultaneously was a unique contribution of this research to the study of sustainable eHealth technology implementation and use.

The use of focus group discussions and interview data of eHMIS and SmartCare cases to develop, validate and verify the system dynamics simulation model of socio-technical and techno-organizational factors eHealth systems is an original contribution of this research study.

Socio-technical

Most eHealth implementation frameworks are modelled linearly that do not clearly reflect the dynamic complexity in real life (Adam and De Savigny, 2012). Although TAM and IS success model are strong and widely used model to facilitate successful implementation of eHealth, they did not capture the non-linear and dynamic interplay of the model variables. The incorporation of dynamicity to TAM in the study of eHealth acceptance by adding time factors and applying system dynamics modelling was one of the unique contributions of this research study. TAM did not put time factors into consideration in explaining the influence of individual perceptions and social factors on technology acceptance. However, this simulation study discovered the varying influence of individual intentions and social factors through time on the acceptance rate of the technology and contributed to the body of knowledge.

The socio-technical system dynamics model of technology acceptance is originally developed by the author in this PhD research is a unique contribution to the knowledge base in the field of sustainable eHealth implementation. The influence of ‘individuals’ intention to use’ on the simulated ‘acceptance rate’ of eHMIS was high in the early years of the implementation. Whereas the social influence of ‘promoters’ and ‘inhibitors’ on the acceptance of technology grew in later years of implementation based on the ‘actual users’ level of satisfaction. This is the original contribution of the simulation research study in the field of eHealth acceptance in resources-constrained settings.

The simulation results showed that increasing ‘information quality’ through improved ‘system quality’ should be the main focus of policymakers. The impact of ‘information quality’ on end-users satisfaction is indicated in the IS success mode (DeLone and McLean, 1992, 2003). However, the influence of end-users satisfaction on ‘information quality’ was another unique contribution of this PhD research project to the body of knowledge.

Techno-organizational

The discussion of sustainable eHealth implementation in the techno-organizational dimension under ‘resources readiness’, ‘management support’, ‘workflow alignment’ and ‘organizational ICT culture’ based on literature and empirical evidence was the original contribution of this research study to the knowledge base. The availability of adequate and skilled human resources and ICT infrastructure to support the implementation of eHealth was addressed under ‘resources readiness’. The electronic system success was largely influenced by the level of top management port (Al-Mamary, Shamsuddin and Aziati, 2014). The level of management support strongly influenced ‘resources readiness’. The techno-organizational system dynamics model of technology acceptance is originally developed by the author as a unique contribution of this PhD research project.

This research study discovered ‘average workforce turnover’ and ‘familiarity with electronic systems’ were the two techno-organizational variables that showed significant influence on the simulated ‘acceptance rate’, ‘information quality’ and ‘satisfied users’. This is a unique contribution to the study of techno-organization dynamics of sustainable eHealth implementation. ‘Average workforce turnover’ and ‘familiarity with electronic systems’ influenced the two organizational factors, ‘resources readiness’ and ‘organizational ICT culture’, respectively.

The policy analysis showed that the simulated ‘acceptance rate’ of both eHMIS and SmartCare systems was strongly influenced by the ‘average workforce turnover’. The “what if” analysis also discovered that the impact of ‘familiarity with electronic systems’ on the simulated ‘information quality’ of eHMIS and SmartCare was stronger than that of ‘average workforce turnover’. The end-users’ familiarity with digital systems improved the organizational ICT culture and ease of technology use. Aqil et al (2009) indicated that organizational ICT culture was an important factor to influence information quality.

Moreover, both ‘average workforce turnover’ and ‘familiarity with electronic systems’ demonstrated significant and growing influence on the simulated ‘satisfied users’ of eHMIS and SmartCare. These are original contributions to the study of sustainable eHealth implementation in the techno-organizational dimensions. These findings identified the key techno-organizational factors that should be given attention to improve technology acceptance, information quality and users satisfaction for sustainable use of eHealth systems in resource-constrained settings.

Techno-economic

A comprehensive systematic literature review of three databases (ScienceDirect, PubMed, SAGE journal) confirmed an increasing number of publications in the techno-economic fields of eHealth technologies. This showed a growing research interest in the economic side of eHealth implementation but the studies were dominantly from developed world. The lack of eHealth economic studies from developing countries revealed the need for techno-economic studies of eHealth systems in the developing world. These are the unique contributions of systematic literature study of techno-organizational factors of sustainable eHealth implementation in the techno-economic dimension.

In this systematic review study, the majority of included studies (nine of fifteen studies, 60%) reported promising evidence of eHealth economic benefits either in terms of cost-effectiveness, cost-savings or cost-minimization. However, the findings were specific to the economic settings of the country, the type of eHealth application, the type of health problems addressed by eHealth intervention, and the perspective of stakeholder groups. This indicated that eHealth economic studies from the developed world could not be transferred to developing countries.

The original contribution of the systematic review includes the long-term sustainability of eHealth projects depend on the financial capacity and commitment of the FMOH. In the developing countries the majority eHealth systems are implemented in donor-driven programs. Donor-funded electronic health systems are typically disease specific interventions with short project span. The implementation of eHealth follows a different financial model in the developing and developed countries. Most eHealth implementation efforts in the developing countries are economically supported by the developed countries. As a result, a large number of donor-funded programs failed to achieve sustainable outcomes of eHealth implementation in many developing countries.

The identification of economic incentive, funding duration, funding amount, funding sources and economic benefits as a possible system dynamic model parameters to develop a techno-economic model of eHealth acceptance in future research is also the original contribution of this research study. Both eHMIS and SmartCare projects in Ethiopia are donor-driven programs. Therefore, techno-economic factors play a vital role in ensuring the long-term sustainability of both cases. Moreover, the long-term sustainability of the eHealth project in the techno-economic dimension mainly depends on the financial capacity and commitment of the FMOH, not on international donors. The financial factors associated with eHealth implementation must be considered in the early phase of the project by the FMOH and international donors to support the scale-up and long-term sustainability of technology.

8.4. Limitations and assumptions of the research study

The three pillars of sustainability, i.e., social, economic and environmental (organizational in this study) are considered as important factors in the process of implementing successful eHealth system (Dodds and Venables, 2005; Musango and Brent, 2010; Hay, Duffy and Whitfield, 2014). Although sustainability theory is usually associated with ecological studies, the three pillars of sustainability are assumed to be a valuable input to the study of sustainable eHealth implementation. This research assumes that the social, organizational and economic factors of healthcare institutions in resource-constrained and resource-abundant environments differ in the implementation of eHealth systems. Moreover, this study proposes successful eHealth systems need to demonstrate long-term sustainability.

Not only developing and developed countries, but also the rural and urban settings exhibit different organizational settings. The availability of ICT infrastructure and skilled workforces vary across healthcare institutions within the same country based on the geographic location of the healthcare institution, i.e., rural or urban. Often healthcare organizations in the urban surrounding have better access to ICT infrastructure and skilled workforce to implement eHealth systems. However, this research did not make any differentiation between rural and urban settings of a system environment.

This research study assumes that the healthcare sector is complex; hence the implementation of eHealth in the healthcare sector cannot be addressed by the traditional linear approach. Systems thinking and systems dynamics modelling is a coherent approach to address complex systems through feedback loops. In this study, the system dynamics simulation model is selected to be a logical process to address the complex factors in the ecosystem of sustainable eHealth systems implementation.

The five-stages of innovation-decision process can broadly be explained as the process and decisions of technology adoption and acceptance (Rogers, 2003). This study assumes that the eHMIS and SmartCare technology had been adopted at a healthcare institution level, i.e., the adoption process was already completed at a firm level. Hence the focus of this research study was the final two stages of the innovation diffusion processes (implementation and confirmation) that usually happens within the organizational settings (Rogers, 2003).

The organizational factors addressed in this research study were internal to the healthcare organization; i.e., under the organization's control. All other environmental factors external to the healthcare organization were not considered in this research study. The political, ethical and legal factors were described as important elements of sustainable eHealth implementation but they were outside the scope of this research study. The successful implementation of eHealth at the healthcare organization level is the basis to a national level success. Therefore, the boundary was set at the healthcare organization level for this research study. However, the national, regional and international collaborations can influence the overall success of eHealth systems.

The result-based intervention process of the sustainable project follows linear delivery processes (input, activities and outputs) and results (outcome and impacts). This study focused only on the delivery process section (i.e., input, processes and outputs) of result-based intervention process in the implementation of eHealth. The study acknowledges the influence of outcome and impact on the sustainability of eHealth systems. Nevertheless, the outcome and impact studies require a prolonged period which is not the scope of this research study. Besides, most eHealth technologies in developing countries are at a pilot phase that a large-scale eHealth implementation data is scarce to measure outcome and impact of the eHealth systems.

SmartCare and eHMIS systems were national EMR and decision support systems respectively in Ethiopia. Furthermore, these two cases represent relatively successful and unsuccessful eHealth systems in Ethiopia. Other eHealth cases such as mHealth, telemedicine and web based application are not included in this study. The two cases in this research study represented the cases in Ethiopia.

The socio-technical and techno-organizational model parameters were chosen from the focus group discussion and literature findings. However, the eHealth success parameters addressed in this research study were only limited to factors critical to the implementation of eHMIS and SmartCare revealed by the focus group team. The simulation model can be expanded further by incorporating other model variables reported in the literature and supported by empirical evidence.

The primary data of techno-economic factors were not accessible for eHMIS and SmartCare implementation in Ethiopia. Moreover, a systematic review of secondary data was not adequate to build and test a system dynamics model of techno-economic factors in developing countries. As a result, this research study only proposed possible model parameters to build and test a system dynamics simulation model of techno-economic factors of sustainable eHealth for future study.

8.5. Opportunities for future researches

This research study considered the impact of differences in the social, organizational and economic settings of developing and developed countries on the successful implmentation of eHealth. However, the rural and urban settings also exhibited different systems environment settings. This research study did not make any distinction between rural and urban in assessing eHealth system environment. Therefore, future studies can measure the rural and urban settings of eHealth systems environment to improve the long-term sustainability.

The result-based intervention process of the sustainable project underlines the importance of outcome and impacts of a project in addition to input, process and output. However, this research study only focused on input, processes and outputs during the implementation of eHealth. The outcome and impact factors were not addressed because most eHealth technologies were in the pilot phase that there were no data to measure the long-term outcome and impact of the eHealth systems. Future studies need to assess the outcomes and impacts of eHealth systems that progressed into a large-scale implementation.

The boundaries of the simulation model of sustainable eHealth implementation were set at organizational level. As a result, some important parameters such as political, legal factors were not considered in this model. Furthermore, ethical issues associated with the use of eHealth systems were not in the scope of this research study. Therefore, future researches can expand the boundaries to the national and regional level to include excluded parameters to assess the long-term sustainability of eHealth systems.

This study assumes that the majority of healthcare organizations understood the benefits and developed a good intention to adopt eHealth systems to improve the quality of care services. Therefore, the focus of the research study was the acceptance of technology by end-users. Future studies need to confirm the diffusion of eHealth systems within the healthcare organization. Furthermore, this research study only addressed EMR and a decision support system in Ethiopia. Hence, the research can be strengthened by including other eHealth cases such as mHealth, telemedicine and web-based application from developing countries. Future research efforts should consider other eHealth systems and compare the EMR and decision support experience of Ethiopia with other developing countries.

Several socio-technical and techno-organizational parameters were discovered from a literature review of published researches (Appendix 1). The parameters of a socio-technical and techno-organizational model of eHealth acceptance in this study were only linked to the focus group discussion and interview data of eHMIS and SmartCare users. The simulation model in this research can be further expanded with more socio-technical and techno-organizational model parameters to enhance the extensiveness of the model.

The techno-economic studies of this research study were only limited to systematic literature review due to a lack of primary data. Moreover, secondary data revealed that techno-economic factors are essential to the sustainability of eHealth but there were no techno-economic studies of eHealth systems from the developing world. Therefore, future research studies on techno-economic factors can significantly contribute to the long-term sustainability of eHealth in developing countries. Furthermore, the simulation model of eHealth acceptance in this research can be improved with the inclusion of techno-economic parameters. The techno-economic study needs to specify all initial investments and on-going costs, benefits to all key stakeholder groups, types of eHealth applications and settings for the study place.

9. REFERENCES

Aardoom, J. J. *et al.* (2016) 'Cost-utility of an internet-based intervention with or without therapist support in comparison with a waiting list for individuals with eating disorder symptoms: a randomized controlled trial.', *The International journal of eating disorders*. United States, 49(12), pp. 1068–1076. doi: 10.1002/eat.22587.

Aarts, J. (2012) 'Towards safe electronic health records: A socio-technical perspective and the need for incident reporting', *Health Policy and Technology*, 1(1), pp. 8–15. doi: 10.1016/j.hlpt.2012.01.008.

Aarts, J., Peel, V. and Wright, G. (1998) 'Organizational issues in health informatics: a model approach', *International Journal of Medical Informatics*, 52(1–3), pp. 235–242. doi: 10.1016/S1386-5056(98)00142-7.

Adam, T. and De Savigny, D. (2012) 'Systems thinking for strengthening health systems in LMICs: Need for a paradigm shift', *Health Policy and Planning*, 27(SUPPL. 4). doi: 10.1093/heapol/czs084.

Adams, K. M. *et al.* (2014) 'Systems Theory as the Foundation for Understanding Systems', *Systems Engineering*, 17(1), pp. 112–123. doi: 10.1002/sys.

Adebesin, F. *et al.* (2013) 'Barriers & challenges to the adoption of E-Health standards in Africa'. Available at: http://researchspace.csir.co.za/dspace/handle/10204/6910 (Accessed: 9 July 2014).

Adler-Milstein, J., Everson, J. and Lee, S.-Y. D. (2015) 'EHR Adoption and Hospital Performance: Time-Related Effects', *Health Services Research*. Blackwell Publishing Inc., 50(6), pp. 1751–1771. doi: 10.1111/1475-6773.12406.

Aggelidis, V. P. and Chatzoglou, P. D. (2009) 'Using a modified technology acceptance model in hospitals', *International Journal of Medical Informatics*, 78(2), pp. 115–126. doi: 10.1016/j.ijmedinf.2008.06.006.

Aggelidis, V. P. and Chatzoglou, P. D. (2012) 'Hospital information systems : Measuring end user computing satisfaction (EUCS)', *Journal of Biomedical Informatics*. Elsevier Inc., 45(3), pp. 566–579. doi: 10.1016/j.jbi.2012.02.009.

Aizstrauta, D. and Ginters, E. (2015) 'Integrated Acceptance and Sustainability Assessment Model Transformations into Executable System Dynamics Model', *Procedia Computer Science*, 77, pp. 92–97. doi: 10.1016/j.procs.2015.12.364.

Akematsu, Y. and Tsuji, M. (2010) 'Empirical analysis of the reduction of medical expenditures by e-health.', *Studies in health technology and informatics*. Netherlands, 160(Pt 1), pp. 754–758.

Al-Aswad, A. and Brownsell, S. (2013) 'A Review Paper of the Current Status of Electronic Health Records Adoption Worldwide: The Gap between Developed and Developing Countries', *… in Developing Countries*, 7(2), pp. 153–164. Available at: http://www.jhidc.org/index.php/jhidc/article/view/106 (Accessed: 10 July 2014).

Al-Mamary, Y. H., Shamsuddin, A. and Aziati, N. (2014) 'Factors Affecting Successful Adoption of Management Information Systems in Organizations towards Enhancing Organizational Performance', *American Journal of Systems and Software*, 2(5), pp. 121–126. doi: 10.12691/ajss-2-5-2.

ALLIANCE (2008) *The National Alliance for Health Information Technology Report to the Office of the National Coordinator for Health Information Technology on Defining Key Health Information Terms*. Chicago, IL. Available at: http://www.hitechanswers.net/wp-content/uploads/2013/05/NAHIT-Definitions2008.pdf.

Anderson, J. G. (2007) 'Social, ethical and legal barriers to E-health', *International Journal of Medical Informatics*, 76(5–6), pp. 480–483. doi: 10.1016/j.ijmedinf.2006.09.016.

Aqil, A., Lippeveld, T. and Hozumi, D. (2009) 'PRISM framework: A paradigm shift for designing, strengthening and evaluating routine health information systems', *Health Policy and Planning*, 24(3), pp. 217–228. doi: 10.1093/heapol/czp010.

ATA (2012) *What is Telemedicine?*, *American Telemedicine Association*. Available at: http://www.americantelemed.org/about-telemedicine/what-is-telemedicine#.Vt_lwtBby9Y (Accessed: 9 March 2016).

ATLAS.ti (2019) *What is ATLAS.ti?* Available at: https://atlasti.com/product/what-is-atlas-ti/ (Accessed: 2 February 2019).

Balanced Scorecard Institute (2013) *Ethiopia Health Sector – Federal Ministry of Health Case Study*. Cary.

Barlas, Y. (1994) 'Model Validation in System Dynamics', *Proceedings of the 1994 International System Dynamics Conference*, pp. 1–10. doi: 10.1002/(SICI)1099-1727(199623)12:3<183::AID-SDR103>3.0.CO;2-4.

Barlas, Y. (1996) 'Formal aspects of model validity and validation in system dynamics.', *System Dynamics Review*, 12(3), pp. 183–210. doi: 10.1002/(SICI)1099-1727(199623)12:3<183::AID-SDR103>3.0.CO;2-4.

Barlas, Y. (2002) 'System Dynamics: systemic feedback modeling for policy analysis', *Knowledge for Sustainable Development: An Insight into the Encyclopedia of Life Support Systems*, pp. 1131–1175. doi: 10.1002/(SICI)1099-1727(199623)12:3<183::AID-SDR103>3.0.CO;2-4.

Barlas, Y. (2016) 'Credibility , validity and testing of Dynamic Simulation Models', in *SIMULTECH, 6th International Conference on Simulation and Modeling Methodologies, Technologies and Applications*. Lisbon, Portugal. Available at: simultech.org/.

Barlas, Y. and Carpenter, S. (1990) 'Philosophical roots of model validation: Two paradigms', *System Dynamics Review*, 6(2), pp. 148–166. doi: 10.1002/sdr.4260060203.

Baxter, G. and Sommerville, I. (2011) 'Socio-technical systems: From design methods to systems engineering', *Interacting with Computers*. Elsevier B.V., 23(1), pp. 4–17. doi: 10.1016/j.intcom.2010.07.003.

Belay, H., Azim, T. and Kassahun, H. (2013) *Assessment of Health Management Information System (HMIS) Performance in SNNPR , Ethiopia*. Hawassa.

Bergmo, T. S. (2015) 'How to Measure Costs and Benefits of eHealth Interventions: An Overview of Methods and Frameworks', *Journal of Medical Internet Research*, 17(11), p. e254. doi: 10.2196/jmir.4521.

Van Beurden, E. K. *et al.* (2013) 'Making sense in a complex landscape: How the cynefin framework from complex adaptive systems theory can inform health promotion practice', *Health Promotion International*, 28(1), pp. 73–83. doi: 10.1093/heapro/dar089.

Beuscart-Zéphir, M.-C., Aarts, J. and Elkin, P. (2010) 'Human factors engineering for IT clinical applications', *Stud Health Technol Inform*, 79, pp. 223–224. doi: 10.1016/j.ijmedinf.2010.01.010.

Bilbao-Osorio, B., Dutta, S. and Bruno Lanvin (2014) *The Global Information Technology Report 2014: Rewards and Risks of Big Data*. Geneva. Available at: http://www3.weforum.org/docs/WEF_GlobalInformationTechnology_Report_2014.pdf.

Blanchard, B. S. (2008) *System Engineering Management*. 4th Editio. New Jersey: John Wiley & Sons.

Blumberg, B., Cooper, D. R. and Schindler, P. S. (2008) *Business Research Methods*. 2nd edn. London: McGraw-Hill.

Boonstra, A. and Broekhuis, M. (2010) 'Barriers to the acceptance of electronic medical records by physicians from systematic review to taxonomy and interventions.', *BMC health services research*. England, 10(1), p. 231. doi: 10.1186/1472-6963-10-231.

Buccoliero, L., Calciolari, S. and Marsilio, M. (2008) 'A methodological and operative framework for the evaluation of an e-health project.', *The International journal of health planning and management*. England, 23(1), pp. 3–20. doi: 10.1002/hpm.881.

Buys, L. *et al.* (2014) 'Creating a Sustainability Scorecard as a predictive tool for measuring the complex social, economic and environmental impacts of industries, a case study: Assessing the viability and sustainability of the dairy industry', *Journal of Environmental Management*, 133, pp. 184–192. Available at: www.elsevier.com/locate/jenvman.

Byrne, C. M. *et al.* (2010) 'The value from investments in health information technology at the U.S. Department of Veterans Affairs.', *Health affairs (Project Hope)*, 29(4), pp. 629–38. doi: 10.1377/hlthaff.2010.0119.

Carayon, P. (2006) 'Human factors of complex sociotechnical systems', *Applied Ergonomics*, 37(4 SPEC. ISS.), pp. 525–535. doi: 10.1016/j.apergo.2006.04.011.

Cargo, M. (2013) *South Africa mHealth Landscape*.

Chang, H.-C., Liu, C.-F. and Hwang, H.-G. (2011) 'Exploring Nursing E-Learning Systems Success Based on Information System Success Model', *CIN: Computers, Informatics, Nursing*, 29(12), pp. 741–747. doi: 10.1097/NCN.0b013e31821a1651.

Chang, I.-C. and Hsu, H.-M. (2012) 'Predicting Medical Staff Intention to Use an Online Reporting System with Modified Unified Theory of Acceptance and Use of Technology', *Telemedicine journal and e-health : the official journal of the American Telemedicine Association*, 18(1), pp. 67–73. doi: 10.1089/tmj.2011.0048.

Chen, Y. (2011) 'Understanding Technology Adoption through System Dynamics Approach: A Case Study of RFID Technology', *2011 IFIP 9th International Conference on Embedded and Ubiquitous Computing*, pp. 366–371. doi: 10.1109/EUC.2011.75.

Chilisa, B. (2012) *Indigenous Research Methodologies*. Los Angeles: SAGE Publications.

Chilisa, B. and Kawulich, B. (2012) 'Selecting a Research Approach:Paradigm, Methodology, and Methods', *Doing Social Research A Global Context*, (October), pp. 51–61. Available at: https://www.researchgate.net/profile/Barbara_Kawulich/publication/257944787_Selecting_a_research_approach_Paradigm_methodology_and_methods/links/56166fc308ae37cfe40910fc/Selecting-a-research-approach-Paradigm-methodology-and-methods.pdf.

Chuang, S., Howley, P. P. and Undercurrent, A. (2012) 'Beyond Root Cause Analysis : An Enriched System Oriented Event Analysis Model for Wide Application', pp. 427–438. doi: 10.1002/sys.

Chung, Y. (2016) 'Trainee Readiness For Diversity Training', *Journal of Diversity Management (JDM)*, 8(2), p. 77. doi: 10.19030/jdm.v8i2.8234.

Coleman, A. (2016) 'Factors influencing e-health implementation by medical doctors in public hospitals in Zimbabwe', pp. 1–9.

Cooper, D. R. and Schindler, P. S. (2001) *Business Research Methods*. Seventh Ed. Singapore: McGraw-Hill.

Cresswell, K. and Sheikh, A. (2012) 'Organizational issues in the implementation and adoption of health information technology innovations : An interpretative review', *International Journal of Medical Informatics*, 82(5), pp. e73–e86. doi: 10.1016/j.ijmedinf.2012.10.007.

CSA and ICF (2012) *Ethiopia Demographic and Health Survey*. Addis Ababa, Ethiopia and Calverton, Maryland, USA. Available at: https://dhsprogram.com/pubs/pdf/FR255/FR255.pdf.

Cummins, R. A. and Gullone, E. (2000) 'Why we should not use 5-point Likert scales: The case for subjective quality of life measurement', in *Second International Conference on Quality of Life in Cities*. Singapore, pp. 74–93.

Da´valos, M. E. *et al.* (2009) 'Economic Evaluation of Telemedicine : Review of the Literature and Research Guidlines for Benefit-Cost Analysis', *TELEMEDICINE and e-HEALTH*, 15(10), pp. 933–948. doi: 10.1089=tmj.2009.0067.

Davis, F. D. (1989) 'Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology', *MIS Quarterly*, 13(3), pp. 319–340.

De-Wall, J. and Buys, A. J. (2007) 'Interoperability and Standardisation in he De[artment of Defence: an Exploratory Study', *SA Journal of Industrial Engineering*, 18(May), pp. 175–190.

DeCuir-Gunby, J. T., Marshall, P. L. and McCulloch, A. W. (2011) 'Developing and using a codebook for the analysis of interview data: An example from a professional development research project', *Field Methods*, 23(2), pp. 136–155. doi: 10.1177/1525822X10388468.

DeLone, W. H. and McLean, E. R. (1992) 'Information Systems Success: The Quest for the Dependent Variable', *Information Systems Research*, 3(1), pp. 60–95. doi: 10.1287/isre.3.1.60.

DeLone, W. H. and McLean, E. R. (2003) 'The DeLone and McLean Model of Information Systems Success : A Ten-Year Update', *Journal of Management Information Systems*, 19(4), pp. 9–30. doi: 10.1073/pnas.0914199107.

Design, L., Rashedi, R. and Hegazy, T. (2016) 'Strategic policy analysis for infrastructure rehabilitation using system dynamics', *Structure and Infrastructure Engineering*. Taylor & Francis, 12(6), pp. 667–681. doi: 10.1080/15732479.2015.1038723.

Diesendorf, M. (2000) 'Sustainability and sustainable development', in *Dunphy, D, Benveniste, J, Griffiths, A and Sutton, P (eds) Sustainability: The corporate challenge of 21st century*. Sydney: Allen & Unwin, chap. 2, pp. 19–37.

Djorlolo, S. A. and Ellingsen, G. (2013) 'Readiness Assessment for Implementation of Electronic Patient Record in Ghana : A Case of University of Ghana Hospital', 7(2), pp. 128–140.

Dodds, R. and Venables, R. (2005) *Engineering for Sustainable Development : Guiding Principles*. London. Available at: www.raeng.org.uk.

Driessen, J. *et al.* (2013) 'Modeling return on investment for an electronic medical record system in Lilongwe, Malawi.', *Journal of the American Medical Informatics Association : JAMIA*, 20(4), pp. 743–748. doi: 10.1136/amiajnl-2012-001242.

Dutta, S. and Mia, I. (2010) *Global Information Technology Report 2009 – 2010: ICT for Sustainability*. Geneva.

van Dyk, L. *et al.* (2012) 'Business Models for Sustained eHealth Implementation: Lessons from Two Continents', *Proceedings of the 42th International Conference for Computers and Industrial Engineering*, 234(July), pp. 1–16.

van Dyk, L. (2014) 'A review of telehealth service implementation frameworks.', *International journal of environmental research and public health*, 11(2), pp. 1279–98. doi: 10.3390/ijerph110201279.

Easterby-Smith, M., Thorpe, R. and Jackson, P. R. (2012) *Management Research*. SAGE edge.

Elbert, N. J. *et al.* (2014) 'Effectiveness and Cost-Effectiveness of eHealth Interventions in Somatic Diseases: A Systematic Review of Systematic Reviews and Meta-Analyses', *Journal of Medical Internet Research*. Canada, 16(4), p. e110. doi: 10.2196/jmir.2790.

EPHI (2014) *Ethiopia Service Provision Assessment Plus Survey*. Addis Ababa, Ethiopia.

EPHI and FMOH (2018) *Services Availability and Readiness Assessment (SARA)*. Addis Ababa.

EPHI, FMOH and WHO (2016) *Ethiopia Health Data Quality Review : System Assessment and Data Verification 2016*. Addis Ababa, Ethiopia.

EPHI, FMOH and WHO (2017) *Ethiopia Service Availability and Readiness Assessment 2016 Summary Report*. Addis Ababa, Ethiopia. Available at: http://www.ephi.gov.et.

Ethiopian Federal Ministry of Health (2014) *HMIS Procedures Manual : Data Recording and Reporting Procedures*. Addis Ababa.

Ethiopian Ministry of Revenues (2018) *Depreciation of Depreciable Assets and Business Intangibles*. Available at: http://www.erca.gov.et/index.php/news/international-news/521-depreciation-of-depreciable-assets-and-business-intangibles (Accessed: 4 February 2019).

Eysenbach, G. (2001) 'What is e-health?', *Journal of Medical Internet Research*, 3(2), p. e20. Available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1761894/.

Fanta, G. B. and Erasmus, L. (2014) 'A Systems Engineering Perspective on eHealth Implementations' Efficiency and Effectiveness: A Case Study involving suppliers', in *INCOSE International Symposium*. Cape Town, pp. 55–68. doi: 10.1002/j.2334-5837.2014.00006.x.

Fiksel, J. (2003) 'Designing resilient, sustainable systems.', *Environmental science & technology*, 37(23), pp. 5330–5339. Available at: http://www.ncbi.nlm.nih.gov/pubmed/14700317.

Finstad, K. (2010) 'Response Interpolation and Scale Sensitivity: Evidence Against 5-Point Scales', *Journal of Usability Studies*, 5(3), pp. 104–110.

Fischer, S. H. *et al.* (2014) 'Acceptance and use of health information technology by community-dwelling elders', *International Journal of Medical Informatics*. Elsevier Ireland Ltd, 83(9), pp. 624–635. doi: 10.1016/j.ijmedinf.2014.06.005.

FMOH (2014a) *Assessment of the Medical Record Units of Federal and Addis Ababa Hospitals*. Addis Ababa, Ethiopia.

FMOH (2014b) *Fiche HospitalEMR visit report*, *Contract*. Addis Ababa.

FMOH (2014c) *Preliminary Report on the 3rd Routine Data Quality Assessment*. Addis Ababa, Ethiopia.

FMOH (2015) *HSTP-Health Sector transformation plan*. Addis Ababa, Ethiopia.

FMOH (2016) *Information Revolution Roadmap*. Addis Ababa, Ethiopia.

FMOH, CDC and TUTAPE (2011) 'SMARTCARE ELECTRONIC HEALTH RECORD SYSTEM USER'S MANUAL'.

FMOH and MEASURE Evaluation (2012) *USAID HMIS Scale-up Project in Ethiopia*. Addis Ababa. Available at: http://www.jsi.com/JSIInternet/Inc/Common/_download_pub.cfm?id=12272&lid=3.

Forrester, J. W. (1994) 'System Dynamics, Systems Thinking, and Soft OR', *System Dynamics Review*, 10(2), pp. 1–14. doi: 10.1002/sdr.4260100211.

Forrester, J. W. and Albin, S. (1997) 'Building a System Dynamics Model Part 1 : Conceptualization'.

Forrester, J. W. and Senge, P. M. (1980) ‘Tests for building confidence in system dynamics models’, *TIMS Studies in the Management Sciences*, pp. 209–228.

Franz-Vasdeki, J. *et al.* (2015) ‘Taking mHealth Solutions to Scale: Enabling Environments and Successful Implementation’, *Journal of Mobile Technology in Medicine*, 4(1), pp. 35–38. doi: 10.7309/jmtm.4.1.8.

Fritz, F., Tilahun, B. and Dugas, M. (2015) ‘Success criteria for electronic medical record implementations in low-resource settings: a systematic review’, *Journal of the American Medical Informatics Association*, 22(2), pp. 479–488. doi: 10.1093/jamia/ocu038.

Gagnon, M. P. *et al.* (2012) ‘Using a modified technology acceptance model to evaluate healthcare professionals’ adoption of a new telemonitoring system’, *Telemed J E Health*, 18(1), pp. 54–59. doi: 10.1089/tmj.2011.0066.

Garcia-Smith, D. and Effken, J. A. (2013) ‘Development and initial evaluation of the Clinical Information Systems Success Model (CISSM)’, *International Journal of Medical Informatics*. Elsevier Ireland Ltd, 82(6), pp. 539–552. doi: 10.1016/j.ijmedinf.2013.01.011.

Geisler, E. and Heller, O. (eds) (1996) *Managing Technology in Healthcare*. Norwell: Kluwer Academic Publishers.

van Gemert-Pijnen, J. E. W. C. *et al.* (2011) ‘A holistic framework to improve the uptake and impact of eHealth technologies.’, *Journal of medical Internet research*, 13(4), p. e111. doi: 10.2196/jmir.1672.

Gesesew, H. A. *et al.* (2016) ‘Health workforce acquisition, retention and turnover in southwest Ethiopian health institutions’, *Ethiopian Journal of Health Sciences*, 26(4), p. 331. doi: 10.4314/ejhs.v26i4.5.

Gmelin, H. and Seuring, S. (2014) ‘Determinants of a sustainable new product development’, *Journal of Cleaner Production*. Elsevier Ltd, 69, pp. 1–9. doi: 10.1016/j.jclepro.2014.01.053.

Gorla, N., Somers, T. M. and Wong, B. (2010) ‘Organizational impact of system quality , information quality , and service quality’, *Journal of Strategic Information Systems*. Elsevier B.V., 19(3), pp. 207–228. doi: 10.1016/j.jsis.2010.05.001.

Gregor, S. and Hevner, A. R. (2013) ‘Positioning and Presenting Design Science Research for Maximum Impact’, *MIS Quarterly*, 37(2), pp. 337–355. doi: 10.2753/MIS0742-1222240302.

Guba, E. G. (1990) *The Paradigm Dialog*. Newbury Park: SAGE Publications.

Hadji, B. *et al.* (2016) ‘14 Years longitudinal evaluation of clinical information systems acceptance: The HEGP case’, *International Journal of Medical Informatics*, 86, pp. 20–29. doi: 10.1016/j.ijmedinf.2015.11.016.

Haileamlak, A. (2018) ‘How Can Ethiopia Mitigate the Health Workforce Gap to Meet Universal Health Coverage ?’, *Ethiopian journal of health sciences*, 28(3), pp. 249–250.

Hale, J. L., Householder, B. J. and Greene, K. L. (2003) ‘The Theory of Reasoned Action’, in *The Persuasion Handbook: Developments in Theory and Practice*. 2455 Teller Road, Thousand Oaks California 91320 United States: SAGE Publications, Inc., pp. 259–286. doi: 10.4135/9781412976046.n14.

Harris, J. M. (2003) ‘Sustainability and Sustainable Development’, *International Society for Ecological Economics*, pp. 1–12. Available at: http://isecoeco.org/pdf/susdev.pdf.

Harrison, M. I., Koppel, R. and Bar-Lev, S. (2007) ‘Unintended consequences of information technologies in health care--an interactive sociotechnical analysis.’, *Journal of the American Medical Informatics Association : JAMIA*, 14(5), pp. 542–9. doi: 10.1197/jamia.M2384.

Hay, L., Duffy, A. and Whitfield, R. I. (2014) ‘The Sustainability Cycle and Loop: models for a more unified understanding of sustainability.', *Journal of environmental management*, 133, pp. 232–57. doi: 10.1016/j.jenvman.2013.11.048.

Hebert, R. J. (2011) 'Economics of health informatics in developing countries.', *Studies in health technology and informatics*. Netherlands, 164, pp. 162–167.

Hekimo, M. and Barlas, Y. (2017) 'Sensitivity analysis for models with multiple behavior modes : a method based on behavior pattern measures', 32(3), pp. 332–362. doi: 10.1002/sdr.1568.

Hekimoglu, M. and Barlas, Y. (2014) 'Sensitivity Analysis of System Dynamics Models by Behavior Pattern Measures', *Systemdynamics.Org*, 54(2), pp. 1–31. doi: 10.1002/job.173.

Hevner, A. *et al.* (2004) 'Design Science Research in Information Systems', *MIS quarterly*, 28(1), pp. 75–105. doi: 10.2307/25148625.

Hevner, A. and Chatterjee, S. (2010) *Design Research in Information Systems: Theory and Practice*. Boston, MA: Springer US (Integrated Series in Information Systems). doi: 10.1007/978-1-4419-5653-8.

Hevner, A. R. (2007) 'A Three Cycle View of Design Science Research', *Scandinavian Journal of Information Systems*, 19(2), pp. 1–6. Available at: http://aisel.aisnet.org/sjis/vol19/iss2/4%0AThis.

Holden, R. J. and Karsh, B.-T. (2010) 'The technology acceptance model: its past and its future in health care.', *Journal of biomedical informatics*. Elsevier Inc., 43(1), pp. 159–172. doi: 10.1016/j.jbi.2009.07.002.

Hou, C. (2012) 'Examining the effect of user satisfaction on system usage and individual performance with business intelligence systems : An empirical study of Taiwan ' s electronics industry', *International Journal of Information Management*, 32, pp. 560–573. doi: 10.1016/j.ijinfomgt.2012.03.001.

Huang, F., Blaschke, S. and Lucas, H. (2017) 'Beyond pilotitis: Taking digital health interventions to the national level in China and Uganda', *Globalization and Health*. Globalization and Health, 13(1), pp. 1–11. doi: 10.1186/s12992-017-0275-z.

Iivari, J. (2005) 'An Empirical Test of the Model of Information System Success', *The DATA BASE for Advances in Information Systems*, 36(2), pp. 8–27. doi: 10.1145/1066149.1066152.

International Energy Agency (2019) *Key stats for Ethiopia, 1990-2016*. Available at: https://www.iea.org/countries/Ethiopia/ (Accessed: 3 February 2019).

Isabalija, S. R., Mbarika, V. and Kituyi, G. M. (2013) 'A framework for sustainable implementation of e-medicine in transitioning countries.', *International journal of telemedicine and applications*, 2013, p. 615617. doi: 10.1155/2013/615617.

Islam, a (2004) 'Health-related millennium development goals: policy challenges for Pakistan.', *JPMA. The Journal of the Pakistan Medical Association*, 54(4), pp. 175–81. Available at: http://www.ncbi.nlm.nih.gov/pubmed/15241993.

ISO (2012) *Health informatics - Capacity-based eHealth architechure roadmap - Part 1: Overview of national eHealth initiatives*. Geneva.

ITU (2015) *Measuring the information society report 2015*, *ITU*. Geneva. Available at: www.itu.int.

ITU (2019) *Percentage of Individuals using the Internet*. Available at: https://www.itu.int (Accessed: 4 February 2019).

Jadun, P. *et al.* (2018) 'Application of a variance-based sensitivity analysis method to the Biomass Scenario Learning Model', 33(3), pp. 311–335. doi: 10.1002/sdr.1594.

Jahangirian, M. and Taylor, S. J. E. (2013) ‘Profiling e-health projects in Africa: trends and funding patterns’, *Information Development*. doi: 10.1177/0266666913511478.

Jahangirian, M. and Taylor, S. J. E. (2015) ‘Profiling e-health projects in Africa: trends and funding patterns’, *Information Development*, 31(3), pp. 199–218. doi: 10.1177/0266666913511478.

Jarosławski, S. and Saberwal, G. (2014) ‘In eHealth in India today, the nature of work, the challenges and the finances: an interview-based study.’, *BMC medical informatics and decision making*, 14, p. 1. doi: 10.1186/1472-6947-14-1.

Jones, T. *et al.* (2009) ‘An economic analysis of the national shared Emergency Care Summary in Scotland.’, *Journal of telemedicine and telecare*. England, 15(3), pp. 129–131. doi: 10.1258/jtt.2009.003007.

Jordan, P. W. *et al.* (1996) *Usability Evaluation In Industry*. London: Taylor & Francis.

Kanjo, C. (2011) ‘Ragmatism or Policy: Implications on Health Infornmation Systems Success’, *EJISDC*, 48(1), pp. 1–20.

Kendall J M (2003) ‘Designing a research project: randomised controlled trials and their principles’, *Emergency Medicine Journal*, 20, pp. 164–168.

Kern, S. E. and Jaron, D. (2003) ‘Healthcare technology, economics, and policy: An evolving balance’, *IEEE Engineering in Medicine and Biology Magazine*, 22(1), pp. 16–19. doi: 10.1109/MEMB.2003.1191444.

Khoja, S. *et al.* (2007) ‘e-Health Readiness Assessment Tools for Healthcare Institutions in Developing Countries’, *TELEMEDICINE and e-HEALTH*, 13(4), pp. 425–431. doi: 10.1089/tmj.2006.0064.

Khoja, S. *et al.* (2013) ‘Conceptual framework for development of comprehensive e-health evaluation tool.’, *Telemedicine journal and e-health : the official journal of the American Telemedicine Association*. United States, 19(1), pp. 48–53. doi: 10.1089/tmj.2012.0073.

Khoumbati, K., Themistocleous, M. and Irani, Z. (2006) ‘Evaluating the adoption of enterprise application integration in health-care organizations’, *Journal of Management Information Systems*, 22(4), pp. 69–108. doi: 10.2753/MIS0742-1222220404.

Kimaro, H. and Nhampossa, J. (2004) ‘The challenges of sustainability of health information systems in developing countries: comparative case studies of Mozambique and Tanzania’, *Journal of Health Informatics in Developing Countries*, 1(1), pp. 1–10. doi: 10.1.1.144.2443.

Kossiakoff, A. *et al.* (2011) *Systems Engineering Principles and Practice*. 2nd ed. New Jersey: John Wiley & Sons.

Kuechler, B. and Petter, S. (2017) ‘Design Science Research in Information Systems’, *Design Science Research in Information Systems*, pp. 1–66. doi: 10.1007/978-3-642-29863-9.

Kumar, R. (2011) *Research Methodology: A Step-by-Step Guide for Beginners*. 3rd edn. London: SAGE Publications.

de la Torre-Diez, I. *et al.* (2015) ‘Cost-utility and cost-effectiveness studies of telemedicine, electronic, and mobile health systems in the literature: a systematic review.’, *Telemedicine journal and e-health : the official journal of the American Telemedicine Association*. United States, 21(2), pp. 81–85. doi: 10.1089/tmj.2014.0053.

Leedy, P. D. and Ormrod, J. E. (2010) *Practical Research: Planning and Design*. 9th Editio. New Jersey: Pearson Education, Inc.

Leon, N., Schneider, H. and Daviaud, E. (2012) ‘Applying a framework for assessing the health system challenges to scaling up mHealth in South Africa.’, *BMC medical informatics and* *decision making*. England, 12(123), p. 123. doi: 10.1186/1472-6947-12-123.

Liberati, A. *et al.* (2009) ‘The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration’, *Bmj*, 339(jul21 1), pp. b2700–b2700. doi: 10.1136/bmj.b2700.

Lipsitz, L. A. (2013) ‘Understanding Health Care as a Complex System: The Foundation for Unintended Consequences’, *American Medical Association*, 308(3), pp. 243–244. doi: 10.1001/jama.2012.7551.

Lluch, M. (2011) ‘Healthcare professionals’ organisational barriers to health information technologies-a literature review.’, *International journal of medical informatics*, 80(12), pp. 849–62. doi: 10.1016/j.ijmedinf.2011.09.005.

Ludwick, D. A. and Doucette, J. (2009) ‘Adopting electronic medical records in primary care: lessons learned from health information systems implementation experience in seven countries.’, *International journal of medical informatics*, 78(1), pp. 22–31. doi: 10.1016/j.ijmedinf.2008.06.005.

Luna-Reyes, L. F. and Andersen, D. L. (2003) ‘Collecting and analyzing qualitative data for system dynamics: Methods and models’, *System Dynamics Review*, 19(4), pp. 271–296. doi: 10.1002/sdr.280.

Luna, D. *et al.* (2014) ‘Health Informatics in Developing Countries: Going beyond Pilot Practices to Sustainable Implementations: A Review of the Current Challenges’, *Healthcare Informatics Research*. Korea (South), 20(1), pp. 3–10. doi: 10.4258/hir.2014.20.1.3.

Lyons, G. J. and Duggan, J. (2017) ‘System dynamics modelling to support policy analysis for sustainable health care System dynamics modelling to support policy analysis for sustainable health care’, 7778. doi: 10.1057/jos.2014.15.

Maffei, R., Burciago, D. and Dunn, K. (2009) ‘Determining business models for financial sustainability in regional health information organizations (RHIOs): a review.’, *Population health management*, 12(5), pp. 273–278. doi: 10.1089/pop.2008.0045.

Marchewka, J. (2003) *Information technology project management- providing measurable organizational value*. John Wiley & Sons, Inc.

Mars, M. (2013) ‘Telemedicine and advances in urban and rural healthcare delivery in Africa’, *Progress in Cardiovascular Diseases*. Elsevier Inc., 56(3), pp. 326–335. doi: 10.1016/j.pcad.2013.10.006.

Mars, M. (2014) ‘Tele-Education in South Africa’, *Frontiers in Public Health*. Switzerland, 2(November), pp. 1–10. doi: 10.3389/fpubh.2014.00173.

Marshall, C., Lewis, D. and Whittaker, M. (2013) *mHealth technologies in developing countries: a feasibility assessment and a proposed framework*. 25. Canberra. Available at: http://www.uq.edu.au/hishub/docs/WP25/WP25 mHealth_web.pdf.

McCabe, C. (2009) *What is cost-utility analysis?*, *Hayward Medical Communications*. Available at: http://www.medicine.ox.ac.uk/bandolier/painres/download/whatis/What_is_cost-util.pdf (Accessed: 30 October 2017).

Mebratu, D. (1998) ‘Sustainability and Sustainable Development: Historical and Conceptual Review’, 9255(98), pp. 493–520.

van der Meijden, M. J. *et al.* (2003) ‘Determinants of Success of Inpatient Clinical Information Systems : A Literature Review’, *Journal of the American Medical Informatics Association : JAMIA*, 10(3), pp. 235–243. doi: 10.1197/jamia.M1094.

Mengesha, G. H. . *et al.* (2013) ‘Stakeholders analysis of ethiopian telemedicine projects: The case of black lion hospital, Addis Ababa, Ethiopia’, *19th Americas Conference on Information*

Systems, AMCIS 2013 - Hyperconnected World: Anything, Anywhere, Anytime, 4, pp. 3066–3075. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-84893211851&partnerID=40&md5=74456a607e4680883f643c4dcd7529ab.

Mettler, T. (2015) ‘Anticipating mismatches of HIT investments: Developing a viability-fit model for e-health services’, *International Journal of Medical Informatics*. Elsevier Ireland Ltd, 85, pp. 104–115. doi: 10.1016/j.ijmedinf.2015.10.002.

Michel-Verkerke, M. B., Stegwee, Robert A` and Spil, T. A. (2015) ‘The six P’s of the next step in electronic patient records in the Netherlands’, *Health Policy and Technology*. Elsevier, 4(2), pp. 137–143. doi: 10.1016/j.hlpt.2015.02.011.

Michel-Verkerke, M. B., Stegwee, Robert A and Spil, T. A. (2015) ‘The six P’s of the next step in electronic patient records in the Netherlands’, *Health Policy and Technology*. Elsevier, 4(2), pp. 137–143. doi: 10.1016/j.hlpt.2015.02.011.

Michel-Verkerke, M. B., Stegwee, Robert a and Spil, T. A. (2015) ‘The six P’s of Electronic Health Records’, *Health Policy and Technology*. Elsevier. doi: 10.1016/j.hlpt.2015.02.011.

Molefi, M. (2010) *An Assessment of e-Health Projects and Initiatives in Africa*.

Montiel, I. and Delgado-Ceballos, J. (2014) ‘Defining and Measuring Corporate Sustainability: Are We There Yet?’, *Organization & Environment*, pp. 1–27. doi: 10.1177/1086026614526413.

Moores, T. T. (2012) ‘Towards an integrated model of IT acceptance in healthcare’, *Decision Support Systems*. Elsevier B.V., 53(3), pp. 507–516. doi: 10.1016/j.dss.2012.04.014.

Musango, J. K. and Brent, A. C. (2010) ‘A conceptual framework for energy technology sustainability assessment’, *Energy for Sustainable Development*, 15(1), pp. 84–91. doi: 10.1016/j.esd.2010.10.005.

Mutingi, M. and Matope, S. (2013) ‘Dynamics of Information Technology Adoption in a Complex Environment’, *2013 IEEE International Conference on Industrial Technology (ICIT)*, pp. 1466–1471. doi: 10.1109/ICIT.2013.6505888.

Mweebo, K. (2014) ‘Security of electronic health records in a resource limited setting : The case of smart-care electronic health record in Zambia’. doi: 10.4225/75/5798297631b47.

Naversnik, K. and Mrhar, A. (2013) ‘Cost-effectiveness of a novel e-health depression service.’, *Telemedicine journal and e-health : the official journal of the American Telemedicine Association*. United States, 19(2), pp. 110–116. doi: 10.1089/tmj.2012.0081.

Naversnik, K. and Mrhar, A. (2014) ‘Routine real-time cost-effectiveness monitoring of a web-based depression intervention: a risk-sharing proposal.’, *Journal of medical Internet research*. Canada, 16(2), p. e67. doi: 10.2196/jmir.2592.

Noben, C. *et al.* (2017) ‘Improving a web-based employability intervention for work-disabled employees: results of a pilot economic evaluation.’, *Disability and rehabilitation. Assistive technology*. England, 12(3), pp. 280–289. doi: 10.3109/17483107.2015.1135999.

Oh, H. *et al.* (2005) ‘What Is eHealth (3): A Systematic Review of Published Definitions’, *Journal of Medical Internet Research*, 7(1). Available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1550636/.

Oliva, R. (2003) ‘Model calibration as a testing strategy for system dynamics models’, *European Journal of Operational Research*, 151(3), pp. 552–568. doi: 10.1016/S0377-2217(02)00622-7.

Oliveira, T. and Martins, M. (2011) ‘Literature Review of Information Technology Adoption Models at Firm Level.’, *Electronic Journal of Information Systems Evaluation*, 14(1), pp. 110–121.

Oluoch, T. and de Keizer, N. F. (2016) ‘Evaluation of Health IT in Low-Income Countries.’, *Studies in Health Technology & Informatics*. Netherlands, 222, pp. 324–335. doi: 10.3233/978-1-61499-635-4-324.

ONC (2014) *Update on the adaption of health information technology and related efforts to facilitate the electrronic use and exchange of health information: Report to Congress*, *2014 Report to Congress on Health IT Adoption and HIE*. Washington, DC. doi: http://healthit.gov/.

Otto, P. and Simon, M. (2009) ‘Coordinating quality care : A policy model to simulate adoption of electronic health records’, in *The 27th International Conference of the System Dynamics Society*. Albuquerque, New Mexico, USA, pp. 1–22.

Pagán, J., Zapater, M. and Ayala, J. L. (2018) ‘Power transmission and workload balancing policies in eHealth mobile cloud computing scenarios’, *Future Generation Computer Systems*, 78, pp. 587–601. doi: 10.1016/j.future.2017.02.015.

Paganini, S. *et al.* (2017) ‘Economic evaluations of internet- and mobile-based interventions for the treatment and prevention of depression: A systematic review’, *Journal of Affective Disorders*. Elsevier B.V., 225(February 2017), pp. 733–755. doi: 10.1016/j.jad.2017.07.018.

Pai, F.-Y. and Huang, K.-I. (2011) ‘Applying the Technology Acceptance Model to the introduction of healthcare information systems’, *Technological Forecasting and Social Change*, 78(4), pp. 650–660. doi: 10.1016/j.techfore.2010.11.007.

Parkes, A. (2002) ‘Critical Success Factors in Workflow Implementation’, *Conference on Information Systems*, pp. 363–380. Available at: http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Critical+Success+Factors+in+Workflow+Implementation#2%5Cnhttp://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Critical+success+factors+in+workflow+implementation#2.

Parsi, K., Chambers, C. J. and Armstrong, A. W. (2012) ‘Cost-effectiveness analysis of a patient-centered care model for management of psoriasis’, *Journal of the American Academy of Dermatology*, 66(4), pp. 563–570. doi: 10.1016/j.jaad.2011.02.022.

Parv, L. *et al.* (2012) ‘Economic impact of a nationwide interoperable e-Health system using the PENG evaluation tool.’, *Studies in health technology and informatics*. Netherlands, 180, pp. 876–80. Available at: http://www.ncbi.nlm.nih.gov/pubmed/22874318.

Patton, M. Q. (2002) *Qualitative Research & Evaluation Methods*. 3rd edn. London: SAGE Publications.

Peek, S. T. M. *et al.* (2014) ‘Factors influencing acceptance of technology for aging in place: A systematic review’, *International Journal of Medical Informatics*. Elsevier Ireland Ltd, 83(4), pp. 235–248. doi: 10.1016/j.ijmedinf.2014.01.004.

Petrakaki, D., Cornford, T. and Klecun, E. (2010) ‘Sociotechnical Changing in Healthcare’, *Studies in Health Technology and Informatics*, 157(November 2015), pp. 25–30. doi: 10.3233/978-1-60750-569-3-25.

Petter, S., Delone, W. and Mclean, E. R. (2012) ‘The Past, Present, and Future of “ IS Success ”’, *Journal of the Association for Informaiton Systems*, 13(May 2012), pp. 341–362.

Petter, S., DeLone, W. and McLean, E. R. (2013) ‘Information systems success: The quest for the independent variables’, *Journal of Management Information Systems*, 29(4), pp. 7–62. doi: 10.2753/MIS0742-1222290401.

Petter, S. and Mclean, E. R. (2009) ‘Information & Management A meta-analytic assessment of the DeLone and McLean IS success model : An examination of IS success at the individual level’, *Information & Management*, 46, pp. 159–166. doi: 10.1016/j.im.2008.12.006.

Pretorius, M. W. (2000) ‘Technology Assessment in the Manufacturing Enterprise : A Holistic Approach’, in *Proceedings of the 9th International Conference on Management of Technology*.

Miami, pp. 1–10.

Program Health Information Systems-SA (2015) *DHIS2*, *HISP*. Available at: http://www.hisp.org/services/dhis-2/ (Accessed: 17 December 2018).

Project Management Institute (2013) *A guide to the project management body of knowledge (PMBOK)*. 5th editio, *Project Management Institute*. 5th editio. Newtown Square, Pennsylvania. doi: 10.1002/pmj.20125.

Pruyt, E. (2006) 'What is System Dynamics ? A Paradigmatic Inquiry Structure , Methodology , Method , or a Set of Techniques', pp. 1–29.

Pruyt, E. (2013) *Small System Dynamics Models for Big Issues: Triple Jump towards Real-World Complexity*. Delft: TU Delft Library.

Quaglio, G. *et al.* (2016) 'Information and communications technologies in low and middle-income countries: Survey results on economic development and health', *Health Policy and Technology*, 5(4), pp. 318–329. doi: 10.1016/j.hlpt.2016.07.003.

Reddy, M. *et al.* (2003) 'Sociotechnical Requirements Analysis for Clinical System', *Methods Inf Med*, 42, pp. 437–444. doi: 10.1267/meth03040437.

Reid, P. P. *et al.* (2005) *BUILDING A BETTER DELIVERY SYSTEM: A New Engineering/Health Care Partnership*. Washington. Available at: http://www.nap.edu/catalog/11378.html.

Van Reijen, M. *et al.* (2017) 'Preventing recurrent ankle sprains: Is the use of an App more cost-effective than a printed Booklet? Results of a RCT.', *Scandinavian journal of medicine & science in sports*. Denmark. doi: 10.1111/sms.12915.

Rippen, H. E. *et al.* (2013) 'Organizational framework for health information technology', *International Journal of Medical Informatics*. Elsevier Ireland Ltd, 82(4), pp. e1–e13. doi: 10.1016/j.ijmedinf.2012.01.012.

Rogers, E. M. (1995) *Diffusion of innovations*. Fifth Edit. New York: Free Press.

Rogers, E. M. (2003) *Diffusion of Innovations*. 5th Editio. New York: Simon & Schuster Inc.

De Rosis, S. and Nuti, S. (2018) 'Public strategies for improving eHealth integration and long-term sustainability in public health care systems: Findings from an Italian case study', *The International Journal of Health Planning and Management*. England, 33(1), pp. e131–e152. doi: 10.1002/hpm.2443.

Saeed, E. *et al.* (2012) 'Factors Influencing Training Effectiveness: Evidence from Public Sector in Bahrain', 13(2), pp. 31–44. Available at: http://journals.univ-danubius.ro/index.php/oeconomica/article/viewFile/3991/3956.

Samarthya-Howard, A. (2016) *Curing Pilot-itis for mHealth*, *Praekelt.org*. Available at: http://blog.praekeltfoundation.org/post/147639334452/curing-pilot-itis-for-mhealth (Accessed: 31 May 2018).

Sauer, C. (1994) *Why Information Systems Fail: A Case Study Approach*. Edited by D. E. Avison and G. Fitzgerald. Hanley-on-Thames: Afred Waller.

Schwaninger, M. and Grösser, S. (2008) 'System dynamics as model-based theory building', in *Systems Research and Behavioral Science*, pp. 447–465. doi: 10.1002/sres.914.

Schweitzer, J. and Synowiec, C. (2012) 'The Economics of eHealth and mHealth', *Journal of Health Communication*. United States, 17(February 2015), pp. 73–81. doi: 10.1080/10810730.2011.649158.

Scotland, J. (2012) 'Exploring the philosophical underpinnings of research: Relating ontology and epistemology to the methodology and methods of the scientific, interpretive, and critical research paradigms', *English Language Teaching*, 5(9), pp. 9–16. doi: 10.5539/elt.v5n9p9.

Scott, R. E. and Mars, M. (2013) 'Principles and framework for eHealth strategy development.', *Journal of medical Internet research*. Journal of Medical Internet Research, 15(7), p. e155. doi: 10.2196/jmir.2250.

Seddon, P. B. (1997) 'A Respecification and Extension of the DeLone and McLean Model of IS Success', *Information Systems Research*, pp. 240–253. doi: 10.1287/isre.8.3.240.

Sevick, L. K. *et al.* (2017) 'A systematic review of the cost and cost-effectiveness of electronic discharge communications.', *BMJ open*. England, 7(6), p. e014722. doi: 10.1136/bmjopen-2016-014722.

Sezgin, E., Alaşehir, O. and Yıldırım, S. Ö. (2014) 'Work in Progress toward Adoption of an e-health Application by Healthcare Personnel: A Model Validation', *Procedia Technology*. Elsevier B.V., 16, pp. 1327–1333. doi: 10.1016/j.protcy.2014.10.149.

Sheikh, Y. H. and Braa, K. (2011) 'MOBILISING LOCAL NETWORKS OF IMPLEMENTERS TO ADDRESS HEALTH INFORMATION SYSTEMS SUSTAINABILITY', *EJISDC*, 48(6), pp. 1–21.

Shiferaw, F. and Zolfo, M. (2012) 'The role of information communication technology (ICT) towards universal health coverage: The first steps of a telemedicine project in Ethiopia', *Global Health Action*, 5(1), p. 15. doi: 10.3402/gha.v5i0.15638.

Sittig, D. F. and Singh, H. (2010) 'A new sociotechnical model for studying health information technology in complex adaptive healthcare systems.', *Quality & safety in health care*, 19 Suppl 3(Suppl 3), pp. i68–i74. doi: 10.1136/qshc.2010.042085.

SNNP RHB & USAID JSI (2015) *eHMIS Electronic Health Management Information System: Facilitator's Guide*.

Snowden, D. J. D. and Boone, M. M. E. (2007) 'A leader's framework for decision making', *Harvard Business Review*, 85(11), pp. 68–76. doi: Article.

Sood, S. *et al.* (2007) 'What is telemedicine? A collection of 104 peer-reviewed perspectives and theoretical underpinnings.', *Telemedicine journal and e-health : the official journal of the American Telemedicine Association*. United States, 13(5), pp. 573–590. doi: 10.1089/tmj.2006.0073.

Spreckley, F. (2009) *Result Based Monitoring and Evaluation: Toolkit*. Herefordshire, UK.

Sterman, J. D. (2000) *Business Dynamics: Systems Thinking and Modeling for a Complex World*. New York: McGraw-Hill.

Stroetmann, K. A. (2015) 'Patient-centric Care and Chronic Disease Management: A Stakeholder Perspective.', *Studies in health technology and informatics*. Netherlands, 208, pp. 324–330.

Stroetmann, K. a *et al.* (2006) *eHealth is Worth it*, *eHealth solutions at ten*. Luxembourg. doi: 10.2759/242.

Stroetmann, V., Motti, D. and Kalra, D. (2015) *Adoption of interoperable EHRs: barriers, challenges, incentives*. Gent.

the World Bank (2017) *Country Classification*, *World Bank Country and Lending Groups*. Available at: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups (Accessed: 10 November 2017).

The World Bank (2017) *The World Bank Data: Ethiopia*, *The World Bank Group*. Available at: https://data.worldbank.org/country/ethiopia?view=chart (Accessed: 25 October 2017).

Thurmond, V. A. (2001) 'The Point of Triangulation', *Journal of Nursing Scholarship*, 33(3), pp.

253–258.

Tilahun, B. and Fritz, F. (2015a) ‘Comprehensive Evaluation of Electronic Medical Record System Use and User Satisfaction at Five Low-Resource Setting Hospitals in Ethiopia’, *JMIR Medical Informatics*, 3(2), p. e22. doi: 10.2196/medinform.4106.

Tilahun, B. and Fritz, F. (2015b) ‘Modeling antecedents of electronic medical record system implementation success in low-resource setting hospitals’, *BMC Medical Informatics and Decision Making*. BMC Medical Informatics and Decision Making, 15(1), p. 61. doi: 10.1186/s12911-015-0192-0.

Tobergte, D. R. and Curtis, S. (2013) ‘Intention to Use Mobile Services: Antecendents and Cross-Service Comparisons’, *Journal of Chemical Information and Modeling*, 53(9), pp. 1689–1699. doi: 10.1017/CBO9781107415324.004.

Tsiknakis, M. and Kouroubali, A. (2009) ‘Organizational factors affecting successful adoption of innovative eHealth services: a case study employing the FITT framework.’, *International journal of medical informatics*, 78(1), pp. 39–52. doi: 10.1016/j.ijmedinf.2008.07.001.

UN (2013) *The Millennium Development Goals Report 2013*. New York. Available at: http://www.un.org/millenniumgoals/pdf/report-2013/mdg-report-2013-english.pdf.

Venkatesh, V. *et al.* (2003) ‘User Acceptance of Information Technology: Toward A Unified View’, *MIS Quarterly*, 27(3), pp. 425–478. doi: 10.2307/30036540.

Venkatesh, V. and Bala, H. (2008) ‘Technology acceptance model 3 and a research agenda on interventions’, *Decision Sciences*, 39(2), pp. 273–315. doi: 10.1111/j.1540-5915.2008.00192.x.

Venkatesh, V. and Davis, F. (2000) ‘Theoretical extension of the Technology Acceptance Model: Four longitudinal field studies’, *Management science*, 46(2), pp. 186–204.

Ventana Systems (2012a) *Monte Carlo Simulations*. Available at: https://www.vensim.com/documentation/index.html?21065.htm (Accessed: 10 January 2019).

Ventana Systems (2012b) *Random Uniform Distribution*, *Ventana Systems, Inc.* Available at: https://www.vensim.com/documentation/index.html?21090.htm (Accessed: 10 January 2019).

Ventana Systems (2015) *How does Vensim compare to other system dynamics software?* Available at: https://vensim.com/faqs/how-does-vensim-compare-to-other-system-dynamics-software/ (Accessed: 10 January 2019).

Vest, J. R. (2010) ‘More than just a question of technology: Factors related to hospitals’ adoption and implementation of health information exchange’, *International Journal of Medical Informatics*. Elsevier Ireland Ltd, 79(12), pp. 797–806. doi: 10.1016/j.ijmedinf.2010.09.003.

VWC (2009) *Health Information Systems in Developing Countries: A Landscape Analysis*.

Wang, W.-T. and Liu, C.-Y. (2005) ‘The Application of the Technology Acceptance Model: A New Way to Evaluate Information System Success’, *Proceedings of the 23rd International Conference of the System Dynamics Society*, p. 149.

Wannaw, F. and Azim, T. (2013) *Technical Report on Electronic Health Management Information System (eHMIS)*. Addis Ababa.

Ward, R. (2013) ‘The application of technology acceptance and diffusion of innovation models in healthcare informatics’, *Health Policy and Technology*, 2(4), pp. 222–228. doi: 10.1016/j.hlpt.2013.07.002.

WCED (1987) ‘Report of the World Commission on Environment and Development: Our Common Future (The Brundtland Report)’, *Medicine, Conflict and Survival*, 4(1), p. 300. doi: 10.1080/07488008808408783.

Weeks, R. V (2012) ‘Healthcare services management: a systems perspective’, *Journal of Contemporary Management*, 9, pp. 382–401.

Weisstein, E. W. (2019) *Uniform Distribution*, *Wolfram MathWorld*. Available at: Uniform Distribution.

Whitworth, B. and Sylla, C. (2012) ‘A social environmental model of socio-technical performance’, *International Journal of Networking and Virtual Organisations*, 11(1), pp. 1–25. doi: 10.1504/IJNVO.2012.047878.

WHO (2005) *Connecting for Health: Global Vision, Local Insight*. Geneva.

WHO (2010a) *eHealth Solutions in the African Region: Current Context and Perspectives*. Malabo.

WHO (2010b) *TELEMEDICINE: Opportunities and developments in Member States: report on the second global survey on eHealth*. Geneva. Available at: http://www.who.int/goe/publications/goe_telemedicine_2010.pdf.

WHO (2011a) *ATLAS eHealth Country Profiles: Based on the findings of the second global survey on eHealth. (Global Observatory for eHealth Series - Volume 1)*. Geneva. Available at: http://www.who.int/goe.

WHO (2011b) *mHealth: New horizons for health through mobile technologies*, *WHO*. Switzerland. doi: ISBN 978 92 4 156425 0.

WHO (2011c) *World Health Statistics 2011*. Geneva.

WHO (2012a) *Framework and Standards for Country Health Information Systems*, *World Health*. Geneva. doi: 10.4018/978-1-60566-988-5.

WHO (2012b) *Management of patient information: Trends and challenges in Member States*. Geneva.

WHO (2014) *World Health Statistics 2014*, *Zhurnal Eksperimental’noi i Teoreticheskoi Fiziki*. Geneva. Available at: http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:No+Title#0 (Accessed: 2 July 2014).

WHO and ITU (2012) *National eHealth Strategy Toolkit*. Geneva.

Williams, D. (2002) ‘Integrating System Dynamics Modelling and Case Study Research Method : A theoretical framework for process improvement’, in *Proceedings from the 20th International Conference of the System Dynamics Society*, pp. 1–27.

Wolstenholme, E. F. (1983) ‘The Development of System Dynamics as a Methodology for System Description and Qualitative Analysis’, *Journal of the Operational Research Society*, 34(7), pp. 569–581. doi: 10.1057/jors.1984.87.

Wolstenholme, E. F. (1990) *System Enquiry: A System Dynamics Approach*. New York, NY, USA: John Wiley & Sons, Inc.

Yin, R. K. (2009) *Case Study Research: Design and Methods*. 4th Editio. Thousand Oaks: SAGE.

Yusof, Maryati Mohd. *et al.* (2008) ‘An evaluation framework for Health Information Systems: human, organization and technology-fit factors (HOT-fit)’, *International Journal of Medical Informatics*, 77(6), pp. 386–398. doi: 10.1016/j.ijmedinf.2007.08.011.

Yusof, Maryati Mohd *et al.* (2008) ‘Investigating evaluation frameworks for health information systems.’, *International journal of medical informatics*, 77(6), pp. 377–85. doi: 10.1016/j.ijmedinf.2007.08.004.

Zeidan, R., Boechat, C. and Fleury, A. (2015) ‘Developing a Sustainability Credit Score System’, *Journal of Business Ethics*, 127(2), pp. 283–296. doi: 10.1007/s10551-013-2034-2.

10. LIST OF ACADEMIC OUTPUTS

Fanta, G.B., Pretorius, L. & Erasmus, L., 2019. Hospitals' readiness to implement sustainable SmartCare systems in Addis Ababa, Ethiopia. In 2019 Portland International Conference on Management of Engineering and Technology (PICMET). IEEE, pp. 1–9.

Fanta, G. B. and Pretorius, L., 2018. A conceptual framework for sustainable ehealth implementation in resource-constrained settings. South African Journal of Industrial Engineering, 29(3), pp. 132–147.

Fanta, G. B., Pretorius, L. and Erasmus, L., 2018. Economic analysis of sustainable ehealth implementation in developing countries : a systematic review. In International Association for Management of Technology (IAMOT) 2018. Birmingham, pp. 1–16.

Fanta, G.B., Pretorius, L. & Erasmus, L., 2017. Technological Dynamics of eHealth Acceptance: A System Dynamics Model. In Proceedings of the 5th Annual System Dynamics Conference. Eskom Research Testing & Development Centre; Johannesburg; South Africa, pp. 1–5.

Fanta, G.B., Pretorius, L. & Erasmus, L., 2017. Organizational Dynamics of Sustainable eHealth Implementation: A Case Study of eHMIS. In 2017 Portland International Conference on Management of Engineering and Technology (PICMET). IEEE, pp. 1–9. Available at: http://ieeexplore.ieee.org/document/8125472/.

Fanta, G., Pretorius, L., & Erasmus, L., 2016. A System Dynamics Model of eHealth Acceptance: A Socio-technical Perspective. In Technology & Future Thinking. In International Association for Management of Technology (IAMOT). Orlando.

Fanta, G.B., Pretorius, L. & Erasmus, L., 2015. A Conceptual Model for the Innovation-Decision Process with focus on Acceptance. In Proceedings of the 3rd Annual System Dynamics Conference. Eskom Research Testing & Development Centre; Johannesburg; South Africa, pp. 48–51.

Fanta, G., Pretorius, L., & Erasmus, L., 2015. An Evaluation of Ehealth Systems Implementation Frameworks for Sustainability in Resource Constrained Environments: a Literature Review. In International Association for Management of Technology (IAMOT) 2015. Cape Town.

Fanta, G. B. and Erasmus, L., 2015. Systems Engineering Perspective on eHealth Implementations : Case Study of users. In 12th INCOSE South Africa Conference. Pretoria.

Fanta, G. B. and Erasmus, L., 2014. A Systems Engineering Perspective on eHealth Implementations' Efficiency and Effectiveness: A Case Study involving suppliers. In INCOSE International Symposium. Cape Town, pp. 55–68. doi: 10.1002/j.2334-5837.2014.00006.x.

11. LIST OF APPENDICES

Appendix 1 eHealth success factors

SN	EHEALTH SUCCESS FACTORS	SOURCES
1	Perceived ease of use	Tung, et al., 2008; Venkatesh & Davis, 2000; Davis, 1989; Venkatesh & Bala, 2008; Venkatesh, Morris & Davis; 2003; Chang & Hsu, 2012
2	Perceived usefulness	Venkatesh & Davis, 2000; Davis, 1989; Venkatesh & Bala, 2008; Venkatesh, Morris & Davis; 2003;
3	Attitude towards technology	Petter et al, 2013
4	Attitude towards change	Petter et al, 2013
5	Enjoyment	Petter et al, 2013; Venkatesh & Bala, 2008
6	Trust	Petter et al, 2013; Tung, et al., 2008
7	Computer Anxiety	Petter et al, 2013; Venkatesh & Bala, 2008; Aggelidis & Chatzoglou, 2009
8	Computer Self-efficacy (Competency)	Petter et al, 2013; Venkatesh & Bala, 2008; Chen, et. Al., 2008; Aggelidis & Chatzoglou, 2009; Belay, Azim & Kassahun, 2014
9	User expectations	Petter et al, 2013
10	Technology experience	Petter et al, 2013
11	Organizational support	Petter et al, 2013; Garcia-Smith & Effken; 2013; Venkatesh, Morris & Davis; 2003; Chang & Hsu, 2012; Venkatesh & Bala, 2008
12	Perception of external control	Venkatesh & Bala, 2008
13	Computer playfulness	Venkatesh & Bala, 2008
14	System Documentation	Dünnebeil, et. Al, 2012 (moderate)
15	Education	Petter et al, 2013
16	Age of the user	Petter et al, 2013
17	Gender of the user	Petter et al, 2013
18	Organizational tenure	Petter et al, 2013
19	Subjective norm	Ventkatesh et al, 2003; Petter et al, 2013
20	Image	Ventkatesh et al, 2003; Petter et al, 2013; Venkatesh & Bala, 2008
21	Visibility	Petter et al, 2013
22	Peer support (social factor)	Petter et al, 2013; Ventkatesh et al, 2003
23	Social support	Garcia-Smith & Effken, 2013
24	Service support	Garcia-Smith & Effken, 2013
25	Easy to use	Tilahun & Fritz, 2015; Chang, Liu & Hwang, 2011; Al-Mamary et al., 2015; Venkatesh & Davis, 2000; Davis, 1989; Venkatesh & Bala, 2008; Venkatesh, Morris & Davis; 2003; Chang & Hsu, 2012
26	User friendliness	Tilahun & Fritz, 2015

27	Acceptable system response time	Tilahun & Fritz, 2015; Chang, Liu & Hwang, 2011; Bossen, Jensen, Udsen, 2013; Al-Mamary et al., 2015; DeLone & McLean, 2003
28	Reliability	Chang, Liu & Hwang, 2011; Garcia-Smith & Effken; 2013; Bossen, Jensen, Udsen, 2013; Al-Mamary et al., 2015; DeLone & McLean, 2003
29	The system is usable(technically sound)	Chang, Liu & Hwang, 2011; DeLone & McLean, 2003; Al-Mamary et al., 2015; Venkatesh & Bala, 2008; Cresswell & Sheikh, 2012
30	The system is Convenient to use	Garcia-Smith & Effken; 2013
31	Easy to learn	Garcia-Smith & Effken; 2013; Bossen, Jensen, Udsen, 2013; Al-Mamary et al., 2015; Davis, 1989; Venkatesh, Morris & Davis; 2003; Aldosari, 2012; Chang & Hsu, 2012
32	Flexibility	Al-Mamary et al., 2015
33	Intuitiveness	Al-Mamary et al., 2015
34	Adaptability	DeLone & McLean, 2003
35	The system is compatible with other systems at use	Garcia-Smith & Effken; 2013
36	Information relevance and usefulness to the work	Tilahun & Fritz, 2015; Garcia-Smith & Effken, 2013; Bossen, Jensen, Udsen, 2013; Al-Mamary et al., 2015; DeLone & McLean, 2003; Venkatesh & Bala, 2008
37	Information Accuracy	Tilahun & Fritz, 2015; Chang, Liu & Hwang, 2011; Garcia-Smith & Effken; 2013
38	Information completeness	Tilahun & Fritz, 2015; Chang, Liu & Hwang, 2011; DeLone & McLean, 2003
39	Timeliness of information	Tilahun & Fritz, 2015; Chang, Liu & Hwang, 2011
40	Information is in useful format	Tilahun & Fritz, 2015; Garcia-Smith & Effken; 2013
41	Information or data security	Chang, Liu & Hwang, 2011; DeLone & McLean, 2003; Dünnebeil, et. Al, 2012
42	Easy to find information	Bossen, Jensen, Udsen, 2013
43	Understand ability	Al-Mamary et al., 2015; DeLone & McLean, 2003
44	Conciseness	Al-Mamary et al., 2015
45	Personalization	DeLone & McLean, 2003
46	The system is dependable	Tilahun & Fritz, 2015
47	Management support	Tilahun & Fritz, 2015; Chang & Hsu, 2012; Garcia-Smith & Effken; 2013; Venkatesh, Morris & Davis; 2003; Venkatesh & Bala, 2008; Petter et al, 2013:39; Al-Mamary et al., 2015

48	Availability of system and information	Tilahun & Fritz, 2015; Bossen, Jensen, Udsen, 2013; Garcia-Smith & Effken; 2013; DeLone & McLean, 2003; Venkatesh & Davis, 2000; Chang, Liu, & Hwang 2011; Venkatesh & Bala, 2008;
49	Access to computers	Tilahun & Fritz, 2015
50	Availability of backup generator and UPS	Tilahun & Fritz, 2015
51	Responsiveness of technical support	Tilahun & Fritz, 2015; Chang, Liu & Hwang, 2011; Al-Mamary, Shamsuddin & Aziati, 2015; DeLone & McLean, 2003
52	Timeliness of technical support	Tilahun & Fritz, 2015
53	Assurance from technical team (understanding users need)	Chang, Liu & Hwang, 2011; ; Al-Mamary, Shamsuddin & Aziati, 2015; DeLone & McLean, 2003
54	The technical support team has Empathy	Chang, Liu & Hwang, 2011; Al-Mamary, Shamsuddin & Aziati, 2015; DeLone & McLean, 2003
55	Provision of accurate technical service.	Al-Mamary, Shamsuddin & Aziati, 2015
56	Reliability of technical support	Al-Mamary, Shamsuddin & Aziati, 2015
57	Competency of support staff	Al-Mamary, Shamsuddin & Aziati, 2015
58	Training for users	Garcia-Smith & Effken; 2013
59	Willingness of technical support staffs	Garcia-Smith & Effken; 2013
60	Availability of necessary resources to use the system	Chang & Hsu, 2012; Garcia-Smith & Effken; 2013
61	Clear guidance to use the system	Venkatesh & Davis, 2000; Davis, 1989; Venkatesh & Bala, 2008; Venkatesh, Morris & Davis, 2003; Aldosari, 2012; Chang & Hsu, 2012
62	The system is not complicated (Sophisticated)	Venkatesh & Davis, 2000; Davis, 1989; Venkatesh & Bala, 2008; Venkatesh, Morris & Davis, 2003; Aldosari, 2013; Al-Mamary et al., 2015
63	Control over the system	Venkatesh & Davis, 2000; Davis, 1989; Venkatesh & Bala, 2008; Venkatesh, Morris & Davis; 2003
64	Flexibility	Venkatesh & Davis, 2000; Davis, 1989; Venkatesh & Bala, 2008; Venkatesh, Morris & Davis; 2003
65	Easy to be skilful	Davis, 1989; Venkatesh, Morris & Davis; 2003; Aldosari, 2012
66	Information culture	Belay, Azim & Kassahun, 2014
67	Satisfaction	Tilahun & Fritz, 2015
68	Efficiency/ Productivity	Al-Mamary, Shamsuddin & Aziati, 2015; Venkatesh, Morris & Davis, 2003; Chang, Liu, & Hwang, 2011; Gorla et al., 2010; Hou, 2012
69	Profitability	Al-Mamary, Shamsuddin & Aziati, 2015

70	Market value	Al-Mamary, Shamsuddin & Aziati, 2015; DeLone & McLean, 2003
71	Competitive advantage	Al-Mamary, Shamsuddin & Aziati, 2015
72	Cost reduction (saving)	Al-Mamary, Shamsuddin & Aziati, 2015; DeLone & McLean, 2003
73	Revenue enhancement	Al-Mamary, Shamsuddin & Aziati, 2015; DeLone & McLean, 2003
74	Overall firm performance	Al-Mamary, Shamsuddin & Aziati, 2015
75	Using the system benefits the organizations	Bossen, Jensen, Udsen, 2013
76	benefit to patient	Bossen, Jensen, Udsen, 2013
77	benefit to healthcare team	Bossen, Jensen, Udsen, 2013
78	Healthcare services improvement	Tilahun & Fritz, 2015
79	Job effectiveness	Venkatesh, Morris & Davis; 2003; Tilahun & Fritz, 2015; Chang, Liu, & Hwang 2011; Hou, 2012; Davis, 1989
80	Accomplish tasks more quickly (time saving)	Venkatesh, Morris & Davis; 2003; Tilahun & Fritz, 2015;Chang, Liu, & Hwang 2011; DeLone & McLean, 2003; Davis, 1989
81	Output quality	Venkatesh & Davis, 2000; Venkatesh, Morris & Davis; 2003; Tilahun & Fritz, 2015; Venkatesh & Bala, 2008;
82	Organizational culture	Belay, Azim & Kassahun, 2014
83	Computer literacy	Tilahun & Fritz, 2015; Al-Mamary, Shamsuddin & Aziati, 2015
84	User Experience	Al-Mamary, Shamsuddin & Aziati, 2015
85	Voluntariness	Venkatesh & Davis, 2000; Venkatesh & Bala, 2008
86	Result Demonstrability (Communicating the outcome)	Venkatesh & Davis, 2000; Venkatesh & Bala, 2008
87	Management/organizational Process	Petter et al, 2013:39; Garcia-Smith & Effken; 2013
88	Motivation	Petter et al, 2013:39; Belay, Azim & Kassahun, 2014
89	Organizational competence	Petter et al, 2013:39
90	IT Infrastructure	Petter et al, 2013:39; Belay, Azim & Kassahun, 2014
91	Users involvement	Petter et al, 2013:17; Garcia-Smith & Effken; 2013;
92	Developer skill	Petter et al, 2013:17
93	Development approach	Petter et al, 2013:17
94	IT planning	Petter et al, 2013:17
95	Project management skill	Petter et al, 2013:17
96	Domain expert knowledge	Petter et al, 2013:17
97	Relationship with developers	Petter et al, 2013:17
98	Third party interaction	Petter et al, 2013:17
99	Type of IS	Petter et al, 2013:18

100	Time since Implementation	Petter et al, 2013:18
101	Voluntariness	Petter et al, 2013:18
102	Job performance	Davis, 1989; Hou, 2012
103	Increase productivity	Davis, 1989
104	Makes job easier	Davis, 1989
105	Controllable	Davis, 1989
106	Clear & understandable	Davis, 1989
107	Flexible	Davis, 1989
108	Easy to become skilful	Davis, 1989
109	Subjective norm	Venkatesh & Bala, 2008
110	Result demonstrability	Venkatesh & Bala, 2008
111	perceptions of ext. control	Venkatesh & Bala, 2008
112	computer anxiety	Venkatesh & Bala, 2008
113	Perceived enjoyment	Venkatesh & Bala, 2008
114	Demand for data	Belay, Azim & Kassahun, 2014
115	Confidence	Belay, Azim & Kassahun, 2014
116	problem solving skill	Belay, Azim & Kassahun, 2014
117	Decision-making quality	Hou, 2012
118	Problem identification speed	Hou, 2012
119	Decision-making speed	Hou, 2012
120	Supplier switch/search costs	Gorla et al., 2010
121	Products/service enhancements	Gorla et al., 2010
122	Market information support	Gorla et al., 2010
123	Product cost control	Gorla et al., 2010
124	Internal organizational	Gorla et al., 2010
125	Expanded markets	DeLone & McLean, 2003
126	Incremental additional sales	DeLone & McLean, 2003

Appendix 2 Technological factors

Appendix 2.1 System quality

System quality	Sources
Ease of use	Tilahun & Fritz, 2015; Chang, Liu & Hwang, 2011; Al-Mamary et al., 2015
User friendly	Tilahun & Fritz, 2015
Response time	Tilahun & Fritz, 2015; Chang, Liu & Hwang, 2011; Bossen, Jensen, Udsen, 2013; Al-Mamary et al., 2015; DeLone & McLean, 2003
Reliability	Chang, Liu & Hwang, 2011; Garcia-Smith & Effken; 2013; Bossen, Jensen, Udsen, 2013; Al-Mamary et al., 2015; DeLone & McLean, 2003
Usability	Chang, Liu & Hwang, 2011; DeLone & McLean, 2003
Availability	Garcia-Smith & Effken; 2013; DeLone & McLean, 2003
Convenient	Garcia-Smith & Effken; 2013
Easy to learn	Garcia-Smith & Effken; 2013; Bossen, Jensen, Udsen, 2013; Al-Mamary et al., 2015
Flexibility	Al-Mamary et al., 2015; Gorla et al. 2010
Sophistication	Al-Mamary et al., 2015; Gorla et al. 2010
Intuitiveness	Al-Mamary et al., 2015
Adaptability	DeLone & McLean, 2003
Compatibility	Garcia-Smith & Effken; 2013

Appendix 2.2 Information quality

Information quality	Sources
Relevance	Tilahun & Fritz, 2015; Garcia-Smith & Effken, 2013; Bossen, Jensen, Udsen, 2013; Al-Mamary et al., 2015; DeLone & McLean, 2003
Accuracy	Tilahun & Fritz, 2015; Chang, Liu & Hwang, 2011; Garcia-Smith & Effken; 2013
Completeness	Tilahun & Fritz, 2015; Chang, Liu & Hwang, 2011; DeLone & McLean, 2003
Timeliness	Tilahun & Fritz, 2015; Chang, Liu & Hwang, 2011
Format	Tilahun & Fritz, 2015; Garcia-Smith & Effken; 2013; Gorla et al. 2010
Security	Chang, Liu & Hwang, 2011; DeLone & McLean, 2003
Relevance	Garcia-Smith & Effken; 2013
Understandability	Al-Mamary et al., 2015; DeLone & McLean, 2003
Conciseness	Al-Mamary et al., 2015
Usability	Al-Mamary et al., 2015
Personalization	DeLone & McLean, 2003
Useful	Tilahun & Fritz, 2015; Garcia-Smith & Effken, 2013; Bossen, Jensen, Udsen, 2013; Al-Mamary et al., 2015; DeLone & McLean, 2003
Content	Bossen, Jensen, Udsen, 2013; Gorla et al. 2010

Appendix 2.3 Services quality

Services quality	**Sources**
Dependable	Tilahun & Fritz, 2015
User manual	Tilahun & Fritz, 2015; Bossen, Jensen, Udsen, 2013
Access	Tilahun & Fritz, 2015
Responsiveness	Tilahun & Fritz, 2015; Chang, Liu & Hwang, 2011; Al-Mamary, Shamsuddin & Aziati, 2015; DeLone & McLean, 2003; Gorla et al. 2010
Timely	Tilahun & Fritz, 2015
Assurance	Chang, Liu & Hwang, 2011; ; Al-Mamary, Shamsuddin & Aziati, 2015; DeLone & McLean, 2003; Gorla et al. 2010
Empathy	Chang, Liu & Hwang, 2011; Al-Mamary, Shamsuddin & Aziati, 2015; DeLone & McLean, 2003; Gorla et al. 2010
Accurate	Al-Mamary, Shamsuddin & Aziati, 2015
Reliability	Al-Mamary, Shamsuddin & Aziati, 2015; Gorla et al. 2010
Competency	Al-Mamary, Shamsuddin & Aziati, 2015
Training	Garcia-Smith & Effken; 2013
Willingness	Garcia-Smith & Effken; 2013
Resource Availability	Chang & Hsu, 2012; Garcia-Smith & Effken; 2013

Appendix 3 Individual perceptions

Appendix 3.1 Perceived usefulness

Perceived usefulness	Sources
Increases productivity (individual)	Venkatesh & Davis, 2000; Davis, 1989; Venkatesh & Bala, 2008; Venkatesh, Morris & Davis; 2003; Chang & Hsu, 2012
Enhance effectiveness of job	Venkatesh & Davis, 2000; Davis, 1989; Venkatesh & Bala, 2008; Venkatesh, Morris & Davis; 2003; Aldosari, 2012
Allow tasks to be accomplished more quickly	Venkatesh & Davis, 2000; Davis, 1989; Venkatesh & Bala, 2008; Venkatesh, Morris & Davis; 2003; ; Aldosari, 2012
Improve job performance	Venkatesh & Davis, 2000; Davis, 1989; Venkatesh & Bala, 2008; Venkatesh, Morris & Davis; 2003; Chang & Hsu, 2012
Makes it easier to do job/work	Davis, 1989; Venkatesh, Morris & Davis; 2003; Aldosari, 2012
Increase quality of care	Davis, 1989; Venkatesh, Morris & Davis; 2003; Aldosari, 2012
Increase quality of work	Aldosari, 2012; Chang & Hsu, 2012
Increase work efficiency	Aldosari, 2012
Allows tasks to be done more accurately	Chang & Hsu, 2012
Allows tasks to be done more objectively	Chang & Hsu, 2012

Appendix 3.2 Perceived ease of use

Perceived ease of use	Sources
Clear	Venkatesh & Davis, 2000; Davis, 1989; Venkatesh & Bala, 2008; Venkatesh, Morris & Davis, 2003; Aldosari, 2012; Chang & Hsu, 2012
Understandable	Venkatesh & Davis, 2000; Davis, 1989; Venkatesh & Bala, 2008; Venkatesh, Morris & Davis, 2003; Aldosari, 2013
Controllable	Venkatesh & Davis, 2000; Davis, 1989; Venkatesh & Bala, 2008; Venkatesh, Morris & Davis; 2003
Time for data entry or report generation	Venkatesh, Morris & Davis; 2003
Flexibility	Venkatesh & Davis, 2000; Davis, 1989; Venkatesh & Bala, 2008; Venkatesh, Morris & Davis; 2003
Easy to learn	Davis, 1989; Venkatesh, Morris & Davis; 2003; Aldosari, 2012; Chang & Hsu, 2012
Easy to be skilful	Davis, 1989; Venkatesh, Morris & Davis; 2003; Aldosari, 2012
Easy to use	Venkatesh & Davis, 2000; Davis, 1989; Venkatesh & Bala, 2008; Venkatesh, Morris & Davis; 2003; Chang & Hsu, 2012

Appendix 3.3 Social influence

Social influence	Sources
My supervisor has been helpful in the use of the system	Garcia-Smith & Effken; 2013; Venkatesh, Morris & Davis; 2003; Chang & Hsu, 2012
The senior management supports the use of the system	Venkatesh, Morris & Davis; 2003; Venkatesh & Bala, 2008
The "super users" on my unit has been helpful in the acceptance of the system.	Garcia-Smith & Effken; 2013
I am involved or well represented in the system decisions (planning, design, and implementation)	Garcia-Smith & Effken; 2013
I use the system because of the proportion of co-workers do use the system	Venkatesh, Morris & Davis; 2003
People who influence my behaviour think that I should use the system	Venkatesh & Davis, 2000; Venkatesh & Bala, 2008
People who are important to me think that I should use the system	Venkatesh & Davis, 2000; Venkatesh & Bala, 2008
People in my organization who use the system have a high profile.	Venkatesh & Davis, 2000; Venkatesh & Bala, 2008

Appendix 4.1 Structured interview questionnaire

Type of eHealth Application: ___________ Date of Implementation: ___________

How long have you been using the eHealth application? _________________months.

Phase of Implementation:

☐Design ☐Development ☐Implementation ☐Pilot ☐Operations

	Strongly disagree ፍጹም አልስማማም	**Disagree አልስማማም**	**Somewhat disagree በመጠኑ አልስማማም**	**No opinion አስተያየት የለኝም**	**Somewhat agree በመጠኑ እስማማለሁ**	**Agree እስማማለሁ**	**Strongly agree ፍጹም እስማማለሁ**
Questions (ጥያቄዎች)	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Behavioural & Social Factors (የተጠቃሚዎች ባህርይና የስራ ባልደረቦች የሚያሳድሩት ጫና)							
Perceived Usefulness (የሲስተሙ ጠቃሚነት ላይ ያለ መረዳት)							
Using the system in my job increases my **productivity** with the same level of effort input.							
ሲስተሙን ለስራዬ በመጠቀሜ በተመሳሳይ ግብአት የተሻለ ውጤት አገኛለሁ።							
Using the system in my job enables me to accomplish tasks more **quickly.**							
ሲስተሙን ለስራዬ መጠቀሙ ስራዬን በተሻለ ፍጥነት ለመጨረስ ያስችለኛል።							
Using the system improves the **quality** of healthcare service.							
ሲስተሙን መጠቀሜ የጤና አገልግሎት ጥራትን ያሻሽለዋል።							
Using the system makes it **easier** to do my job.							
ሲስተሙን መጠቀሜ ስራዬን ያቀልልኛል።							
Using the system improves my **performance** in my Job							
ሲስተሙን መጠቀሜ የስራ አፈጻጸሜን ያሻሽለዋል።							
Overall, I find the system to be **useful** in my job.							
በአጠቃላይ ሲስተሙ ለስራዬ ጠቃሚ ነው።							
Perceived Ease of Use (የሲስተሙ አጠቃቀም ቀላልነት ላይ ያለ መረዳት)							
Interacting with the system interface is **clear and understandable** (not complicated).							
የሲስተሙ አጠቃቀም ግልጽና ያልተወሳሰበ ነው።							
I find it **easy** to get the system to do what I want it to do.							
ሲስተሙ የምፈልገውን እንዲሰራልኝ ማድረግ ቀላል ነው።							
Learning to operate the system is easy for me (e**asy to learn**).							
የሲስተሙን አጠቃቀም መማር ቀላል ነው።							
It is **easy** for me to become **skillful** in using the system.							
ሲስተሙን በብቃት መጠቀም ቀላል ነው።							
Using the system doesn't take too much time for data entry, report generation … (**responsive**)							
ወደ ሲስተሙ መረጃ ማስገባትም ሆነ ከሲስተሙ መረጃ ማግኘት ጊዜ አይፈጅም።							
Overall, I find the system to be **easy to use.**							
በአጠቃላይ ሲስተሙን መጠቀም ቀላል ነው።							
Influence of social environment (የስራ ባልደረቦች የሚያሳድሩት ተጽእኖ)							
My **supervisor** has been helpful in the use of the system.							
የቅርብ አለቃዬ ሲስተሙን እንድጠቀም ይረዳኛል።							
The **senior management supports** the use of the system.							
ከፍተኛ አመራሮች ሲስተሙን መጠቀሜን ይደግፋሉ።							
I am **involved or well represented** in the planning, design and implementation of a system.							
ሲስተሙ ሲታቀድም ሆነ ሲተገበር ተሳትፌያለሁ ወይም በበቂ ሁኔታ ተወክያለሁ::							
People who influence my behavior think that I should use the system.							
ባህሪዬ ላይ ተጽእኖ የሚያሳድሩ ሰዎች ሲስተሙን መጠቀም እንዳለብኝ ያስባሉ።							
People in my organization who use the system have a high profile.							
በመስሪያ ቤታችን ውስጥ ሲስተሙን የሚጠቀሙ ሰዎች ከፍ ያለ ስም(ክብር) አላቸው።							
In general, the **organization supports** the use of the system.							
በአጠቃላይ ድርጅታችን ሲስተሙን እንድጠቀም ድጋፍ ይሰጣል።							

	Strongly disagree ፍጹም አልስማማም	Disagree አልስማማም	Somewhat disagree በመጠኑ አልስማማም	No opinion አስተያየት የለኝም	Somewhat agree በመጠኑ እስማማለሁ	Agree እስማማለሁ	Strongly agree ፍጹም እስማማለሁ
Questions (ጥያቄዎች)	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Technological Factors (ቴክኖሎጂ)							
System Quality (የሲስተም ጥራት)							
The **response** time of the system is acceptable.							
ስጠቀምበት ሲስተሙ ምላሽ የሚሰጥበት ጊዜ ተቀባይነት አለው።							
The system seldom encounters software or hardware crash or error (**Reliability**).							
ሲስተሙ የሶፍትዌርና የሃርድዌር ችግር የሚገጥመው አልፎ አልፎ ነው።							
The system is **easy to learn** and takes little effort to master.							
ሲስተሙ በቀላሉ መማር የምችለው ነው።							
The system is **easy to use**.							
ሲስተሙ ለመጠቀም ቀላል ነው።							
The system is fit for the purpose of facilitating daily operations **(Usability).**							
ሲስተሙ የእለት ተግባሬን ለመፈጸም የሚያስችል አገልግሎት ይሰጣል።							
The system is up and available when I need it (**Availability**).							
መጠቀም በምፈልበት ሰአት ሲስተሙ ዝግጁ ነው።							
Information Quality (የመረጃ ጥራት)							
The system provides sufficient information to enable me to do my tasks (**Relevant** and useful to my work).							
ሲስተሙ ለስራዬ አስፈላጊና ጠቃሚ የሆነ በቂ መረጃ ይሰጠኛል።							
I am satisfied with the **Accuracy** of the information from the system.							
ከሲስተሙ የማገኘው የመረጃ ትክክለኛነት አርኪ ነው።							
The system generates complete report relevant to my job **(Completeness).**							
ሲስተሙ ለስራዬ ጠቃሚ የሆነ የተሟላ መረጃ ይሰጠኛል።							
The system enables me to access the information I need in time **(Timeliness)**.							
ሲስተሙ የምፈልገውን መረጃ በወቅቱ እንዳገኝ አስችሎናል።							
The reports from other departments are in the **format** of my need (**useful forma**t)							
ከሌሎች የስራ ሂደቶች የሚመጡ ሪፖርቶች በምፈልገው መልኩ የተዘጋጁ ናቸው።							
The system protects information from illegal disclosure **(Security -** authorization and authentication**).**							
ሲስተሙ ህጋዊ ያልሆኑ ሰዎች መረጃ እንዳያገኙ ይከላከላል።							
Service Quality (የአገልግሎት አሰጣጥ ጥራት)							
I receive prompt technical support for problems in using the system **(Responsiveness)**							
ሲስተሙን ስጠቀም ለሚገጥሙኝ ችግሮች ፈጣን የሆነ የቴክኒክ ድጋፍ አገኛለሁ።							
Technical team understands specific users need & have the knowledge to do their job well **(Assurance)**							
የቴክኒክ ድጋፍ የሚሰጡ አካላት የተጠቃሚዎችን ፍላጎት የሚረዱና ለመርዳትም እውቀቱ ያላቸው ናቸው።							
The technical support teams have users' best interests at heart. **(Empathy)**							
የቴክኒክ ድጋፍ የሚሰጡ አካላት ለተጠቃሚዎች ስሜት ይጠነቀቃሉ።							
I have access to the necessary resources to use the system (power supply, computers, printer, internet, scanner)							
ሲስተሙን ለመጠቀም የሚያስፈልጉኝን መሳርያዎች ሁሉ አገኛለሁ። (ኤሌክትሪክ: ኮምፒውተር: ፕሪንተር: ኢንተርኔት: ስካነር ...)							
The reported bugs/errors on the system get fixed in acceptable time frame **(Timely)**							
ሲስተሙ ያለበትን ችግር ሪፖርት ሳደርግ በፍጥነት ይስተካከላል።							
Technical support team provides dependable service **(Reliability)**							
በማገኘው የቴክኒክ ድጋፍ እተማመናለሁ።							

	Strongly disagree ፍጹም አልስማማም	Disagree አልስማማም	Somewhat disagree በመጠኑ አልስማማም	No opinion አስተያየት የለኝም	Somewhat agree በመጠኑ እስማማለሁ	Agree እስማማለሁ	Strongly agree ፍጹም እስማማለሁ
Questions (ጥያቄዎች)	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Technology and Information Use Factors (የቴክኖሎጂና የመረጃ አጠቃቀም)							
Intention to use							
Given that I have access to the system, I am willing to use it.							
ሲስተሙን ለመጠቀም እድል ካገኘሁኝ ለመጠቀም ፈቃደኛ ነኝ።							
I predict the system can reduce my work burden.							
ሲስተሙ የስራ ጫና እንደሚቀንስልኝ እገምታለሁ።							
I feel the system is necessary to do my job.							
ሲስተሙ ለስራዬ አስፈላጊ እንደሆነ ይሰማኛል።							
Actual Use (መጠቀም)							
I frequently use the system for my tasks (frequency of use).							
እለታዊ ስራዬን ለመስራት ሲስተሙን በተደጋጋሚ እጠቀማለሁ።							
I am dependent on the system for my task.							
ስራዬን ለመስራት በሲስተሙ ላይ እደገፋለሁ።							
I use the system for all data entry and report generation.							
መረጃ ለማስገባትም ሆነ መረጃ ለማግኘት የምጠቀመው ሲስተሙን ነው።							
I use the information for decision making.							
ከሲስተሙ የማገኘውን መረጃ ውሳኔ ለመስጠት እጠቀምበታለሁ።							
User Satisfaction (የተጠቃሚ እርካታ)							
I can finish my task faster with the system.							
ሲስተሙ የስራ አፈጻጸሜን አሻሽሎታል።							
The system improves my performance.							
ሲስተሙ ስራዬን በፍጥነት ለመፈጸም አስችሎኛል።							
The system has improved the quality of my work.							
ሲስተሙ የስራዬን ጥራቴ ጨምሮታል።							
Information generated from the system improves my decision							
ከሲስተሙ የማገኘው መረጃ የውሳኔ አሰጣጤን አሻሽሎታል።							
Overall I am satisfied with the system.							
በአጠቃላይ በሲስተሙ እረክቻለሁ።							

Appendix 4.2 Focus group discussion questions

Socio-technical dimensions

1. **Technological factors**: What are the key technological factors (in terms of system, information and technical services quality) to the success of eHealth implementation?
2. **Behavioural and social factors**: Describe the impact of human factors (individual's behaviour and impact of social environment) on successful implementation of eHealth technology.
3. **Technology use:** How do you evaluate the use of technology by its intended users?
4. **Technology on social & behavioural factors:** Describe the influence of technological factors on the individual behaviour and social environment.
5. **Technology on its usability:** Describe the influence of technological factors on the usability of the technology.
6. **Social on technology use:** Describe how the individual behaviour and social environment influence the technology use.
7. **Benefits:** What are the expected improvements of healthcare service delivery through the implementation of eHealth?
8. **Benefit on social & technological factors:** Describe how these healthcare service outcomes (benefits) influence the technology, individual behaviour and social environment.

Techno-organizational Dimensions

1. **Management Support**: How do you describe the support from the top management to the successful implementation of eHealth? Example: planning, training, supervision, resources …
2. **Infrastructure**: How do you describe the readiness of IT infrastructure (computer, network, internet, power, printer …) within the organization to the successful implementation of eHealth technology?
3. **Skill**: How do you describe the availability of skills required to use and support the eHealth system? And the organization’s approach to develop the required skill through trainings or other ways?
4. **Workflow Processes**: How do you describe the convenience of existing workflow processes and involvement of users during the development, implementation and use of eHealth application?
5. **Change Management**: How do you manage the changes in the work flow processes associated with the introduction of eHealth technology?
6. **Culture:** How do you describe the culture of technology use; information need, use and dissemination in the organization? What is the organization’s approach to promote information and technology culture?
7. **Project management:** How do you describe the planning, organising, leading and controlling functions of the project towards the effective use of resources to deliver the required system quality within the planed time?
8. **Policy:** How do you describe the organizations policy towards promoting or demoting the implementation and use eHealth technology? [national, regional or facility level]

Techno-economic Dimensions

1. **Key stakeholders**: Who are the key stakeholders in the process of eHealth implementation? What is their role? (funding, using, benefiting … from the technology)
2. **Funding**: Who provides funding to the development, implementation and maintenance of eHealth project?
3. **Cost categories**: Describe the fixed investment and variable cost categories associated with eHealth Implementation.
4. **Cost estimation**: Can you estimate the monitory value of fixed and variable costs associated with eHealth implementation?
5. **Benefit categories**: Identify the areas of economic benefits (cost saving) from eHealth program in your organizations.
6. **Benefit estimation**: Can you put monitory value to the benefits?

Appendix 4.3 Interview data and variables description

Name	FT	R	Date	UP	SyQ	IQ	SrQ	PU	PEOU	SI	IU	AU	US
Repondent 1	1	1	2012	60	7	7	7	7	7	6	7	7	7
Repondent 2	1	1	2012	10	7	7	5	7	7	6	7	7	7
Repondent 3	1	1	2012	10	6	7	5	7	7	1	7	7	7
Repondent 4	1	1	2014	12	6	6	3	6	4	5	7	6	6
Repondent 5	1	1	2014	27	6	7	3	7	5	4	7	7	7
Repondent 6	1	1	2010	72	5	5	4	7	4	4	6	6	6
Repondent 7	1	1			6	6	6	6	6	5	6	6	6
Repondent 8	1	1		57	5	5	4	6	4	3	6	5	5
Repondent 9	2	1	2010	60	7	7	7	7	7	6	7	7	7
Repondent 10	2	1	2010	60	6	6	4	6	6	3	7	6	6
Repondent 11	2	1	2012		7	7	7	7	7	5	7	7	7
Repondent 12	2	1	2012		7	7	7	7	7	5	7	7	7
Repondent 13	2	1	2012	24	7	7	7	7	7	6	7	7	7
Repondent 14	2	1	2012	4	6	7	7	6	7	7	7	7	7
Repondent 15	2	1	2012		7	7	7	7	7	5	7	7	6
Repondent 16	2	2	2013	48	6	6	6	6	6	5	6	6	6
Repondent 17	2	2	2013	48	6	7	7	7	6	6	7	6	7
Repondent 18	1	2	2010	48	6	6	5	6	6	7	6	7	7
Repondent 19	1	2	2015	24	6	7	6	7	6	6	6	7	6
Repondent 20	1	2	2015	8	4	7	6	7	7	6	7	7	6
Repondent 21	2	2	2014	4	7	7	6	7	6	7	7	7	7
Repondent 22	4	2	2010	36	5	6	6	7	6	6	7	7	6
Repondent 23	3	2	2010	96	6	7	6	7	7	6	7	7	7
Repondent 24	1	2	2015	12	5	5	5	5	5	5	5	5	5
Repondent 25	1	2	2015	22	6	7	6	7	6	7	7	7	7
Repondent 26	1	2	2016	2	6	7	5	7	7	3	7	5	5
Repondent 27	6	1	2010	30	7	6	7	7	6	6	7	7	7
Repondent 28	6	1	2010		4	6	5	7	5	5	6	6	6
Repondent 29	6	1	2010	24	1	3	3	2	2	4	2	7	3
Repondent 30	6	1	2010	48	3	5	4	4	5	4	5	5	3
Repondent 31	6	1	2010		6	5	5	7	6	6	7	6	6
Repondent 32	6	1	2010	45	3	5	4	6	5	5	6	6	5
Repondent 33	6	1	2010	48	5	4	6	6	6	6	6	7	6
Repondent 34	6	1	2010	72	2	3	2	5	2	3	6	5	3
Repondent 35	5	1	2012	60	6	5	4	7	5	5	6	6	5
Repondent 36	5	1	2012	24	5	5	2	7	6	4	6	7	6
Repondent 37	5	1	2012	12	5	3	2	6	6	4	3	5	3
Repondent 38	5	1	2012		6	6	4	6	6	5	6	5	5
Repondent 39	5	1	2012	19	5	5	6	7	6	4	6	6	5
Repondent 40	5	2	2011	30	4	5	3	7	7	3	7	7	6

Variables description

The period the respondents used the system	UP	Period of use (Months)
Technological Factors	SyQ	System Quality
	IQ	Information Quality
	SrQ	Services Quality
Behavioural & Social Factors	PU	Perceived Usefulness
	PEOU	Perceived Ease of Use
	SI	Social Influence
Technology and Information Use Factors	IU	Intention to use
	AU	Actual Use
	US	User Satisfaction
System implementation date (year)	Date	System implementation date
The name of interviewee	Name	
Type of facility	FT	1= Health centre; 2=Hospital; 3=WHO; 4=ZHB; 5=RHB; 6=FMOH
Region	R	1= Addis Ababa; 2=SNNPR

Appendix 4.4 ATLAS.ti Codebook

Code Groups	Code	Comment	Example
Benefits	Ben_Complete information	The availability of full information to improve healthcare services delivery.	The EMR aims at enabling individuals to have their full medical reports with them anytime. This improves the healthcare service they get when needed.
Benefits	Ben_Improve decision	Refers to better decision-making due to access to accurate and timely healthcare information.	In terms of public health interventions, electronic HMIS enabled higher officials to get access to timely information to make fast and evidence-based decisions.
Benefits	Ben_Improve healthcare quality	Refers to better healthcare services experience of patients or society that meet their expectations.	The EMR system reduced the waiting time for visiting patients. It also enabled caregivers to have a complete health record of patients improving the quality of healthcare services
Benefits	Ben_Improve information quality	Refers to availability of timely and accurate content of information systems to make informed healthcare decisions.	Electronic health systems improve the quality of data by validating human data entry errors through information integration and cross-checking the information from other sources.
Benefits	Ben_Informed citizen	Citizen’s awareness level about the health-related information to improve their health status.	The electronic health system offers a platform to inform a wide range of society about health-related information to create health literate community. The penetration of mobile phone is increasing and the opportunity can be used to reach the community directly using electronic health system, to create healthcare awareness and to mobilize the community to build healthy a community.

Benefits	Ben_Manage disease outbreak	Refers to a benefit of eHealth to control the cases of disease when occurred in excess of what would normally be expected in a defined community, geographical area or season.	Healthcare related problems require timely interventions. For example, where there is a disease outbreak, the information needs to reach to the decision makers as fast as possible. Electronic health systems are better than paper systems in providing a platform for quick and timely reporting of information for decision making. The electronic health systems facilitate the delivery of reports quickly to decision makers for fast actions even from a very remote area.
Benefits	Ben_Reduce waiting time	Refers to the contribution of eHealth to reduce the time it takes for a patient to receive treatment in a health facilities.	The EMR system reduced the waiting time for visiting patients. It also enabled caregivers to have a complete health record of patients improving the quality of healthcare services delivery.
eHealth	eHMIS	Refers to an automated HMIS that helps to accurately and timely collect, aggregate, store, analyse and evaluate health-related data from health facility to federal level.	The HMIS data is first captured on paper from each ward or service units before transferred into the electronic system.
eHealth	SmartCare	Refers to an integrated EMR system to capture the electronic format of patients' medical record.	The system completeness is very critical. The EMR system does not cover all the processes that the users need to execute their tasks. For example, the EMR implemented in Ayder hospital doesn't have an exhaustive list of diseases. When the users encounter the diseases that are not available in the pre-loaded lists, the users chose other and return to use paper.

Implementation	Impl_Change management	Assessing and understanding of the nature and content of clinical workflow and align the operation of eHealth system with it.	To reduce users' resistance to using an electronic system, it is important to coach users closely until they become comfortable in using the system. When a new system is introduced there users are reluctant to use the system and they easily transfer the blame to the poor quality of the system for not using it. Some users even do not want to see the system when they face minor difficulty. Following the manual workflow processes and keeping the technical support close to the users and provide quick technical support (immediate response to any difficulties) until they became conformable in using the system facilitated the technology use.
Implementation	Impl_Communications	An effective exchange of timely and accurate information with all relevant stakeholders to create awareness about the benefits of eHealth.	First of all, we need to create awareness about the advantages of using the technology and communicate the benefits achieved in facilities where the technology has been implemented.
Implementation	Impl_Data management	Addresses the collection, storage, quality control and flow, processing, compilation, analysis and presentation of data.	The people at the service units only care about capturing their department data on HMIS form. They consider themselves as supporting member of HMIS. Hence they don't involve in the entire process of data management, they feel that is the duty of HMIS focal person. The data collection, digitalization of information and data quality are believed to be the responsibility of only HMIS focal person.
Implementation	Impl_Project management	An application of knowledge, skills, tools, and techniques to project activities in order to fulfil stakeholder needs and to balance schedule, quality and budget expectations.	In general, the implementation of eHealth technology in Ethiopia does not follow the concept of project management. The start and end date of the projects are not clearly known, the resource allocation is not planned, and the project outcome is not evaluated again the requirements of the project. Economic feasibility studies were not done to evaluate the potential benefits of the project.

Implementation	Impl_Stakeholders engagement	The involvement of key stakeholders in the process of eHealth implementation starting from the planning phase to reduce resistance, increase acceptance, and meet the needs of users.	The involvement of users is weak in the process of eHealth implementation. The top-down approach is used to push the technology to the health facilities. As a result, when users begin to use the system, they get frustrated because it fails to meet all the needs of users ... The users are not involved in requirement gathering, and prototype testing; furthermore, no feedback from users is incorporated into the system to mature it further. The systems are developed and pushed to the users.
Implementation	Impl_Training	The amount of training provided to the eHealth users in the healthcare institutions by internal or external entities to facilitate technology use.	The users needed continuous training because the physicians' turnover was high. The newly appointed doctors needed immediate training on system use. eHMIS users were more motivated than SmartCare users to learn about the technology.
Individual	Ind_ICT use skill	The ability to use electronic systems to execute day-to-day tasks.	The ease of use is an important element of electronic systems. Most electronic systems are developed with advanced users in mind. However, In the developing countries like Ethiopia, physicians have very limited ICT skills. Therefore, the system must be designed and developed to accommodate users with very little skill in using computer systems.
Information quality	Info quality_data accuracy	The correctness of data values stored in the system.	The data discrepancy was observed between the source data and the reported data. The majority of data discrepancy was related to arithmetic errors. The data collected from the register at each department and the information reported through electronic system differ, posing data quality problem. The clinical users of eHMIS were dissatisfied users who did not provide accurate information. Data quality decreases as one went from the FMOH to the facility level. Sharing of log-in credentials was another data quality concern in eHMIS use. Personal health information is sensitive, therefore, SmartCare needs strong attention to secure data.

Organization	Org_ICT culture	The culture of using ICT within an organization to support information and knowledge management.	The situation in the world is driving people to use technology in the health sector to improve the use of information. The use of the mobile application in day to day activities is an evidence of the growing culture of technology use in the society. Similarly, people within the organizations are developing the culture of technology use in the work environment. The fear factors to use ICT is going down as people actively use computers, tablets, and phones for personal needs.
Organization	Org_Management support	The willingness of top management to deploy and use eHealth, and allocate necessary resources for its success.	The top management gives strong support on electronic tool selection, resource allocation, and budgeting for the implementation of and providing expert support. The top management is willing and supportive of eHealth implementation, but there are gaps and weaknesses in the project management.
Organization	Org_Organizational structure	The availability of organizational units such as the IT department and project management unit to support the successful implementation of SmartCare and eHMIS.	The lack of ICT support structure from the Federal to health facility level is one of the main reason for slow technical services. To give fast response time during technical support, we need to have local ICT support team at health facility level which is missing in the current structure. The role of the technical support team at health facility level is not clearly defined. As a result, they are more involved in data entry and reporting activities than technical support because they report to the Planning department instead of HITD.

Organization	Org_Resources readiness	Assesses the adequacy of human resources and ICT infrastructure to implement successful eHealth system.	Our infrastructure readiness assessment before the implementation of EMR in health facilities indicated that most of the health facilities have not put electronic systems into consideration during the construction phase. As a result, there is very poor infrastructure to support the implementation of the electronic system ... Most health facilities do not have the internet connectivity, and the infrastructure readiness level is low to implement a robust electronic health system.
Organization	Org_Workflow process	Understanding the current workflow processes in the service units, identifying service units where eHealth will be implemented, and determining possible changes of workflow processes to align the technology with existing workflow processes.	Moreover, the system should follow the manual workflow processes. A minor change in the electronic system process flow from the existing manual work process creates a lot of confusion. The eHealth system is relatively a new technology so it is too early to ask clinicians to adjust themselves towards the electronic system.
Services quality	Services Qlty_Access to support	The availability of technical support to fix eHealth system problems.	Because of frequent electric power fluctuation, the computer machines that run SmartCare (EMR) program failed after over five thousands backlog patient information was captured. The users said that the technology was helping a lot in avoiding duplicate patient records, in simplifying registration of patients and easily locating patient records, but because of lack of technical support service, they moved back to the old paper system.
Services quality	Services Qlty_Competency	The skill of technical support team to deliver efficient technical support.	The support services problem of EMR can be viewed from two perspectives. One is the lack of support team close to the users in a health facility (lack of access to professionals) and the second is the lack of skill to provide good technical support.

Services quality	Services Qlty_Fragmented support	The lack of coordinated technical support to address eHealth problems.	The EMR support services do not support end-to-end healthcare service delivery processes of the healthcare facility as a result of fragmented EMR modules implemented by different organizations. For example, the laboratory information system (LIS) in Ayder hospital is not part of the EMR system. The LIS module is developed and implemented by a different organization and it is not interoperable with the EMR system.
Services quality	Services Qlty_Resource availability	Availability of maintenance tools and professionals.	The third support services challenge is related to the availability of maintenance tools. The professionals trained to give technical support are available and are willing to give support. However, especially in case of EMR, the support team lacks maintenance toolkits to offer support services. A minimum of one IT professional is needed to support 100 eHealth users and two HITs at each health facilities.
Services quality	Service Qlty_Timely response	The speed of technical support team to fix eHealth problems.	Frequent software crashes on both eHMIS and EMR is frustrating to users at a health facility and federal levels. There is a routine of software crash and fix in the daily operation of both systems. The time between failures, i.e., the time between software crashes and the time between maintenance (fix) are high. The frequency of software failure must be minimized and the time between maintenance must be made short to keep the users satisfied.
Social	Soc_Co-worker influence	The influence of co-workers towards eHealth use.	The culture of technology and information use is heavily dependent on one individual expert. The whole information system collapses when the influence of an individual expert is lost because of employee’s turnover which is very common in health facilities. With a new expert on board, the data gathering, analysis and reporting cycle starts as a fresh process all over again.

Social	Soc_Supervisor influence	The influence of supervisors towards eHealth implementation and technology use.	Technology section is done at the top level of management, so the users have little input to technology selection. Hence as a person joins the FMOH, the employees must use the technology whether they understand the benefit or not.
Social	Soc_Teamwork culture	The culture of teamwork to facilitate data management process.	There is a discrepancy between HMIS and program people. The program people are the source of data, they record all information on the registry. The program people are at the front line in data collection but they do not consider data management as their mandate. As a result, they lag behind HMIS personnel whose track and report the information. The HMIS people accepted that data management is their responsibility. This is the big discrepancy in the process of HMIS data management and processing.
System quality	System Qlty_ Capability	The ability or completeness of the system to meet users' requirements.	There is a design problem with EMR system. The EMR is not designed to interface with health technology machines (interoperability). The EMR could have captured laboratory results from laboratory machines directly, however, the EMR does not have that functionality. The LIS module from Polytech interfaced with laboratory machines to capture laboratory results directly from the machines. However, the system doesn't talk to EMR in Ayder hospital lacking the capacity to covering the end-to-end service delivery process.

System quality	System Qlty_Ease of use	The ease of technology use or user-friendliness as perceived by the end-users.	Moreover, the system needs to be implemented in the local context or localized. For example, the language and the calendar system is adopted from abroad which is different from Ethiopian national language and calendar system. Both EMR and eHMIS are not developed in the local context or culture which makes the national level implementation difficult. Because of the uniqueness of Ethiopian calendar, the fiscal year is different from the rest of the world. Therefore, generating a report in the context of Ethiopian calendar from a system that uses the Gregorian calendar is a challenge.
System quality	System Qlty_Performance	The speed of eHealth applications to execute end-users instructions.	One of the important system quality factors is system performance. In the case of eHMIS, the system fails to execute commands quickly. Report generation takes a long time.
System quality	System Qlty_Reliability	The ability of eHealth system to ensure continuity of the service.	Frequent software crashes on both eHMIS and EMR is frustrating to users at a health facility and federal levels. There is a routine of software crash and fix in the daily operation of both systems. A SmartCare system had only one EMR server at a health facility without a failover server as a backup in the event of server failure.
Intention to use	Use_Burden	The level of burden the end-users perceive to use eHealth system.	The physicians perceive using EMR as a burden that adds extra workload on the busy schedule. EMR is not considered as part of the solution that facilitates and supports the physician’s task, but an extra task. This perception might come from the medical training of the physicians or other factors, but EMR is seen as an additional task, not as a tool that supports their task.
Intention to use	Use_Necessary to job	The importance of eHealth to accomplish tasks better and quicker.	If the users perceive or accept the system as a tool that gives a solution to some of their day-to-day operational problems, then the technology will have a good acceptance

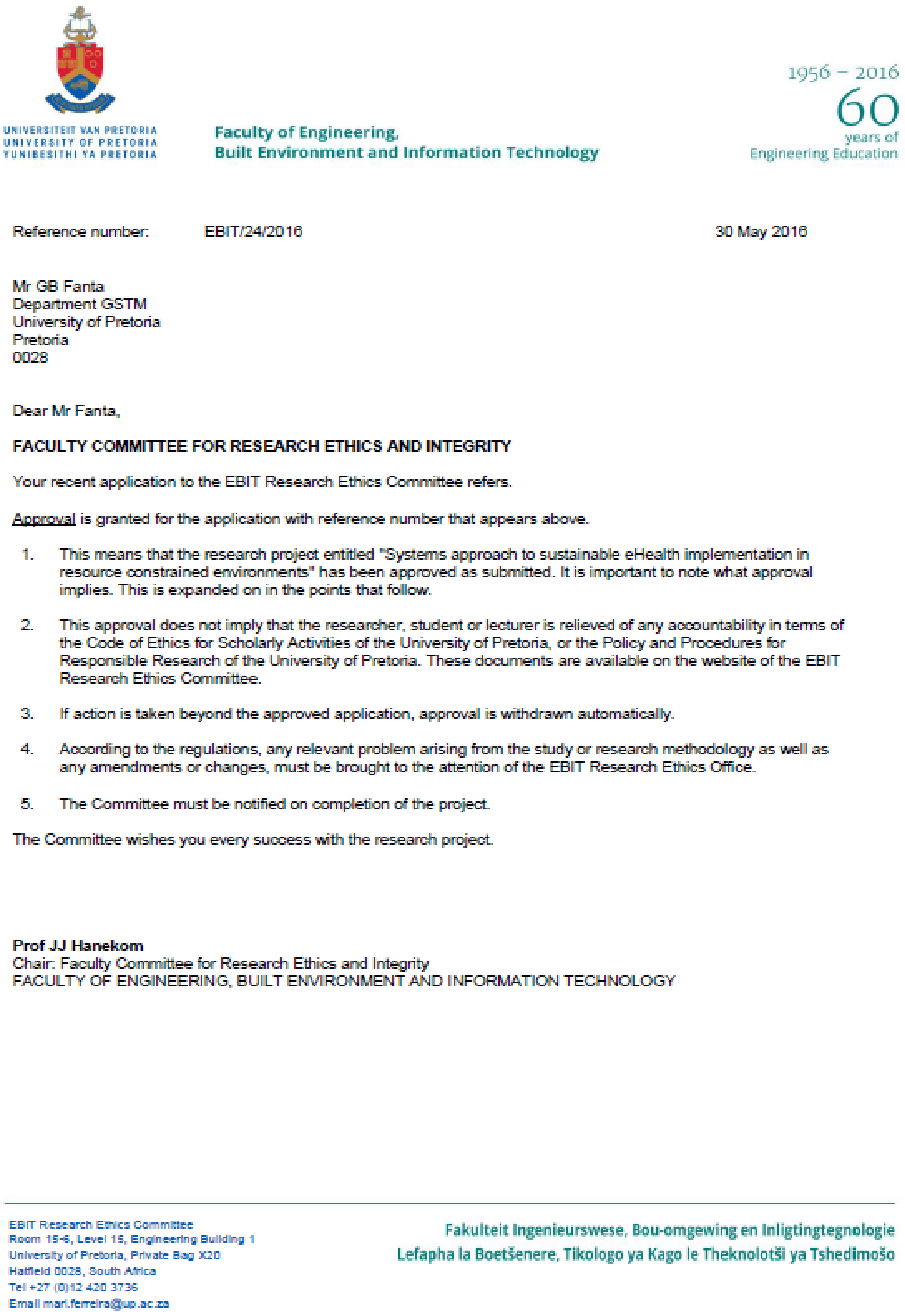
Intention to use	Use_Willingness	The intention of end-users to use technology for their day-to-day tasks in healthcare organizations.	Those users with low experience of using computers and electronic technologies may not be voluntary users even if they understand the usefulness of the technology to perform their duty. This is mainly because of the fear of technology. Hence the technology use becomes mandatory for these groups of users.
Satisfaction	Use_Improve decisions	The ability to make accurate decision through the use of eHealth information product.	The use of electronic system helps to make an evidence-based decision towards better healthcare service delivery. Besides it enables to monitor and evaluate the progress and improvements towards better healthcare services
Satisfaction	Use_Improve work performance	Improvement in end-users work efficiency through the use of eHealth in health facilities.	The eHMIS and EMR users are expected to enter the data into the electronic system, but they do not see the benefit of data collection in their day to day work activity. Can you imagine how the doctors feel frustrated if he/she is asked to enter data but does not really see the value of entering data? The information might be used at a regional or national level for decision making, yet the use of information for decision making is low at the data entry level. This leaves users dissatisfied. The system needs to improve end-users performance.
Satisfaction	Use_Improve services quality	Improvement in healthcare services delivery because of eHealth use in the facility.	EMR for example, a patient visiting a doctor wants to get improved services quality. If the technology contributed to a better patient experience, then I consider it as evidence of technology use and use it to measure technology use. Second, if the sick patient is encouraged to visit the doctor again without waiting until he/she is critically sick. If the technology increased satisfaction then it is an indication of technology use in the healthcare.

Actual use	Use_Information Use	The use of reports generated from the eHealth system for discussions, advocacy, decisions, and referrals for action at a higher level.	A doctor or physician who is capturing patient record on EMR might use the information when treating a visiting patient for diagnosis and decision making. How can a data entry clerk at health facility level use eHMIS data for decision making?
Actual use	Use_Technology use	The use of eHealth technology for day-to-day work purpose.	Although you provide smart and well-designed electronic solution, there are some individuals who are technophobic. Some physicians' are not familiar with typing in keyboards and they do not want to be exposed or seen by their patients or colleagues when using computers. The physician's ego or not to be exposed to the slow typing skill also cause resistance to EMR use by physicians. The frequency of SmartCare use is high compared to eHMIS.

Appendix 4.5 Summary of eHMIS database - SNNPR

Years	Number of facility began using eHMIS
2009	14
2010	1146
2011	1765
2012	1264
2013	343
2014	46
2015	333
2016	365
2017	60
2018	37

Appendix 4.6 Ethics Approval



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Engineering,
Built Environment and Information Technology

1956 – 2016
60
years of
Engineering Education

Reference number:	EBIT/24/2016	30 May 2016

Mr GB Fanta
Department GSTM
University of Pretoria
Pretoria
0028

Dear Mr Fanta,

FACULTY COMMITTEE FOR RESEARCH ETHICS AND INTEGRITY

Your recent application to the EBIT Research Ethics Committee refers.

Approval is granted for the application with reference number that appears above.

1. This means that the research project entitled "Systems approach to sustainable eHealth implementation in resource constrained environments" has been approved as submitted. It is important to note what approval implies. This is expanded on in the points that follow.
2. This approval does not imply that the researcher, student or lecturer is relieved of any accountability in terms of the Code of Ethics for Scholarly Activities of the University of Pretoria, or the Policy and Procedures for Responsible Research of the University of Pretoria. These documents are available on the website of the EBIT Research Ethics Committee.
3. If action is taken beyond the approved application, approval is withdrawn automatically.
4. According to the regulations, any relevant problem arising from the study or research methodology as well as any amendments or changes, must be brought to the attention of the EBIT Research Ethics Office.
5. The Committee must be notified on completion of the project.

The Committee wishes you every success with the research project.

Prof JJ Hanekom
Chair: Faculty Committee for Research Ethics and Integrity
FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY

EBIT Research Ethics Committee
Room 15-6, Level 15, Engineering Building 1
University of Pretoria, Private Bag X20
Hatfield 0028, South Africa
Tel +27 (0)12 420 3736
Email mari.ferreira@up.ac.za

Fakulteit Ingenieurswese, Bou-omgewing en Inligtingtegnologie
Lefapha la Boetšenere, Tikologo ya Kago le Theknolotši ya Tshedimošo

Appendix 5.1 The values and equations of the socio-technical model parameters of eHMIS

Acceptance rate=IF THEN ELSE(Individuals' intention to use+Promoters > Inhibitors, MIN(Potential users/Delay time, Individuals' intention to use+Promoters - Inhibitors), MIN(Potential users/Delay time,Individuals' intention to use))
Units: Persons/Year [0,6500]

Actual users= INTEG (Acceptance rate-Dissatisfaction rate-Satisfaction rate, 0)
Units: Persons [0,6500]

Adjustment time= WITH LOOKUP (Effectiveness of Training,([(0,0)-(1,10)],(0,10),(1,1)))
Units: Year [0.01,10]

Adopted population= 26000
Units: Persons [0,50000,1]

Change in perception to use=Difference in perception/Adjustment time
Units: 1/Year

Contact rate= 20
Units: 1/Year [1,300,1]

Delay time= 2
Units: Year [1,15,0.1]

Difference in perception=System usefulness and ease of use-Individual perception to use
Units: Dmnl

Dissatisfaction rate=Actual users*Technological flaws/Period of use
Units: Persons/Year [0,6500]

Dissatisfied users= INTEG (Dissatisfaction rate-Intervention rate-Termination rate, 0)
Units: Persons [0,6500]

Effectiveness of Training= 0.56
Units: Dmnl [0,1,0.05]

Frequency of use= 120
Units: 1/Year [1,10000,1]

Incentives=0.2
Units: Dmnl [0,1,0.05]

Individual perception to use= INTEG (Change in perception to use,0.01)
Units: Dmnl [0,1]

Individuals' intention to use=MAX(Potential users*Individual perception to use/Time to training,0)
Units: Persons/Year

Information quality=System quality*Satisfied users/(Dissatisfied users+Satisfied users)
Units: Dmnl [0,1,0.01]

Inhibitors=

MAX(Terminated users*System flaw*Contact rate*Potential users/Adopted population,0)
Units: Persons/Year [0,4000]

Intervention rate=Dissatisfied users*Intervention step/Time to intervention
Units: Persons/Year [0,6500]

Intervention step=
STEP(Technological quality*(Effectiveness of Training+Incentives)/2, Time to intervention)
Units: Dmnl [0,1]

Performance improvement rate= 0.3
Units: 1/Year [0,1,0.01]

Period of use=5
Units: Year [1,15,0.1]

Potential users= INTEG (-Acceptance rate, 6500)
Units: Persons [0,10000]

Promoters=
MAX(Satisfied users*Contact rate*Technological quality*Potential users/Adopted population,0)
Units: Persons/Year [0,7000]

Reduce work burden= 0.94
Units: Dmnl [0,1,0.01]

Satisfaction rate=Actual users*Technological quality*Performance improvement rate Units: Persons/Year [0,7000]

Satisfied users= INTEG (Intervention rate+Satisfaction rate, 1)
Units: Persons [0,6500]

Services quality= 0.8
Units: Dmnl [0,1,0.01]

System flaw=1-(Technological quality+Effectiveness of Training)/2
Units: Dmnl

System quality=0.8
Units: Dmnl [0,1,0.01]

System usefulness and ease of use=
Technological quality * (Effectiveness of Training + Reduce work burden)/2
Units: Dmnl

Technological flaws=1-Technological quality
Units: Dmnl

Technological quality=
(Information quality+Services quality+System quality)/3 Units: Dmnl [0,1]

Terminated users= INTEG (Termination rate,0)
Units: Persons [0,6500]

Termination rate=Dissatisfied users*Termination step/Termination time
Units: Persons/Year [0,6500]

Termination step=IF THEN ELSE(Period of use >= (Trials before termination/Frequency of use), STEP((Frequency of use*Period of use-Trials before termination)/(Frequency of use*Period of use), Trials before termination/Frequency of use), 0)
Units: Dmnl

Termination time=MAX (Trials before termination/Frequency of use,1)
Units: Year [1,15,0.5]

Time to intervention= 2
Units: Year [1,15,0.1]

Time to training= 1
Units: Year [1,15,0.1]

Trials before termination= 240
Units: Dmnl [1,10000,1]

Appendix 5.2 The values and equations of socio-technical model parameters of SmartCare

Acceptance rate=IF THEN ELSE(Individuals' intention to use+Promoters > Inhibitors, MIN(Potential users/Delay time, Individuals' intention to use+Promoters - Inhibitors), MIN(Potential users/Delay time,Individuals' intention to use))
Units: Persons/Year [0,6500]

Actual users= INTEG (Acceptance rate-Dissatisfaction rate-Satisfaction rate, 0)
Units: Persons [0,6500]

Adjustment time= WITH LOOKUP (Effectiveness of Training,([(0,0)-(1,10)],(0,10),(1,1)))
Units: Year [0.01,10]

Adopted population= 320
Units: Persons [0,500,1]

Change in perception to use=Difference in perception/Adjustment time
Units: 1/Year

Contact rate= 20
Units: 1/Year [1,300,1]

Delay time= 3
Units: Year [1,15,0.1]

Difference in perception=System usefulness and ease of use-Individual perception to use
Units: Dmnl

Dissatisfaction rate=Actual users*Technological flaws/Period of use
Units: Persons/Year [0,6500]

Dissatisfied users= INTEG (Dissatisfaction rate-Intervention rate-Termination rate, 0)
Units: Persons [0,6500]

Effectiveness of Training= 0.4
Units: Dmnl [0,1,0.05]

Frequency of use= 7500
Units: 1/Year [1,10000,1]

Incentives=0
Units: Dmnl [0,1,0.05]

Individual perception to use= INTEG (Change in perception to use,0.01)
Units: Dmnl [0,1]

Individuals' intention to use=MAX(Potential users*Individual perception to use/Time to training,0)
Units: Persons/Year

Information quality=System quality*Satisfied users/(Dissatisfied users+Satisfied users)
Units: Dmnl [0,1,0.01]

Inhibitors=

MAX(Terminated users*System flaw*Contact rate*Potential users/Adopted population,0)
Units: Persons/Year [0,4000]

Intervention rate=Dissatisfied users*Intervention step/Time to intervention
Units: Persons/Year [0,6500]

Intervention step=
STEP(Technological quality*(Effectiveness of Training+Incentives)/2, Time to intervention)
Units: Dmnl [0,1]

Performance improvement rate= 0.2
Units: 1/Year [0,1,0.01]

Period of use=1
Units: Year [1,15,0.1]

Potential users= INTEG (-Acceptance rate, 200)
Units: Persons [0,500]

Promoters=
MAX(Satisfied users*Contact rate*Technological quality*Potential users/Adopted population,0)
Units: Persons/Year [0,7000]

Reduce work burden= 0.2
Units: Dmnl [0,1,0.01]

Satisfaction rate=Actual users*Technological quality*Performance improvement rate
Units: Persons/Year [0,7000]

Satisfied users= INTEG (Intervention rate+Satisfaction rate, 1)
Units: Persons [0,6500]

Services quality= 0.3
Units: Dmnl [0,1,0.01]

System flaw=1-(Technological quality+Effectiveness of Training)/2
Units: Dmnl

System quality=0.4
Units: Dmnl [0,1,0.01]

System usefulness and ease of use=(Effectiveness of Training + Reduce work burden)/2
Units: Dmnl

Technological flaws=1-Technological quality
Units: Dmnl

Technological quality=(Information quality+Services quality+System quality)/3
Units: Dmnl [0,1]

Terminated users= INTEG (Termination rate,0)
Units: Persons [0,6500]

Termination rate=Dissatisfied users*Termination step/Termination time

Units: Persons/Year [0,6500]

Termination step=IF THEN ELSE(Period of use >= (Trials before termination/Frequency of use
), STEP((Frequency of use*Period of use-Trials before termination)/(Frequency of use*Period of use), Trials before termination/Frequency of use), 0)
Units: Dmnl

Termination time=MAX (Trials before termination/Frequency of use,1)
Units: Year [1,15,0.5]

Time to intervention= 4
Units: Year [1,15,0.1]

Time to training= 2
Units: Year [1,15,0.1]

Trials before termination= 1500
Units: Dmnl [1,10000,1]

Appendix 6.1 Values and equations of techno-organizational model parameters of eHMIS

Acceptance rate=
IF THEN ELSE(Individuals' intention to use+Promoters > Inhibitors, MIN(Potential users/Delay time, Individuals' intention to use+Promoters - Inhibitors), MAX(Potential users/Delay time,Individuals' intention to use))
Units: Persons/Year [0,13000]

Actual users= INTEG (Acceptance rate-Dissatisfaction rate-Satisfaction rate, 0)
Units: Persons [0,13000]

Adjustment time= WITH LOOKUP (Effectiveness of training,([(0,0)-(1,10)],(0,10),(1,1)))
Units: Year [0.01,10]

Adopted population=26000+Current Workforce-6500
Units: Persons [0,50000,1]

Average workforce training= 0.33
Units: 1/Year [0,1,0.01]

Average workforce turnover= 0.092
Units: 1/Year [0,1,0.01]

Change in perception to use= Difference in perception/Adjustment time
Units: 1/Year

Contact rate= 20
Units: 1/Year [1,300,1]

Current Infrastructure= INTEG (Installation rate-Depreciation rate, 0.39)
Units: Dmnl

Current Workforce= INTEG (Hiring rate-Turnover rate, 6500)
Units: Persons

Delay time= 2
Units: Year [1,15,0.1]

Depreciation rate=Current Infrastructure*Power and digital equipment depreciation rate
Units: 1/Year

Desired infrastructure = 1
Units: Dmnl [0,1,0.01]

Desired workforce= 13000
Units: Persons

Difference in perception=System usefulness and ease of use-Individual perception to use
Units: Dmnl

Dissatisfaction rate= Actual users*Technological flaws/Period of use
Units: Persons/Year [0,6500]

Dissatisfied users= INTEG (Dissatisfaction rate-Intervention rate-Termination rate, 0)

Units: Persons [0,6500]

Effectiveness of training=(Management support+Trainee motivation)/2
Units: Dmnl [0,1,0.05]

Digital equipment installation rate= 0.005
Units: 1/Year [0,1,0.01]

Familiarity with electronic systems= 0.2
Units: Dmnl [0,1,0.01]

Frequency of use= 120
Units: 1/Year [1,10000,1]

Hiring rate= Management support*Workforce gap*Average workforce training
Units: Persons/Year

Incentives= 0.2
Units: Dmnl [0,1,0.05]

Individual perception to use= INTEG (Change in perception to use, 0.01)
Units: Dmnl [0,1]

Individuals' intention to use= MAX(Individual perception to use*Potential users/Time to training,0)
Units: Persons/Year [0,13000]

Information quality=
(Organizational ICT culture+System quality)*Satisfied users/(2*(Dissatisfied users +Satisfied users))
Units: Dmnl [0,1,0.01]

Infrastructure gap = Desired infrastructure – Current infrastructure
Units: Dmnl [0,1]

Inhibitors= MAX(Terminated users*System flaw*Contact rate*Potential users/Adopted population ,0)
Units: Persons/Year [0,13000]

Installation rate= Management support*(Power installation rate+Internet installation rate+Digital equipment installation rate)/3
Units: 1/Year

Internet installation rate= 0.024
Units: 1/Year [0,1,0.01]

Intervention rate= Dissatisfied users*Intervention step/Time to intervention
Units: Persons/Year [0,6500]

Intervention step=
STEP(Technological quality*(Effectiveness of training+Incentives)/2, Time to intervention)
Units: Dmnl [0,1]

Management support= (Supportive policy+Organizational ICT culture)/2
Units: Dmnl [0,1]

Organizational ICT culture= Familiarity with electronic systems
Units: Dmnl [0,1]

Performance improvement rate= 0.3
Units: 1/Year

Period of use= 5
Units: Year [1,15,0.1]

Potential users= INTEG (
IF THEN ELSE(Acceptance rate>0,MIN(Hiring rate-Turnover rate-Acceptance rate ,0),0), 6500)
Units: Persons [0,13000]

Power and electronic equipmenet depreciation rate= 0.2
Units: 1/Year

Power installation rate= 0.04
Units: 1/Year [0,1,0.01]

Promoters=
MAX(Satisfied users*Contact rate*Technological quality*Potential users/Adopted population ,0)
Units: Persons/Year [0,13000]

Reduce work burden=0.94
Units: Dmnl [0,1,0.01]

Resources readiness= (Current Infrastructure+Current Workforce/Desired workforce)/2
Units: Dmnl [0,1]

Satisfaction rate=
Actual users*Performance improvement rate*(Technological quality+Workflow alignment)/2
Units: Persons/Year

Satisfied users= INTEG (Intervention rate+Satisfaction rate, 1)
Units: Persons [0,6500]

Services quality=(Resources readiness+Supportive organizational structure)/2
Units: Dmnl [0,1,0.01]

Supportive organizational structure= 0.2
Units: Dmnl [0,1,0.01]

Supportive policy= 1
Units: Dmnl [0,1,0.01]

System flaw=1-(Technological quality+Effectiveness of training)/2
Units: Dmnl

System quality=0.8
Units: Dmnl [0,1,0.01]

System usefulness and ease of use= (Effectiveness of training + Reduce work burden)/2

Units: Dmnl

Technological flaws=1-Technological quality
Units: Dmnl

Technological quality=(Information quality+Services quality+System quality)/3
Units: Dmnl [0,1]

Terminated users= INTEG (Termination rate,0)
Units: Persons [0,6500]

Termination rate=Dissatisfied users*Termination step/Termination time
Units: Persons/Year [0,6500]

Termination step= IF THEN ELSE(Period of use >= (Trials before termination/Frequency of use), STEP((Frequency of use*Period of use-Trials before termination)/(Frequency of use *Period of use), Trials before termination/Frequency of use), 0)
Units: Dmnl

Termination time=MAX (Trials before termination/Frequency of use,1)
Units: Year [1,15,0.5]

Time to intervention= 2
Units: Year [1,15,0.1]

Time to training= 1
Units: Year [1,15,0.1]

Trainee motivation= 0.6
Units: Dmnl [0,1,0.01]

Trials before termination= 240
Units: Dmnl [1,10000,1]

Turnover rate=Current Workforce*Average workforce turnover
Units: Persons/Year [0,10000]

Workflow alignment=
(Management support+Effectiveness of training)/2 Units: Dmnl

Workforce gap=
MAX(Desired workforce-Current Workforce,0) Units: Persons

Appendix 6.2 Values and equations of techno-organizational model parameters of SmartCare

Acceptance rate=
IF THEN ELSE(Individuals' intention to use+Promoters > Inhibitors, MIN(Potential users /Delay time, Individuals' intention to use+Promoters - Inhibitors), MAX(Potential users /Delay time,0))
Units: Persons/Year [0,6500]

Actual users= INTEG (
Acceptance rate-Dissatisfaction rate-Satisfaction rate, 0)
Units: Persons [0,1000]

Adjustment time= WITH LOOKUP (Effectiveness of training, ([(0,0)-(1,10)],(0,10),(1,1)))
Units: Year [0.01,10]

Adopted population= 320+Current Workforce-200
Units: Persons [0,1000,1]

Average workforce training= 0.33
Units: 1/Year [0,1,0.01]

Average workforce turnover= 0.092
Units: 1/Year [0,1,0.01]

Change in perception to use=Difference in perception/Adjustment time
Units: 1/Year

Contact rate= 20
Units: 1/Year [1,300,1]

Current Infrastructure= INTEG (Installation rate-Depreciation rate, 0.67)
Units: Dmnl

Current Workforce= INTEG (Hiring rate-Turnover rate, 200)
Units: Persons [0,1000]

Delay time= 3
Units: Year [1,15,0.1]

Depreciation rate=Current Infrastructure*Power and digital equipment depreciation rate
Units: 1/Year

Desired infrastructure = 1
Units: Dmnl [0,1,0.01]

Desired workforce= 879
Units: Persons

Difference in perception= System usefulness and ease of use-Individual perception to use
Units: Dmnl

Dissatisfaction rate= Actual users*Technological flaws/Period of use
Units: Persons/Year [0,6500]

Dissatisfied users= INTEG (Dissatisfaction rate-Intervention rate-Termination rate, 0)
Units: Persons [0,6500]

Effectiveness of training=(Management support+Trainee motivation)/2
Units: Dmnl [0,1,0.05]

Digital equipment installation rate= 0.03
Units: 1/Year [0,1,0.01]

Familiarity with electronic systems= 0.3
Units: Dmnl [0,1,0.01]

Frequency of use= 7500
Units: 1/Year [1,10000,1]

Hiring rate=Management support*Workforce gap*Average workforce training
Units: Persons/Year

Incentives= 0
Units: Dmnl [0,1,0.05]

Individual perception to use= INTEG (Change in perception to use,0.01)
Units: Dmnl [0,1]

Individuals' intention to use= MAX(Individual perception to use*Potential users/Time to training,0)
Units: Persons/Year [0,1000]

Information quality=
Organizational ICT Culture*System quality*Satisfied users/(Dissatisfied users+Satisfied users)
Units: Dmnl [0,1,0.01]

Infrastructure gap=Desired infrastructure – Current infrastructure
Units: Dmnl [0,1]

Inhibitors=MAX(Terminated users*System flaw*Contact rate*Potential users/Adopted population,0)
Units: Persons/Year [0,1000]

Installation rate=Management support*(Power installation rate+Internet installation rate+Digital equipment installation rate)/3
Units: 1/Year

Internet installation rate= 0.024
Units: 1/Year [0,1,0.01]

Intervention rate=Dissatisfied users*Intervention step/Time to intervention
Units: Persons/Year [0,6500]

Intervention step=STEP(Technological quality*(Effectiveness of training+Incentives+Resources readiness
)/3, Time to intervention)
Units: Dmnl [0,1]

Management support=(Supportive policy+Organizational ICT Culture)/2

Units: Dmnl [0,1]

Organizational ICT Culture= Familiarity with electronic systems
Units: Dmnl [0,1]

Performance improvement rate= 0.2
Units: 1/Year

Period of use=1
Units: Year [1,15,0.1]

Potential users= INTEG (
IF THEN ELSE(Acceptance rate>0,MIN(Hiring rate-Turnover rate-Acceptance rate,0),0), 200)
Units: Persons [0,1000]

Power and digital equipment depreciation rate= 0.2
Units: 1/Year [0,1,0.01]

Power installation rate= 0.04
Units: 1/Year [0,1,0.01]

Promoters= MAX(Satisfied users*Contact rate*Technological quality*Potential users/Adopted population,0)
Units: Persons/Year [0,1000]

Reduce work burden=0.2
Units: Dmnl [0,1,0.01]

Resources readiness=(Current Infrastructure+Current Workforce/Desired workforce)/2
Units: Dmnl [0,1]

Satisfaction rate=
Actual users*Performance improvement rate*(Technological quality+Workflow alignment)/2
Units: Persons/Year

Satisfied users= INTEG (Intervention rate+Satisfaction rate, 1)
Units: Persons [0,6500]

Services quality=(Resources readiness+Supportive Organizational Structure)/2
Units: Dmnl [0,1,0.01]

Supportive Organizational Structure= 0.4
Units: Dmnl [0,1,0.01]

Supportive policy= 1
Units: Dmnl [0,1,0.01]

System flaw=1-(Technological quality+Effectiveness of training)/2
Units: Dmnl

System quality=0.4
Units: Dmnl [0,1,0.01]

System usefulness and ease of use=(Effectiveness of training + Reduce work burden)/2
Units: Dmnl

Technological flaws= 1-Technological quality
Units: Dmnl

Technological quality=(Information quality+Services quality+System quality)/3
Units: Dmnl [0,1]

Terminated users= INTEG (Termination rate,0)
Units: Persons [0,6500]

Termination rate=Dissatisfied users*Termination step/Termination time
Units: Persons/Year [0,6500]

Termination step=IF THEN ELSE(Period of use >= (Trials before termination/Frequency of use), STEP((Frequency of use*Period of use-Trials before termination)/(Frequency of use *Period of use), Trials before termination/Frequency of use), 0)
Units: Dmnl

Termination time=MAX (Trials before termination/Frequency of use,1)
Units: Year [1,15,0.5]

Time to intervention= 4
Units: Year [1,15,0.1]

Time to training= 2
Units: Year [1,15,0.1]

Trainee motivation= 0.15
Units: Dmnl [0,1,0.01]

Trials before termination= 1500
Units: Dmnl [1,10000,1]

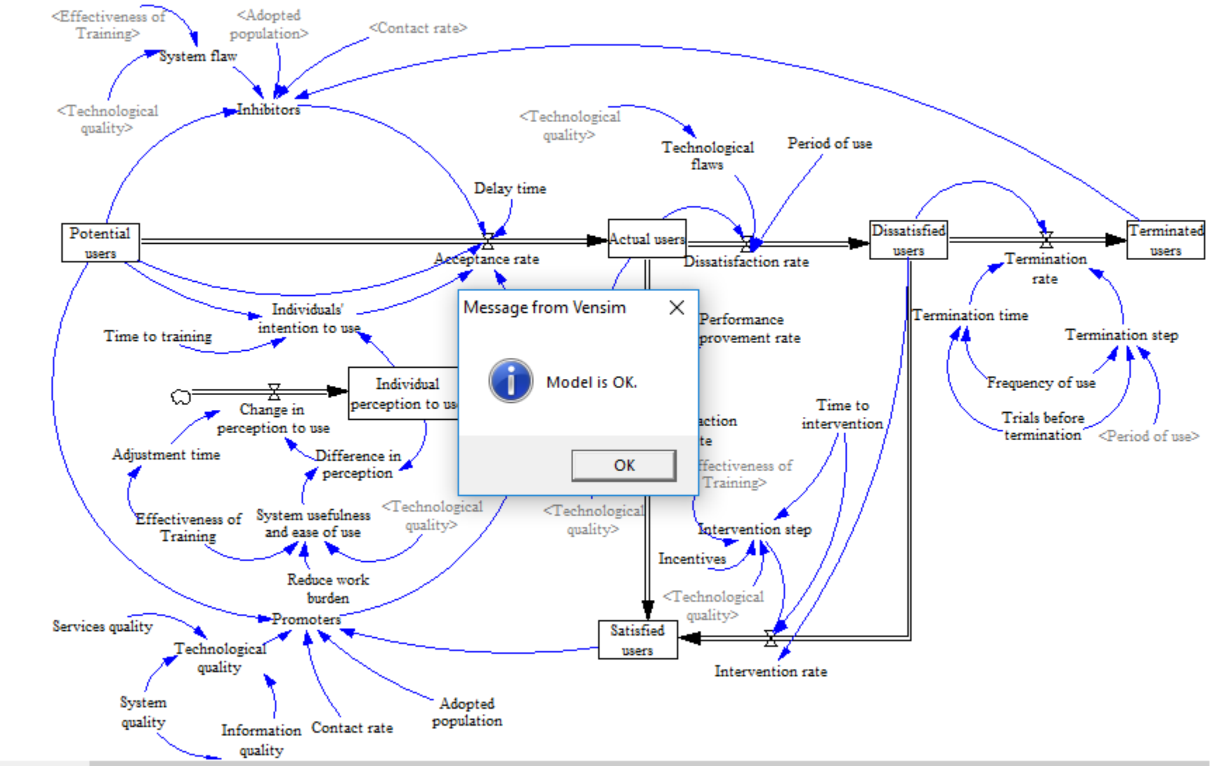
Turnover rate=Current Workforce*Average workforce turnover
Units: Persons/Year [0,1000]

Workflow alignment=(Management support + Effectiveness of training)/2
Units: Dmnl

Workforce gap=MAX(Desired workforce-Current Workforce,0)
Units: Persons

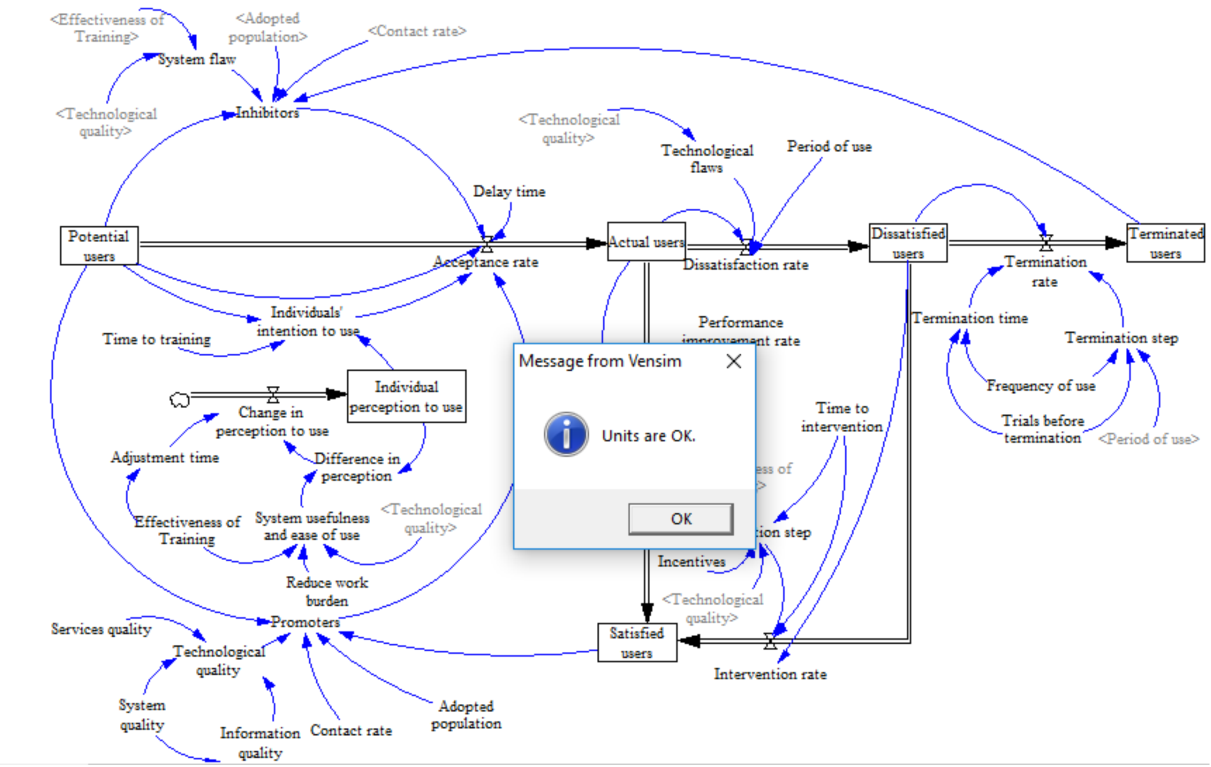
Appendix 7 Model structure tests and unit checks using Vensim

Appendix 7.1 Model structure test using Vensim



Model is OK.

Appendix 7.2 Unit checks using Vensim



Message from Vensim

Units are OK.