Sociotechnical factors of sustainable digital health systems: A system dynamics model

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ABSTRACT

Background

The introduction of digital health technology in a healthcare facility results in emergent and recursive interactions between new technology and existing social systems, technologies, and operating environments.

Objectives

The study aims at developing a sociotechnical system dynamics model of digital health systems to assess the influence of sociotechnical factors on the sustainable use of an electronic Health Information Management System (eHMIS).

Methods

A total of 40 face-to-face interviews in 18 healthcare facilities and two separate sessions of focus group discussions were conducted to study eHMIS implementation in Ethiopia. A system dynamics modelling of digital health systems implementation is developed, tested and verified with a case of eHMIS implementation in Ethiopia.

Results

The long-term sustainability of the digital health system requires acceptance of technology, improved information quality to make appropriate decisions and better end-user satisfaction. The 'individuals' intention to use' drives technology acceptance in the early years of the eHMIS use and social factors in the later stage. Besides, the role of technology to improve work performance determines the level of users' satisfaction. The effort of improving 'information quality' is strongly influenced by the quality systems, i.e., reliable, easy to use, and capable to meet end-user requirements.

Conclusions

The system's acceptance was improved through effective training and communication, whereas the 'information quality' was enhanced through 'system quality' and users' satisfaction. The ability of technology to improve work performance and reduce the burden on end-users has increased the satisfaction of end-users.

Keywords: Digital Health; Sociotechnical; Technology acceptance, Information quality, System Dynamics.

PUBLIC INTEREST SUMMARY

The influence of sociotechnical factors on the sustainable use of digital health systems is assessed using a system dynamics simulation study. The acceptance of technology, quality information to make appropriate decisions, and satisfied users are essential elements of a sustainable digital health system. Results from previous studies discovered that usefulness and ease of use are vital in improving technology acceptance. This system dynamics simulation study shows that eHMIS acceptance is considerably improved through adequate training and communication. Furthermore, the study confirmed 'information quality' can be improved through system quality and satisfied users. Dissatisfied users are one of the sources of poor-quality data entry leading to unreliable information output. The quality of the digital systems (i.e., reliable, easy to use, etc.) has demonstrated the most decisive impact on the information quality. The contribution of digital technology towards increasing end-users work performance and reducing job burden enhances users' satisfaction.

1. INTRODUCTION

The importance of digital health to improve the operational efficiency of healthcare services by providing support for the management of patient records has been well-recognized by major stakeholder groups (1). However, the diffusion of digital health solutions within healthcare remains limited, especially in developing countries, because of the shortage of financial resources, complexity, privacy concerns and legal barriers (3). The challenges associated with sustainability, uptake and use of digital health systems are still unresolved issues that require further analysis and intervention (4,5). The focus of digital health implementation in developing countries needs to shift beyond the pilot towards sustainability on a large-scale rollout (5). In this paper, sustainability is associated with the long-term operations of technology.

The success of digital health implementation is hindered by technical flaws and the undesirable outcomes of social and behavioural factors (6). The introduction of eHealth technology in a healthcare facility results in emergent and recursive interactions between new technology and existing social systems, technologies, and physical environments (6). These dynamic sociotechnical interactions during eHealth implementation are the major sources of unintended consequences that can sometimes undermine the quality and safety of healthcare service delivery and can lead to implementation failure (6). The research study reported in this paper seeks to answer how the dynamic interactions between social and technical factors impact the sustainable use of digital health technology. The objective of the study presented in this paper is to develop a sociotechnical system dynamics model of a sustainable digital health system to assess the influence of sociotechnical factors on the sustainable use of digital health systems.

The next section presents the findings of the literature studies. The research methodology and a system dynamics (SD) modelling approach are discussed in sections 3 and 4 respectively. A SD simulation model of eHealth acceptance is explained in section 5 followed by the discussions of the sociotechnical factors of technology acceptance in section 6. The simulation results are presented in section 7 and section 8 describes the validation and verification of the SD model. Sensitivity analysis is performed in section 9 before the concluding remark in the last section.

2. THEORETICAL BACKGROUND: LITERATURE REVIEW

The technology diffusion model, Technology Acceptance Model (TAM) and Information Systems (IS) success models have different focus areas in the implementation of successful technology, yet they overlap each other (1,7,8). Individual perception and social factors are the focus areas of the TAM (9,10). Likewise, the IS success model shares various factors such as intention to use, technology use and satisfaction with TAM (7,10,11). Moreover, the IS Success Model addresses the technological factors under three quality groups and the influences of benefits from the technology on the acceptance and success of technology implementation (7,11). The literature studies show that elements of these two models are widely used to assess the success level of different digital technologies.

2.1. Technological factors in the Information System (IS) Success Model

The system quality, information quality and service quality in the IS Success Model describe and measure the technological dimension of digital technology acceptance (7,11,12). *System quality* represents the technical characteristics and is measured by functionality, reliability, flexibility, portability, integration, ease of use, and importance (7,11,12). *Information quality* refers to the quality of information system outputs. It is measured by the accuracy, timeliness, completeness, relevance and consistency of information outputs (7,11,13,14). *Service quality* is concerned with the reliability, responsiveness, assurance, and empathy of technical support provided to end-users (7,11,12,14).

2.2. Social factors in the Technology Acceptance Model (TAM)

The social subsystem refers to people and cultural factors that developed from the relationships between people within and across organizations (15,16). The social factors address stakeholders-related issues such as ethical, behavioural, cultural and relationships between people within organizations in the implementation and operation of digital technology as well (16,17). The individual's feelings about the usefulness of the system, perceived ease of use, motivation, the user's problem-solving skills, competence and confidence to use the system are factors that directly influence the process and performance of Health Information Systems (HIS) (9,12,13).

The TAM indicates that the acceptance of digital technology is influenced by perceived usefulness and perceived ease of use (14,18). The Theory of Reasoned Action (TRA) states that an individuals' intention to use technology is jointly determined by the individual attitude and the perceived social influence or subjective norm of those people important to the individual (19). TAM therefore identifies social factors critical to the acceptance of technology by the end-users. The TAM is a widely used, useful and popular model that has evolved through time and has been empirically validated by several research studies (10,18,20).

2.3. Sociotechnical factors of technology acceptance

The complex interaction between social and technical systems creates a sociotechnical system (6,15,16,21). A digital sociotechnical systems design deals with the complexity of digitally enabled systems and the interaction of technology, individuals, processes, organizations and the actors in the large ecosystem (21,22). The conceptual framework for sustainable eHealth implementation (Figure 1) uses TAM and IS success model in an integrated manner to depict the influence of social and technological factors on technology and information use. This simulation study focuses on the sociotechnical dimension of the conceptual framework (23) and uses empirical evidence from the eHMIS implementation in Ethiopia. The framework (Figure 1) served as a basis to develop a causal loop diagram (CLD) of the sociotechnical model of technology acceptance discussed in Section 4 (Figure 2).

The dynamic and complex interaction of sociotechnical systems during digital health design, development, implementation and operation significantly affects the usability of the system by end-users (16,21). The sociotechnical framework for eHealth acceptance depicts the nonlinear interactions of technological factors (system, information, and service quality) as indicated in the IS Success Model, and the constructs of TAM (social and individual perceptions) in the social dimension (23). In general, social factors represent individuals and their relationships, whereas sociotechnical factors focus on social and technical subsystems and their interaction in adopting and using new technology (12,16).

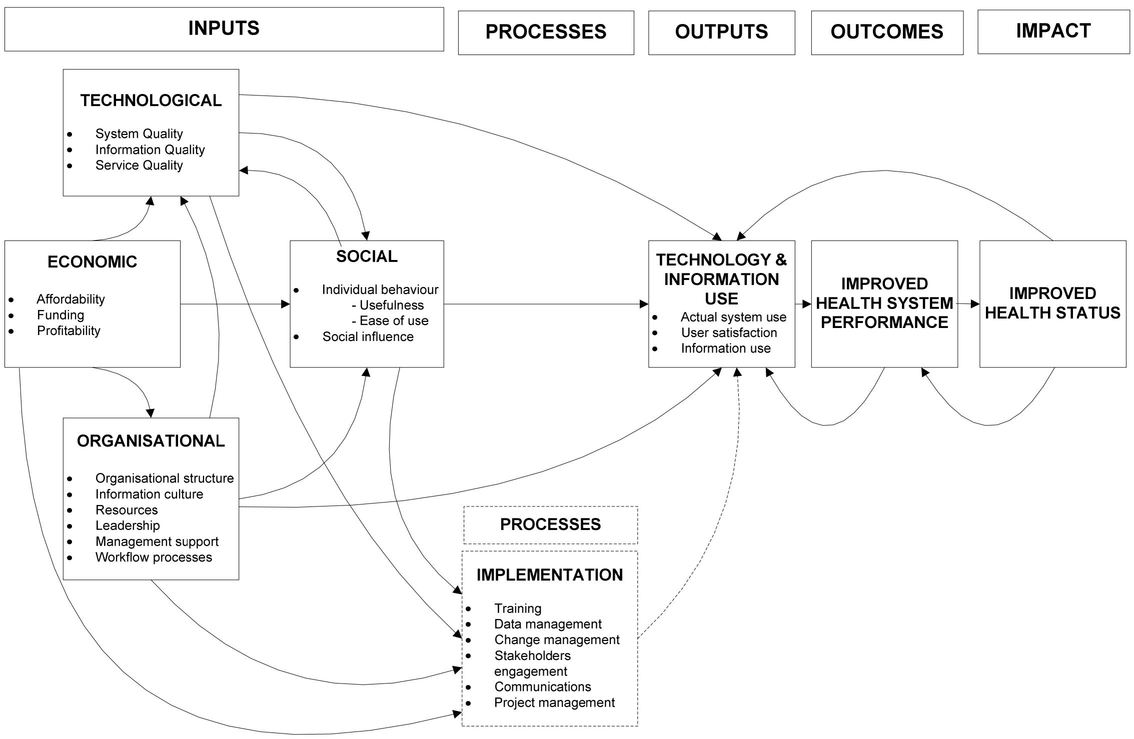

Figure 1: A conceptual framework for sustainable eHealth implementation (23)

The use of technology by the intended end-users is one of the key success factors of information systems (IS) implementation (1,7). The sustainability of digital health systems can be achieved when the technology is accepted by the end-users (18,20), the quality of information product is good enough to make accurate decisions (13,24), and the end-users are satisfied with using the systems and the information product (7). The next section presents the research methodology applied in this research.

2.4. Ethiopian healthcare system and status

The quality, availability, and equity of healthcare service delivery in Ethiopia are challenged by poor infrastructure and the shortage of skilled healthcare workers (24). The Information Revolution document was published by the Federal Ministry of Health (FMOH) aiming at maximizing the availability, accessibility, quality, and use of health information through the appropriate use of Information and Communication Technology (ICT) to improve the access, quality, and equity of healthcare delivery at all levels (24). The transformation in the culture of health data use, and the implementation and scale-up of health information systems are the two pillars of the information revolution for sustainable HIS governance (24). Since 2010, the FMOH together with John Snow, Inc. (JSI) and TUTAPE has begun implementing eHMIS nationally in Ethiopia to improve the accuracy and timeliness of public health-related data. eHMIS is used to submit monthly aggregated health monitoring and evaluation reports so the frequency of use for eHMIS is relatively low. As of June 2016, eHMIS was implemented nationally in over 30,000 health facilities and health administrative offices in Ethiopia. This then serves as a concise background to the case study selected for this paper.

3. RESEARCH METHOD

The complex and dynamic nature of the healthcare system requires system thinking approach that can address the complexity of the interconnected components of health systems and their stakeholders. System dynamics is a method to deal with the dynamic complexity of systems and enhance the learning process of nonlinear systems (25). Hence SD modelling and a case study research approach are used in this research (26).

Sample selection

A purposive sampling is used to select health facilities in the Ethiopian case context based on recommendations from Addis Ababa Regional Health Bureau, partner organizations, and FMOH personnel. The selection criteria were motivated by the availability of operational eHMIS, reporting performance via eHMIS, ICT infrastructure availability, health facility's management support level, and access to data. Based on selection criteria, poor, average and good-performing health facilities are included to gain a holistic understanding of the system. eHMIS users in the health facilities and eHMIS focal persons were interviewed. A total of 40 face-to-face interviews were conducted in 18 purposefully selected health facilities and health departments (Table 1).

Table 1. The health facilities and departments visited and personnel interviewed.

Regions	Health facility type	Health facilities visited	Interviewed personnel	Interviewees Role
Addis Ababa	Hospital	3	7	Nurses and HIT focal person
	Health Centre	8	8	Nurses and HIT focal person
	Regional Health Bureau	1	5	Planning and Monitoring officers
	Federal Ministry of Health	1	8	Planning and Monitoring officers
SNNPR (South Nations, Nationalities and People Region)	Hospital	2	3	Nurses and HIT focal person
	Health Centre	5	6	Nurses and HIT focal person
	District/Woreda Health Office	1	1	Planning and Monitoring officer
	Zonal Health Bureau	1	1	Planning and Monitoring officer
	Regional Health Bureau	1	1	Planning and Monitoring officer
Total		**18**	**40**	

*HIT – Health Information Technology

Research instrument

The data collection instruments were first drafted based on the findings of an extensive literature review (23). The questionnaires were later updated based on the inputs captured from the pilot focus group discussions and interviews with HITD teams. The structured questionnaire explores users' experience in terms of eHMIS's technical quality, social and behavioural factors, use of technology and use of information (Table 2).

Table 2. Contents of interview questions.

Technological Factors	
System Quality	Response time; Reliability; Easy to learn; Easy to use; Usability; Availability.
Information Quality	Relevant; Accuracy; Completeness; Timeliness; Useful format; Security.
Service Quality	Responsiveness; Assurance; Empathy; Access; Timely; Reliability.
Behavioural & Social Factors	
Perceived Usefulness	Productivity; Do job quickly; Performance; Easy to do jobs; Useful.
Perceived Ease of Use	Clear and understandable; Easy to operate; Responsive; Easy to become skilful.
Influence of social environment	Management support, Involved or well represented, organizational support, Profile of people who use the system.
Technology and Information Use Factors	
Intention to use	Access to the system; Reduce the work burden; Necessary to do the job.
Actual Use	Frequency of use; Use of the information from the system; Dependency on the system to do tasks.
User Satisfaction	Finish tasks faster; Performance improvement; Improve work quality; Improve decisions.

The semi-structured questions are designed to capture in-depth phenomena of eHMIS implementation in Ethiopia during the focus group discussions. Eight questions in the socio-technical dimension are shown below.

- **Technological factors**: What are the key technological factors (system, information, and technical services quality) to the success of eHealth implementation?
- **Behavioural and social factors**: Describe the impact of human factors (individual's behaviour and impact of social environment) on the successful implementation of eHealth technology.
- **Technology use**: How do you evaluate the use of technology by its intended users?
- **Technology on social & behavioural factors:** Describe the influence of technological factors on individual behaviour and social environment.
- **Technology on its usability:** Describe the influence of technological factors on the usability of the technology.
- **Social on technology use:** Describe how the individual behaviour and social environment influence technology use.
- **Benefits:** What are the expected improvements of healthcare service delivery through the implementation of eHealth?
- **Benefit on social & technological factors:** Describe how these healthcare service outcomes (benefits) influence the technology, individual behaviour, and social environment.

Data collection

The researcher travelled to healthcare sites for face-to-face interviews in two regions of Ethiopia, i.e., Addis Ababa and South Nations, Nationalities and People Region (SNNPR). Moreover, 10 min to 15 min observations were made and notes were taken on the workflow as end-users operate the system in their day-to-day work activity and the availability of digital infrastructure (such as internet connection, electric power, computers etc.), the overall impression of end-users. The face-to-face interview method gave flexibility as it allowed clarification of definitions, elaboration on topics, and collection of respondents' explanations in their own words. The interview with each eHMIS user took approximately 20 min to 45 min.

Additionally, two separate sessions of focus group discussion were conducted with teams from the Federal Ministry of Health (FMOH) and partners in Ethiopia. The same semi-structured questionnaire was used to guide both focus group discussion sessions. The official language of Ethiopia, Amharic, was used for data gathering. The first focus group team consisted of three informants from the project team of the eHMIS implementing partner of the FMOH. The informants were active eHMIS project members who were involved in the project management, software development, implementation, training, and support activities. The discussion was carried out in Pretoria, South Africa and lasted for 135 minutes.

The second 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. The focus group discussion was conducted in two rounds for a total of 170 minutes. The focus group members were composed of a project manager, software developers, software analysts, infrastructure and system support, and Geographic Information System (GIS) experts who were actively involved in the design and implementation of eHMIS.

Analysis

The audio recordings of the focus group discussions were transcribed and later translated into English. Field notes and data from the eHMIS database, document archives, focus group discussions, observations and informal discussion records are captured as memos during ATLAS.ti analysis. In the thematic analysis process, the initial theory-driven codes mainly from literature, TAM and IS Success Model were reviewed and revised within the context of data through repeated reading of raw data. Through iterative coding processes, a codebook was developed with a list of codes, code groups (themes), definitions, and examples. To ensure the reliability of the coding process, the researcher discussed the codes with three other fellow researchers once a week, for 4 sessions for a total of 4 hours.

The final codes and code groups (themes) generated from the data analysis and a conceptual framework (Figure 1) were translated into a system dynamics model of a causal loop diagram (Figure 2) and later to a stock and flow diagram (SFD) in Figure 3. The codes were used to determine model variables in the modelling process and causal influences among model variables were decided by causes tree generated from the qualitative analysis using ATLAS.ti. The interview data, document archives and information from the eHMIS database were used to estimate model parameter values. The use of several sources of data in the case study research supports the estimation of model parameter values in the system dynamics modelling processes (26).

Vensim DSS Version 6.3D is used to model and simulate the SD model over 15 years with a one-year time step for the different values of the parameters. The simulation results were shared with the focus group members for their input before the results were published. Ethics and research integrity clearance has been obtained from the Faculty of Engineering, Built Environment and Information Technology, the University of Pretoria (Ref. EBIT/24/2016). The names and details are replaced with codes and only aggregate findings are reported to protect the identity of informants. The recordings of the focus group discussions were stored in a secured folder and interview files locked in a drawer. A system dynamics modelling approach used in this research is discussed in the following section.

4. SYSTEM DYNAMICS MODELLING

The complexity, nonlinearity, and feedback loop structures of social and physical systems in real world can be represented adequately using a SD modelling method. It aids the design of effective policies and organizations through computer simulation of complex systems (25). Causal loop diagram (CLD), stock and flow diagram (SFD), and model boundary diagrams are some of the basic diagrammatic tools used in SD modelling to communicate the system boundary and represent causal structure (25).

The CLD of a sociotechnical model of eHealth acceptance depicted in Figure 2 is developed by applying the systems thinking approach to the findings of the literature studies integrating TAM and IS Success Model (Figure 1) and code book generated from qualitative analysis using Atlas.ti. The final codes and code groups generated from the qualitative data analysis are translated into a CLD and later to a SFD. The CLD of a sociotechnical model of eHealth acceptance consists of three reinforcing loops and one balancing loop to explain the behaviour of the sociotechnical dynamics of eHealth acceptance in this model.

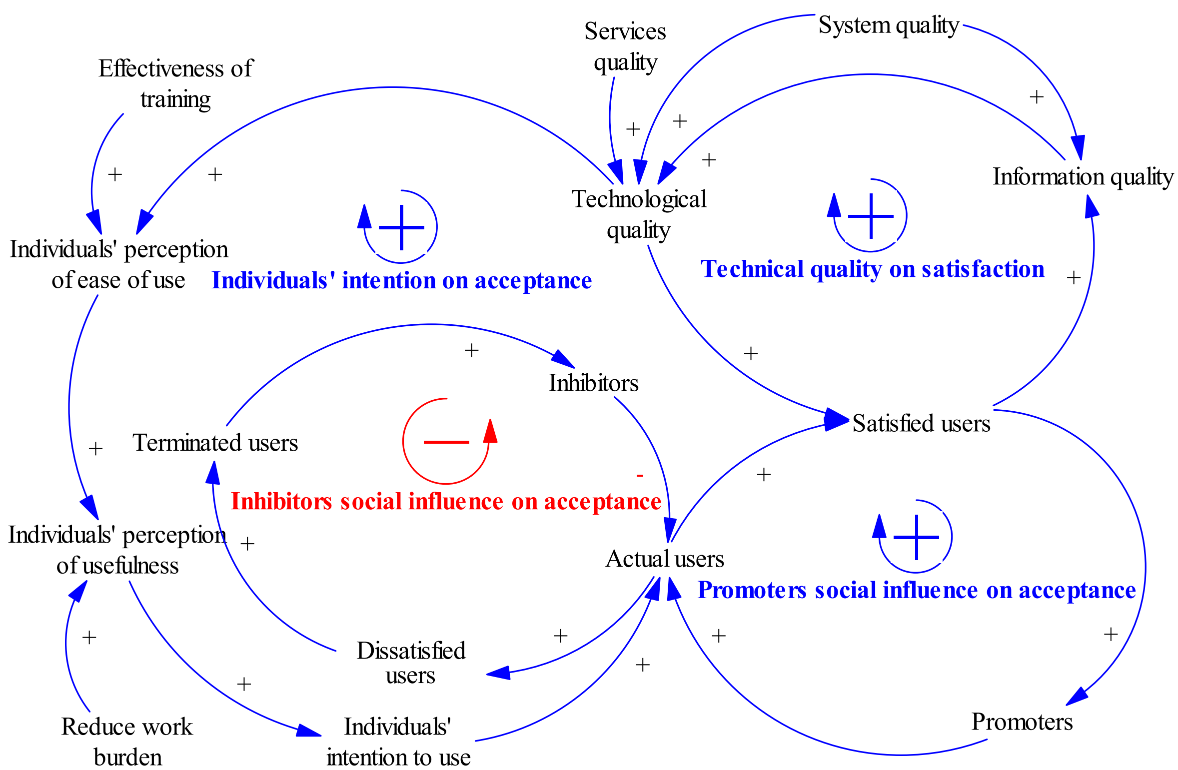

Figure 2. CLD of the sociotechnical model of technology acceptance.

The reinforcing loops (+) in Figure 2 describe the interplay between the sociotechnical factors to facilitate acceptance of eHealth systems and users' satisfaction. Furthermore, the reinforcing loop depicts the potential impact of technological quality in driving the satisfaction of users to a higher level. On the contrary, the balancing loop (-) in Figure 2 shows the dynamic influence of rejected users on the behaviour of the social circle to hinder the acceptance of eHealth systems.

5. A SYSTEM DYNAMICS MODEL FOR EHEALTH ACCEPTANCE AND USE

The bass diffusion model describes how potential adopters of innovation become actual adopters through external sources of awareness (advertisement) and the word of mouth from social exposure and imitation is used as a starting model and extended to develop a sociotechnical model of eHealth acceptance (8,25). Through iterative system dynamic modelling processes, the CLD (Figure 2) is translated and extended into stocks and flows diagrams (SFD). The SD model of sociotechnical factors of technology acceptance shown in Figure 3 incorporates the concepts of the TAM, IS Success Model and TRA referred in Section 2 and is supported by literature (7,9,10,18–20). Some equations used in the SD model are presented here for illustration:

The rate at which the potential users become actual users is the 'Acceptance rate' (27) which is influenced by individual intention to use, social promoters and social inhibitors (Equation 1).

$$\begin{aligned} &Acceptance\ Rate\ (AR) \\ &\quad = Individual\ Intention\ to\ Use\ (I) + Influence\ from\ Social\ Promoters\ (SP) \\ &\quad - Influence\ from\ Social\ Inhibitors\ \ (SI) \end{aligned} \tag{1}$$

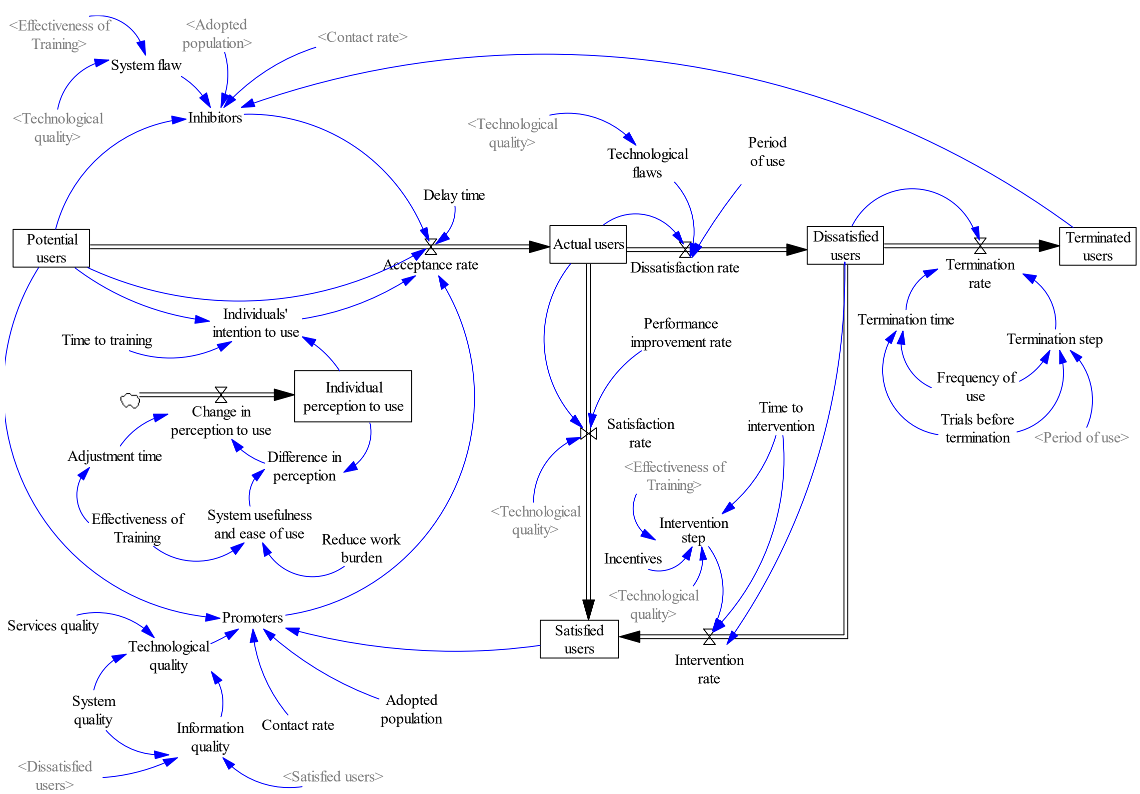

Figure 3. SD model of sociotechnical factors of technology acceptance.

The 'Individuals' intention to use' indicates the end-users conscious action to accept or use a technology that develops from the individuals' perception of technology usefulness and ease of use according to TAM (9,10,18,20). The 'Influence from social promoters' represents the positive impact of satisfied individuals on potential users towards using the system. Conversely, 'Terminated users' are those who stopped using the system because of dissatisfaction (27).

'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 (14,28). 'Trials before termination' refer to the number of times (measured in counts) the 'Dissatisfied users' are willing to using the technology before they quit. 'Performance improvement rate' represents the level of gains achieved due to the use of digital technology on individual work performance. Full details of the SD model developed can be found in first author's PhD thesis (30).

6. RESULTS AND DISCUSSIONS OF THE SOCIOTECHNICAL FACTORS OF TECHNOLOGY ACCEPTANCE

The implementation of eHMIS in Ethiopia started in 2010 and was 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 health services. The sociotechnical factors of sustainable eHMIS implementation are discussed under users' acceptance, information quality, and users' satisfaction in the following section.

6.1. Acceptance of eHMIS

The focus group discussions conducted in Ethiopia confirmed that individuals' intention to use technology and the influence of social circles on the end-users played a critical role in the acceptance or rejection of eHMIS. Through iterative coding processes, a codebook of eHMIS acceptance is developed through a thematic analysis process using ATLAS.ti software (Table 3) for analysing the focus group empirical data collected in this research.

6.1.1. The individuals' intention to use eHMIS

These focus group discussions discovered that work burden, ICT skills, technophobia, and understanding of benefits were key factors to influence the individuals' intention to use eHMIS. These determinants relate to the volunteer acceptance of technology reported by (9,10,18), i.e., ease of use (associated with the level of ICT skills) and technology usefulness (linked to an understanding of the benefits).

The focus group team proposed the design and development of a system should focus on using available ICT skill sets instead of forcing the end-users to use sophisticated digital systems that require advanced ICT skills. Moreover, willingness to use a system increases with the knowledge of system benefits or usefulness; hence creating awareness about the benefits of technology through training and workshops can shape the perception of end-users towards using digital health systems.

6.1.2. The influence of social networks on the use of eHMIS

The three social influence parameters that impacted the acceptance rate – the influence of expert users, the influence of supervisors, and the influence of teamwork culture – were discovered from the focus group discussion. When describing the influence of expert individuals on technology use, a member of the focus group said, "The digital system started to crumble immediately following the resignation of the data manager from a health facility".

Weak teamwork culture in health facilities resulted in low eHMIS data quality and weak motivation to use the digital system (29). The lack of teamwork culture was associated with the 'inhibitors' whereas the influence of expert co-workers was reflected as 'promoters' in the SD model. Supervisors had both inhibiting and promoting influence on technology use as captured in the model.

Table 3: ATLAS.ti Codebook of eHMIS acceptance.

Code Groups	Code	Examples
Intention to use	ICT skills	Most electronic systems are developed with advanced users in mind. In developing countries like Ethiopia, where physicians have limited ICT skills, a digital system must be designed and developed to accommodate available ICT skill set instead of forcing the end-users to use sophisticated digital system that requires advanced ICT skills.
Intention to use	Burden	Many healthcare teams do not consider digital systems as part of a solution that facilitates and supports the physician's task but as an additional workload. However, the low frequent use of eHMIS reduced the burden of system use. eHMIS is used to submit monthly aggregated health monitoring and evaluation reports.
Intention to use	Understanding benefits	Digital technology demonstrates a good level of acceptance when users perceive or accept the system as a tool that solves their day-to-day operational problems.
Intention to use	Techno-phobia	Those users with low experience in using computers and electronic technologies may not be voluntary even if they understand the usefulness of the technology to perform their duty. This is mainly because of the fear of technology (techno-phobia). Hence technology use becomes mandatory for these groups of users.
Social	Expert users influence	The digital system started to crumble immediately following the resignation of a data manager in a health facility.
Social	Supervisor influence	The influence of supervisors started from the technology selection stage and continued to the operation levels. The top managers influenced technology acceptance by awarding, promoting and recognising champion users.
Social	Teamwork culture	eHMIS users focused only on reporting their department's data points without considering the entire data management process due to weak teamwork culture. This resulted in low data quality and weak motivation to use the digital system.

6.2. Users' satisfaction with using eHMIS

The qualitative analysis shows that the level of users' satisfaction is influenced by the capacity of eHMIS to improve work performance, decisions, and services quality (Table 4).

6.3. Information Quality of eHMIS

Data collection, data entry, data analysis, reporting, information dissemination and information use stages can contribute to the data quality problem (13). The focus group discussion highlighted that data entry without the meaningful use of information at the health facility level was the main source of eHMIS data quality problems and dissatisfaction by end-users. Besides, the researchers observed that sharing login credentials among eHMIS end-users contributed to the data quality problem. The information quality of eHMIS was influenced by system quality, satisfied users, and dissatisfied users.

The qualitative data analysis from focus group sessions uncovered that the acceptance of technology, satisfaction of users and quality of information were key sociotechnical factors of sustainable eHMIS implementation. The simulation results from DS modelling are discussed in the next section.

Table 4: ATLAS.ti Codebook of eHMIS users' satisfaction.

Code Groups	Code	Example
Satisfaction	Improve decisions	The use of electronic systems helps to make an evidence-based decision towards better healthcare service delivery. Besides, it enables monitoring and evaluates the progress and improvements towards better healthcare services.
Satisfaction	Improve work performance	The eHMIS users enter 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 the frustration level of the healthcare team if they cannot benefit from their data entry effort?" The information is used for decision-making at the management level, yet the use of information for decision-making is low at the data entry level. This leaves users dissatisfied.
Satisfaction	Improve services quality	When digital technology contributes to better healthcare service delivery, it is evidence of technology use. The satisfaction of end-users with digital technology is an indication of technology use in healthcare.

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7. THE SIMULATION RESULTS OF SOCIOTECHNICAL FACTORS

The simulation results from SD modelling presented in this section show possible behavioural changes in the rate of technology acceptance, users' satisfaction and information quality concerning changes in the model parameters. A SD model of the sociotechnical factors of technology acceptance, reflected on in section 5, is simulated with a TIME STEP of 1 year for a period of 15 years. Vensim DSS Version 6.3D software is used to develop, simulate, and test the SD model of sociotechnical factors. The model parameter values were obtained through interviews, focus group discussions, the eHMIS database, and the FMOH reports. The details of endogenous, exogenous and excluded variables, and all SD model parameter values are available in the first author's PhD thesis, Chapter 5.2.1 (30).

7.1. The simulation results of eHMIS acceptance rate

The three key factors that influence the acceptance rate of digital health systems are 'individuals' intention to use', 'social promotion' and 'social inhibitions' as discussed in the previous section. Figure 4 shows from the SD simulation results that the 'individuals' intention to use' (red) is a dominant factor in the early years of technology acceptance followed by the promoters (brown) and inhibitors (green) social influence in the later phases of technology acceptance cycle (blue).

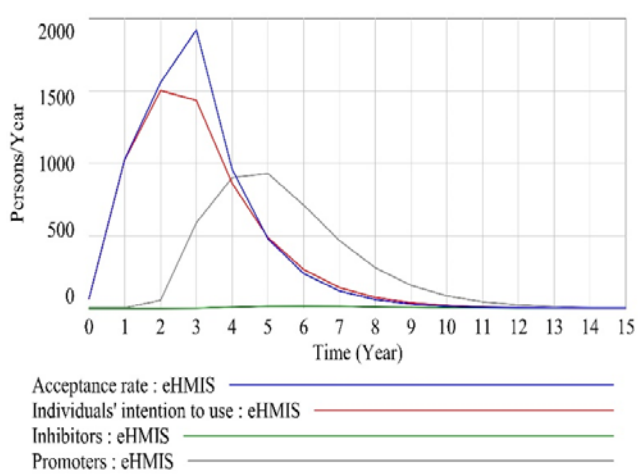

Figure 4. The influence of 'individuals' intention to use', 'promoters' and 'inhibitors' on eHMIS acceptance rate: SD Simulation results.

The training and communication shaped the 'potential users' perception of technology usefulness and ease of use to drive technology acceptance. The positive word of mouth from satisfied users played a key role in promoting eHMIS acceptance among 'potential users' in later stages. Unsatisfied users affect the rate of acceptance hence proper intervention measures are needed.

7.2. Simulation results of users' satisfaction

Figure 5 shows that the simulated satisfaction rate (red) is higher than the dissatisfaction rate (blue) in eHMIS. The higher level of users' satisfaction seems to be due to the well-recognised benefits of eHMIS. In general, the level of users' satisfaction is associated with the benefits that can be achieved from using digital systems.

eHMIS is used to submit weekly or monthly aggregated health systems monitoring and evaluation data to the central data repository. The reduced burden of eHMIS use contributed to the users' satisfaction as most healthcare workers complained about the high workload in health facilities.

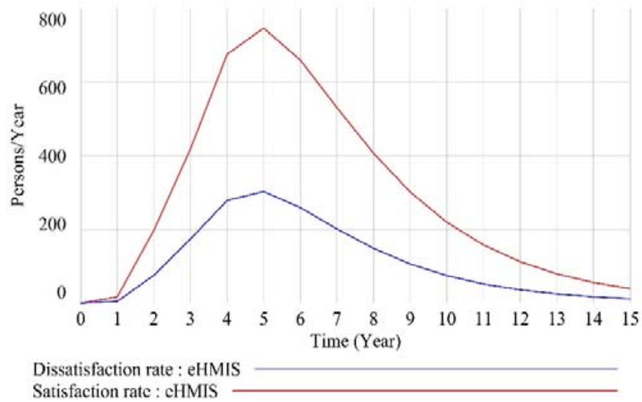

Figure 5. eHMIS users' satisfaction and dissatisfaction rate.

7.3. The simulation results of information quality

The quality of information products impacts the satisfaction of users and the long-term sustainability of the technology. Satisfied users and good system quality contribute to better information quality, whereas dissatisfied users compromise the overall data quality of the digital health system. The system quality has shown a strong direct influence on the information quality, shown in figure 6, at the beginning followed by the satisfaction and dissatisfaction of users as the system use progresses (11,31).

Figure 6. Information quality of eHMIS.

The focus group indicated that dissatisfied users did not use the digital system consistently leading to incomplete and inaccurate data in the eHMIS database. Data quality was one of the major problems to the long-term sustainability of eHMIS in Ethiopia. The level of satisfaction has improved as end-users have gained experience and become comfortable with eHMIS resulting in better data quality. The verification and validation of the SD model of sociotechnical factors are discussed in the following section.

8. THE VERIFICATION AND VALIDATION OF THE SOCIOTECHNICAL MODEL

The structural and behavioural validity of the current sociotechnical SD model of eHealth acceptance (Figure 3) is tested through direct and indirect structure tests. The concepts behind the SD model structure, numerical parameters and equations are supported by literature findings and the focus group members that were involved in the design, implementation, and operation of the eHMIS in Ethiopia. The model boundary is set at a healthcare facility instead of a national level for this study.

The extreme conditions test assesses the response of the simulation behaviour to the inputs of extreme values to quickly identify the precise source of the flaw (25,32).

8.1. Extreme conditions of technological quality

Technological quality encompasses system quality, information quality, and services quality (7,11). The extreme conditions test of technological quality is performed by assigning the minimum (zero) and maximum (one) values to the system and services quality (Table 5) of the SD model.

Table 5. Extreme condition values of 'system quality' and 'services quality'.

	Case 1	Case 2
System quality	0	1
Services quality	0	1

The simulation result shows the acceptance rate is very low and drops to zero quickly when both system and services qualities are set to zero (Case 1 in red colour, Figure 7). Conversely, the simulated 'acceptance rate' attains the maximum level (Case 2 in blue colour, Figure 7) in a short time when both system quality and services quality are assigned the highest value (one). The simulation graph confirms the expected real-life behaviour of the acceptance rate to changes in the system and services quality.

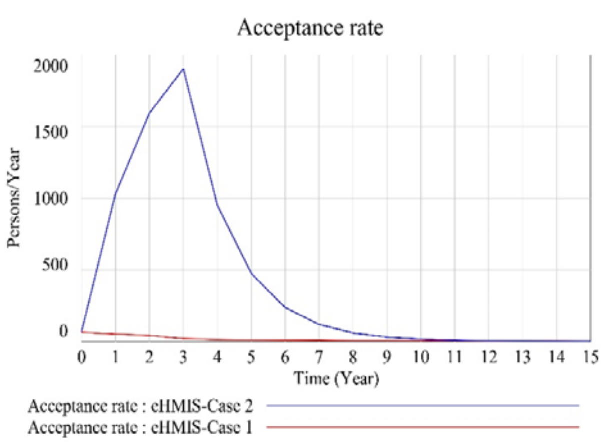

Figure 7. Extreme conditions test of system and services quality on 'acceptance rate'.

8.2. Extreme conditions of training effectiveness

The simulated 'acceptance rate' attains its maximum value (in blue colour) in a short period of time when the 'effectiveness of training' is held at the maximum value (one), (Figure 8). In contrast, the simulated 'acceptance rate' takes a long period to achieve its smaller peak value (in red colour) when the 'effectiveness of training' is set to a minimum value. The simulation graph of the 'acceptance rate' agrees with an expected response for the effectiveness of training in real life (Figure 8).

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 the 'acceptance rate' of eHMIS.

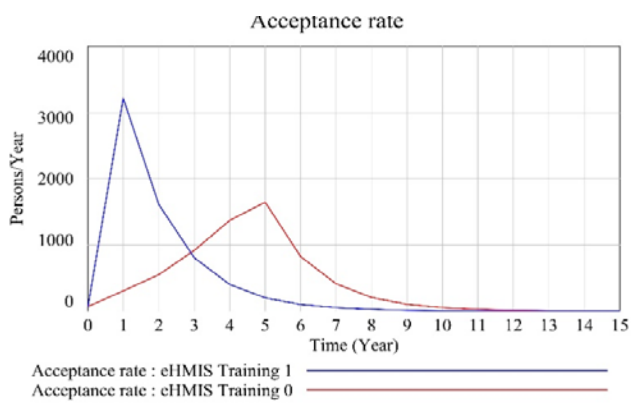

Figure 8. Extreme conditions test of training effectiveness on eHMIS 'acceptance rate'.

8.3. Extreme conditions of 'performance improvement rate'

The minimum level of 'performance improvement rate' has resulted in a small number of 'satisfied users' over time (in blue colour). On the contrary, the maximum value of 'performance improvement rate' has produced many simulated 'satisfied users' (in red colour) in a short period (Figure 9). The simulation results have produced the expected behaviour of 'satisfied users' to changes in the 'performance improvement rate' (Figure 9).

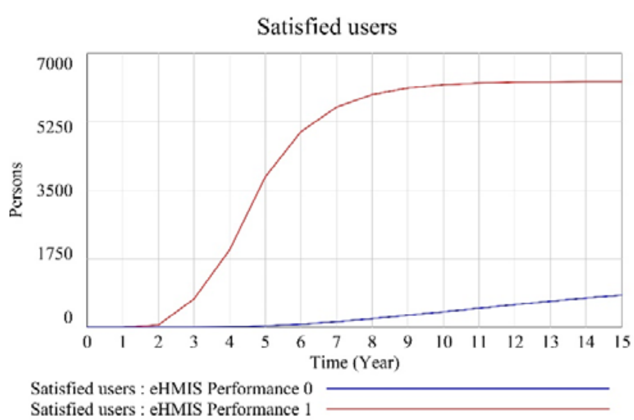

Figure 9. Extreme conditions of 'performance improvement rate' on 'satisfied users' of eHMIS.

In summary, the extreme condition tests have confirmed the plausibility of the new SD model for eHealth acceptance responses to extreme input values (policies, shocks, and parameters) as suggested by Barlas (32). The following section addresses a univariate and multivariate sensitivity analysis of a sociotechnical model of eHealth acceptance.

9. SENSITIVITY ANALYSIS

A univariate sensitivity analysis followed by a multivariate sensitivity analysis is conducted in Vensim using a random uniform distribution with 200 simulations in Vensim (25,33). The proposed minimum and maximum values in Table 6 are in the distribution range of $\pm$ 20% of the actual model value determined from the real system (25). High 'trials before termination' represents a longer period of technology use before end-users decide to stop. All the sensitivity SD results presented here seem to support the intention of sustainability of eHealth acceptance in the sense of attempting to avoid an early collapse of eHealth acceptance.

Table 6. Exogenous variables used in the sensitivity analysis.

Exogenous variables	Estimated Value in basic model	Proposed minimum values	Proposed Maximum values
System quality	0.8 (dimensionless)	0.6	1
Services quality	0.8 (dimensionless)	0.6	1
Effectiveness of training	0.56 (dimensionless)	0.36	0.76
Performance improvement rate	0.3 (dimensionless)	0.1	0.5
Trials before termination	240 (dimensionless)	190	290

The univariate analysis with random variations of 'system quality', 'services quality', 'effectiveness of training', 'performance improvement rate' and 'trials before termination' produced no fundamental change in the essential behaviour pattern of 'acceptance rate' of eHMIS. However, the change in the 'effectiveness of training' has produced significant variations in the simulated eHMIS 'acceptance rate' (Figure 10). The behaviour mode sensitivity test reveals that the model is essentially robust and numerical variations show the possible policy interventions for improvements.

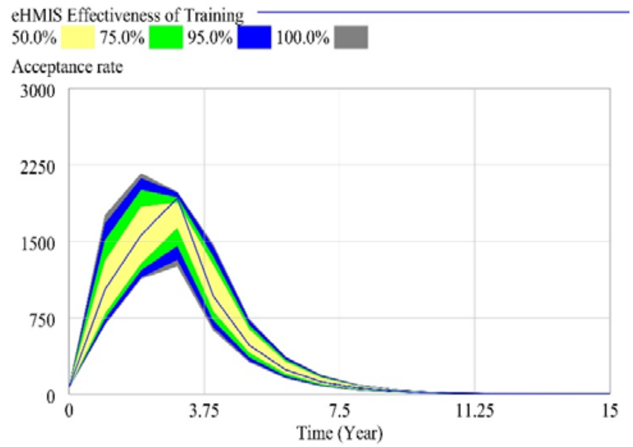

Figure 10. A univariate analysis of eHMIS 'acceptance rate' under uncertainty of 'effectiveness of training' for an interval (0.36, 0.76).

The multivariate sensitivity analysis of the 'acceptance rate' of eHMIS has shown that the behaviour pattern essentially has remained unchanged throughout the entire simulation (Figure 11). The multivariate analysis has demonstrated the model is fundamentally robust in maintaining the simulated behaviour pattern of 'acceptance rate', 'satisfied users', and 'information quality'. The numerical variation indicates the possibility for alternative policy design to improve technology acceptance 'information quality', and users' satisfaction.

9.1. Policy analysis

The what-if scenario analysis conducted in this SD simulation research 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' (25,32). Candidate exogenous variables for policy analysis were varied and tested in different scenarios for alternative policies.

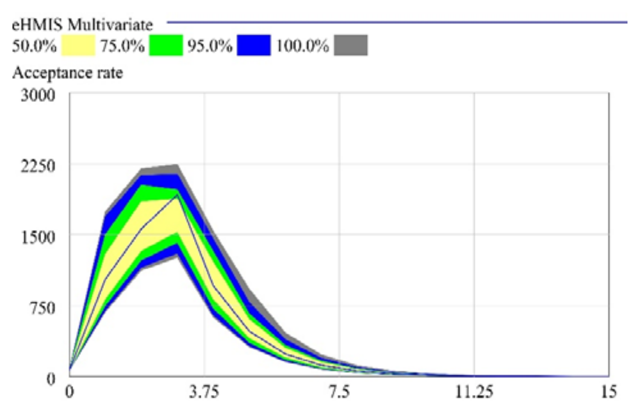

Figure 11. A multivariate analysis of eHMIS 'acceptance rate'.

9.1.1. Improving 'acceptance rate' of eHMIS

The policy analysis shows that the simulated 'acceptance rate' of eHMIS is more improved by increasing the 'effectiveness of training' than by improving 'system quality', 'services quality' or 'performance improvement rate' (Figure 12). The impact of 'performance improvement rate' on the simulated 'acceptance rate' of eHMIS is weaker than the moderate influence of ‘system quality’ and ‘services quality’. Hence, improving the ‘effectiveness of training’ may be the primary focus of managers and policymakers to improve the ‘acceptance rate’ of eHMIS technology and thus contribute to eHealth sustainability.

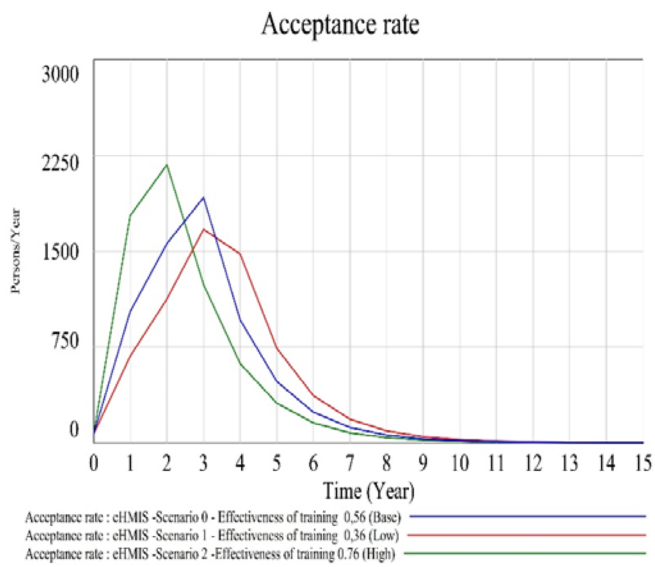

Figure 12. What-if analysis of the ‘acceptance rate’ of eHMIS to changes in the ‘effectiveness of training’.

9.1.2. Improving the ‘satisfied users’ of eHMIS

Figure 13 shows the simulated ‘satisfied users’ of eHMIS in response to improved or weakened ‘performance improvement rate’ by 0.2 (20%) from the base scenario (in blue colour), which is the reference behaviour. ‘Performance improvement rate’ shows almost twice stronger impact on ‘satisfied users’ compared to 'effectiveness of training', 'system quality' and 'services quality'. Therefore, involving end-users in the early phases of system design, development and implementation process supports the effort of addressing users’ needs and improves the work performance rate.

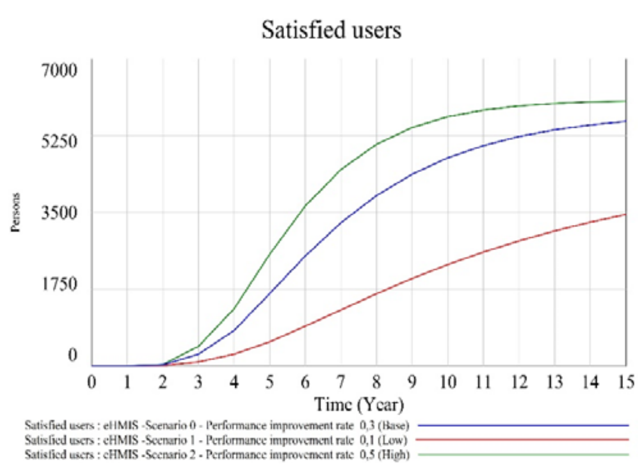

Figure 13. What-if analysis of ‘satisfied users’ of eHMIS to changes in ‘performance improvement rate’.

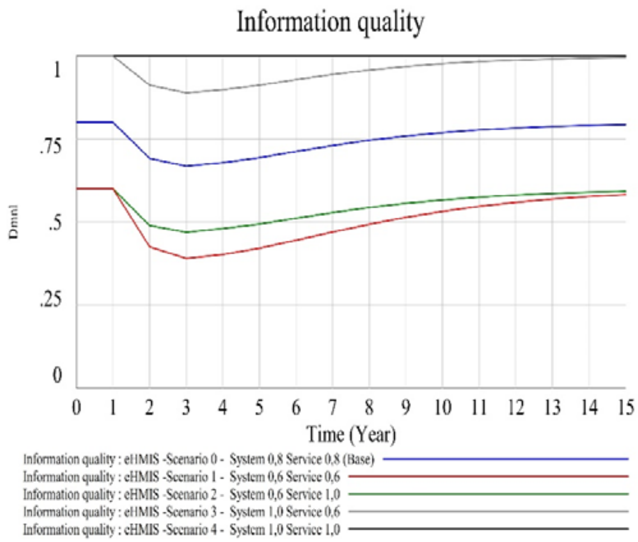

Figure 14. What-if analysis of 'information quality' of eHMIS to changes in the system and services quality.

9.1.3. Improving the 'information quality' of eHMIS

The simulated 'information quality' of the eHMIS behaviour response shows the stronger influence of 'system quality' on the 'information quality' compared to the 'services quality' (Figure 14). 'System quality' like reliability, ease of use, and the capability of a system that met end-user's requirements play a critical role in improving 'information quality'. Furthermore, 'services quality' and 'performance improvement rate' show a moderate influence on the simulated 'information quality'; whereas the influence of 'effectiveness of training' is weak.

10. CONCLUSIONS

The acceptance of technology by the potential users, good information quality to make accurate decisions, and a high level of satisfaction by end-users are essential elements of a sustainable digital health system, as indicated by literature and illustrated using SD simulation in this paper. The SD simulation results of eHMIS acceptance in Ethiopia show the dominant influence of 'individuals' intention to use' in the early years of the implementation. Adequate training and communication improve end-users ICT skills and create awareness about the benefits of technology to increase technology acceptance. The training and communication efforts drive the perceived ease of use; whereas user engagement influences the perception of technology usefulness also supported by literature (14,34). End-users must be well-trained and informed before implementing digital technology in the healthcare sector to improve technology acceptance.

The SD simulation results presented in this paper confirm that 'system quality' has the most decisive impact on 'information quality' also supported by literature (11,31). The quality of an information product can only be as good as the technology producing it. Therefore eHealth systems implementation should focus on developing high-quality systems, i.e., reliable, easy to use, and capable of meeting end-user requirements (7,11). The results presented in this paper study confirmed that 'information quality' can be enhanced through 'system quality' and satisfied users. Dissatisfied users are one of the sources of poor-quality data entry leading to unreliable information output.

SD simulation study and empirical evidence gathered from eHMIS implementation in Ethiopia as a case study confirmed that end-user satisfaction can be improved by the ability of technology to enhance work performance and reduce the burden of end-users. Moreover, high system quality and timely technical support services have moderately increased the satisfaction level of eHMIS users in Ethiopia. Setting system requirements with key stakeholders (cocreating) in the early phase of the project implementation can enhance the capacity of technology to meet the end-users need (14,35). The study further shows that continuous training, workshops, and on-the-job training also contribute to the satisfaction of end-users in Ethiopia where the ICT skill level is low.

Developing a sociotechnical system dynamics model of eHMIS acceptance and simulating to observe model behaviour is a unique contribution of this study, but it is not without assumptions and limitations. This research study assumes that the healthcare system is complex and system dynamics simulation model is a logical process to address the complexity during the implementation of eHealth systems. The model parameters in this study are derived from TAM and IS Success Model; however, the study can be strengthened further in future research by including variables from other systems development and delivery frameworks. This study attempted to verify and validate the SD sociotechnical model using empirical evidence from eHMIS. Yet, future research studies can use eHealth applications such as mHealth, EMR and telemedicine to study the model behaviour in more detail.

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