The Development of an Electronic Dashboard to Promote Obstetric Emergency Clinical Readiness in Amhara, Ethiopia

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Submitted in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy
under the Executive Committee
of the Graduate School of Arts and Sciences

COLUMBIA UNIVERSITY

2024

Abstract

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BACKGROUND: Maternal mortality remains a persistent public health concern in Sub-Saharan African countries such as Ethiopia. The Ethiopian Ministry of Health has made it a priority to improve maternal health outcomes within the country. Health information technology (HIT) solutions are a flexible and low-cost method for improving health outcomes and have been proven beneficial in low-to-middle income countries, like Ethiopia. The aims of this dissertation were: (a) to characterize the use of HIT usability evaluations in Africa; (b) to quantify facility clinical readiness for obstetric emergencies; (c) to explore the obstetric emergency supply chain dynamics and information flow; (d) to create a visualization dashboard to monitor obstetric emergency readiness; and (e) to evaluate the usability of the dashboard.

METHODS: This dissertation comprised six studies with a variety of quantitative and qualitative methods: (1) a scoping review of the literature to identify the types and timing of HIT evaluations occurring in Africa; (2) a prospective, cross-sectional, facility-level comparison of obstetric emergency clinical readiness in Amhara, Ethiopia as measured by the Signal Functions and Clinical Cascades methods; (3) qualitative semi-structured interviews to gain an understanding of the current supply chain in the region, communication flow, and the current barriers and facilitators to success; (4) a case study summarizing the process for the development of the dashboard prototype through integrating existing technology, current literature, and qualitative interview findings; (5) user-centered design sessions with individuals who interact with the obstetric emergency supply chain to create an electronic dashboard prototype to monitor facility readiness to manage obstetric emergencies; and (6) expert review of the dashboard including sessions with a domain expert and information visualization experts and a heuristic usability evaluation with human-computer interaction experts to evaluate and improve the ease of use and usefulness of the prototype.

RESULTS: The scoping review found that many usability evaluations in Africa lacked theoretical frameworks to support their work, and that most studies occurred later in the development process when the HIT was close to implementation in practice. The quantitative analysis of facility readiness found that many facilities were missing critical supplies for managing obstetric emergencies and identified a 29.6% discrepancy between the Signal Function tracer items and the Clinical Cascades readiness classifications indicating that the former, which is recommended by the World Health Organization, overestimates facility readiness. The qualitative interviews identified several locations within the current obstetric emergency supply chain where barriers such as bridging the gap of data availability between facilities and regional hubs could be addressed to improve overall facility-level readiness and pointed towards a dashboard as a potential solution. Once a prototype dashboard was developed, user-centered design sessions refined the terminology and colors that should be used throughout the dashboard screens and identified critical graphics and data elements that users believed should be included. Following domain and visualization expert review and iterative refinement of the dashboard, human-computer interaction experts rated the dashboards highly usable.

CONCLUSIONS: Dashboards are a novel method for promoting facility-level readiness to manage obstetric emergencies. By exploring the existing supply chain and including targeted end-users and experts in the design process the author was able to tailor the dashboard to meet user needs, fit into the existing integrated pharmaceutical logistics system, and ensure that it

follows best practices. Consequently, these studies contribute to strategies to address maternal mortality in Ethiopia.

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Acknowledgments

I would like to acknowledge my dissertation sponsor, Dr. Suzanne Bakken without whose expert guidance, generosity, and unwavering support this dissertation would not have been possible. I cannot articulate how much I appreciate your support of my incredibly ambitious dissertation project, and willingness to travel to Ethiopia to help me complete it. I would like to thank Dr. Elizabeth Corwin for her thoughtful mentorship throughout my PhD journey. Additionally, I would like to thank Dr. John Cranmer for the incredible opportunity to work with you and Emory Ethiopia Partnership. Without your openness to take on a student from another university, it would not have been possible for me to complete such a thorough and rich project focusing on maternal global health. I will forever be grateful for the opportunity to learn from and collaborate with you. To the Emory Ethiopia team, especially the Bahir Dar and Addis Ababa offices, you all made this work possible. I appreciate you welcoming me both into your research and communities during my time in Ethiopia. I thank my dissertation committee, including my blinded readers, Dr. Olivia Velez and Dr. Natalie Benda for your guidance and support during my time as a predoctoral student. My collaboration with all of you provided an incredible mentorship team and helped me to grow as an independent nurse researcher. A special thanks must go to Dr. Adriana Arcia for identifying the informatics implications of my project and opening up new research possibilities for me. To my PhD cohort, I thank you for your friendship and support as we grew together and learned how to begin a PhD program virtually during a global pandemic. I must thank the individuals who inspired me to pursue a PhD in the first place. Dr. Janie Heath and Dr. Kirsten Ashford, I will never be able to fully explain how much your guidance, support, and mentorship while at the University of Kentucky changed the trajectory of my career and future. Thank you for fostering the budding research interests of a young nursing student. Finally, to my family, you have all been on this wild journey from the beginning. Mom and Dad, sorry I've given you so many heart attacks by working in unique locations but thank you for being my first and strongest supporters. To my mother, a fellow nurse, thank you for inspiring my original dream to help and serve others. I got us that terminal degree.

Funding

Kylie Dougherty received pre-doctoral funding through a National Institute of Nursing Research T-32 training grant led by Dr. Suzanne Bakken, and an individual F-31 pre-doctoral training grant also funded by the National Institute of Nursing Research. This dissertation research was made possible through a Fulbright US Student Research grant to Ethiopia and the generosity of Dr. Suzanne Bakken, Columbia University School of Nursing PhD program, and Columbia University School of Nursing Department of Global Health research. Furthermore, Sigma Theta Tau International Alpha Zeta chapter and the Global Financing Facility UNICEF-Ethiopia provided funding.

Dedication

This dissertation is dedicated to Emory Ethiopia Partnership in honor of all the incredible work they have accomplished to promote positive newborn and maternal health outcomes in Ethiopia.

Chapter 1: Introduction

1.1 Maternal Mortality

Maternal mortality (MM) remains a significant public health concern (World Health Organization, 2019b). The World Health Organization (WHO) reported in 2017 that worldwide approximately 810 women died every day from preventable causes related to their pregnancy and/or delivery (World Health Organization, 2019b). Furthermore, women living in low-to-middle income countries (LMICs) carry an even greater risk of death when they become pregnant; 94% of all maternal deaths occur in LMICs (World Health Organization, 2019b). Additionally, within LMICs, Sub-Saharan Africa reports the largest portion of MM cases annually (World Health Organization, 2019b).

In 2017, Ethiopia was ranked in the top four countries globally for the highest total number of maternal deaths (World Health Organization, 2019a, 2019b). Although MM rates in Ethiopia have recently improved, women still face a 1 in 52 chance of dying from a childbirth-related cause (Emory Nell Hodgson Woodruff School of Nursing). Many deaths are due to healthcare facilities being unprepared to handle obstetric emergencies (Central Statistical Agency Addis Ababa Ethiopia & Inner City Fund, 2016; Emory Nell Hodgson Woodruff School of Nursing; Ethiopian Public Health Institute Addis Ababa & Federal Ministry of Health Addis Ababa, 2019; Mengesha et al., 2020; Saltzman, 2021). Lack of preparedness is due in large part to the absence of functional supply chains, which in this context is the process of managing and distributing obstetric medical supplies (Jbaily et al., 2020; Krautmann et al., 2020; Navarro et al., 2020; Saltzman, 2021). A 2017 study found a lack of basic obstetric supplies, such as magnesium sulfate and intravenous (IV) tubing, and services in Ethiopia, which could contribute to the current devastating MM rates (Tessema et al., 2017). Furthermore, Tefera et al. stated that when hospitals in Ethiopia ran out of medications and supplies they were forced to delay treatments or use less effective substitutes (Tefera et al., 2021).

The author selected Amhara as the focus of this research, due to the fact it consistently ranks higher in mortality rates compared to other regions in Ethiopia (Central Statistical Agency Addis Ababa, Ethiopia & ICF, 2016, p. 254; WHO, 2019a). Furthermore, Amhara reported worse health outcomes for mothers and lower rates of facility utilization during delivery as compared to several other regions, including the capital Addis Ababa, and neighboring Tigray (Central Statistical Agency Addis Ababa, Ethiopia & Inner City Fund [ICF], 2016, p. 254). Over the last decade, the number of women delivering at health facilities has greatly increased from 5% in 2000 to 54.2% in 2019. However, when compared to Addis Ababa which had facility delivery rates of 97%, and Tigray with 62.9%, facility delivery rates in Amhara are lower than both those regions (Central Statistical Agency Addis Ababa, Ethiopia & ICF, 2016, p. 149; Ethiopian Public Health Institute Addis Ababa & Federal Ministry of Health (MOH) Addis Ababa, 2019, p. 13). Moreover, the Health and Demographics survey conducted in 2016 found that four out of five women who delivered in the Amhara region did not receive a postnatal checkup within 48 hours of delivery (p. 152). This information highlights the crucial need to target interventions to improve maternal outcomes in Amhara, Ethiopia.

1.2 Health Information Technology

Health information technology (HIT) is a potential mechanism to improve patient outcomes and clinical care. HIT, which the U.S. Department of Health and Human Services defines as "the processing, storage, and exchange of health information in an electronic environment" (2020, para. 1), has proven to improve efficiency and patient satisfaction, decrease unintentional errors and costs, assist healthcare providers in making decisions, and expand access to healthcare (Brenner et al., 2016; Corrao et al., 2010; Nielsen, 2012; Open Medical Record System, 2017; U.S. Department of Health & Human Services, 2020). Furthermore, in LMICs, such as Ethiopia, HIT has assisted in improving health outcomes (Bukachi & Pakenham-Walsh, 2007; Lewis et al., 2012). For this reason, researchers have dedicated a substantial amount of time and resources to create new and efficient technology that will promote positive health outcomes (Alotaibi & Federico, 2017).

However, not all HIT is created equal. The full benefits of HIT can only be realized when the technology fits the environment it is intended to be used in and meets the needs of its targeted end-users. In other words, to ensure the benefits of HIT, the individuals involved in creating and implementing the technology must ensure usability. Usability is defined by the International Organization for Standardization (ISO) as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" (International Organization for Standardization, 2013, para. 2). Table 1.1 provides detailed definitions of effectiveness, efficiency, and satisfaction as they relate to usability.

Table 1.1: ISO Definitions of Usability Components

Component of Usability	Definition
Effectiveness	Accuracy and completeness with which users achieve specified goals
Efficiency	Resources expended in relation to the accuracy and completeness with which users achieve goals
Satisfaction	Freedom from discomfort, and positive attitudes towards the use of the product

(International Organization for Standardization, 2013)

HIT with poor usability can unintentionally lead to adverse outcomes. Technology with poor usability typically encounters barriers to implementation and utilization in new environments, along with incurring unexpected costs (Frith, 2019b; International Organization for Standardization, 2013; Nielsen, 2012). Furthermore, end-users are more likely to make mistakes, such as medication errors, as well as experience lower levels of productivity, and unintended medical supply stockouts when usability is suboptimal (Frith, 2019b; International Organization for Standardization, 2013; Nielsen, 2012). While HIT has the potential to greatly influence health outcomes, researchers must work to ensure usability of the technology they develop to achieve this potential.

1.3 The Use of HIT in Ethiopia to Enhance Clinical Capacity

Ethiopia has made great strides in improving its integrated pharmaceutical logistic system (IPLS) (e.g., the procurement system that helps facilities in Ethiopia obtain supplies from their central supplier). However, breakdowns in the IPLS exist. There are delays in the process from facilities requesting supplies to receiving them. Gaps in the availability of time-sensitive emergency supplies drive MM and adverse outcomes. Before 2009, Ethiopia's healthcare supply chain was fragmented and supply chain stakeholders struggled to communicate in a timely and effective manner (Mengesha et al., 2020; Tefera et al., 2021). Since 2010 the Ethiopian MOH has worked to increase accessibility and transparency of the supply chain to healthcare facilities throughout the country using the IPLS. This initiative improved inventory management and increased the flow of information throughout the supply chain which ultimately increased the availability of critical medical supplies throughout the country (Tefera et al., 2021).

However, IPLS, and maintaining an efficient supply chain in Ethiopia are not without their challenges. To enhance the feasibility of IPLS implementation, the Ethiopian MOH focused on a few medications and clinical conditions, such as HIV/AIDS, tuberculosis (TB), malaria, and processes such as vaccine distribution. Because of this, clinical readiness to manage obstetric emergencies, as measured through the availability of medications and supplies, has significantly lagged behind clinical readiness to manage TB (i.e., consistent availability of TB medications) (Mengesha et al., 2020). Consequently, facility gaps in critical obstetric supplies continue to blunt Ethiopia's ability to combat MM (Mengesha et al., 2020).

Additionally, while communication within the capital, Addis Ababa, has improved, communication between federal medical distributors and smaller regional health posts is still fragmented (Mengesha et al., 2020). Previous studies identified several barriers hindering IPLS success, including a lack of inter-sectoral collaboration, continued needs in infrastructure development, and a dearth of high-quality electronic mechanisms for reporting and requesting medications and medical supplies (Alemu et al., 2020; Mengesha et al., 2020). A systematic review of the challenges and prospects of Ethiopia's IPLS found that many facilities in regions outside of Addis Ababa still rely heavily on paper-based supply requests. This system is dependent on paper requests that are updated every two months (Mengesha et al., 2020). The over-reliance on paper-based requests decreases the quality of available data and hinders decision-making related to the distribution of medical supplies and medications. This leads to increased emergency ordering of supplies and higher rates of medical supply stockouts (i.e., running out of supplies) (Mengesha et al., 2020).

Mengesha et al. (2020) highlighted several pressing needs, including the incorporation of more medications in the IPLS, such as those necessary to treat obstetric emergencies, additional electronic dashboards to support the increased utilization of the IPLS, and upgrading the current dashboards in the system to better meet user needs. Ethiopia's IPLS needs additional content and features such as dashboards to meet the needs of the users in the obstetric emergency supply chain. A user-centered design process is critical to ensure that the new content and features meet the needs of various stakeholders and that the resulting system enhancements are easy to use and useful.

1.4 Gaps in the Literature

While HIT utilization increased over the years, much about the development and evaluation process in Africa is unknown (Bukachi & Pakenham-Walsh, 2007). This includes the types of evaluations and time points during the development and implementation process that evaluations are occurring. Furthermore, a lack of information related to the current obstetric emergency supply chain hinders HIT creation and use. The typical bottlenecks within the system causing breakdowns in communication and information flow are currently unknown (Cranmer et al., 2020). Additionally, the strengths and facilitators of success currently present in the system are not well established (Cranmer et al., 2020). Increasing the understanding of these barriers and facilitators is important preliminary work to understanding the information flow through the supply chain and thus develop systems that enhance clinical capacity.

Despite the benefits of incorporating IPLS into Ethiopia's healthcare supply chain, the system has not been expanded or tested with obstetric emergency supplies (Mengesha et al., 2020). This choice to focus on other clinical conditions led to gaps in the availability of crucial supplies, suboptimal care for mothers experiencing obstetric emergencies, and the persistence of high MM rates in Ethiopia (Mengesha et al., 2020; Tefera et al., 2021; Tessema et al., 2017). Furthermore, Ethiopia's current interventions to improve patient referrals and provider training have done little to impact MM (Austin et al., 2014). This led to an increased focus on improving the quality of care, instead of simply the number of providers available (Austin et al., 2014). To enhance the quality of obstetric emergency care, the consistent availability of necessary medications and supplies is crucial. Without the necessary data to monitor and manage supply movements, this consistency is difficult to achieve. The Ethiopian MOH, Amhara Regional Health Bureau, and Amhara Public Health Institute identified the promotion of survival during and after labor and the creation of "real-time data-to-action strategies to strengthen the [healthcare] system's readiness to manage labor-related emergencies" as critical needs (Cranmer et al., 2020). Through a partnership between Amhara Regional Health Bureau, Amhara Public Health Institute, and Emory-Ethiopia Partnership, the stakeholders identified the need for a "real-time demand-side system for emergency readiness monitoring and resource procurement to prevent essential emergency supply stock-outs at [healthcare] facilities" (Cranmer et al., 2020). The development of the electronic dashboard proposed in this dissertation work will support the flow of information as the foundation for enhancing clinical readiness to manage obstetric emergencies.

1.5 Theoretical Framework

HIT development and improvement is a complex process that involves multiple components interacting with one another, including the system, its intended users, required tasks, and the environment where this is all occurring. The author selected the Socio-technical Framework (Figure 1.1) (Sittig & Singh, 2010) to guide this dissertation work because it portrays the interactive and adaptive nature of HIT development and improvement. The Socio-technical Framework focuses on challenges related to designing, developing, implementing, and evaluating HIT changes "within a complex and adaptive healthcare system"(Sittig & Singh). The framework portrays the interactive nature of the eight dimensions and how they influence one another. The specific dimensions within this framework include *hardware and software, clinical content, human computer interface, people, workflow and communication, internal organization features, external rules and regulations,* and *measuring and monitoring* (Sittig & Singh).

Hardware and software consist of the equipment and digital infrastructure needed to use the HIT. *Clinical content* is the data, graphics, and numbers that make up the "language" of the HIT. *Human-computer interface* relates to the experience of the intended user, this includes all the components of the technology that an individual can see, touch, hear, or manipulate. *People* are the system users from those who develop the HIT to the targeted end-users of the system. *Workflow and communication* comprises the progression that a user must go through to complete their needed tasks effectively and efficiently. *Internal organizational features* refer to the rules, regulations, and policies that are in place in the intended organization or environment that is set to use the system. *External rules and regulations* are the policies and procedures that are present in the larger geographical area, outside the intended organization, where the HIT is implemented. Finally, *measuring and monitoring* is the process necessary to evaluate the efficiency and effectiveness of the HIT to accomplish its intended goals and to identify unintended consequences of the technology.

The dimensions are not hierarchical or sequential but instead are interdependent, and a change in one dimension impacts a change in the other dimensions (Sittig & Singh, 2010). Before an improvement or introduction of a HIT application occurs, a researcher must explore the impact that change will have on all the dimensions, even if the change is only occurring in one.

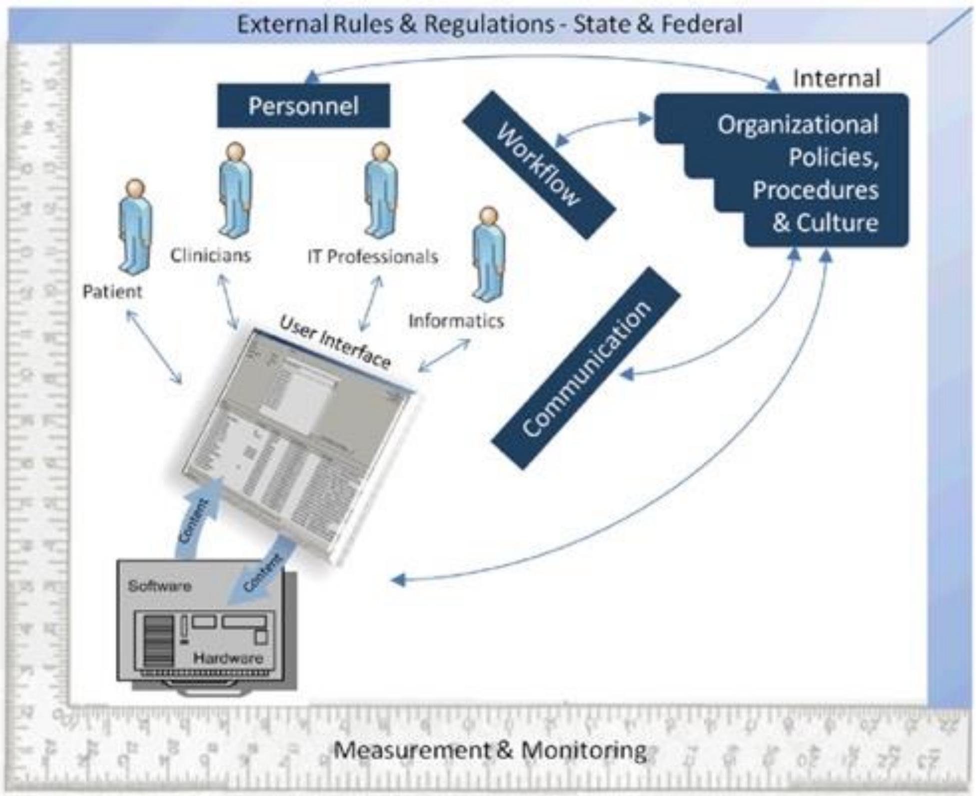


Figure 1.1: Socio-technical Framework

The dimensions of the Socio-technical Framework were operationalized for the dissertation studies as described in the following and summarized in Table 1.2. Aim 1 (Chapter 2) addresses measuring and monitoring, by investigating which methods are currently used to evaluate the usability of HIT in Africa. Aim 2 (Chapter 3), explores the clinical content to determine what medical supply information is critical to include in the dashboard to promote facility and regional readiness. Aim 3 (Chapter 4) examines all eight Socio-technical Framework dimensions through qualitative interviews with supply-chain users. Aim 4 (Chapters 5 and 6) investigates the human-computer interface, workflow and communication, and clinical content through the development of a dashboard prototype and user-centered design sessions. Aim 5 (Chapter 7) evaluates the eighth dimension, measuring and monitoring, through usability evaluations of the dashboard prototype. Aims 3 through 5 (Chapters 4-7) addresses the fourth dimension, people, by keeping the future dashboard users and current IPLS users at the center of dissertation investigation including design and evaluation of the dashboard. By examining the role of each of the eight dimensions during the development of the dashboard, the dissertation research aims to promote regional readiness to manage obstetric emergencies and thus enhance the obstetric clinical capacity of the region.

1.6 Dissertation Overview

The dissertation consists of six manuscripts, one for research aims 1-3 and 5, and two manuscripts for aim 4. Together the manuscripts address the gap in identifying where the communication and information breakdowns are occurring in the obstetric emergency supply chain in Amhara Ethiopia and creating and evaluating a dashboard to improve real-time clinical readiness and monitor obstetric emergency supply movement throughout the region. This dissertation has the following five aims: **Aim 1:** To characterize the use of HIT usability evaluations in Africa through a scoping review. **Aim 2:** To quantify facility readiness for obstetric emergencies as measured by Signal Function tracer items and the Clinical Cascades. **Aim 3:** To explore the obstetric emergency supply chain dynamics and information flow in qualitative semi-structured interviews. **Aim 4:** To create a visualization dashboard to monitor obstetric emergency readiness. **Aim 5:** To evaluate the usability of the dashboard. This dissertation examines the current state of Amhara's obstetric emergency supply chain at each level within the system, from the federal government to individual healthcare posts, and created a solution within IPLS that takes advantage of its infrastructure and functionality.

The first manuscript (Chapter 2) summarizes when HIT usability evaluations are occurring, and the interactions explored in studies in Africa based on the integrated framework using Stead's System Development Life Cycle (SDLC) and Bennett and Shackel's usability models. This scoping review was published in in the *Journal of the American Medical Informatics Association (JAMIA)* (Dougherty et al., 2022). The second manuscript (Chapter 3) is a quantitative data analysis measuring facility capacity to manage obstetric emergencies in Amhara Ethiopia. The analysis measures facility readiness using the *Signal Functions tracer items* and *Clinical Cascades*, as well as comparing their classifications. This analysis is published in *PLOSOne* (Dougherty et al., 2023). Guided by the qualitative descriptive methodology, the third manuscript (Chapter 4) explores user perspectives on the current breakdowns, facilitators, and barriers to efficient management of supplies and monitoring of clinical readiness (i.e., the consistent availability of medications and medical supplies needed to treat obstetric emergencies) using a purposive sample from positions at all levels of Ethiopia's obstetric emergency supply chain. The author plans to submit this qualitative manuscript for publication in *Informatics for Health and Social Care*. The fourth manuscript (Chapter 5) is a case study and describes the process for creating the first prototype of the dashboard. The fifth manuscript (Chapter 6) describes the user-centered design process to further develop and refine a real-time dashboard that is easy to use and capable of measuring readiness in a manner most pertinent (i.e., useful) to Amhara's regional distribution hubs and individual facilities. The author plans to submit this usability manuscript for publication in *Digital Health*. The sixth manuscript (Chapter 7) describes expert reviews of the dashboard as well as the results of the human-computer interaction expert heuristics usability evaluation. The author plans to submit this manuscript for publication in *Digital Health*. Finally, Chapter 8 summarizes and discusses the results of the previous manuscripts. Table 1.2 summarizes the research aims, proposed chapters and methods, their associated theoretical framework components, and targeted journals.

Table 1.2: Proposed Dissertation Outline

Chapter	Relevant Aspect of Theoretical Framework	Study Methods	Targeted Journal
Aim 1: To characterize the use of HIT usability evaluations in Africa through a scoping review			
Chapter 2	• Measuring and monitoring	• Scoping review	Journal of American Medical Informatics Association [Published]
Aim 2: To quantify facility readiness for obstetric emergencies as measured by Signal Function tracer items and the Clinical Cascades			
Chapter 3	• Clinical content	• Quantitative data analysis of facility-level data	PLOSOne [Published]
Aim 3: To explore the obstetric emergency supply chain dynamics and information flow in qualitative semi-structured interviews			
Chapter 4	• People • Hardware and software • Internal organizational features • Workflow and communication • External rules and regulations	• Semi-structured qualitative interviews	Informatics for Health and Social Care
Aim 4: To create a visualization dashboard to monitor obstetric emergency readiness			
Chapter 5	• Human computer interface • Clinical content	• Semi-structured qualitative interviews • Review of currently available technology • Review of design best practices in the literature	Not Applicable
Chapter 6	• People • Human computer interface • Workflow and communication • Clinical content	• User-centered design sessions	Digital Health
Aim 5: To evaluate the usability of the dashboard			
Chapter 7	• People • Measuring and monitoring	• Review by a domain expert • Review by information visualization experts • Heuristic usability evaluations with human-computer interaction experts	Digital Health

In summary, the dissertation addresses critically important gaps in promoting positive maternal health outcomes in Amhara Ethiopia: identifying barriers and breakdowns to efficient communication and information sharing in the obstetric supply chain and creating a tool to monitor and maintain obstetric emergency readiness in the region. Ultimately, this work will provide a foundation for the future development of efficient obstetric emergency supply chain management in LMICs, like Amhara, Ethiopia, which will subsequently improve obstetric emergency care and promote positive maternal outcomes.

Chapter 2: A Scoping Review of Health Information Technology Usability Evaluations in Africa[1]

2.1 Introduction

Promoting good health and well-being is a crucial priority for all countries, and is a sustainable development goal set by the United Nations (Nations, 2020). The continent of Africa is an economically diverse geographical area with countries with high gross national income, like Seychelles, and others, such as Burundi, with much lower gross national income (World Population Review, 2021). Health outcomes also vary widely throughout the continent. For example, in terms of maternal mortality (MM) Chad had the highest rate among African countries with 1,140 deaths per 100,000 live births in 2017, while Egypt only reported 37 deaths per 100,000 live births (CIA World Factbook, 2017).

Despite the economic diversity within the continent, Africa has the largest proportion of low-income countries with 23 of the 27 poorest countries in the world, and 21 of the world's 55 lower-middle-income countries (World Population Review, 2021). In comparison to other continents, Africa has greater health inequities, worse health outcomes, the lowest average life expectancy, and the highest proportion of under-five mortality and MM ratios (Statista, 2021; World Health Organization, 2018; World Population Review, 2021). Furthermore, a 2018 World Health Organization review found that most countries in Africa were unable to achieve their targets for sustainable development goals of improving health outcomes (World Health Organization, 2018). Thus, it is imperative that research and health policies focus on removing barriers to equitable health and improving health outcomes in this region.

[1]This manuscript is published in *JAMIA* (Dougherty, K., Hobensack, M., & Bakken, S. (2022). Scoping review of health information technology usability methods leveraged in Africa. *Journal of the American Medical Informatics Association, 30*(4), 726-737. https://doi.org/10.1093/jamia/ocac236)

Development and utilization of health information technology (HIT) can contribute to improving health outcomes in both high and low resource areas. HIT is the "processing, storage, and exchange of health information in an electronic environment"(U.S. Department of Health & Human Services, 2020) and has been shown to improve the quality and delivery of care, decrease costs, improve patient safety and health outcomes, assist healthcare providers in efficiently completing tasks, improve patient-provider interactions and decrease inadvertent errors (Bukachi & Pakenham-Walsh, 2007; International Organization for Standardization, 2013; Lewis et al., 2012; Nielsen, 2012; Office of Disease Prevention and Health Promotion, 2020; Tomasi et al., 2004; U.S. Department of Health & Human Services, 2020; World Health Organization, 2018).

Over the last decade, the growth and use of internet services and mobile devices rapidly expanded in both urban and rural communities in Africa (Lewis et al., 2012). This uptake of mobile devices and information technology led to the rapid development of HIT and increased utilization of technology by healthcare workers and patients for communication, collaboration, and access to health-related information (Bukachi & Pakenham-Walsh, 2007; Lewis et al., 2012). Previous research on the impact of HIT in low-to-middle income countries (LMICs) found the technology to be useful in enhancing the efficiency of task completion, which is in line with the positive effects of HIT in high-income countries (Tomasi et al., 2004).

However, HIT must be used deliberately. If the creation, implementation, and use of HIT are not carefully enacted, unintentional consequences may occur (Ratwani et al., 2018). Tomasi et al. also highlights the importance of conscientious implementation and stakeholder involvement to ensure optimal impact of system implementation in a specific environment (Tomasi et al., 2004). System usability is critical to ensuring the positive influence of HIT on outcomes of interest (Nielsen, 2012). The International Organization for Standardization (ISO) defines usability as “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specific context of use”(U.S. Department of Health & Human Services, 2020). ISO definitions for the usability components of effectiveness, efficiency, and satisfaction are shown in Table 2.1.

Table 2.1: ISO Definitions of Usability Components

Component of Usability	Definition
Effectiveness	Accuracy and completeness with which users achieve specified goals
Efficiency	Resources expended in relation to the accuracy and completeness with which users achieve goals
Satisfaction	Freedom from discomfort, and positive attitudes towards the use of the product

Note. Definitions from the International Organization for Standardization (2013)

Poor usability can increase the time needed to complete tasks, increase the risk of errors occurring, lead to higher costs related to implementation and use, and discourage users from incorporating the technology into their daily activities, among many other negative consequences (Friedman, 2006; International Organization for Standardization, 2013; Nielsen, 2012; Shackel, 1991; Stead et al., 1994). Thus, researchers must perform usability evaluations to ensure they are cognizant of the preexisting environment, have support from local stakeholders and targeted end-users of the HIT, and that sufficient resources exist to promote the uptake of the system (Kaufman et al., 2006). Moreover, usability evaluations should occur at multiple stages of system development rather than at a single point in time to ensure an adequate fit between the technology and task requirements.

The author conducted a scoping review to explore the state of HIT usability evaluation in Africa. Specifically, the author applied Bennett and Shackel’s usability models (Bennett, 1984; Shackel, 1991) to characterize the types of usability interactions assessed and methods used and categorize the timing of the evaluation according to the stages of the System Development Life Cycle (SDLC)(Stead et al., 1994).

2.2 Methods

This scoping review follows the Joanna Brigg's scoping review framework (Peters, 2020). The author used the Population-Concept-Context framework (Peters et al., 2015) to inform the inclusion criteria (Appendix A) and developed an unpublished a priori protocol based on the PROSPERO guidelines (Appendix B)(University of York Center for Reviews and Dissemination, 2016). Results were reported according to Stead's SDLC stages (Stead et al., 1994) and Bennett's and Shackel's usability models (Bennett, 1984; Shackel, 1991).

2.2.1 Eligibility Criteria

This scoping review included articles if their main objective was HIT usability evaluation in African countries. The author did not include articles of studies that explore general informatics aspects, such as information-seeking behavior or evaluations of personal technology usage, studies that evaluate specific methods, models, or frameworks, or studies focusing on information systems for security, bioinformatics, or research purposes not related to health outcomes or the promotion of positive health behaviors (Appendix B). The eligibility criteria comprised quantitative, qualitative, and mixed-method studies reported in journals, conference proceedings, and gray literature. While the author did not limit the date of publication, the search was limited to the English language. The removal of the non-English articles from the original search results occurred during the title and abstract screening. However, one article had an English abstract but during full text review, the reviewers found the full article was not available in English and was removed.

2.2.2 Information Sources and Search Strategy

The author consulted an informationist from the Columbia University Irving Medical Center library to develop the search strategy for the review. The research team searched

PubMed, Embase, and the Association for Computing Machinery (ACM) (Appendix C). The author also performed an ancestry search of reference lists in the retrieved papers.

2.2.3 Study Selection and Data Extraction

The literature search retrieved a total of 1,088 results comprising articles reporting HIT evaluation findings, study protocols, and conference papers. Two authors (KD and MH) screened, evaluated, and extracted data using Covidence (Veritas Health Innovation). The reviewers removed 94 duplicates and added 11 articles from the search of reference lists resulting in 1002 titles and abstracts that were screened for inclusion. KD and MH subsequently reviewed 183 full text articles resulting in 73 that met our inclusion criteria (Figure 2.1).

The reviewers extracted data about author information, date of publication, study sample and size, study location, type of HIT evaluated, study design, methods used to explore usability, and framework used (if stated). Appendix D summarizes study descriptions.

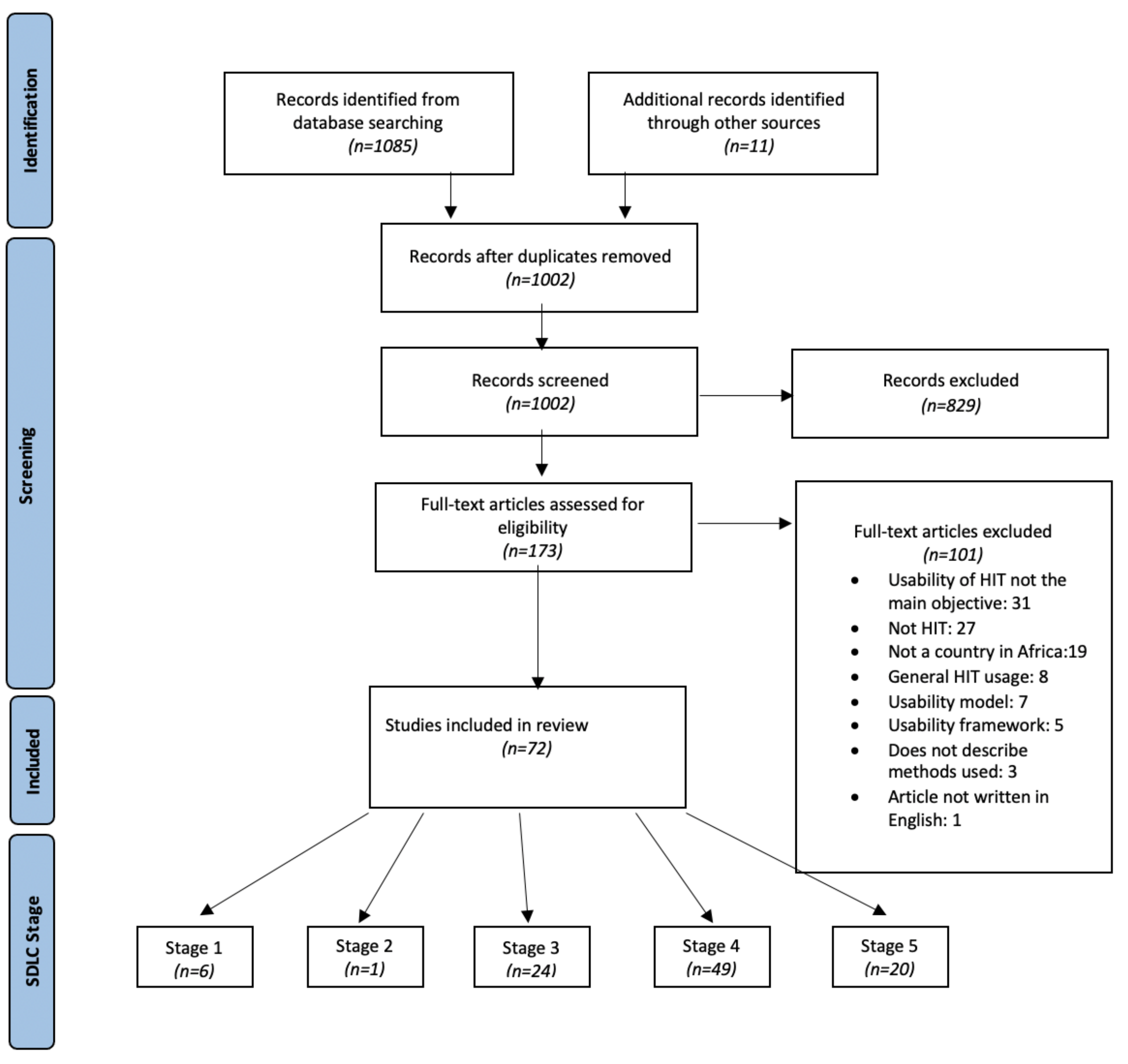


Figure 2.1: PRISMA Flow Chart

2.2.4 Data Extraction from Individual Sources of Evidence

To extract and categorize the SDLC stage and types of interactions studied in Africa, the author applied Yen et al.'s evaluation framework that combined the SDLC with Bennett's and Shackel's usability models to determine the *when* and the *what* of usability studies in the United States (Yen & Bakken, 2011). The *when* refers to the point along the SDLC the evaluation is occurring. Table 2.2 presents specific study categorization criteria for each of the SDLC stages.

Bennett's and Shackel's usability models explore the *what* of usability evaluations, which is the component(s) being explored in the study. These components consist of the *task* needing to be accomplished, the *system* or HIT, the *users* of the system, and the *environment* where all of this is occurring (Bennett, 1984; Shackel, 1991).

Table 2.2: Criteria for study categorization based on the System Development Life Cycle (SDLC) Stages

SDLC Stage	Study categorization criteria
Stage 1	Needs assessments with design methods described
Stage 2	System validation evaluations, such as sensitivity and specificity analyses, ROC curve, and observer variation
Stage 3	Human-computer interaction evaluations focusing on outcome quality, user perception, and user performance in the laboratory setting
Stage 4	Field testing; experimental or quasi-experimental designs with control groups in one setting
Stage 5	Field testing; experimental or quasi-experimental designs with control groups in multiple sites; post-implementation evaluation only; self-control, such as evaluation before and after implementation

System Development Life Cycle, (SDLC); Receiver operating characteristic, (ROC)
Note. Criteria from Yen et al.(Yen & Bakken, 2011)

Figure 2.2 depicts how these four components interact with one another. The five component interaction types that are included in these models are (Type 0) task alone, (Type 1) user-task interaction, (Type 2) system-task interaction, (Type 3) system-user-task interaction, and (Type 4) system-user-task-environment (Bennett, 1984; Shackel, 1991). Table 2.3 displays the combined evaluation framework used in this literature review.

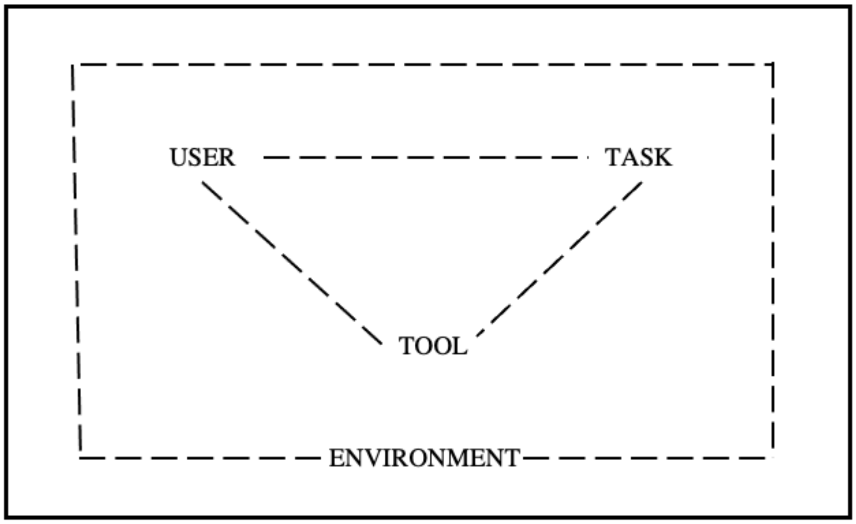


Figure 2.2: Shackel's Four Principal Components of Human-Machine Systems
Note. Usability component figure from Shackel and Richardson (1991)

Table 2.3: Usability Evaluation Frameworks

Stead SDLC	Bennett and Shackel Evaluation type
Stage 1: Specification	Type 0: task Type 1: user-task
Stage 2: Component development	Type 2: system-task Type 3: system-user-task
Stage 3: Combination of components into a system	Type 2: system-task Type 3: system-user-task
Stage 4: Integration of system into environment	Type 2: system-task Type 3: system-user-task Type 4: system-user-task-environment
Stage 5: Routine use	Type 2: system-task Type 3: system-user-task Type 4: system-user-task-environment

System Development Life Cycle, (SDLC); Note. Integrated usability framework from Yen et al.(Yen & Bakken, 2011)

2.3 Results

2.3.1 Description of Included Studies

Of the 73 articles included in this review, 20 (27%) are from the last two years and 31 (42%) from the last 3 to 5 years. The earliest study included was published in 2010 and 2019 had the most publications (n=14, 19%). Healthcare workers providing direct patient care were the most frequently targeted HIT end-users (n=48, 66%). Others included health administrators and leadership, patients, caregivers, and content experts, such as HIV treatment experts (Appendix D). Sample sizes varied widely among the studies from 5 (Vedanthan et al., 2015) to 2327 (Bagayoko et al., 2020). The studies reflect implementation of HIT in multiple different settings including clinics (n=16), hospitals (n=17), communities (n=19), long-term care facilities (n=1), academia (n=1), and health departments (n=1). Additionally, 16 studies describe implementation of HIT in multiple settings.

We describe the details of the 73 articles in this scoping review including the type of HIT, SDLC stage, usability interactions, and theories supporting the studies in the following sections. Some publications describe multistage usability evaluations, so the number of publications at each stage does not match the total number of studies included in the review. A table of the included studies can be found in Appendix D.

The countries with the most publications were Kenya and Uganda (n=10, 14% for each) followed by South Africa (n=9, 12%). The remaining countries had 1-6 publications (Table 2.4). Two studies occurred in more than one country, one in Kenya and Uganda, and another in Kenya and Mozambique. Most articles are from the southeast region of the continent (Figure 2.3). Thirty-six countries did not have publications that met eligibility criteria, i.e., no articles from north or southwest Africa.

Table 2.4: Number of Articles from Each African Country

Country	Number of Articles
Kenya	10
Uganda	10
South Africa	9
Ethiopia	6
Ghana	6

Malawi	6
Nigeria	6
Tanzania	4
Botswana	3
Mozambique	3
Sierra Leone	3
Madagascar	2
Rwanda	2
Burkina Faso	1
Burundi	1
Central African Republic	1
Gabon	1
Zimbabwe	1

Figure 2.3: Map of Where Included Studies Occurred

2.3.2 Types of HIT Evaluated

The most common types of HIT evaluated were clinical decision support systems (CDSS) (n=24, 33%) and clinical information systems (n=13, 18%), which include electronic health records (EHR), information systems, and documentation systems (Table 2.5). The least common type of HIT was adverse event reporting (n=1). In terms of application domain, 21% (n=15) of HIT evaluated was for HIV care (n=15, 21%). Very few studies utilized or evaluated preexisting HIT in their work. The exception is Lim et al. who leveraged two health applications that were previously evaluated for usability to enhance the design of their CDSS (2015). This allowed them to quickly move to stage 3 and 4 usability evaluations rather than duplicate the previous work.

Table 2.5: Number of Health IT Systems Evaluated by Type

Category	Number
1. Population-Based System	**9**
a. Registry	2
b. Population surveys	2
c. Disease control	5
2. Clinical information system	**13**
a. Electronic health record	7
b. Information system	5
c. Documentation system	1
3. Clinical Decisions Support System (CDSS)	**24**
a. For information management (e.g., information needs)	1
b. For focusing attention (e.g., reminder/ alerts)	2
c. For providing patient-specific recommendations	21
4. Patient/Consumer Facing Decision Support System	**6**
a. For information management (e.g., information needs)	1
b. For focusing attention (e.g., reminder/ alerts)	5
5. Telehealth system- Provider-patient consultation	**8**
6. Training system	**7**
a. Provider education	3
b. Patient education	4
7. Adverse event reporting	**1**
8. Logistics system	**5**
a. Patient admissions	2
b. Medical supplies	1
c. Pharmaceuticals	2

Note. Health information technology (HIT) categories were based on Gremy and Degoulet's classifications, clinical decision support system (CDSS) classifications described by Musen, AHRQ, and logistic systems are categorized by the item they are tracking (Grémy & Degoulet, 1993; Musen et al., 2013; Quality, 2019)

2.3.3 Stages of the System Development Life Cycle

Most publications (n=48, 66%) describe single-stage evaluations. While many methods are similar across stages, some are unique to an individual stage, such as cost-benefit analysis and quality-adjusted life year (QALY) score calculations at stage 5 evaluations (Table 2.6). Mixed methods was the most common study design (n=43, 59%), typically including some form of qualitative interviews or focus groups as well as administration of quantitative questionnaires.

Table 2.6: Methods Used at Each System Develop Life Cycle (SDLC) Stage

SDLC Stage	Methods Used
Stage 1: Specify needs and setting	**Data Collection/Data Sources** • Questionnaire/survey • Focus group • Interview • Brainstorming design session **Data Analysis** • Deductive coding • Inductive coding • Manual content analysis • Logistic regression • Logical workflow model creation • Mind map creation
Stage 2: System component development	**Data Collection/Data Sources** • CDSS treatment recommendations • CDSS reminders • Patient clinical notes **Data Analysis** • Test-retest reliability (Repeating clinician diagnostic decisions based on patient notes) • Inter-rater reliability (Comparison of provider clinical decisions/recommendations using old system and new HIT) • Sensitivity and specificity (Comparison of pulse oximetry readings reported in patient clinical notes and CDSS reminder creation using old systems and new HITs)
Stage 3: Combination of components	**Data Collection/Data Sources** • Think-aloud protocol • Heuristic evaluation • Low-fidelity prototyping • Rapid prototyping • Lab simulation with predetermined tasks and patients • Hybrid lab-live software evaluation • One-to-one theoretical usability workshop • Questionnaire/survey • Focus group • Interview • Observation • User-experience expert review **Data Analysis** • Descriptive statistics (e.g., time on task, percentage of user errors, severity of errors) • Thematic analysis

	• Inductive coding • Deductive coding • Fisher's Exact Test •
Stage 4: Integrate health IT into a real environment	**Data Collection/Data Sources** • Field usability testing • Think-aloud protocol • User engagement report • Weekly stock report/facility surveillance report • Patient health record • Questionnaire/survey • Focus group • Interview • Observation • Retrospective probing technique **Data Analysis** • Descriptive statistics (Comparison to old system using presence of missing records, errors present, time-on-task, number of IT support request tickets) • Inter-rater reliability • Sensitivity, specificity, positive predictive value, and negative predictive value • Fisher's Exact Test • Multivariate logistic regression • Cause of error analysis • Correlation analyses
Stage 5: Routine use	**Data Collection/Data Sources** • Questionnaire/survey • Focus group • Interview • Observation • Facility surveillance report • User engagement report **Data Analysis** • Descriptive statistics (Comparison to old system using frequency of missing records, percentage of errors present) • Sensitivity and specificity • Test-retest reliability • Ranked correlation analysis • QALY analysis • Cost-benefit analysis • Multivariable regression models (to compare success, adherence, and task completion)

System Development Life Cycle, (SDLC); Note. Clinical Decision Support System (CDSS)

Stage 1: Specify Needs and Setting

Stage 1 focuses on determining the specific tasks and needs that the technology will support along with user preferences. Evaluations at this stage can occur in the laboratory or the field. A total of six articles (8%) included stage 1 evaluations. To determine specific user needs and knowledge some studies reviewed the current literature (Oza et al., 2019; Tochukwu Arinze

& Rita, 2016). To identify task requirements and workflow needs two publications used consultations with domain experts (Gbadamosi et al., 2018; Nhavoto et al., 2015). These experts included professionals from implementation science, informatics, and disease-specific treatments, such as HIV/TB. The studies recruited health administrators and officers for their understanding of the health technology infrastructure and policy requirements to create HIT that can be easily implemented into the community (Bagayoko et al., 2017; Kabukye et al., 2017; Oza et al., 2019). All stage 1 evaluations focused on the emic perspective, or insider perspective, and recruited healthcare workers and patients as the intended HIT end-users (Bagayoko et al., 2017; Gbadamosi et al., 2018; Kabukye et al., 2017; Nhavoto et al., 2015; Oza et al., 2019; Tochukwu Arinze & Rita, 2016). Most studies included qualitative data collection strategies such as interviews, focus groups, and brainstorming design sessions. These studies used inductive and/or deductive coding strategies to analyze their data (Gbadamosi et al., 2018; Kabukye et al., 2017; Nhavoto et al., 2017; Oza et al., 2019). Bagayoko et al. is the only study to use quantitative surveys to elicit targeted end-user knowledge during stage 1 development (2020). They used the survey responses to perform logistic regression to determine which variables were associated with healthcare provider perspectives on a national electronic health system (Bagayoko et al., 2020).

Stage 2: System Component Development

The purpose of stage 2 evaluations is to determine the validity and reliability of the HIT or its individual components. These evaluations occur in the laboratory, or a controlled environment that excludes many real-world conditions. Three articles report performing stage 2 evaluations (Azfar et al., 2014; Dumisani & Janet, 2014; Hudson et al., 2012) and calculate sensitivity and specificity, inter-rater reliability, and test-retest reliability to ensure the accuracy and validity of the HIT or its components (Azfar et al., 2014; Dumisani & Janet, 2014; Hudson et al., 2012). For example, to ensure validity of their HIT Azfar et al. performed traditional face-to-face dermatology appointments with participants and made clinical diagnoses and treatment decisions based on these appointments to create a gold standard for comparison with a teledermatology system (2014). Researchers compared the provider decisions in the two appointment modes to determine congruence. To explore test-retest reliability, the researchers provided the healthcare providers with blinded versions of the old cases using the information obtained from the teledermatology visits and asked them to make clinical decisions based on the information collected in the telehealth visits (Azfar et al., 2014). By performing these tests, the authors could ensure reliability and validity of their tool before exploring usability concerns or real-world performance.

Stage 3: Combination of Components

Stage 3 evaluations occur in the laboratory setting and aim to determine if the HIT can decrease human error and improve the user's experience performing the task. There were twenty-eight articles (38%) with stage 3 evaluations. To explore users' perceptions of HIT, researchers used both quantitative and qualitative methods. The most common quantitative method for obtaining user perceptions was usability surveys. Many studies used existing tools, such as International Business Machines Corporation (IBM) usability questionnaires, System Usability Scale, and the Health Information Technology Usability Evaluation Scale (Coppock et al., 2017; Crehan et al., 2019; Dumisani & Janet, 2014; Heys et al., 2018; Lim et al., 2015; Vélez et al., 2014). However, other studies chose to create their own surveys or modify existing surveys (Ezeanolue et al., 2017; Feldacker et al., 2019; Fischer et al., 2021; Ginsburg et al., 2016; Heather et al., 2013; Mawji et al., 2020; Vanosdoll et al., 2019). Typically, authors used descriptive statistics to summarize these subjective usability measures. Additionally, 18 of the 28 articles with stage 3 evaluations used focus groups and interviews to gather additional user perceptions. The authors used both inductive and deductive coding to analyze the transcripts from these sessions.

Researchers used several different simulated activities to gain a better understanding of how targeted end-users might complete required tasks using the HIT. These simulated activities include think-aloud protocol, hybrid lab-live software evaluation, low-fidelity prototyping, direct observations, and one-to-one theoretical usability workshops. The most common of these methods was the think-aloud protocol (Coppock et al., 2017; Ezeanolue et al., 2017; Kawakyu et al., 2019; Lim et al., 2015; Mawji et al., 2020; Vedanthan et al., 2015). During think-aloud protocols, participants verbalize their thought processes as they complete tasks (Odukoya & Chui, 2012). Researchers are also interested in ensuring their HIT not only has high usability with end-users but also meets best practices (i.e., heuristics) for user-interface design. Two studies used heuristic evaluations by HIT experts to identify usability violations (Ezeanolue et al., 2017; Vélez et al., 2014).

Stage 4: Integrate HIT Into a Real Environment

Most articles included stage 4 evaluations (n=53, 73%). Stage 4 evaluations occur in the field and evaluate how the HIT will perform in real-world conditions. A defining characteristic of stage 4 evaluations is that the HIT is typically still under the control of the individuals who developed it. Most articles describing stage 4 evaluations were pilot studies exploring the ease of implementation and use of the HIT at one or several sites. To identify barriers to implementation researchers performed cause of error analyses (Desrosiers et al., 2021). To evaluate user satisfaction researchers used questionnaires (n=34), focus groups (n=32), and interviews (n=28).

Additionally, chart review, user-engagement reports, frequency of IT support ticket submission, guideline adherence, and outcome comparison to the previously used system were all leveraged to evaluate both efficiency and effectiveness of the HIT during real-world performance. Similar to stage 3 evaluations in the laboratory, time-on-task, counting the number of errors that occurred during HIT use, and asking participants to perform think-aloud protocol during direct observation measured system efficiency (Ezeanolue et al., 2017; Ginsburg et al., 2016; Ha et al., 2016; Lim et al., 2015; Mawji et al., 2020). One study compared clinical care decisions made by nurses using a novel telehealth system and traditional face-to-face appointments to determine the reliability of nursing hypothesized diagnoses and feedback (Qin et al., 2013).

Stage 5: Routine Use

The focus of stage 5 evaluations is to determine the long-term impact of the HIT. These evaluations occur in the field, typically when the HIT is no longer under the control of its original developers, and explore the effect of HIT on health outcomes, individuals, and communities (Stead et al., 1994). Nineteen (26%) articles had stage 5 evaluations. Data sources included user-engagement reports, weekly stock reports, patient health reports, and observations. For example, one study used facility inventory checklists to examine the impact of HIT on facilities' capacity to provide antenatal care (Abejirinde et al., 2018). The follow-up period for these studies ranged from one month to one year following HIT implementation. Most of the studies applied mixed methods, while four were only quantitative (Habtamu et al., 2019; Liang et al., 2018; Martindale et al., 2018; Muhindo et al., 2021), and five were only qualitative (Ide et al., 2019; Janssen et al., 2020; Landis-Lewis et al., 2015; Mwaisaka et al., 2021; Thomsen et al., 2019). Overall, fourteen articles used qualitative interviews to explore the influence of HIT on patient outcomes, user experiences, and workflow. Additional methods used in stage 5 evaluations included cost-benefit analysis, QALY analysis, and multivariable regression models to evaluate the influence of the HIT on treatment adherence and success (Byonanebye et al., 2021; Martindale et al., 2018; Tochukwu Arinze & Rita, 2016).

2.3.4 Bennett and Shackel's Usability Interactions

None of the articles included in this review performed a Type 0: task evaluation. The interaction evaluations included were: Type 1: user-task (n=2, 3%) during SDLC stage 1; Type 2: system-task (n=13, 18%); Type 3: system-user-task (n=29, 40%); and Type 4: system-user-task-environment (n=29, 40%). Type 4 interactions occur during stages 3, 4, and 5 evaluations since these studies occur in the field and researchers can explore the environmental component of usability as it relates to the technology.

2.3.5 Theories and Frameworks Guiding the Usability Studies

Theoretical models and frameworks guide study activities and support study rationale. Most articles did not include any framework or theory to support their work (n=44, 60%). Of the 29 articles that used theories the most common was the Technology Acceptance Model (n=6, 8%). More than one study used the unified theory of acceptance, the use of technology model, and the consolidated framework for implementation research. See Appendix D for the individual frameworks used in each study.

2.4 Discussion

2.4.1 Overview

This scoping review of HIT usability evaluations conducted in African countries identifies and describes *when* evaluations were occurring and *what* components of usability were evaluated. The review includes more articles (n=73) than a recent review about the presence of HIT in Africa (n=14) (Koumamba et al., 2021) but fewer than a similar HIT usability literature review focusing on articles in the United States (n=346) (Yen & Bakken, 2011). However, this reflects a significant number of such studies in Africa given that Africa only accounts for approximately 1.1% of global investments in research and development (Simpkin et al., 2019).

2.4.2 SDLC Stages & Bennett and Shackel's Usability Interactions

Most articles in the review consisted of later-stage evaluations where HIT was about to be deployed into the field or was already in real-world use. While several articles provided details on the methods they used to perform early-stage evaluations, many simply alluded to prior research or earlier development without providing any details on the methods used or samples for usability assessments (Gbadamosi et al., 2018; Hollander et al., 2020; Liang et al., 2018; Morse et al., 2021; Oza et al., 2019; Velloza et al., 2019). Review of those articles' reference lists revealed no additional publications describing the methods in greater detail. Without additional detail, it is difficult to determine the rigor of the methods applied or the fit of HIT produced to the user or task.

Furthermore, most articles did not describe early-stage evaluations. By ignoring early-stage usability concerns, researchers may develop and deploy HIT that does not perform its required tasks effectively. Additionally, it is more difficult to articulate and address specific usability concerns in later stage evaluations because the interactions are more complex at later development stages (Yen & Bakken, 2011). These findings align with a recent review exploring HIT usability in the United States that also found a predominance of HIT evaluations at stages 4 and 5 (Yen & Bakken, 2011). This consistency across the two reviews may reflect a broader trend in reporting only later-stage evaluations even if earlier stage evaluations were conducted. Publication bias may play a role in that there are fewer dissemination venues for formative and typically small sample user-centered studies that may be specific to a single system or site despite the critical role of such evaluations in creating usable HIT.

2.4.3 Methodological Characteristics

The majority of the articles in this review applied mixed methods approaches. By leveraging multiple types of data sources, evaluation methods, and analyses, researchers were able to obtain objective and subjective measures of usability and identify barriers to efficient HIT utilization. Use of mixed methods also enables exploration of multiple usability components (e.g., efficiency, effectiveness, and satisfaction) (International Organization for Standardization, 2013).

Theoretical frameworks provide a rationale for studies, a lens for interpretation of findings, and a basis for establishing the contribution of findings to advance knowledge generation in the field (Grant & Osanloo, 2015). However, fewer than half of the articles in the scoping review explicitly included theoretical frameworks or models. This finding is consistent with Yen et al.'s review of HIT usability studies in the United States so does not reflect a trend specific to Africa (Yen & Bakken, 2011). To enhance the quality of research related to HIT usability, and enable explication of the research studies findings to advance knowledge generation, researchers should incorporate theoretical frameworks/models into their work. Furthermore, future research should identify theoretical frameworks that are appropriate for evaluations at each SDLC stage.

2.4.4. Gaps in the Literature and Future Research Implications

This review found several significant gaps in the literature related to HIT usability evaluations in Africa that are comparable to a similar review in the United States (Yen & Bakken, 2011). As previously mentioned, much of the literature did not include early-stage or preliminary interaction type evaluations. Without rigorous evaluations along the SDLC stages, HIT has a limited potential to influence health outcomes and reduce health disparities (Kaufman et al., 2006).

Furthermore, few studies evaluated or incorporated preexisting HIT into their work. This gap may be associated with the lack of early-stage evaluations, which would have identified preexisting tools that could answer researchers' questions or health task needs. The use of preexisting tools can create robust and flexible technology that has proven usability in a wide range of situations. Researchers should perform environmental scans to identify potential solutions that meet the user-task-environment needs. This scan can save researchers time and energy if they can incorporate components of the preexisting HIT or adopt strategies to address common HIT development barriers encountered in prior research. Lim et al. is the only study that leveraged two health applications that had already undergone usability evaluations (Lim et al., 2015). If researchers can incorporate preexisting HIT components that have undergone usability evaluation into their HIT product, they can focus on later-stage usability evaluations exploring the short and long-term influence of the HIT on health outcomes.

2.4.5 Limitations

This review has several limitations. It excluded non-English literature. Since English is not the national or common language in half of the countries in Africa this may have led to an unintentional exclusion of articles without an English version. This single language selection may explain why the review did not include any North African countries, such as Arabic-speaking countries like Egypt and Morocco which have more developed healthcare systems and infrastructure and publish the majority of Africa's scientific research (Duermeijer et al., 2018; Dworkin, 2020). However, of the 54 countries that make up Africa twenty-seven African countries include English as an official language, so the exclusion of non-English publications is not a major limitation to this review (Oluwole, 2021). Furthermore, the review is based on a search of only three databases, PubMed, Embase, and ACM. However, the use of ACM, an informatics-focused database, along with a thorough reference list review supported the decision to not search additional databases.

2.5 Conclusion

Developing and enhancing usable HIT is critical to promoting equitable health service delivery and high-quality care in Africa. The trend of more recent usability evaluations aligns with the increased development and utilization of HIT in LMICs. The use of mixed methods to obtain a comprehensive understanding of HIT usability is critical and provides researchers with rich results that they can leverage to further tailor their technology. This scoping review aimed to determine *when* usability evaluations were occurring and *what* components of usability they were exploring and found gaps in the current literature and minimal advancement of theoretical approaches for HIT usability evaluation. In future studies, researchers need to incorporate theoretical frameworks to provide a stronger rationale for their work and enhance the rigor of usability evaluation research. The current literature shows that most articles focused on later-stage evaluations right before or at the point of HIT implementation. Early-stage evaluations (Stages 1 and 2) and interactions (Types 0 and 1) should receive special attention in future research. To overcome the health inequalities found in Africa it is critical that HIT is rigorously tested, highly usable, and tailored to the cultural, geographic, and disease-specific needs.

Chapter 3: Comparison of Obstetric Emergency Clinical Readiness: A Cross-Sectional Analysis of Hospitals in Amhara, Ethiopia[2]

3.1 Introduction

3.1.1 Obstetric Emergency Readiness

To have a profound impact on maternal outcomes Ministries of Health (MOH) can use specific and effective tools that are capable of accurately measuring a facility's clinical readiness to manage an obstetric emergency. This would provide the MOH with the ability to track the availability of adequate obstetric care. When the functional capacity of a facility is known, along with its weaknesses, interventions can be deployed to improve them. This will in turn increase the caliber of care being delivered and decrease maternal mortality (MM). Obstetric emergency readiness at the facility level is defined as the "proportion of specified clinical items that are present at a facility on the day a facility inventory is conducted" (Cranmer et al., 2018). This readiness can be evaluated as a whole, or researchers can look at readiness to manage individual obstetric emergencies. Both the Signal Functions (SF) tracer items and Clinical Cascades (CC) categorize readiness for the six most common obstetric emergencies into two different types of readiness. The two categories are *medical readiness* and *manual readiness. Medical readiness* included the ability to manage sepsis/infection, manage hemorrhage, and manage hypertensive emergencies. These conditions are defined as medical because they require some form of medication administration to treat the condition. The second category, *manual readiness*, includes the ability to manage retained placentas, incomplete abortions, and prolonged labor.

[2]This manuscript was adapted and expanded following publication in *PLoSOne* (Dougherty, K., Gobezayehu, A. G., Lijalem, Alamineh, L., M.,Biza, H. & Cranmer, J. (2023). Comparison of obstetric emergency clinical readiness: A cross-sectional analysis of hospitals in Amhara, Ethiopia. *PLoSOne*, *18*(8), e0289496. https://doi.org/10.1371/journal.pone.0289496)

These conditions are defined as manual because their treatment requires some form of manual action to treat the emergency.

3.1.2 Signal Functions (SF) for Obstetric Emergency Readiness

The SF tool was created to provide succinct indicators of a facility's readiness to provide Basic Emergency Obstetric Care (BEmOC). It consists of three medical and three manual procedures that cover the care necessary to handle the six most common causes of MM (Cranmer et al., 2018; Hussein & Clapham, 2005). The most common global obstetric emergencies are hemorrhage (27.1%), infections or sepsis (10.7%), pre-eclampsia and eclampsia (14.0%), incomplete abortion or ectopic pregnancy (7.9%), delivery complications and retained placenta (9.6%) (Say et al., 2014). In the World Health Organization's (WHO) Service Readiness Index methodology (SRI) specific items, also known as tracers, are used as proxies to objectively measure SF facility readiness for emergencies. (Whaley, 2020). These tracer items are the core resources most essential for managing the emergency. The medical tracer items include three parenteral drugs (uterotonic, antibiotic, and anticonvulsant), three intravenous items (Intravenous (IV) solution, and a 2-part IV infusion kit (tubing and needle or cannula)), a manual vacuum apparatus (MVA), and two multi-purpose items (gloves and a light source) (Cranmer et al., 2018). The SRI application of the SF uses these tracer items to create an overall emergency readiness indicator for facilities, countries, or regions based on the overall percentage of these items present at a facility on the day of assessment (World Health Organization, 2015). Table 3.1 maps the SF tracer items to the emergency it is used to treat.

Table 3.1: Tracer Items and Their Corresponding Obstetric Emergencies

Tracer Item	Obstetric Emergency[a]
IV Solution	1, 2, 3, 4, 5, 6
2-Part IV Kit (tubing, needle/cannula)	1, 2, 3, 4, 5, 6

Parenteral Antibiotic	1, 4, 5, 6
Light Source	4, 5, 6
Parenteral Uterotonic	2, 4
Manual Vacuum Aspiration Kit	5, 6
Parenteral Anticonvulsant	3
Gloves	2

[a]Obstetric Emergencies: (1) Sepsis-Infection, (2) Hemorrhage, (3) Hypertensive Emergency, (4) Retained Placenta, (5) Incomplete Abortion, (6) Prolonged Labor.

The SF approach to using tracer items has emerged as the dominant approach for measuring BEmOC readiness at facilities around the world. This SF-based method is still the method recommended by WHO (Cranmer et al., 2018). However, in recent years, researchers have called for improvements in the SF tracers or alternative methods for assessing BEmOC globally (Bailey et al., 2006; Bhutta et al., 2014; Brenner et al., 2015; Collender et al., 2012; Cranmer et al., 2018; Gabrysch et al., 2012; Paxton et al., 2006; Spangler, 2012). First, the SF tracer item indicators have not yet been used to predict labor-related outcomes or a facility's practical readiness to identify and treat specific obstetric emergencies since the SRI readiness indicator is a pooled percent readiness for all six emergencies (Bailey et al., 2006; Spangler, 2012). Additionally, some studies have measured facility readiness using the SF tracers and other readiness tools and determined that a facility estimate of emergency readiness based only on SF tracer items consistently overestimates practical readiness (Collender et al., 2012; Cranmer et al., 2018; Whaley, 2020). If the SRI-SF estimates of facility readiness do overestimate a facility's practical readiness, it may make true readiness loss in a facility or region seem smaller than it actually is.

3.1.3 Clinical Cascade (CC) Readiness for Obstetric Emergency Readiness

The CC for obstetric emergencies is an emerging set of readiness indicators designed in response to the apparent overestimates of emergency readiness from the commonly used SRI-SF tracer-based indicators (World Health Organization, 2015). The CC is a “clinically-oriented approach to measuring facility readiness” that measures the “step-wise cascading relationship between emergency resources [loss]” (Whaley, 2020). As with the SF tracer item readiness estimates, the CC uses an obstetric commodity inventory to estimate readiness. All SF tracer items are included in the cascade model. However, the CC adds a few additional durable goods, medications, and supplies that are critical to clinically manage each of the six common basic obstetric emergencies.

A unique feature of the CC is its attempt to measure the potential for providing quality care using commodities related to monitoring the initial treatment’s efficacy and then adjusting-escalating treatment as indicated by the patient’s initial response to therapy. To accomplish this, the CC reports the presence of resources, drugs, and emergency protocols required to adjust therapy if the patient does not successfully respond to initial treatment. For example, for a facility to be classified as ready to monitor and modify care for maternal hemorrhage, the facility would need a sphygmomanometer, stethoscope, uterotonic, urinary catheter, oxygen, and a hemorrhage protocol. While the presence of protocols and resources for escalating treatment does not guarantee the level of clinician skill, and the absence of protocols does not guarantee a lack of clinician ability, measuring these resources for monitoring-modifying therapy provides a commodity-based, readily measurable approach to estimating the quality of obstetric emergency care.

3.1.4 Clinical Logic for Clinical Cascades

The CC categorizes emergency obstetric care (EmOC) readiness into three phases, identification of the emergency, treatment of the emergency, and monitoring and modification of treatment as clinically necessary (Cranmer et al., 2018). Within this measurement, there is also a scale to determine readiness for each of the six most common obstetric emergencies individually. For a facility to be deemed ready to manage an obstetric emergency it must have all the necessary supplies to identify, treat, and monitor care for the specific obstetric emergency. The purpose of this study is to quantify facility readiness for BEmOC in Amhara, Ethiopia as measured by the SF tracer items and CC.

3.2 Methods

3.2.1 Study Design, Setting, and Sample

This is a prospective, cross-sectional, facility-based analysis of basic obstetric emergency clinical readiness in Amhara, Ethiopia. Emergency-specific variables were identified from twenty hospitals as part of the national "Saving Little Lives" program being implemented in the region (SLL) (Ministry of Health-Ethiopia, 2020). SLL is an evidence-based intervention led by the Ethiopian government targeting child survival, specifically the key drivers of mortality for small babies, including respiratory distress, infection, and birth asphyxia (Laerdal, 2023). SLL is a multi-year project with a targeted population of 290 hospitals in four regions in Ethiopia. Emory University is one of the collaborating partners in this project. To obtain our sample of hospitals, the team used the same included twenty hospitals that were already participating in SLL's year one work in Amhara.

3.2.2 Study Assumptions

While the use of protocols within the monitoring and modification phase of the CC assists in ensuring clinician knowledge to manage and monitor care following the treatment of an obstetric emergency, clinician skill was not measured. For this reason, a 100% skill level was assumed for the data analysis of CC readiness since skill level is not formally assessed in the SF readiness estimates or the CC model. Both approaches use commodities to estimate readiness.

3.2.3 Ethics Approval and Consent to Participate

This study was approved on December 13, 2021, by Amhara Public Health Institute and did not require individual consent because it was a system-level quality of care intervention. All methods were carried out in accordance with Amhara Public Health Institute guidelines and regulations. The study was exempt from Institutional Review Board oversight per Emory University's review as a public health activity. The need for informed consent was waived by Emory's Institutional Review Board committee because this work was viewed as a system-level public health activity. There were no deviations from the study protocol after approval from Amhara Public Health Institute and Emory University's Institutional Review Board committee was obtained.

3.2.4 Data Collection

As part of baseline data collection for the SLL study, inventory data from twenty facilities was collected in May of 2021 in the Amhara region of Ethiopia. Facilities were co-selected for year one SLL interventions by the Emory-Ethiopia Partnership and Amhara Regional Health Bureau prior to this nested commodity-based study. The Emory-Ethiopia Partnership described the nature of the study, project objectives, and budget and the Regional Health Bureau assisted in identifying facilities from different hospital levels in the region that met project needs. Data were collected by trained data collectors on mobile tablets using Open Data Kit (ODK) (*KoBo Toolbox*, 2020). The original database was designed using KoBo Toolbox (*KoBo Toolbox*, 2020). The data were exported to STATA version 17 for analysis ("Stata Press," 2021). The twenty year one SLL hospitals represent the continuum of available BEmOC care in the region (primary, general, and referral hospitals) (World Health Organization, 2017). Select aggregate indicators were obtained from facility records (e.g., birth outcomes). Hospital leaders, including medical directors and labor and delivery unit heads, were interviewed to obtain facility-level information (e.g., target population, staffing). Permanent employees of the Emory-Ethiopia Amhara Regional Office in Bahir Dar were trained on data ODK and mobile tablet data collection procedures. All data collectors were health professionals, including clinical nurses and health officers, and gave technical input in the facility inventory data collection tools. Data collectors visualized the physical commodities used to create the SF- and CC indicators.

3.2.5 Data Analysis

Obstetric variables and facility characteristics were described with standard descriptive statistics (e.g., median and interquartile range for continuous variables that were not normally distributed or percentages for categorical variables). Readiness classifications were calculated using if-then logic. If then logic tabulates how many facilities have one specific medication or medical supply. If the facilities do have the item, the logic then takes that number and tabulates how many facilities met the criteria of having the original medication/medical supply plus an additional medication/medical supply. This logic is carried through the whole cascade from identification, to treatment, and monitoring and modification of an obstetric emergency. So, if a facility is missing an item in the identification phase, then they will not be included in the later calculation for readiness to treat or manage and modify care of an obstetric emergency. Five core readiness indicators were calculated.

Pooled Mean Readiness

Aggregate medical readiness (management of sepsis/infection, hemorrhage, hypertensive emergency) and manual readiness (management of retained placenta, incomplete abortion, prolonged labor) were reported as the pooled mean medical readiness and pooled mean manual readiness respectively for both SF tracer item method and CC method. Then the aggregate readiness across all six obstetric emergencies was reported as the overall pooled mean readiness using both tools.

Signal Function and Clinical Cascade Readiness Discrepancy

Readiness classifications for each facility and each of the six most common obstetric emergencies were calculated using both the SF tracer item method and the CC. These readiness percentages determined the discrepancies between the two classifications by subtracting the pooled mean readiness for all facilities per emergency using the CC method from the mean pooled readiness for all facilities per emergency using the SF tracer method (SF estimate [–] CC estimate = SF readiness overestimate).

Readiness Loss by Stage of Care

Readiness loss along the stages of care, from identification, to treatment, and monitoring and modifying care, were calculated using the CC. Drop-offs in readiness between the stages of care were quantified as percentages (% of facilities ready to identify the emergency - % of facilities ready to treat the emergency = stage 2 readiness loss).

Readiness Loss Across the Treatment Cascade

Readiness loss across all three stages as a pooled mean loss was calculated using the CC. The mean drop-off in readiness for each individual emergency was quantified as a percentage ((stage 1 readiness loss + stage 2 readiness loss + stage 3 readiness loss)/3 = readiness loss across the treatment cascade).

Impact of Excluding Protocols from Stage 3 Readiness Classifications

Facility readiness to manage the six most common obstetric emergencies using the CC method was calculated with the inclusion of the variable protocols and the exclusion of protocols in the readiness calculations. The difference in stage 3, management and monitoring care, was calculated between these two measurements to determine the significance of the presence of protocols on readiness scores (stage 3 readiness with protocols excluded – stage 3 readiness with protocols included = the impact of protocols on stage 3 readiness).

3.2.6 Emergency Readiness and Clinical Quality

For this analysis, obstetric emergency readiness using the CC was calculated both with and without the inclusion of clinical protocols, during the monitor-modify phase since many facilities did not have protocols. For the primary analysis, the author retained the protocols since this has been done in previous studies. Estimates of monitor-modify readiness without the protocols are reported as a secondary analysis.

3.3 Results

3.3.1 Facility Characteristics

The twenty hospitals in Amhara involved in year one study activities for SLL were included in the data collection for facility readiness. Data collection occurred between May 17 to the 27, 2021. All facilities reported they were capable of providing BEmOC services by SF standards. All hospitals reported they had the resources to perform blood transfusions and had performed a cesarean section within 6 months from the date of data collection. All hospitals reported having at least one anesthetist on staff, however, only two hospitals reported having an anesthesiologist on staff. Additionally, only seven of the sample hospitals reported having obstetrics and gynecology (OBGYN) personnel on staff, and 18 reported having an emergency surgeon on staff. Table 3.2 provides a description of the facility characteristics.

Table 3.2: Facility Characteristics

Characteristics	n=20	%

Zone		
South Gondar	5	25.0
Bahir Dar	3	15.0
West Gojam	7	35.0
Awi	5	25.0
Facility Type		
Primary Hospital	15	75.0
General Hospital	2	10.0
Referral Hospital	3	15.0
Catchment Population		
100,000-499,999	13	65.0
500,000-999,999	2	10.0
1,000,000-4,999,999	3	15.0
≥ 5,000,000	2	10.0

3.3.2 Overall Emergency Obstetric Resource Availability

The facility surveillance identified several critical supplies for managing obstetric emergencies that were often missing from the facilities. For medication, parenteral forms of diazepam (55.0% of facilities missing), gentamicin (65.0%), and penicillin (95.0%) were commonly missing. Many facilities also did not have protocols for offering quality obstetric emergency care including protocols for hemorrhage (65.0%), retained placenta (85.0%), incomplete abortion (85.0%), and infection-sepsis (100%). Finally, common commodities, such as aseptic gloves were often out of stock, with 65.0% of the surveyed facilities not having any available on the day of the inventory. For a detailed breakdown of the availability of critical obstetric emergency resources see Appendix E.

3.3.3 Pooled Mean Readiness

Signal Function Estimates of Emergency Readiness

The overall pooled mean estimate of readiness, as defined by the presence of SF tracer items for the six common obstetric emergencies was 92.9%. Using the SF model, facilities were least prepared to manage prolonged labor (90.0%), and most prepared to manage hypertensive emergencies (98.8%). Facilities were generally less prepared to manage manual emergencies (92.9% ready) compared to medical emergencies (95.3% ready). See Appendix F for individual emergency readiness using SF.

Clinical Cascade Estimates of Emergency Readiness

The overall pooled mean estimate of readiness using the CC model was 63.3%. Facilities were least prepared to manage retained placentas (30.0%), and most prepared to manage hypertensive emergencies (85.0%). Unlike the SF estimates, there were larger discrepancies between medical readiness (70.0%) than manual readiness (56.7%). See Appendix F for individual emergency readiness.

3.3.4 Signal Function and Clinical Cascade Readiness Discrepancy: Quantifying the Relationship Between Signal Functions and Clinical Cascade Readiness Estimates

The SF tracer items model overestimated obstetric emergency readiness by 29.6% compared to the CC model. The discrepancy was smaller for medical readiness, with an overestimate of 25.3%. However, the SF overestimate of readiness for manual procedures was larger at 29.6%. For individual emergencies, the smallest discrepancy was with managing hypertensive emergencies (13.8%), and the largest was with managing retained placentas (60.7%). Figure 3.1 shows the pooled mean facility readiness estimates using both the SF and CC models for the six emergencies.

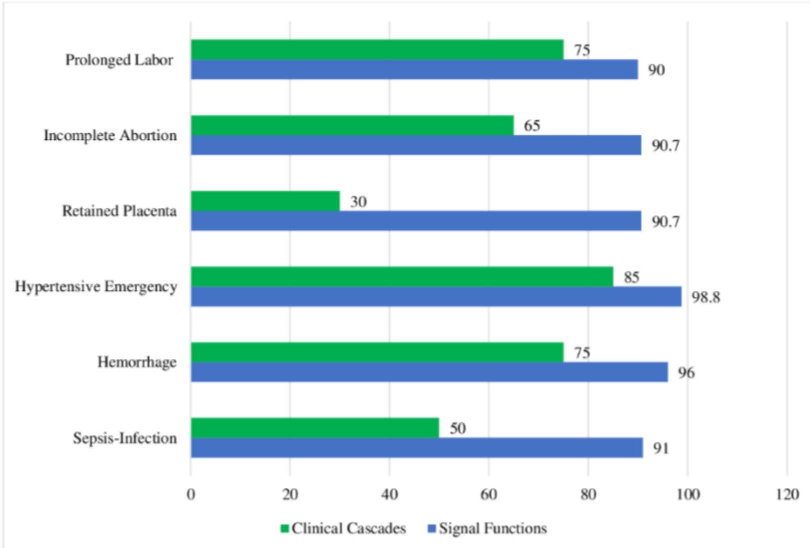


Figure 3.1: Pooled Percentage of Facilities Ready to Manage Obstetric Emergencies Using Signal Function and Clinical Cascade Models

3.3.5 Readiness Loss by Stages of Care

There was a consistent decrease in facility readiness from identification (stage 1) to treatment (stage 2) and monitoring-modifying therapy (stage 3) in all six obstetric emergencies. There was a substantive drop-off in readiness to manage and modify care compared to providing the first-line treatment (Treat, Stage 2 [-] Monitor-Modify Stage 3). No facility in this sample was prepared to perform stage three activities (monitor and modify care) for sepsis/infection, hemorrhage, and retained placentas. Only five percent of facilities could manage incomplete abortions, and 10% could manage hypertensive emergencies. Facilities were most prepared to monitor and modify therapy for prolonged labor, however, this was only 25.0% of the facilities. Consequently, the emergency the Amhara facilities were most prepared to respond to still had 75% of the sample facilities unprepared to manage prolonged labor. Across the six emergencies, the largest drop-off in readiness occurred between stage 2 (treatment) and stage 3 (monitoring and modifying care). All the facilities were prepared to identify hemorrhage (stage 1), but the entirety of this readiness was lost by stage 3. Figure 3.2 shows the step-wise decrease in facility readiness through the treatment stages of obstetric emergencies, and Figure 3.3 depicts the increase in readiness loss across all six of the obstetric emergencies from identification of the condition to treatment, and monitoring and modification of care.

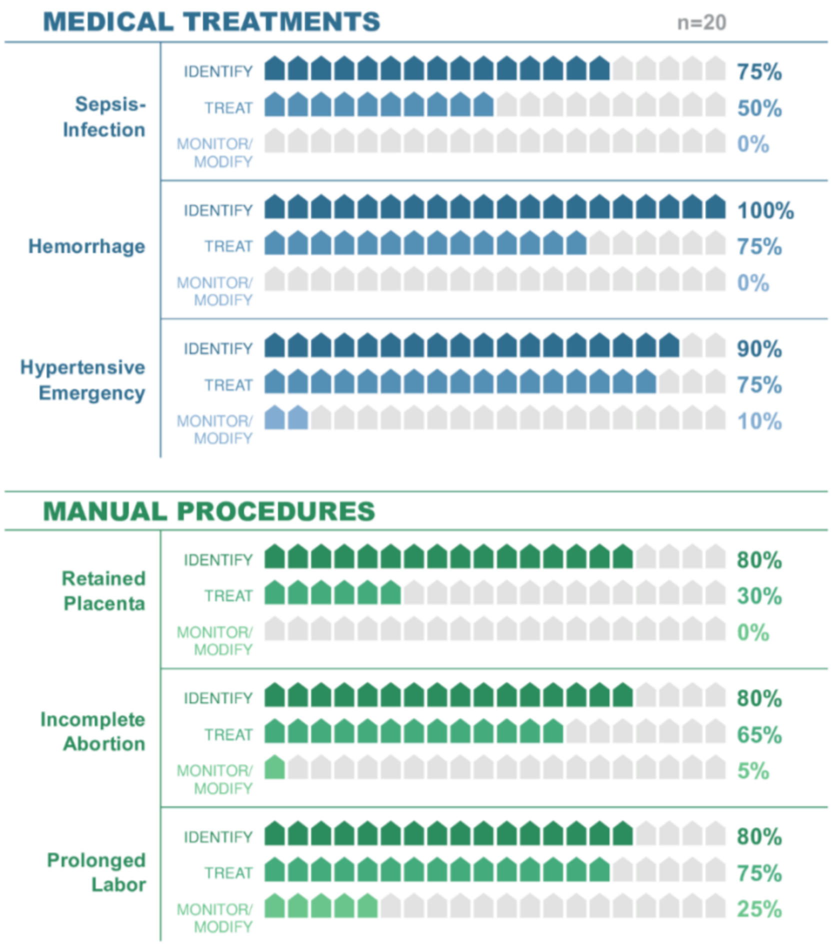


Figure 3.2: Obstetric Emergency Readiness Loss by Stage of Care. Clinical Cascades Readiness by Stage

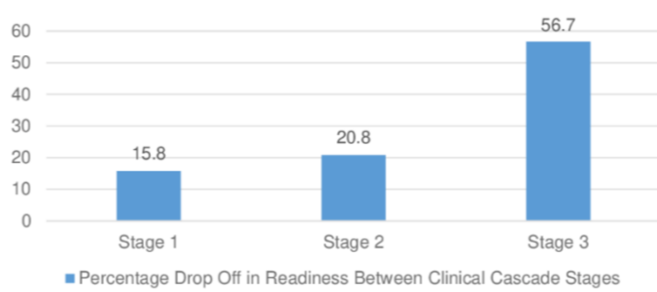


Figure 3.3: Mean Readiness Loss Between Clinical Cascade Stages of Care

3.3.6 Readiness Loss Across the Treatment Cascade

This study revealed a pattern of a 30.7% drop-off in readiness across the six obstetric emergencies and stages of care (SD=28.0). Hypertensive emergencies had the smallest drop in readiness across the cascade stages (M=25.0%, SD=22.9). The other 5 emergencies had mean drops ranging from 31.7%-33.3%. Table 3.3 displays the pooled mean drop-off across the three cascade stages of care and variability in the drop-off for each emergency using the standard deviation.

Table 3.3: Mean Drop Off in Readiness by Cascade Across All Three Stages and Among All Facilities[1,2]

Clinical Cascade	Mean Drop Off Across 3 Cascade Stages	SD
Sepsis-Infection	33.3%	14.4
Hemorrhage	33.3%	38.2
Hypertensive Emergency	30.0%	39.1
Retained Placenta	33.3%	15.3
Incomplete Abortion	31.7%	24.7
Prolonged Labor	25.0%	22.9
Mean of All Emergencies	***30.7%***[3]	***28.0***[4]

[1]n=20 facilities
[2]The total number and percentage of facilities out of 20 that do not have the capacity to fulfill these tasks
[3]Mean readiness drop off across 3 clinical cascade stages and 6 emergency cascades
[4]Standard deviations across 3 stages and 6 emergency cascades

3.3.7 Impact of Excluding Protocols from Stage 3 Readiness Calculations

While the inclusion of protocols in stage 3 CC calculations is critical to gauge the quality of care offered to mothers experiencing obstetric emergencies in our surveyed facilities, the author was interested in exploring the impact these guidelines had on readiness estimates. Consequently, the author conducted a sub-analysis of estimated readiness when the protocols were not used to measure a facility's readiness to monitor-modify therapy. In this sample of Ethiopian facilities, a large percentage of readiness was lost in stage 3 when readiness was based on the presence of protocols. There is a 50.0% discrepancy in stage 3 readiness measured with and without protocols for the sepsis-infection cascade. With protocols, the readiness is 0.0% and without protocols, the readiness is 50.0%. However, for monitoring-modifying therapy for the retained placenta cascade, the discrepancy is much smaller at 5.0% (0.0% with protocol and 5.0% without). Figure 3.4 displays a comparison of facility readiness for each obstetric emergency when including and excluding protocols from CC calculations.

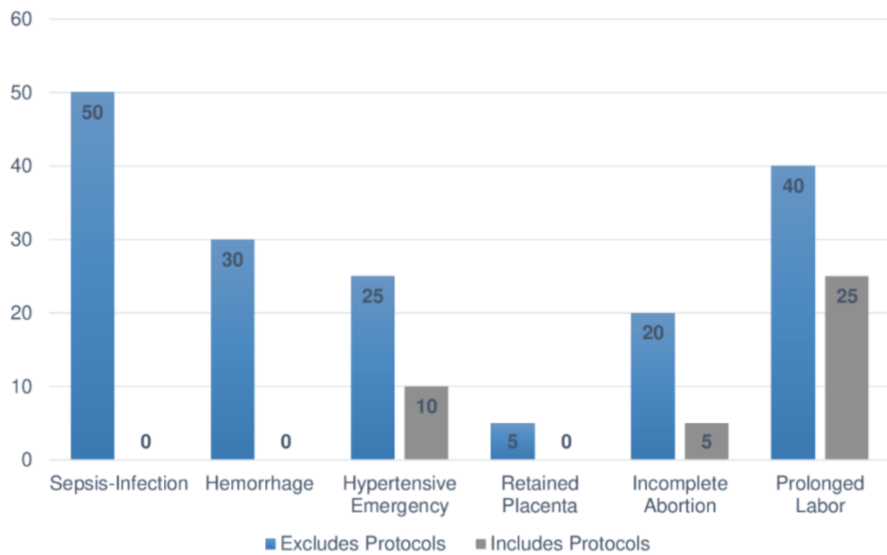


Figure 3.4: Readiness Lost in the Monitor-Modify Therapy Stage. Estimates With & Without Emergency Protocols

3.4 Discussion

3.4.1 Implications for Obstetric Care

The discrepancy between the SF tracer items and CC can lead to the development of an "invisible need" where hospitals that are deemed ready to manage obstetric emergencies by the SF tracer items are in reality not ready to handle these cases. However, these facilities will not receive the necessary attention and resources they need because health planners and supply chain employees do not know that the problem exists. This is because federal and regional health planners lack critical inventory information that they need to make informed decisions on how best to use their resources and focus their attention. This can then lead to the primary global health metrics overestimating actual hospital readiness. Our findings align with previous research conducted in Kenya and Uganda, which found SF tracer items overestimate facility readiness to manage obstetric emergencies.(Cranmer et al., 2018) Researchers and health planners should consider modifying the SF tracer items or updating the indicator to prevent an overestimate of obstetric emergency readiness. Furthermore, future research should include outcome studies that explore the CC's ability to predict maternal morbidity and mortality rates.

3.4.2 Implications for Clinicians

On a local level, the continued use of the SF tracer items leads to the potential for facilities to be at risk of being unprepared to manage common obstetric emergencies. If the necessary supplies and medications are not available when a mother comes to the healthcare facility during an obstetric emergency then healthcare providers will not be able to provide high-quality care, even if they have the skills and clinical knowledge to do so. This lower-quality care can lead to worse health outcomes for the mother and the persistently high MM rates seen around the world, especially in areas such as SSA, including Ethiopia.

3.4.3 Influence of Protocols

As stated previously, the clinical cascades use the presence of protocols as a proxy for measuring the quality of care because it stands to reason that if there is a protocol available, then healthcare providers can use the protocol to guide their treatment even if they are unfamiliar with treating a particular obstetric emergency. As the analysis found, the presence of protocols can have a significant impact on readiness percentages, such as a 50% change in readiness for managing sepsis/infection. While the authors do not recommend removing protocols from readiness classifications, it is important to explore their impact to gain a granular understanding of readiness. Additionally, this information can help to identify an area for readiness improvement that can significantly impact readiness classifications. For example, if the Amhara

Regional Health Bureau were to focus on ensuring all their facilities that manage deliveries have up-to-date clinical protocols for managing obstetric emergencies, then providers would have the necessary resources to guide their care, and readiness scores based on the CC would increase for all six of the most common obstetric emergencies.

3.4.4 Closing the Gap in Key Commodity Availability

Maintaining an accurate and real-time understanding of facility readiness to manage obstetric emergencies is critical to ensuring women receive quality care. This analysis was the first step in a larger study aimed at ensuring facility readiness to manage obstetric emergencies in Amhara, Ethiopia. This analysis helped to determine if accurate measurements are being used to determine readiness. The CC provide a detailed understanding of facility-level obstetric emergency readiness. The use of electronic dashboards and integrated pharmaceutical logistics systems can track this information in real-time or closer to real-time, based on a location's technological capabilities, and close the gap in key commodity availability. The next step in the author's work is exploring where and why breakdowns are occurring in the obstetric emergency supply chain which is causing the loss of readiness seen in this analysis. Additionally, future work will explore the role health information technology (HIT) can play in promoting facility-level readiness to manage obstetric emergencies.

3.4.5 Role of Health Information Technology in Supply Chain Readiness

HIT is the "processing, storage, and exchange of health information in an electronic environment"(U.S. Department of Health & Human Services, 2020). Previous research has shown that HIT can increase the efficiency with which individuals obtain logistical data, monitor the movement of supplies, and create predictions for product consumption and needs (Toledo, 2021). HIT can be used for establishing and monitoring benchmarks, which will help to decrease potential stockouts of critical inventory (Toledo, 2021). Furthermore, data-informed supply chain decisions have fewer ordering errors and shorter wait times for supplies to arrive at their needed facilities (USF Health, 2020).

When considering what type of HIT will be most beneficial for specific supply chain issues researchers, technology developers, and healthcare stakeholders must explore the benefits and uses of various types of technology. For example, researchers must decide if they want their technology to be active or passive decision support as well as integrated or standalone systems. Passive HIT is technology that does not directly engage and interact with its users (Rief et al., 2017). With passive HIT users can still explore the available data and dig deeper into the story presented through their own initiative (Hiltbrand, 2016). Examples of passive HIT components include problem lists, information about patients health history or facility demographics, lab test results, and other critical information needed to make clinical decisions (Rief et al., 2017). However, when using passive HIT users may miss critical dashboards or reports that have been created to assist them because the user is working under their own intuition (Hiltbrand, 2016). On the contrary, active HIT can include all the components associated with passive HIT but also include personalized alerts or messages that can be directly sent to users to alert them of critical information (Rief et al., 2017). Active HIT leverages effectively placed calls to action, like user alerts and messages, to guide users to critical dashboards and HIT components and enhance user engagement (Hiltbrand, 2016). Both passive and active HIT have benefits and challenges. Active HIT can increase user engagement and enhance communication, however, too many alerts can lead to alarm fatigue and cause users to ignore future alerts (Rief et al., 2017; Woo, 2020). Standalone HIT can only be used for its singular designed task, while integrated HIT is technology that is incorporated into a larger system (DesRoches et al., 2010). Both types of technology have strengths and weaknesses. Integrated systems can improve the ease of performing various tasks because everything is in one place, however, standalone HIT may make it easier for users to complete desired tasks because they do not have to move through a complex system to find information (DesRoches et al., 2010).

The findings of this study provide an important foundation for exploring potential HIT solutions. However, to develop the most efficient system for managing and monitoring facilities' obstetric emergency readiness in Amhara, user-centered studies are needed to determine what types of HIT will be useful in this context and how to take advantage of existing HIT infrastructures such as Ethiopia's IPLS, an electronic system that helps facilities in Ethiopia obtain supplies from their central supplier (Mengesha et al., 2020).

3.5 Conclusion

The CC are an emerging method for measuring facility readiness to manage obstetric emergencies. The clinical cascades provide a clinically-oriented, granular approach to exploring facility readiness. By identifying the point along the treatment cascade regional health planners and policymakers can more accurately target interventions to ensure facilities are prepared for the most common obstetric emergencies. The average readiness classifications provided by the CC are also an efficient way to compare readiness in a region over time or compare readiness rates across geographical areas.

Chapter 4: Qualitative Study of the Obstetric Emergency Supply Chain Dynamics and Information Flow

4.1 Introduction

For the past several decades the Ethiopian Ministry of Health (MOH) has worked to decrease maternal mortality (MM) rates (USAID, 2021). By focusing on training healthcare providers and bolstering the system's referral process, Ethiopia was able to decrease its MM rate (Austin et al., 2014). However, these interventions were unable to fully combat the high rates of MM; the Demographic and Health Survey in 2011 estimated that the MM rate was around 676 maternal deaths per 100,000 live births, which is higher than the estimate in 2005, of 673 maternal deaths per 100,000 live births (Central Statistical Agency Addis Ababa Ethiopia & Inner City Fund, 2016). For this reason, the Ethiopian MOH is focusing on improving "the health systems' capacity to offer quality care that meets women's needs (the supply side)" (Austin et al., 2014; Central Statistical Agency Addis Ababa Ethiopia & Inner City Fund, 2016). In striving for this goal, the Regional Health Bureau and Public Health Institute in Amhara have identified the need for a real-time obstetric emergency readiness tool, which will assist in measuring and monitoring facility-level readiness (Cranmer et al., 2020). By ensuring readiness, facilities will have the necessary supplies and medication to adequately care for mothers experiencing obstetric emergencies, which in turn will improve maternal outcomes (Biadgo et al., 2021).

Before creating a real-time emergency readiness system, developers need to articulate the specific needs, barriers, and facilitators for such technology. Without performing the necessary formative work, system developers may unintentionally create health information technology (HIT) that does not encompass all required needs, or the technology may not match the environment in which it is being deployed (Kaufman et al., 2006).

The aim of this study was to explore the obstetric emergency supply chain dynamics and information flow through semi-structured qualitative interviews with key informants from different levels of Ethiopia's healthcare system. The results of this study enhanced understanding of information needs related to obstetric emergency supply chain management, strengths within the current system, and common locations where information and communication breakdowns occur.

4.2 Methods

4.2.1 Theoretical Framework

The Socio-technical Framework guided this study (Sittig & Singh, 2010). The Socio-technical Framework is a dynamic and interconnected model that provides a thorough picture of the process for designing, implementing, and evaluating HIT. This process occurs in a complex environment influenced by multiple unique factors. This framework identifies eight dimensions that play a role in the process of creating, using, and improving HIT: *hardware and software, clinical content, human computer interface, people, workflow and communication, internal organization features, external rules and regulations,* and *measuring and monitoring* (Sittig & Singh, 2010). These dimensions are interconnected and a change in one will be influenced by and have an impact on the other dimensions. Prior to developing, implementing, or modifying HIT, researchers must investigate the impact that their actions will have on the Socio-technical dimensions, which ultimately influence the success and utilization of the HIT of interest. This qualitative study explored the dimensions of the Socio-technical Framework in the context of Ethiopia's obstetric emergency supply chain. Figure 4.1 displays the Socio-technical Framework, and Table 4.1 presents the eight dimensions and their definitions.

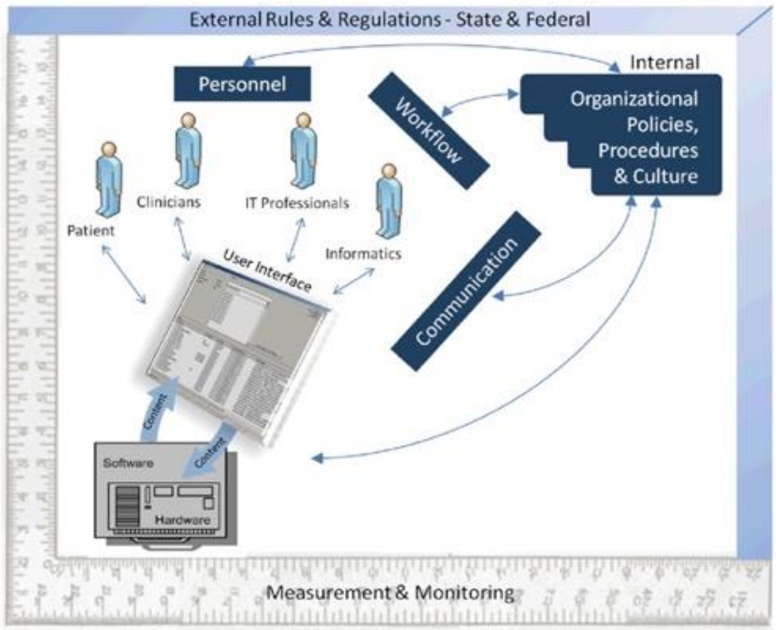


Figure 4.1: Socio-technical Framework

Note. Socio-technical Framework from (Sittig & Singh, 2010)

Table 4.1. Socio-technical Framework Dimensions and Definitions

Model Dimension	Dimension Definition
Hardware & Software	The digital infrastructure and equipment that is used to operationalize the clinical application being explored
Clinical Content	The categorical or numerical data and images that make up the "language" of the clinical application
Human-Computer Interface	All aspects of the digital application that the user can see, touch, hear or manipulate
People	The application users from the developers of the HIT to the end-users
Workflow & Communication	The necessary steps that a user must accomplish to successfully and effectively complete the task at hand
Internal Organizational Features	The policies, procedures and culture within the specific organization using the HIT
External Rules and Regulations	The policies, procedures, and culture within the larger geographical location that the HIT is located
Measuring & Monitoring	The evaluation process and method of measuring the effectiveness of the HIT change including both intended and unintended consequences

4.2.2 Guiding Methodology

Guided by qualitative descriptive methodology, members of the research team conducted semi-structured qualitative interviews to contextualize information and communication breakdowns discovered during the preliminary work (see Chapter 3). Qualitative descriptive methodology is an appropriate choice since the sample was purposively selected and the research question is straightforward requiring answers that Sandelowski describes as "largely unadorned" (Sandelowski, 2000). Qualitative descriptive methodology is often used in health intervention research and is appropriate for health program development, such as the development of an electronic dashboard (Bradshaw et al., 2017; Sullivan-Bolyai et al., 2005). The interviews explored multifactorial causes of emergency commodity stockouts, current health system approaches to restocking commodities (from the federal level to regional and local facilities), and information flow dynamics that contribute to stockouts. Following the qualitative descriptive methodology, data collection and analysis occurred simultaneously (Sandelowski, 2000).

4.2.3 Recruitment and Sample

The study enrolled federal MOH officials (working in supply chain and maternal survival in Addis Ababa), Regional Health Bureau officials with obstetric expertise, regional pharmaceutical supply system employees, and supply managers and pharmacists from individual healthcare facilities. Emory Ethiopia Partnership (EEP) and Amhara Regional Health Bureau staff identified obstetric emergency supply chain stakeholders and reached out to determine if they were interested in participating. A member of the research team followed up with individual participants who indicated interest to provide further details about the study. This study purposively sampled individuals with firsthand experience working within the obstetric emergency supply chain in Amhara, Ethiopia. To be included in this study, participants had to be at least 18 years old and speak English and Amharic. Study participants were Ethiopian citizens and full-time employees in one aspect of Amhara's current obstetric emergency supply chain, including jobs such as managers of individual health posts, regional maternal health policy planners, or federal health employees working in Ethiopia's MOH.

4.2.4 Informed Consent and Human Subject Protection

The research team reached out via phone call, email, and WhatsApp messages to interested participants to explain the study in detail and answer any questions. They then set a time to meet in person to obtain verbal consent using the study information sheet and then perform the research activities.

4.2.5 Data Collection: Semi-Structured Interviews

The interviews explored multifactorial causes of emergency commodity stockouts, current health system approaches to restocking commodities (from the federal level to individual facilities), and information flow dynamics that contribute to stockouts. To direct the interviews, the research team created an interview guide using an iterative process as recommended by Kallio (Kallio et al., 2016) (Appendix I). The guide included open-ended questions to explore the flow of information through the obstetric emergency supply chain and contextualize barriers identified in the preliminary data analysis. See Table 4.2 for example questions and related probes. Interviews were audio-recorded and lasted approximately 60 minutes. They were conducted in English and Amharic since Amharic is the national language and individuals working in Ethiopia's healthcare field received their training and education in English (Addis Ababa University, 2021a, 2021b). During the interviews, data collectors performed member checks by summarizing the main concepts and ideas the participants voiced and asking for confirmation to ensure accuracy (Guba, 1981).

Table 4.2: Sample Interview Guide Questions

What do you see as the major challenges to having the right supplies on hand to deal with obstetric emergencies when they occur? (Communication breakdowns, frequently unable to obtain certain items, computers available and/or consistent Wi-Fi)
Can you describe your process for ordering (or shipping) obstetric emergency supplies? (Barriers and facilitators in the process, how often it occurs, who does this task, was there any training, decision making process)
What are your impressions of the paper-based supply request system? (Likes, dislikes, barriers and facilitators for use, areas of improvement)
Can you describe your experience using the integrated pharmaceutical logistics system? (Likes, dislikes, barriers and facilitators for use, areas of improvement, training if it occurred)
Is there anything else that you'd like me to know about the topics that we've discussed today that I didn't ask about?

4.2.6 Data Management and Preparation

Audio files were stored behind the Columbia firewall. All interviewees were identified by a participant number linked to the level in the supply chain they work in, such as federal, regional, or local. The participant numbers were linked to a list of participants' names that was also stored behind Columbia's firewall and only accessible by the study's Columbia Principal Investigator and the author. A member of the research team checked the transcripts for accuracy against the audio recording in English or Amharic and ensured de-identification prior to sharing with other research team members. ATLAS.ti (ATLAS.ti, 2021) was used to manage all data.

4.2.7 Data Analysis Plan

The research team performed deductive analysis using the a priori constructs taken from the dimensions of the Socio-technical Framework (Sittig & Singh, 2010). The analysis explored the study participants' perceptions regarding the current obstetric emergency supply chain. The eight dimensions of the Socio-technical Framework (Sittig & Singh, 2010) served as predetermined codes. Within each dimension, the coder identified general information about the process of supply chain management as well as facilitators and barriers to securing commodities. In the case of this study, facilitators are factors that assist in the success and efficient utilization of the obstetric emergency supply chain in Amhara, Ethiopia. While barriers are factors that impede successful utilization of the system or prevent it from functioning at the system's highest level. A priori codes were mapped to the concepts extracted from the interview transcripts (Besworth, 2016). Additionally, KD allowed themes to inductively emerge from the data within the deductively refined categories. While utilizing the same a priori code structure of general, barriers, and facilitators KD added additional details and codes to the *human-computer interface* section since that data was crucial for the following research activities of developing, refining, and evaluating an electronic dashboard prototype. Two members of the research team (KD and SB) designed the codebook, read all transcripts, and iteratively refined the codebook (Appendix H). KD independently coded all transcripts and generated themes. Saturation tables were created concurrently with ongoing data analysis to document if and when data saturation, a measure of data adequacy that signals that no further data collection is needed, had occurred. (Guest et al., 2006)

4.2.8 Strategies to Enhance Rigor

Following the recommendations of Ancker et al., the author leveraged several strategies to enhance the rigor of her qualitative work for informatics research (2021).

Rigor in Sampling and Justification of Sample Size

The author used purposive sampling since this recruitment strategy targets individuals who likely have experience and perspectives related to the phenomenon of interest (Ancker et al., 2021). Purposive sampling can also maximize the range of information that is discovered during the interviews (Guba, 1981). This sampling technique allowed the author to obtain the viewpoint of multiple stakeholders from different job levels within Ethiopia's obstetric emergency supply chain. By using purposive sampling, the author was able to select participants who have a wealth of knowledge related to the phenomenon of interest, which is facility-level obstetric emergency readiness in Amhara, Ethiopia (Coyne, 1997). This sampling technique is appropriate for the study because the phenomenon the author was exploring is a specific topic for the particular purpose of informing the design of electronic dashboards to monitor facility readiness for obstetric emergencies in the region. Additionally, the sample size was based on data saturation; as detailed in the data analysis section, the author used a saturation table to measure data adequacy, i.e., a point at which no new substantive content arises in the data collection and determine when to stop recruitment and data collection.

Rigor in Data Collection

All team members who conducted semi-structured interviews used the same interview guide, to ensure that all participants were being asked the same types of questions, and to ensure the research team was obtaining the correct data from all participants. Furthermore, to ensure the trustworthiness of the data collected during these interviews, research team members performed member checking by summarizing the information provided by participants and asking if the summary was a correct understanding of what the participant had said (Guba, 1981). Finally, to enhance the rigor of data collection most interviews (12 out of 17) were conducted in Amharic by a native Amharan medical anthropologist (YA). Having this individual conduct most of the interviews allowed the participants to communicate in whichever language they felt most comfortable with. Furthermore, the inclusion of YA helped to combat any cultural biases that may have been present with American team members conducting research in Ethiopia.

Rigor in Data Analysis

The author used the Socio-technical Framework to identify a priori codes for the deductive analysis of the transcripts (Sittig & Singh, 2010). The author created and used an audit trail during data collection and analysis to improve the dependability of coding (Ancker et al., 2021). An example of an audit trail used in this study is the creation and continued refinement of a codebook. The author also recorded recruitment, data collection, and data analysis procedures to bolster the audit trail (Guba, 1981). These steps helped to improve the credibility of the interpretation of results and reduce researcher bias (Ancker et al., 2021). Using an audit trail process, SB reviewed KD's code assignment using the codebook, made suggestions for refinements in code assignment and themes, and discussed with KD for final code assignment and thematic analysis.

4.3 Results

The research team conducted 17 interviews with individuals involved in Ethiopia's obstetric emergency supply chain from February 17th through March 17th. Five of these individuals came from the federal level, five from the regional level, and seven from individual healthcare facilities in Amhara, Ethiopia. The research team relied on the qualitative research experience of the data collectors, (KD and YA), to guide their decision on when to stop participant recruitment. In most instances, they determined that data saturation was reached because the data were adequate to reach conclusions (Table 4.3) (George et al., 2020). As expected, some themes only arose for participants at a specific level of the system. For example, measuring and monitoring the electronic system emerged at the regional or facility level but not at the federal level due to differences in roles and responsibilities. Consequently, data collection was deemed adequate, and no further data were collected.

The age of participants ranged from 30 to 60 years old, and years of experience working within the supply chain ranged from two to 38 years. Table 4.4 provides a detailed breakdown of the study participant demographics. The findings from the qualitative interviews are divided into the components of the Socio-technical Framework and explore general information about those topics as well as barriers and facilitators to maintaining facility readiness to manage obstetric emergencies. Table 4.5 summarizes the key barriers and facilitators identified and provides quotes from study participants supporting these findings.

Table 4.3: Saturation Table: Codes Observed During Each Data Collection Session

Codes and Categories	F1	F2	F3	F4	F5	R1	R2	R3	R4 & R5	H1	H2	H3	H4	H5	H6	H7
Hardware & Software	X	X	X	X		X	X	X	X	X	X	X	X	X		
Hardware & Software Barriers	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
Hardware & Software Facilitators	X	X	X	X		X	X	X	X	X	X	X		X	X	X
Clinical Content	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
Clinical Content Barriers	X		X	X		X	X	X	X	X	X	X		X		X
Clinical Content Facilitators	X	X								X		X	X		X	
Human-Computer Interface	X			X	X	X		X	X	X		X		X	X	X
Human-Computer Interface Barriers	X			X				X	X	X		X				X
Human-Computer Interface Facilitators	X	X	X				X	X	X	X		X			X	
People	X	X		X	X		X	X	X	X	X		X	X	X	
People Barriers	X		X		X	X	X	X	X	X	X		X		X	X
People Facilitators	X	X	X	X		X	X	X	X		X	X	X	X	X	X
Workflow & Communication	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Workflow & Communication Barriers	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Workflow & Communication Facilitators		X	X	X	X	X		X	X	X	X	X	X	X	X	X
Internal Organizational Features	X			X		X	X			X	X	X			X	
Internal Organization Features Barriers			X	X	X	X		X	X	X	X	X	X	X		X
Internal Organizational Features Facilitators	X				X				X		X			X		X
External Rules & Regulations	X	X		X		X		X				X				
External Rules & Regulations Barriers	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
External Rules & regulations Facilitators		X				X					X					
Measuring & Monitoring						X			X	X	X					

Measuring & Monitoring Barriers									X	X						
Measuring & Monitoring Facilitators																
Data Sources	X	X	X	X		X	X	X	X	X	X			X	X	

Note. F=federal level respondent, R= regional level respondent, H=healthcare facility level respondent; X= indicates which specific codes were explicated during each data collection sessions; R4 and R5 interviews occurred together during one discussion so the codes that were mentioned during their session are combined

Table 4.4: Study Participant Demographics

Population Characteristic	Number of Participants (%)
Level of the supply chain	
Federal (MOH)	5 (29.4%)
Regional (ARHB)	5 (29.4%)
Local	7 (41.2%)
Gender	
Male	14 (82.3%)
Female	3 (17.7%)
Age	
Less than or equal to 35	3 (17.6%)
Between 36-45	9 (53.0%)
46 and older	5 (29.4%)
Years of experience working the supply chain	
10 years and less	6 (35.3%)
Between 11-15 years	6 (35.3%)
Greater than 15 years	5 (29.4%)

Table 4.5: Barriers and Facilitators Summary Table

Component	Themes	Quotes
Workflow & Communication *The necessary steps that a user must accomplish to successfully and effectively complete the task at hand*	Barriers -Inaccurate forecasting	*"The forecasting error at Ethiopia's health facility is not better than 35%, and you see 40%, very good facilities are forecasting at 50%. What does this mean, they are either over-quantifying or under-quantifying." Federal #1* *"The knowledge gap about capacity and forecasting error is evident." Federal #1* *"There is a [communication] barrier, the hub knows only the stock on hand issued data, so as a logisticians, the issue data is the proxy data [for] consumption, that is not the actual consumption but we use it as a proxy data as consumption and we usually use this data for the national quantification so it might exaggerate or decrease the national quantification and the forecasting that might occur." Federal #3* *"If we request medical equipment, we have to consider consumption, but currently, we request the amount of medical equipment by guessing, not based on consumption data, so this exposes us to medical equipment scarcity." Hospital #2*
	-Outdated forms (both paper and electronic)	*"There is something that needs to be improved. I think it [IPLS] has not changed since the first format design. Therefore, the format must be adjusted, now the information network has grown." Hospital #3*
	-Over reliance on paper-based methods	*"The other challenge is the system problem. Most of our health facilities use a manual method of requesting and ordering medical supplies and equipment." Regional #1* *"If it is paper based, it is like to be blinded. It's going to be difficult to find out the medicine that we are running out of stock, so it must be digital to analyze the data. Paper-based has nothing to show the expert how much demand there is today and what demand there will be tomorrow. Paper-based is not good. I think it should be updated." Hospital #3*

		"Paper-based systems are not appropriate for the 21st century; they are archaic, tedious, difficult to access, and unsuitable for auditing." Hospital #7 *"In the current situation, the system between health facilities and us [regional hub] is still manual, so it's also possible for us to make several mistakes when it comes to requesting medicines due to this manual system." Regional #4* *"The paper-based or hard-copy system of supplying or requesting the information is very helpful, but it is very difficult to share information immediately." Regional #5*
	Facilitators -There is an established process for ordering medical supplies through IPLS	*"The integrated system is very good, and all requests are sent in the same direction and in a coordinated manner." Hospital #2*
Hardware & Software *The digital infrastructure and equipment that is used to operational the clinical application being explored*	Barriers -Lack of and/or outdated laptops, tablets, and phones	*"Most health facilities lack a computer, a printer, or the training required to actively utilize the [current electronic system[s]." Regional #1* *"Updating our computers and laptops would be a good idea since we've been using them for a decade! It's tough to get them to work in this setting." Regional #4*
	-Unstable and inaccessible internet	*"In general, 75% of the facilities have no internet access." Federal #2*
	-Technology is not tailored for use on mobile phones or offline	*"There are many things that need to be updated. Many systems have changed, but they are not keeping up with the change. For example, we have to find information on our mobile phones. But there is not much like that. It should be transparent." Hospital #3* *"I want the IPLS system to be mobile application-based; if it is, then EPSS or other health offices should be checking the…hospital system." Hospital #7*
	Facilitators -Tablets provided to some facilities	*"We distributed tablets to all health posts to track the workflow of health posts as well as any commodity-related issue activities" Federal #2*
	-Most employees have access to mobile phones	*"Almost all health extension workers have a mobile phone and can easily see any piece of information" Federal #2*
	-Some IPLS components can work offline if source of electrical power is available	*"In some areas, the facilities are using solar panels." Federal #2*
Clinical Content *The categorical or numerical data and images that make up the "language" of the clinical application*	Barriers -Lack of accurate, high quality consumption data	*"When we go to [look at] the health facility level, especially the primary centers like health posts and health centers, it is very difficult to visualize what they have or do not have." Federal #2* *"The expert tries to send information by speculation; this is also another problem because you may take more equipment than you need, which will lead to expired equipment and sometimes the institution also faces a shortage of equipment because they send false information. Thus, using guessing information will create overstock and understock problems." Regional #1*

		"Accurate and on time information is highly needed and very vital to get the right supplies on hand to deal with problems, but unfortunately, we don't gather reliable information and we are making mistakes." Regional #1 *"We are using the issue data as a proxy data [for] consumption and we usually use this data for the national quantification so it might exaggerate or decrease the national quantification." Federal #3* *"The IPLS does not take the average monthly consumption component into account, necessitating a review of these issues." Hospital #7*
	Facilitators	
	-High integration of medical supplies into one place	*"Compared to the previous IPLS, the current IPLS manual system is highly integrated. The previous system was very scattered because the pharmacy sent requests by themselves, the laboratory sent requests by themselves, and others did the same thing, and it was very uncoordinated. As of right now, the integrated system is very good, and all requests are sent in the same direction and in a coordinated manner." Hospital #2* *"Most of our facilities are integrated into IPLS, particularly most maternal commodities, which were integrated into IPLS after the 2009 Ethiopian calendar. Therefore, everyone can check what they have, what they do not have, what is nearing its expiration date." Federal #2* *"Following EPSS's establishment, the fragmented administration system completely stopped. For example, when we deliver medicines such as TB, HIV medicines, HIV examination kits, and mother-and-child-related medicines, we do so in an integrated way, not in fragments. When we deliver, we take all the HIV, TB, and medicines through one route because it is an IPLS system, which means we deliver integrated." Regional #4*
Human-Computer Interface *All aspects of the digital application that the user can see, touch, hear or manipulate*	Barriers	
	-Gap in data visibility of supply inventory (especially between hubs and healthcare facilities)	*"We need single, connected, straight [forward] and transparent software, in general, to make the supply chain management system healthy and simple." Regional #3* *"Departments are unable to determine which supplies are in stock and which are not" Hospital #1* *"Although they [current dashboards] are helpful, they also have problems with data visibility." Regional #3* *"There is no dashboard between health facilities and us. This means it is very difficult to access the health facility data because their data is not visible to us." Regional #4* *"One of the main supply chain challenges in our country is end to end data visibility." Federal #4* *"It is crucial to create and make available such a dashboard, especially for policymakers, decision-makes, and even health management and for health facilities at all levels. If it is available, everyone can view it and it encourages prompt action." Federal #5*
	-Perceived low ease of use	*"Most of them [facility-level employees], you know, are not doing good with DAGU2 [facility-level software] due to the complexity of the system and its needs like connectivity." Federal #4*
	Facilitators	

	-Central EPSS and regional hubs, and some individual healthcare facilities can use electronic dashboards to view current inventory levels	*[The current electronic system] "can provide the item's serial number, name, unit of measurement, and expiration date in addition to the quantity available and the average monthly consumption for this month." Federal #1* *"We can browse the library [dashboard] and learn what is available in various hubs thanks to this tool [dashboard], and we can utilize the dashboard by making requests by checking the progress of other stocks. It also enables us to produce other reports, including those on expired and those that are waste. Therefore, it is without a doubt, really beneficial." Regional #2* *"There is a dashboard between the central and branch offices, we can view each other's data. To your surprise, we can also see the data of other branches, like Negele Borona and Arba Minch. The other branches can also see our data." Regional #4* *"This system [central and hub dashboards] is very important because we can show and see the products for all branches. For example, if there is a misdistribution of the products and the central EPSS sends all products to only three branches out of the 17 active branches by mistake, this dashboard shows where all the products go, and immediately the central office informs the three institutions to distribute the products to all 17 branches. Similarly, branches can also request products because they know where their products go thanks to this dashboard." Regional #4*
	-Perceived strong usefulness of the current technology	*"IPLS is a crucial system that helps developing nations like Ethiopia, it helps improve their supply chain management, reduce waste, and increase availability." Regional #3* *"Certainly, it [the dashboard] is quite helpful [for task completion]. For instance, it may be used to transfer information, make decisions, check for medicine availability, and it also issues and gives us alarm by flashing a red light when a drug is about to expire." Hospital #1* *"Without a doubt, it [the current dashboards] is very useful. It saves time, lowers labor costs, helps to determine when items pass their expiration dates, and lowers the rate of waste. In general, it is crucial for controlling." Hospital #5* *The [electronic] IPLS system is capable of calculating and quantification of supplies more accurately and its capacity to minimize errors in the calculations." Hospital #4* *"The [IPLS] system is very important because it makes it easier for us to complete our tasks and helps us to understand our responsibilities. If the data is stored clearly and is not blocked, we can easily access it and obtain the items we need, including those we receive, those we want to issue, the people to whom we issue them, and the data we issue. Knowing what is stocked out and what is to expire is helpful. It decreases waste as well." Hospital #5*
	-Perceived high ease of use of the current technology	*"Other than a few amenities, IPLS is a user-friendly system." Federal #1* *"In the past, we have faced different challenges in using this electronic system, but currently it is very easy." Federal #2*

		"Because the computer quantifies things on its own, if it is computerized, it makes things very simple." Hospital #1
People *The application users from the developers of the technology to the end-users*	Barriers -High attrition rate amongst pharmacists	*"The necessity for ongoing training arises from the fact that when attrition occurs, every health facility employee does not pass on manuals or share their knowledge with the subsequent employee. Attrition is a major issue for health facilities, and the next issue is a capacity deficit." Federal #1*
	-Lack of computer literacy at smaller facility level	*"Many of these institutions' workers lack computer skills so using paper based is advantageous for these situations." Regional #2*
	-Inconsistent training for application end-users	*"People might not properly complete the quantity request form." Regional #3* *"I wish for the manager, or the leader of these activities should not only order activities for other experts to work on but he/she should follow-up how experts are working on all the activities." Hospital #4* *"We weren't given any lessons [training] oh how to use the purchasing system. And even in the store, I couldn't get training on how to store or work with it [supply request process]. Basically, we were all just assigned without any prior knowledge of purchasing or store training." Hospital #6* *"Since the practices we were using two or three years ago have changed now and may change in the future, it is important for health care providers to do so based on both national guidelines and international recommendations." Federal #5*
	-Not all necessary personnel have authorization to use the technology	*"If I want to know what is happening at this institution, I cannot. It means that only authorized people can see it." Hospital #3*
	Facilitators -Pharmacists receive IPLS training before they graduate	*"IPLS training is included in the preservice training before the students (Pharmacy) graduated. They will learn about IPLS because training might not be included at the health profession" Federal #3*
	-Opportunities for continuing education	*"Virtually all experts have training and experience. Experience is a consideration even during the hiring process. In addition, we provide courses to strengthen the skills of our experts with the assistance of partners after they join us." Regional #2* *"Our office [Amhara regional health bureau supply chain office] started improving professional skill of staff members at health facilities through training and follow-up in order to solve such issues." Regional #3* *"If there are not trained experts, we send a request to the concerned body to provide the training for them." Hospital #2*
	-Facility-level expertise	*"Currently, we have recruited several experts to work on supply management" Hospital #4* *"The medical unit, emergency unit, laboratory unit, and pharmacy unit are some of the departments that make up the MTC [consumption and ordering committee]. The committee's job is evaluation; it assesses the departments' requests and prioritizes issues before making final conclusion which happen after thorough discussion among committee members. The cost is taken into account when they make a decision." Hospital #5*
	Barriers	

Internal Organizational Features *The policies, procedures and culture within the specific organization using the technology*	-Inability to charge for services	*"Maternal services are free, but hospitals do not [receive supplies] for free. There is nobody that replaces what has been purchased after it has been used. So, what will happen to the hospital? The purchasing power is weakening. As it gets weaker, it will not provide proper service at the end…There must be a body to be responsible to cover the costs for maternal healthcare services. But not the hospital, if it is a regional hospital than the regional government should cover [the costs], if it is a district hospital that district office should cover." Hospital #3*
	-Supply purchasing restrictions	*"Without the permission of the EPSS, we cannot buy the medical supplies from outside market, even though we have the money to do so." Hospital #2* *"The case of the…hospital, we planned for our hospital with an anticipated cost of more than 90 million birr. However, the government has not yet provided this 90 million birr, so the hospital is currently unable to purchase and we are unable to provide important health services that are expected from this hospital." Hospital #7*
	-The supply chain cannot keep up with the demand of large, busy hospitals	*"We always have problems [preventing stockouts] because our institution is so big and giving services to so many people…We face shortage of medical supplies, equipment, and medicine because we always need and use all these materials every day and we face shortage." Hospital #4* *"Although EPSS is a major supplier of healthcare facilities, it is now unable to meet our demands. That is what I noticed and what the staff as a whole reports." Hospital #5* *"The internal manufacturers are not able to meet the country's demand. Assume that is they have the capacity to cover the country's demand, we can save time, money, and labor. Unfortunately, they cannot afford to satisfy medicine demand." Regional #5*
	Facilitators -Government-level buy-in to support the implementation and utilization of IPLS	*"The Ethiopian government is constantly keen to increase access to healthcare for all inhabitants." Federal #1*
	-Strong transportation system	*"The EPSS transports the medical supplies needed [for] obstetric emergency and those needed to give services to the mothers and children, and family planning themselves." Hospital #2*
	-New reimbursement process	*"The finance system also improved, such as our financing system for example we now use Model 9 for [reimbursement], and where we also use Model 22 to send disbursements." Regional #1*
	-Central EPSS offsets costs when it can	*"In some areas, the government covers the cost of the data or the internet connectivity." Federal #2*
External Rules & Regulations *The policies, procedures and culture within the larger geographical location that technology is located*	Barriers -Supply cost	*"How can we order and what can we do if there is no budget?" Hospital #1* *"Some of the medical equipment we require is not always available on the market because it is very expensive and difficult to obtain." Hospital #2* *"The major challenges [of] the availability it starts from the national level because we usually quantify the national requirement every year but because of the budget shortage we didn't procure all the commodities and all the requirements based on our available budget." Federal #3* *"When we purchase from a private provider, there is another problem: cost variance. The price differences between public and private supplies are*

		very obvious. We can significantly reduce costs if we can quickly and easily get what we need from the government vendors. So, in my opinion, the main problem is that supplies from government-owned providers are not available as needed." Hospital #5 *"The majority of people in the area use their own data, which they pay for themselves." Federal #2*
	-Scarcity of products available on the global market	*"A surgeon's glove is essential, but there is a lack of them in our hospital because they are not readily available for purchase. As a result of the supply shortfall, we are currently not providing the desired level of service." Hospital #5* *"The majority of the time, a delay happens when the necessary supplies are not available on the market." Hospital #5*
	-Contractors that do not fulfill requests in a timely manner	*"The majority of the supplies for our healthcare facilities come from abroad. For instance, after receiving the contractual agreement, some of the contracted agencies might delay in delivering the goods on time, and others might violate the agreement, which could lead to a lack of items for healthcare facilities." Regional #3*
	-Geographically difficult to reach locations and transportation difficulties	*"Sometimes, there is a transportation problem, especially for remote health facilities and hospitals that are too far away to take the supplies on time." Regional #1* *"Transporting goods is a challenging undertaking; the majority of the time, there are delays in shipping these obstetric emergency supplies." Hospital #7*
	-Civil unrest disrupting the supply chain	*"The…zone [in Amhara] has security concerns, which adds another hurdle to the shipping of obstetric emergency supplies." Regional #2*
	Facilitators -Strong transportation infrastructure nationally	*"We do not have a transportation problem." Hospital #2*
Measuring & Monitoring *The evaluation process and method of measuring the effectiveness of the technology change including both intended and unintended consequences*	Barriers -Unclear monitoring process for IPLS	*"Currently we don't know the status of the [IPLS] system and how effective it is through undertaking evaluation." Regional #5*
	-Unintended negative consequences of technology updates	*"Dagu 1 was user friendly, very visualized; it was a very simple way like you can select 100 products at a time and proceed with other information, but that's not the case when you come to Dagu 2." Federal #4* *"The transaction for example, if you have an invoice from EPSS you can click and populate that with Dagu 1 but now that's not the way, and even it is complicated like to go from this step to if you have to check another step, you will lose that information." Federal #4*
	Facilitators -Linking EPSS and facility-level supply request data	*"We had computer engineer people who were working on the designing part so we developed Dagu 2 we based which is interlinked with the EPSS data system, so the health facilities can directly see RRFs." Federal #4*

4.3.1 Hardware and Software: The digital infrastructure and equipment that is used to operationalize the clinical application being explored

In 2014, Ethiopia launched its integrated pharmaceutical logistics system (IPLS). This system allows facilities to place orders for medical supplies either electronically or through paper forms. One stakeholder stated, “The primary goal of using IPLS is to assist institutions in assessing their demand, including what is available, how many [items] are being consumed, and how to plan for future requests.” The system also allows central Ethiopian Pharmaceutical Supply System (EPSS) and regional hubs to see reports on supply availability.

Furthermore, there are two software systems used within the obstetric emergency supply chain to monitor the movement of medical supplies. Vitas is the system used by central EPSS, which is the department that supplies the country with medication and medical supplies. The director of EPSS, along with input officers have access to dashboards within the system that allows them to check supply availability and track commodities at both the federal and hub level. Dagu is the software used at individual healthcare facilities. Dagu can also monitor human resources and service availability, but it does not have dashboards for medical supply logistics and movement. The current software used in Ethiopia has components that function offline while other features are reliant on internet access.

Barriers

While there is hardware and software currently available within the obstetric emergency supply chain, stakeholders identified several barriers to the successful utilization of the technology. Common barriers identified by respondents were a lack of access to computers, tablets, and consistent internet or having computers that are difficult to use because they are so old. One regional participant provided a recommendation related to the hardware and software stating, “Updating our computers and laptops would be a good idea since we’ve been using them for a decade! It’s tough to get them to work in this setting.” Furthermore, connectivity issues can occur when too many individuals are attempting to utilize some of the technology, such as the electronic component of IPLS. Many individual healthcare facility participants described how they use the software on tablets and smartphones instead of computers. However, the IPLS technology is not tailored for use with alternative devices, such as smartphones. These issues have led many facility-level users to elect to continue using paper-based IPLS forms instead of transitioning to the electronic version.

Facilitators

Respondents identified several strengths related to hardware and software in the current obstetric emergency supply chain that facilitate efficient supply movement. First, federal respondents reported that the government tries to supply tablets to health posts and other small healthcare facilities to encourage the uptake of their current software and technology. Additionally, most health extension workers do have access to mobile phones which provide an access point for using the IPLS electronic features if a tablet or computer is not available. The EPSS has also expanded the IPLS to include various electronic components and dashboards that can work at different levels of the supply chain. For example, there are dashboards that connect different hubs, or regional distribution warehouses, within Amhara. This allows one hub to check the inventory status and supply availability of other hubs in their region, which can be especially useful when one hub is stocked out of an item and looking for ways to resupply itself. Furthermore, some of the IPLS electronic components can function offline. In some cases, healthcare facility employees can input data related to their clinical workflow into their electronic systems and have it saved locally, and then upload or publish the data to the whole system once they have access to internet.

4.3.2 Clinical Content: The categorical or numerical data and images that make up the "language" of the clinical application

Respondents at all levels of the supply chain agreed several pieces of information are critical to ensure facility readiness and prevent stockouts. Table 4.6 defines these data points. In many healthcare facilities the calculation of last month's consumption, average monthly consumption, and forecasting future supply needs is done by hand by pharmacists. The forecasted supply needs information helps pharmacists determine next year's supply demand. However, some healthcare facilities utilized components of the electronic IPLS to calculate expiration and current quantity of supplies automatically. These respondents stated that the automatic calculations assisted in the consumption calculations. Overall, participants reported a desire for an automated system at all healthcare facilities that will calculate consumption, waste, and medication expiration in real time.

Table 4.6: Critical Data Points for Facility Readiness

Data Points	Description
Stock on hand	Total number of product available at a healthcare facility or regional hub
Quantity close to expiration	Total number of a specific product that is near its use-by or expiration date
Waste	Total number of products that expired or was damaged before it could be used
Quantity at the start of the month	Total number of a specific type of product that is available at the start of a month this includes expired and damaged product as well
Monthly consumption	Total number of a specific product used to treat patients in the previous month
Average monthly consumption (AMC)	The quantity of a specific product used on average over a specified period.

Upon receiving orders from hubs, healthcare facilities must know and report the number of items they originally ordered, the number of items received, the number of items missing from the order, who sent and received the shipment, and the date the supplies arrived at the healthcare facility. These pieces of information are stored in various data sources, such as bin cards. Table 4.7 describes the available data sources within the obstetric emergency supply chain. Some of these data sources are paper-based and others are electronic.

Table 4.7: Data Sources and Communication Channels

Source	Description	Format	Update Frequency
Bin Card	A form kept in the pharmacy with the supplies and used at individual healthcare facilities to track stock on hand, quantity issued/received, losses and adjustments, average monthly consumption, batch number and expiry date The bin card also reports product name, strength and dosage, unit of issue, and product group	Paper-based	1 month and when products are issued/received or transferred to another facility
Cost Analysis Worksheet	Form sent by healthcare facilities along with RRFs to adjust and prioritize supply requests based on budget availability. The worksheet includes the original request with quantities needed to reach maximum level, unit price, and total price, along with the adjusted request reporting quantities needed to reach maximum level, unit price and total price after prioritizing items to fit the budget.	Electronic or paper-based	1-2 months
Dagu	Digital system used at the facility level that manages both the health program and revolving commodities. The system has dashboards displaying key performance indicators for health services, such as the number of antenatal visits, newborn deliveries, and human resource information.	Electronic	As needed
Delivery/ Distribution Invoice and Stock Transfer Voucher (STV)	Forms created by the central level of EPSS that are shipped with the requested supplies to hubs and healthcare facilities reporting what is included in the shipment.	Paper-based	1 month[1]
Drug list	All medication that should be available at a healthcare facility or regional hub. The list includes drug names, unit of measurement, serial number, expiration date, lot number from its shipment, manufacturer, and price.	Electronic or paper-based	As needed
Integrated Pharmaceutical	National system for ordering and receiving medical supplies. The system contains most maternal	Electronic or paper-based	Every month

Logistic System (IPLS)	commodities, and electronic components of the system can show consumption, forecasting, and requested supply information.		
Internal Request and Reporting Form (IRFF)	Form completed by each department and laboratory to the main pharmacy reporting stock on hand, quantity received and losses/adjustments, calculated consumption, quantity needed to reach maximum stock status and quantity to be supplied.	Paper-based	Every 2 weeks
Report and Request Form (RRF)	Form sent from individual healthcare facilities to regional hubs and from hubs to central EPSS. The forms include the initial balance, stock on hand, delivery report, quantity received, losses and adjustments, ending balance, report of any additional drugs that an institution purchases from another institution, overstock, date of stock out, ordered quantity, products with a shelf-life less than 6 months, and calculated consumption. This form also reports calculated consumption days out of stock, quantity needed to reach maximum stock status and quantity ordered. The RRF is also used when a facility receives an order to check if it is the quantity they ordered.	Electronic or paper-based	1-2 months[2]
Stock Record Card	A form kept in the office of the pharmacy head and used at health centers and hospitals to track stock on hand, quantity issued/received, losses and adjustments, unit price, expiry date and location. The bin card also reports product name, strength and dosage, unit of issue, and product group	Paper-based	1 month and when products are issued/received or transferred to another facility
Telegram channels	Messaging application used at federal and regional level to convey information	Electronic	As needed
Telephone	Healthcare facilities, hubs, and central EPSS will call each other when orders are incorrect/items are missing	N/A	As needed
Vitas	Digital system used by the central office of the Ethiopian Pharmaceutical Supply System (EPSS). It has dashboards that are used at the federal and hub level displaying information on the availability of drugs and medical supplies. Central EPSS and hub employees can check the availability of medical supplies.	Electronic	As needed[3]

[1]Can also be sent with an emergency stockout request
[2]Can also be sent as an emergency when stockouts occur
[3] May be updated monthly if hubs and EPSS receive RRFs as a paper-copy or immediately if the forms are sent electronically

Furthermore, when individual healthcare facilities are determining how much medicine and medical supplies to order, they must also know the disease burden in the population that they serve, and which items are available for ordering. For example, with obstetric emergencies, facilities should know the estimated size of their catchment population, how many mothers give birth at their healthcare facility, how many pregnant women attend the healthcare facility, and the number of mothers who are typically referred to higher facility levels for more intensive treatment.

Barriers

One of the largest barriers to ensuring facility readiness to manage obstetric emergencies is a lack of quality supply consumption data. Stakeholders at the federal, regional, and local levels all stated that healthcare facilities estimate their historic consumption numbers, which they then use to make forecasting predictions and supply orders, and these supply request and order estimations may be an over or underestimation of true need. Furthermore, pharmacists at some healthcare facilities calculate consumption rates themselves which can introduce unintended errors and incorrect consumption data. One pharmacist reported, “There are always issues when we fill out the number of people who receive services and the number of drugs that have been used.”

The identified data quality gap then leads to forecasting errors which are carried through from the facility level to the regional hubs and up to the central EPSS office. Federal and regional stakeholders believed that the information used to make supply decisions at both the hub and central levels is not always reliable. One participant reported, “Accurate and on-time information is highly needed and very vital to get the right supplies on hand to deal with problems, but unfortunately, we don’t gather reliable information and we are making mistakes.” Participants reported that data related to supply inventory was available but there were serious concerns related to the quality of the available data. Furthermore, regional respondents stated hubs only know their stock on hand and issue dates for supplies going to healthcare facilities, and they do not know the exact stock levels at those facilities. This means that the central EPSS and hubs do not have real-time visibility of facility-level stock status and must rely on a facility's self-reported requesting and reporting forms. One regional participant reported, "There are also issues with the quality of data because there is no way for us to make sure the person sent a valid report with real information or not."

Facilitators

There are factors related to the clinical content available in the current supply chain that promote effective utilization of the system. The electronic version of the IPLS has incorporated a considerable number of supplies necessary for different medical conditions into one place, which means pharmacists can find the data necessary to make supply ordering decisions without having to check multiple systems. Having inventory data available in the electronic IPLS was viewed positively by many facility-level respondents. A respondent from one of the healthcare facilities that use electronic IPLS at their facility reported that the automatically tracked and calculated information available in the system makes their job far simpler. Furthermore, participants at the hub level found it useful to not only be able to see their inventory but also the inventory status at other hubs.

4.3.3 Workflow and Communication: The necessary steps that a user must accomplish to successfully and effectively complete the task at hand

In the Amhara region, there are 918 health facilities, 120 hospitals, and 19 supply hubs. To determine how much and what type of medical supplies a facility needs to order they must first determine what their monthly consumption was and then use that information, along with the average monthly consumption, to forecast how much they will need. When requesting supplies facilities can request up to a maximum of 4 months of stock. The head of each department at the healthcare facility plans monthly consumption every two weeks and will submit an internal request and reporting forms (IRRF) to the central store or pharmacy. It is the role of the pharmacist to review and fulfill these biweekly requests. The pharmacist is also in charge of filling out and submitting requesting and reporting forms (RRFs) to their designated hub, or distribution warehouse, in the region. Pharmacists submit these forms every one to two months depending on the size of the population they serve; pharmacists will also submit an emergency RRF if they have less than two weeks' supply of an item or experience a stockout. The RRFs are either submitted in paper form or electronically through the IPLS. The IPLS is described as the request and resupply system's brain, specifically, a healthcare facility-level respondent describes it saying, "It acts as the system's brain and is crucial for having the right medication in the right quantity and of the right quality at the right time. In my opinion, we might live horrible lives if there was no IPLS."

After receiving the RRFs through the IPLS, regional hubs will review the forms and if they have the stock will create a stock transfer voucher and fulfill the request of the facility. Additionally, the hub will consolidate the consumption reports and RRFs for the individual healthcare facilities under their jurisdiction and estimate overall consumption and forecasting for the upcoming months, which they will report in an RRF and send to the central office of the EPSS for fulfillment every one to two months.

Central EPSS reviews the RRFs from their hubs and fulfills the orders based on consumption reports and local and national forecasting numbers. The hubs receive the products from central EPSS and review the orders to see if they received the full or partial order. The hubs compare this information to the requests they have received from their healthcare facilities and send the supplies to them every one to two months. After receiving the order from their designated hub, healthcare facilities then review what they have received and disperse it amongst their various departments. They track the new deliveries and existing inventory with bin cards and stock record cards. Table 4.7 provides a summary of the various data sources, and communication systems present in this supply chain, and Figure 4.2 displays the procurement process.

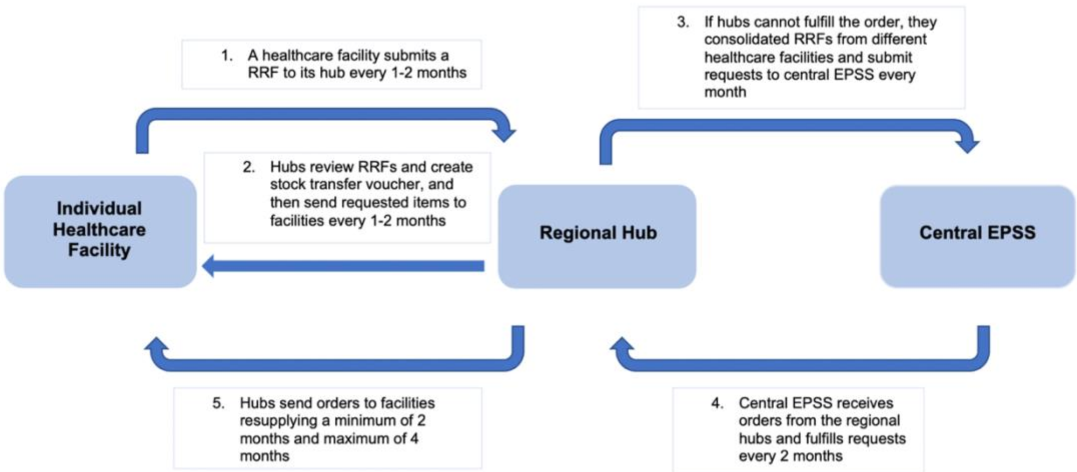


Figure 4.2: Procurement Process

Barriers

A large barrier to efficient emergency supply chain workflow, identified by respondents at all three levels (federal, regional, local), is inaccurate forecasting. Currently, healthcare facilities and regional hubs use issue data, which is the date that medical supplies are shipped from central EPPS or regional hubs to the individual healthcare facilities along with the type and number of supplies sent, as a proxy for monthly consumption. Furthermore, a federal respondent explained since the central EPSS does not have accurate consumption data they will use expert opinion and global prevalence rates, which has led, for example, to an oversupply of magnesium sulfate that is at risk of expiration at the central EPSS level. Inaccurate estimates sent from healthcare facilities to regional hubs cause the hubs to request incorrect supply numbers from central EPSS.

A particular barrier at the health facility level is that IPLS has not been updated or modified since its original implementation. For example, there is no place within the electronic or paper-based RRFs where healthcare facilities can justify their demand for an increase or decrease in requested supplies. Historically, healthcare facilities have seen seasonal increase and decrease for various supplies, but there is no place in the current order forms where pharmacists can justify changing needs to the assigned regional hub.

Regional-level respondents stated that the largest breakdown in communication occurs between the hub and the healthcare facility level for multiple reasons. One is that the current electronic systems do not have good communication channels between hubs and healthcare facilities. Additionally, facilities are sometimes delayed in requesting supplies because they cannot monitor their inventory efficiently with the manual, paper-based RRFs, bin cards, and stock record cards that they often use.

Respondents at all levels identified an overreliance on paper-based RRFs, instead of electronic forms, to be a problem. A participant at the regional level stated, "The other challenge is the system problem. Most of our health facilities use a manual method of requesting and ordering medical supplies and equipment." Additionally, healthcare facility-level interviewees reported that paper-based RRFs and inventory forms make it more difficult for them to forecast their future needs, or they may forget what medication and supplies they have available when they are completing the paper RRFs. Respondents reported that it was difficult to track down all the individuals needed to sign the paper-based RRFs prior to submission increasing the amount of time it takes facilities to prepare and submit their forms. The paper-based RRFs also increase the risk that requests are lost or misplaced which can lead to supply stockouts.

Facilitators

All respondents reported that the high standardization present in the current IPLS has helped perform supply request activities. All facilities, hubs, and central EPSS use the same supply request process. Some facilities may be completely electronic while others rely solely on the paper-based form, but all facilities use the same forms for requests and follow the same process for requesting and receiving supplies. By having one uniform system for requesting supplies federal participants saw a decrease in medication wastage due to expiration.

4.3.4 People: The application users from the developers of the HIT to the end-users

It is the responsibility of individual healthcare facilities to quantify their consumption and then forecast their upcoming needs. It is the role of the pharmacist to complete the monthly orders with collaboration and assistance from multiple teams (i.e., distribution, house inventory management, quantification, marketing) to determine forecasting numbers. Store managers at individual healthcare facilities receive the shipments from their designated hubs and check that they received the proper inventory. It is the role of an individual at the dispensing unit, such as an employee in the maternal child unit, to internally request supplies from the pharmacist. Medical directors and health facility managers work together to try and overcome budget constraints so they can continually order the necessary supplies.

Barriers

Insufficient human resources can introduce barriers to ensuring facility readiness. Federal respondents reported there is a high level of attrition and inadequate onboard training for new hires. While pharmacists receive some training on how to order supplies and utilize the existing software during their education, there is not consistent training and continuing education to ensure they are aware of the current technology or how it can assist their daily tasks.

Furthermore, healthcare facility respondents reported that they did not always have access or authorization to view electronic components of the IPLS.

Respondents at all levels reported a lack of expertise and familiarity with the IPLS request process, specifically, the electronic components, to be a barrier to ensuring facility readiness. Employees, especially at smaller and more rural facilities did not always have the necessary computer skills to use the technology. Additionally, pharmacists have not always known when to order supplies, so they instead wait until an item is completely stocked out to request new supplies, which leads to gaps in supply availability. Beyond this, facility-level respondents reported that managers and team leaders do not always follow up with their pharmacists to ensure they have ordered supplies correctly and in a timely manner.

Facilitators

The Ethiopian government is committed to improving maternal health outcomes and enhancing its health information technology and tries to provide the personnel and resources to ensure the success of IPLS. Additionally, respondents at all three levels identified the training pharmacists receive in school as critical to the success of IPLS and incredibly useful. One participant reported "IPLS training is included in the preservice training before the students graduated. They will learn about IPLS because training might not be included at the health profession." Furthermore, if there are no trained experts at a healthcare facility, that facility can send a request to central EPSS to obtain training for their health facility personnel. There are also opportunities for additional training and continuing education.

Some hospitals and individual healthcare facilities have dedicated personnel to assist in managing supplies. Some facilities have experts in supply management on staff, and others have drug and therapeutic teams that evaluate the quantification and forecasting of needs and compare those needs to their available budget to make prioritization decisions. However, these individuals are not present at all healthcare facilities in Amhara.

4.3.5 Internal Organizational Features: The policies, procedures, and culture within the specific organization using the technology

The federal government mandated that it is the role of EPSS to deliver and control medicine and medical equipment throughout the country. Additionally, it is the role of EPSS to negotiate contracts with suppliers to obtain medical supplies that they cannot get in Ethiopia. It is the job of regional hubs to consolidate the needs of individual healthcare facilities and submit requests to central EPSS. When problems with orders occur EPSS will reach out to hubs and management at individual healthcare facilities to make them aware of the concern.

Barriers

Federal and regional stakeholders reported barriers at higher levels of the supply chain, such as issues at the central EPSS or hub level, while healthcare facility respondents discussed both higher-level barriers and internal organizational barriers within their healthcare facility. One internal barrier related to stocking obstetric emergency supplies is related to how the services are paid for. In Ethiopia maternal services are free to their citizens, however, there is not a clear funding mechanism to pay for the supplies utilized during the free services, which can make restocking supplies difficult. If healthcare facilities do not have the supplies necessary to treat mothers, the mothers may be sent to more expensive outside/private facilities where they cannot afford to get treatment.

Furthermore, there are issues related to hubs and central EPSS restocking high-volume healthcare facilities. Facility-level respondents reported a reason their facilities are frequently stocked out of critical supplies is that they are using the supplies every day and EPSS is unable to keep up with the demand. This issue is compounded by the fact that there are purchasing restrictions placed on healthcare facilities so that facilities are unable to purchase supplies from outside markets unless they have permission or funds from EPSS. One pharmacist describes this issue stating, “The case of [our] hospital, we planned for our hospital with an anticipated cost of more than 90 million birr. However, the government has not yet provided these 90 million birr, so the hospital is currently unable to purchase [supplies], and we are unable to provide important health services that are expected from this hospital.”

Facilitators

IPLS has a large amount of government and facility-level buy-in. Federal-level employees described how the support at the Ethiopian MOH encouraged facilities to transition from paper-based RRFs to the electronic version available through IPLS. Federal and regional respondents described initiatives taken at their level of the supply chain to support the overall effectiveness of IPLS. One example is that central EPSS has improved the reimbursement system which makes refunding healthcare facilities for the supplies they purchase more efficient. Some of the facility-level respondents said the strong transportation system available through EPSS is a reason they can maintain adequate stock levels.

4.3.6 External Rules and Regulation: The policies, procedures, and culture within the larger geographical location that the HIT is located

While strides have been made to improve the obstetric emergency supply chain in Ethiopia, progress is still dependent on many outside influences. These include donations from international organizations such as the World Health Organization, global markets and pricing, civil unrest, and the availability of funds to purchase medical supplies and medication internationally and within Ethiopia.

Barriers

Respondents at all three levels reported the cost of medical supplies and insufficient budgets to be a large barrier. In some cases, they did not have enough funds to purchase the supplies they forecasted they would need and thus had to make decisions on which items were most important and should be purchased before others. This is especially obvious at the national level, a federal respondent describes this challenge stating, "The major challenges [of] the availability it starts from the national level because we usually quantify the national requirement every year but because of the budget shortage we did not procure all the commodities and all the requirements based on our available budget."

Additionally, global inflation and price fluctuations also impact supply availability. One federal-level respondent explained how the ability to ensure supplies are always available is sometimes out of their hands, with contractors failing to deliver on their end of the agreement. Additionally, some medical items are not available on the private market, so if central EPSS is not able to procure the items through their contractual agreements with international providers then it can be extremely difficult to find another way to source them. The concerns related to available funds in the budget are felt at the individual healthcare facility level because, at some smaller health posts and hospitals, employees must pay for data usage themselves to complete work activities online. This is because the government does not always cover the costs of data and internet usage at the facilities.

External political and geographic concerns can also introduce barriers to consistent facility readiness. For example, a regional respondent noted that some healthcare facilities in the Amhara region are in extremely rural areas where the roads are not good, which can make it more difficult for hubs to ensure necessary medical supplies arrive at those facilities in a timely manner. Furthermore, national security problems and civil unrest can disrupt supply chain logistics and the movement of medical supplies, leading to delays in the arrival of products to healthcare facilities.

Facilitators

However, some respondents provided a contrasting opinion related to transportation. They believe the country has a strong transportation system and this allows for the easy shipment of supplies throughout the country.

4.3.7 Measuring and Monitoring: The evaluation process and method of measuring the effectiveness of the HIT change including both intended and unintended consequences

Very little was reported related to measuring and monitoring the current HIT that supports the obstetric emergency supply chain. Participants touched on the unintended consequences of recent software updates, along with the need for monitoring the IPLS system as a whole. However, data saturation was not achieved for this category of codes.

Barriers

The main barrier related to measuring and monitoring the current system is that there is no clear process for doing this. One regional respondent stated they remembered IPLS being reviewed around five years ago but no monitoring of the system as a whole had occurred since. This individual stated, "Currently we don't know the status of the system [IPLS] and how effective it is through undertaking evaluation."

Furthermore, there were unintended consequences when the Dagu 1 software was upgraded to the Dagu 2 version. One federal-level respondent reported that individuals at the healthcare facilities found version two to be more difficult to use. The federal respondent said, "Dagu 1 was user friendly, very visualized; it was a very simple way like you can select 100 products at a time and proceed with other information, but that's not the case when you come to Dagu 2." One of the reasons is that Dagu1 was a desktop system while Dagu 2 is web-based and thus dependent on internet access. Additionally, Dagu 2 uses a different search strategy that is more restrictive than the previous version. An example given was that with Dagu 1 users could search for the drug amoxicillin by searching things such as "ox" or "mrx", whereas the search strategy for Dagu 2 will only give you amoxicillin if a user searches "am." Finally, the workflow between versions one and two is different and healthcare facility employees reported to our federal respondent that they did not like the new workflow. The respondent explained, "The transaction for example, if you have an invoice from EPSS you can click and populate that with Dagu 1 but now that's not the way, and even it is complicated like to go from this step to if you have to check another step, you will lose that information." These barriers are all unintended consequences of the software update.

Facilitators

One of the intended changes that resulted from updating Dagu 1 to Dagu 2 was that the new software became interlinked with EPSS's data system, which allows healthcare facilities to see and submit electronic RRFs.

4.3.8 Human-Computer Interface: All aspects of the digital application that the user can see, touch, hear or manipulate

The findings of this study identified three use cases for individuals who interact with the system. These use cases represent individuals interacting with the system at the federal, regional, and individual healthcare facility levels of the obstetric emergency supply chain. Table 4.8 describes the needs of the three types of users as well as how they interact with the interfaces available to them. Some of the interfaces that are currently available can link data between parts of the supply chain. For example, the electronic RRFs connect central EPSS with the hubs throughout the country as well as connecting hubs to one another. One regional respondent stated, “We can browse the library [dashboard] and learn what is available in various hubs thanks to this tool [dashboard], and we can utilize the dashboard to make requests by checking the progress of other stocks.” Other respondents reported preferences and desires for additional technology. For example, some respondents wanted the electronic IPLS to be accessible via a mobile application or on mobile devices so that they have greater access to the data.

Table 4.8: Currently Available Human-Computer Interfaces

Interface Description	Central EPPSS Office	Regional Hub	Healthcare Facility
Bin Cards: Paper • Reports stock on hand, quantities issued/received, losses and adjustments, average monthly consumption, batch number and expiry date, product names, strengths and dosage, and product groups	• N/A	• N/A	• Reports changes in supply quantities • Views inventory data
Drug List: Electronic • Provides information related to drug names, unit of measurement, stock on hand, serial number, expiration date, lot number from its shipment, manufacturer, and price that should be available • Prints reports on the drug information	• Views information on the drugs that should be available	• Views information on the drugs that should be available at the hub level	• Views information on the drugs that should be available at the healthcare facility[1]
Drug Lists: Paper • Provides information related to drug names, unit of measurement, stock on hand, serial number, expiration date, lot number from its shipment, manufacturer, and price that should be available	• N/A	• N/A	• Views information on the drugs that should be available at the healthcare facility

RRF: Electronic • Reports stock initial balance, stock on hand, delivery reports, quantity received, losses and adjustments, reports of any additional drugs than an institution purchases from another institution, ending balance, overstock, date of stock out, ordered quantity, and products with a self-life less than six months • Supports entry of last month's consumption • Supports entry of calculated consumption days out of stock • Reports quantity needed to reach maximum stock status • Calculates average monthly consumption (AMC) • Prints paper copies of RRFs	• Views supply requests from regional hubs • Views the number of supplies consumed throughout the country • Views forecasted supply needs for the next several months • Tracks how much stock was shipped to each hub • Views AMC	• Views supply requests from individual healthcare facilities • Reports consumption rates • Reports calculated consumption days out of stock, and quantity needed to reach maximum stock status • Reports quantity ordered for the upcoming time period • Tracks how much stock has been shipped to individual facilities • Views AMC	• Views supply availability[1] • Views expiration status of supplies • Reports consumption rates • Reports calculated consumption days out of stock, and quantity needed to reach maximum stock status • Reports quantity ordered for the upcoming time period • Views AMC
RRF: Paper • Reports stock initial balance, stock on hand, delivery reports, quantity received, losses and adjustments, reports of any	N/A	• Views supply requests from individual healthcare facilities • Views AMC	• Views supply availability • Views expiration status of supplies • Reports consumption rates • Reports calculated consumption days out of

additional drugs than an institution purchases from another institution, ending balance, overstock, date of stock out, ordered quantity, and products with a self-life less than six months • Supports entry of last month's consumption • Supports entry of calculated consumption days out of stock • Reports quantity needed to reach maximum stock status • Reports quantity ordered • Reports AMC			stock, and quantity needed to reach maximum stock status • Reports quantity ordered for the upcoming time period • Views AMC
Stock Status Dashboard: Electronic • Calculates expiration status and stock quantity levels • Prints reports related to supply availability and expiration status • Offers a color-coded view of stock availability (ex. overstock, normal, below minimum, emergency order point, and stockout)	• Views inventory data the central level • Views inventory data at the hub level • Views how much supplies have been ordered	• Views inventory data at the user's hub • Views inventory data at other hubs in the region • Views how much supplies have been ordered	• N/A
Stock Record Card: Paper • Reports stock on hand, quantity issued/received, losses and adjustments,	• N/A	• N/A	• Reports changes in supply quantities • Views inventory data

unit price, expiry date, product name, strength and dosage, and product group			

[1] Not available and/or used at all healthcare facilities

Barriers

At the individual facility level, there is wide variability in the technology that users can interact with. In some cases, facilities did not have the hardware to access the electronic IPLS system, so they did not interact with it at all and instead order supplies using the paper-based RRFs.

Several stakeholders identified a gap in the visibility of supply inventory between the various supply chain levels; there are currently no interfaces available that allow hubs to see inventory data at healthcare facilities in close to real time. A regional respondent stated, "There is no dashboards between health facilities and us [regional hub]. This means it is very difficult to access the health facility data because their data is not visible to us." This missing link prevents both federal and regional supply chain employees from being able to monitor inventory data at the facility level. This led one respondent to request the development of a "single, connected, straight-forward and transparent software, in general, to make the supply chain management system healthy and simple."

Additionally, regional respondents frequently criticized the things they disliked related to the electronic system and gave recommendations for areas to change or strengthen the current system. Some interviewees identified issues related to the ease of use of the current technology. One regional respondent reported, "We have a major problem with the way we use this dashboard, as well as the experience we have with it even though the dashboard is very helpful and useful." An example of this difficulty is described by an interviewee who explained that the current electronic system was difficult to use and not very intuitive which caused other individuals working in the supply chain to not want to engage with the system. Finally, technology was not always accessible to individuals at healthcare facilities which negatively impacted their ability to monitor inventory levels. This is seen in a pharmacist's comment, "departments are unable to determine which supplies are in stock and which are not, on their own."

Facilitators

While participants identified several issues with the human-computer interface, they also reported several things they found helpful. Individuals at the federal level, or central EPSS, and those working in the regional hubs appreciate the technology that is currently available to them, and which allows them to check supply inventory and expiration dates. Hub employees stated their dashboards can also show what is available at different hubs which they said helps them to restock their own supplies when they are running low. Federal and regional stakeholders also found their dashboards to be helpful in transferring information, making decisions, checking supply availability, and providing a warning when drugs are close to expiration, which helped them to efficiently complete daily tasks. Additionally, in contrast to other regional and facility-level respondents, some participants had very few complaints related to the ease of use of the current system.

Furthermore, some facilities did have access to the electronic components of IPLS, such as electronic drug lists and RRFs. Individual healthcare facility employees reported the currently available software helps them to manage their own inventory because they can see information such as serial number, item name, the unit of measurement, expiration status, and average monthly consumption. Healthcare facility respondents said the current system is useful in preventing the wastage of drugs due to the expiration monitoring feature, stating, "Certainly, it [the dashboard] is quite helpful [for task completion]. For instance, it may be used to… make decisions, check for medicine availability, and it also issues and gives us alarm by flashing a red light when a drug is about to expire." Specifically, individual healthcare facility employees found the electronic RRFs to be efficient and very useful. One respondent stated, "there are lots of benefits to using computer system [electronic RRFs], it's usually way easier to fill out a form using a computer than to do it by hand. Plus, since it's all done on a computer, the calculations are much more accurate." Overall, when the system is working properly respondents said the individual software available at their level of the supply chain makes their job tasks easier to complete.

4.4 Discussion

The author used the Socio-technical Framework to guide the data analysis identifying barriers and facilitators within the obstetric emergency supply chain. This allowed her to identify several areas for improvement and specific locations where one can intervene within Amhara's obstetric emergency supply. Changing one component within the obstetric emergency supply chain will influence the success of the system, but current barriers may still impede or interact with the system in unique and unintended ways. To ensure the success of the electronic components of IPLS the researchers and individuals working within this field need to address and rectify the barriers and concerns stated throughout this manuscript.

4.4.1 Hardware and Software

The lack of access to computers and tablets led to lower utilization of the electronic components of IPLS. If facilities do not have the equipment to access IPLS then they will continue to rely on the paper-based method, which was often the case at small, rural health posts. However, when the MOH did provide tablets to individual facilities, they were more likely to utilize the electronic components of IPLS. Additionally, even if facilities had the hardware available, if they did not have consistent access to the internet the electronic systems were still of little use because some features of the technology are not able to work offline. Creating dashboards and electronic components of the IPLS that work offline is crucial because internet access is not always consistent in all parts of Amhara. To encourage users to transition from paper-based forms, and ensure facilities can leverage the benefits of the electronic system central EPSS and the MOH need to ensure the hubs and individual healthcare facilities have the physical supplies necessary to access the technology.

4.4.2 Clinical Content

The old, siloed process for ordering medical supplies for each health program or clinical condition was tedious and time consuming. Having all the supplies needed to manage obstetric emergencies in one place, along with supplies for other medical situations, makes the ordering process more streamlined. Furthermore, having all this information available in one place is useful when pharmacists and supply managers are trying to view inventory levels, determine their consumption, and forecast future needs. Pharmacists stated they enjoy having this information available to them electronically. Next steps should include attempts to automate the electronic components of IPLS at all healthcare facilities which will help with the calculation of monthly consumption, waste, and expiration so pharmacists can have this current data available when they are making supply requests. Additionally, knowing what is available at various hubs can assist in making supply distribution decisions. Without rich inventory data available facilities will continue to remain in the dark about their true readiness to manage obstetric emergencies, and central EPSS and regional hubs will not have the necessary information to act.

4.4.3 Workflow and Communication

Using the same process for ordering and obtaining supplies be it electronic, paper, or hybrid was incredibly helpful for healthcare facilities. Using one system to order supplies created a uniform communication flow between individual healthcare facilities, regional hubs, and central EPSS.

However, as the IPLS ages, it needs to continually adapt to the changing needs of the system's users. For example, providing space to justify seasonal differences in supply request quantities would allow facilities to explain the change in demand and would help hubs and central EPSS to both forecast future needs based on season trends, and also help in the cases where they must distribute a smaller number of supplies to multiple facilities.

The greatest concern related to the workflow and communication of the obstetric emergency supply chain was an inability to accurately forecast future supply needs. This is a critical issue because inaccurate forecasting can lead to both under-supplying and stockouts or oversupplying and waste of medication. When individuals know their true consumption, they can trend their historic usage and forecast their future needs. Increasing data visibility is not only a concern at the facility level but also crucial at every stage of the supply chain. Currently, the greatest communication breakdown occurs between regional hubs and individual facilities. Bridging the gap between these two areas will not only assist with forecasting but also provide an additional level of surveillance at the hub level which can monitor inventory levels at facilities and send out supplies if they notice a facility is reaching critically low levels.

4.4.4 People

By training pharmacists during school, the EPSS ensures that they have a basic understanding of IPLS and its electronic components before beginning work at their first job. The opportunity for continuing education and additional training is also useful to ensure personnel are up to date on any changes within IPLS and how to leverage the system to achieve optimal benefits.

However, some barriers still exist related to the individuals who interact with the obstetric emergency supply chain. If personnel do not have the authorization to look at and use the electronic systems, then they will not be able to make informed decisions based on supply availability or may have difficulties communicating with other levels of the obstetric emergency supply chain. An important place to ensure access would be department unit heads, such as the unit head for maternal child health. These individuals will be the ones who monitor the supply availability within their specific department and make internal requests to the pharmacy for restocking needs. It is imperative that these individuals have access to comprehensive supply inventory data so they can make informed decisions on the best way to ensure supply availability within their unit. Furthermore, when program managers, facility directors, commodity managers, and other personnel who interact with the obstetric emergency supply chain receive access to the dashboards then these individuals will be better equipped to monitor their facility readiness and perform more accurate forecasting and supply ordering.

Additionally, employees, especially at smaller and more rural facilities do not always have the necessary computer skills to use the technology. If employees do not have the necessary computer skills, training, or competency they may prefer to use the paper-based request system, even if the technology is available at their healthcare facility. If adequate onboarding and continuing education are unavailable personnel may be unsure how to properly complete the request forms or how often to submit them which can lead to mistakes with orders and stockouts. Additionally, facility-level employees are at times unaware of the different resources available through the current technology, or they do not know how to use it, which leads to an overreliance on the paper-based request system since they are more familiar with the older process. For these reasons, EPSS should work with its regional hubs and individual healthcare facilities to ensure all necessary individuals are receiving consistent training.

4.4.5 Internal Organizational Features

The strong support and buy-in from the government encourage continued utilization of the system. Having support at the highest level of the system encourages all the subsequent levels to incorporate the electronic components of IPLS into their daily tasks. Additionally, the new reimbursement process ensures facilities receive efficient funds for critical items in a timely manner so that the facilities have the money necessary to continue ordering supplies and medication. Another strength of the internal organization is the strong transportation system EPSS has created which assists in delivering medical supplies to individual facilities.

Individuals working within the obstetric emergency supply chain will need to address some concerns related to the internal organization features. One concern is the funding mechanisms for obstetric emergency supplies. Since facilities are unable to charge mothers for the supplies used to treat them during obstetric emergencies and there is not a clearly established mechanism for obtaining funds to pay for these items then facilities find themselves in a difficult situation where they are using the critical supplies to treat women, but they have no way to restock their supplies. If services are to remain free, then central EPSS and the regional hubs need to determine a way to provide the supplies necessary to handle these emergencies at no to low cost for the facilities. Additionally, the purchasing restrictions require a healthcare facility to obtain permission to source supplies from outside EPSS, even if central EPSS or the regional hubs cannot supply all the facility's needs leading to frequent stockouts. Facilities need flexibility to procure supplies from various avenues if it is not possible to obtain them through the traditional supply request process.

4.4.6 External Rules and Regulations

In many cases, healthcare facilities did not have enough funds to purchase the supplies they forecasted they would need and thus had to make decisions on which items were more important and should be purchased before others. When facilities are unable to purchase all the forecasted items, they are already planning to experience a shortage of supplies and potential stockouts. This budget burden causing individuals to determine which items are more important than others is most profound at the central level. When the central EPSS is unable to purchase all the necessary supplies this scarcity trickles down to hubs and individual facilities, because the central EPSS is not able to fulfill all orders. While outside the scope of this study, it is important to note that budgets and appropriate funds are important barriers that need to be addressed. The MOH and other stakeholders invested in the success of the IPLS, and obstetric emergency readiness must work to ensure adequate funds are available to purchase supplies. This is vital because no improvement in technology will be able to overcome a situation where supplies are simply not available for use at any level of the supply chain.

4.4.7 Measuring and Monitoring

It is critical that technology updates and changes be reviewed and monitored not only to measure their success, but also to investigate if there are any positive or negative unintended consequences of the technology updates. This is clearly seen in the Dagu 1 to Dagu 2 updates which improved data transparency within the system but also introduced barriers to efficient use of the system at the facility level. Before implementing changes within the electronic components of IPLS those individuals who are leading these updates should establish a process to monitor and measure the impact of these changes. As the author continues to develop dashboards to assist in monitoring facility readiness, she will continually measure the impact and consequences of those changes through the lens of the Socio-technical Framework.

4.4.8 Human-Computer Interface

The findings from these interviews highlight the need to bridge the data visibility gap present between healthcare facilities and regional hubs. Furthermore, facility-level participants stated that they would appreciate the ability to view inventory data electronically and that having that information available would assist in forecasting decisions and supply requests. The discussions with individuals at all levels of the supply chain underscore the importance of having data views that are tailored to the different job types. Providing dashboards with different views for the various stakeholders in the supply chain is helpful because it can provide a granular view for each stakeholder depending on their information needs. Different types of dashboards that could be useful would include those for individuals who work at healthcare facilities and regional hub employees. The individual facility employees can use the dashboards to assist with performing accurate forecasting and supply requests, as well as monitoring their day-to-day inventory levels. In contrast, the dashboards for region hub employees could assist with the employee's ability to monitor the inventory levels of the facilities under their jurisdiction.

Based on these findings, the author's next steps will be to create electronic dashboards for monitoring facility readiness to manage obstetric emergencies. The qualitative findings will be used to tailor the usage and workflow of the dashboards. The author will use similar frameworks and color schemes when creating the new dashboards, so they are congruent with the currently available technology and maintain the same level of usefulness that participants report during the interviews. One facilitator of the current human-computer interface is that there is already strong buy-in from the users because they believe the technology is both useful and easy to use. While some participants reported complaints related to ease of use, the majority of comments related to system usability were positive. It is imperative that the new dashboards maintain these strengths. Future steps should be taken to curate individualized dashboards that provide the information that is most pertinent for each stakeholder, from healthcare facilities to regional hubs and the central EPSS. Additionally, if individuals continue to use the technology on tablets or mobile devices, then EPSS must ensure the technology is tailored for use on those devices instead of only computers, such as ensuring their technology follows usability heuristics for mobile health technology.

4.4.9 Limitations

One potential limitation is that when transcripts were translated from Amharic to English there may have been unintended translation errors. However, to mitigate this concern a medical anthropologist who lives in Amhara and has over 14 years of experience performing qualitative data collection and translating data from Amharic to English performed the translations. Additionally, while our work surrounds healthcare facilities in the Amhara region of Ethiopia all participants came from Bahir Dar city. This was due to civil unrest within the region that prevented team members from safely visiting other locations for data collection. While this is a limitation, we believe our sample representing different hospital levels and regional positions still provides a rich understanding of the current obstetric emergency supply chain. Finally, our sample was predominately male which may have unintentionally excluded the opinions and experiences of females working within the obstetric emergency supply chain.

4.5 Conclusions

This study captures insight into the information and communication flow within Amhara's obstetric emergency supply chain. Participant responses identified several strengths and barriers related to the success of the current IPLS. A frequently noted strength was the training that is available to pharmacists to support their work with IPLS, and the high degree of integration of medications and supplies that can be purchased through the system. Common barriers include a lack of data transparency at the facility level and between facilities and regional hubs, as well as purchasing difficulties and insufficient budgets. The findings offer several recommendations for how future technology can be designed and tailored to meet the needs of current obstetric emergency supply chain employees. Additionally, the results of the interviews underscore the importance of conducting qualitative research early in the developmental process of HIT to ensure a rich understanding of the current environment and user tasks that the technology will need to accomplish. This information is crucial to inform the future co-design processes of electronic dashboards to monitor facility readiness to manage obstetric emergencies.

Chapter 5: Development of an Electronic Dashboard to Promote Facility Readiness in Amhara, Ethiopia: A Case Study

5.1 Introduction

With the increased utilization and development of technology and cellular services in Africa, health information technology (HIT) has seen an increase in growth and uptake (Bukachi & Pakenham-Walsh, 2007; Lewis et al., 2012). Findings from the qualitative interviews in Chapter 4 identified a need for additional technology to support information needs related to obstetrical emergency supply chain management and ensuring facilities do not face critical commodity stockout. These findings informed the decision to create an electronic dashboard prototype that could assist users in overcoming communication barriers and provide those in the supply chain at the regional and facility level with essential data for making informed supply request decisions. Rabiei and Almasi define dashboards as “data management tools that collect data from various information systems available in the organization and present it in a concise, comprehensive, meaningful, and intelligent manner in the form of key performance indicators with alerts on the status of these indicators” (2022). Dashboards can be used to track critical information, provide alerts, assess performance indicators, develop reports, and customize data views as well as a host of other tasks (Rabiei & Almasi, 2022). For example, dashboards have been successfully used in Ethiopia to monitor the supply inventory of malaria medications to prevent stockouts from occurring (USAID, 2020). Furthermore, related to maternal mortality, dashboards can be used to track the movement of critical medications and supplies needed to treat the most common obstetric emergencies and monitor a facility’s capacity to manage those conditions (Cranmer et al., 2020).

When designed appropriately dashboards can help individuals synthesize large quantities of data and help users identify trends and make informed decisions related to their daily tasks. Within the current literature, there is a set of best practices or principles that health technology should follow to meet basic usability standards (Dowding & Merrill, 2018; Nielsen, 2012). The best practices related to HIT in general focus broadly on the general usability of technology. The HIT best practices that are most relevant for dashboard design include *visibility of system status, match between system and the real world, user control and freedom, consistency and standards, recognition rather than recall, flexibility and efficiency of use,* and *aesthetic and minimalist design* (Dowding & Merrill, 2018; Nielsen, 1994a). However, just following general HIT best practices is not enough when one wants to create information visualizations, such as dashboards. To ensure that dashboards are designed to function in the most efficient and meaningful way for users, designers must also follow unique best practices related to dashboard and visualization design. These best practices address visual representations of information, perceptual and cognitive issues related to that representation, and data interaction mechanisms (Dowding & Merrill, 2018). These best practices include *spatial organization, information coding,* and *orientation and help* (Dowding & Merrill, 2018). Table 5.1 provides descriptions for each of these best practices.

Table 5.1: Health Information Technology Best Practices

Best Practice	Best Practice Type	Definition
Visibility of system status	HIT	The system should always keep users informed about what is going on through appropriate feedback within a reasonable time.
Match between system and the real world	HIT	The system should speak the user's language, with words, phrases, and concepts familiar to the user. The system should follow real-world conventions and ensure the dashboard fits within the existing workflow and technology system.

User control and freedom	HIT	Users should be free to select and sequence tasks and make their own decisions regarding the cost of exiting current work. Users should have clearly marked "emergency exit" to leave the unwanted state.
Consistency and standards	HIT	Users should not have to wonder whether different words, situations, or actions mean the same thing. Systems should maintain interface design choices in similar contexts and differ in different contexts.
Recognition rather than recall	HIT	The user should not have to remember information from one part of the dialogue to another. Objects, actions, and options should be easily visible, and instructions should be visible or easily retrievable whenever appropriate.
Flexibility and efficiency of use	HIT	The system should offer users several options for finding content. Users should be able to customize their interface and achieve their goals in an efficient manner, and the system should have the capacity to adapt to users' needs.
Aesthetic and minimalist design	HIT	The main dashboard should not contain information that is irrelevant or rarely needed. The system should present the largest amount of data with the least amount of ink.
Spatial organization	Information Visualization	The overall layout of a visual representation should make it easy for the user to locate an information element in the display.
Information coding	Information Visualization	The symbols and numbers used in the visualization should aid perception. The numeracy and graph literacy of the visualization should match the intended users' ability.
Orientation and help	Information Visualization	The system should provide support for the user and help to orient them in their visualization.

The purpose of this chapter is to describe the data and information sources and processes that were used to develop the initial prototype of the dashboards for monitoring clinical readiness for managing obstetrical emergencies.

5.2 Methods

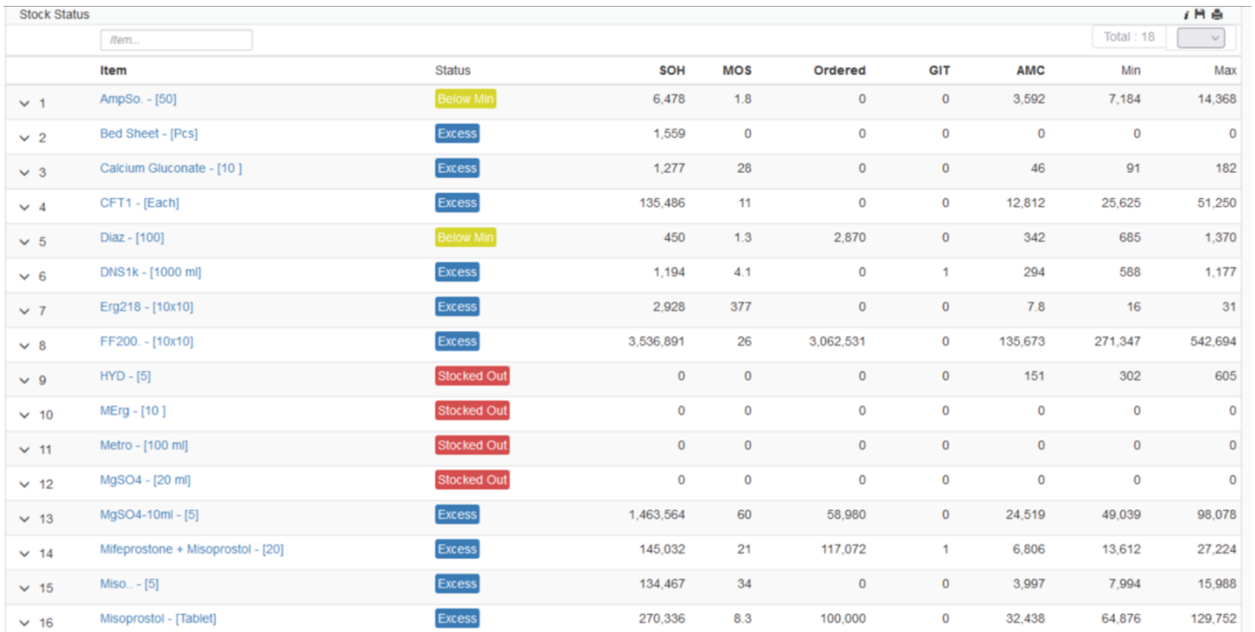
The author combined the findings from Chapter 4 qualitative interviews, along with the currently available dashboards, and literature on HIT and dashboard best practices to create the initial mockup of the dashboards.

5.2.1 Building Off the Qualitative Interviews

Prior to beginning the qualitative interviews, the author created three use cases for the tasks that the dashboards would need to complete (Appendix G). A use case is a written description of how a user will perform tasks using specific HIT, the use case outlines the steps a beginner must accomplish to complete a goal and how the system will behave and respond to those steps (Usability.gov, n.d.). Use cases contain functions, which are specific goals or objectives that the HIT intends or should be able to accomplish (Spacey, 2017). Findings from the semi-structured interviews summarized in Chapter 4 were used to refine and expand the use case functions and tasks for the dashboard prototype. These use-case functions assisted the author in determining which features to include in the dashboard design. Features are the tools within HIT that assist users in accomplishing functions (Spacey, 2017). Beyond the refinement of the use cases, the qualitative interviews also provided user preferences and desires related to specific features that they wanted incorporated into the new dashboards.

5.2.2 Utilizing the Existing Dashboards

During the qualitative interviews, participants described the technology that was currently available within the integrated pharmaceutical logistics system (IPLS) including different types of dashboards. One of the research participants provided the author with screenshots of the dashboards that are currently available in Ethiopia’s medical supply chain. The author used these examples to develop the overall look of the prototype. She did this to ensure that users would be familiar with the new dashboards since the prototype mimicked the feel of the technology currently available. The intention was for future users to be accustomed to the general layout and capabilities of the dashboards. Figure 5.1 shows an example of the comprehensive electronic drug list dashboard that the author used to model some components of the first prototype.



Stock Status

Item... Total : 18

	Item	Status	SOH	MOS	Ordered	GIT	AMC	Min	Max
1	AmpSo. - [50]	Below Min	6,478	1.8	0	0	3,592	7,184	14,368
2	Bed Sheet - [Pcs]	Excess	1,559	0	0	0	0	0	0
3	Calcium Gluconate - [10]	Excess	1,277	28	0	0	46	91	182
4	CFT1 - [Each]	Excess	135,486	11	0	0	12,812	25,625	51,250
5	Diaz - [100]	Below Min	450	1.3	2,870	0	342	685	1,370
6	DNS1k - [1000 ml]	Excess	1,194	4.1	0	1	294	588	1,177
7	Erg218 - [10x10]	Excess	2,928	377	0	0	7.8	16	31
8	FF200. - [10x10]	Excess	3,536,891	26	3,062,531	0	135,673	271,347	542,694
9	HYD - [5]	Stocked Out	0	0	0	0	151	302	605
10	MErg - [10]	Stocked Out	0	0	0	0	0	0	0
11	Metro - [100 ml]	Stocked Out	0	0	0	0	0	0	0
12	MgSO4 - [20 ml]	Stocked Out	0	0	0	0	0	0	0
13	MgSO4-10ml - [5]	Excess	1,463,564	60	58,980	0	24,519	49,039	98,078
14	Mifeprostone + Misoprostol - [20]	Excess	145,032	21	117,072	1	6,806	13,612	27,224
15	Miso.. - [5]	Excess	134,467	34	0	0	3,997	7,994	15,988
16	Misoprostol - [Tablet]	Excess	270,336	8.3	100,000	0	32,438	64,876	129,752

Figure 5.1: Comprehensive Drug List Dashboard

5.2.3 Following Best Practices

The author also followed the literature's best practices for HIT and dashboard development. This included using Nielsen's usability heuristics and Dowding's information visualization heuristics to ensure the appropriate design of the initial prototype (Dowding & Merrill, 2018; Nielsen, 1994a) as described in Table 5.1.

5.3 Results

Results include: (1) refined use cases and functions, (2) dashboard design features; and (3) the initial dashboard prototype.

5.3.1 Refined Use Cases and Functions

The original use cases (Appendix G) were refined as a result of the qualitative interviews in Chapter 4 and used to develop detailed functions for the prototype. Table 5.2 shows the changes from the initial use case tasks to the functions defined following the interviews. During the qualitative interviews, participants described several different types of dashboards that were available for individuals at the federal level to monitor inventory and obstetric emergency readiness. They also noted the location with the greatest breakdown in communication and data transparency is between the regional distribution hubs and individual healthcare facilities. For these reasons, the author decided not to focus on federal-level dashboards and developed dashboards that would bridge the gap between regional hubs and individual healthcare facilities, and promote data exchange between the two levels.

Additionally, participants, explained that they wanted to be able to view inventory data electronically. So, the author created an emergency-specific dashboard view for facilities that included crucial pieces of inventory data. This dashboard view also incorporated data elements that could be found in the preexisting dashboards as well as paper supply request forms, which consolidated all the necessary information needed to make informed supply request decisions into one place instead of having the information spread out amongst different electronic platforms and paper forms. This helps to enhance data visibility and improve users' ability to forecast supply needs.

Table 5.2: Refined Dashboard Use Cases with Functions

Original Use Cases	Refined Use Cases
Federal Level	**Federal Level**
The individual will be able to identify overall regional readiness to manage obstetric emergencies The individual will be able to pinpoint the emergency/area least prepared to manage obstetric emergencies	Not applicable, chose to remove this from the scope of the dashboard prototype following qualitative interviews due to existence of dashboards for supply chain management at the facility level
Regional Level	**Regional Level**
The individual will be able to identify the facilities in Amhara that are not ready to manage obstetric emergencies If not ready, the individual will be able to identify which emergency and supplies/medicine are needed	The individual will be able to identify the facilities in Amhara that are not ready to manage obstetric emergencies • View the obstetric emergency readiness of all healthcare facilities in Amhara • Print screenshot of facilities' overall readiness to manage the six most common obstetric emergencies • Navigate the system in an efficient manner If not ready, the individual will be able to identify which emergency supplies/medicine are needed • View inventory data electronically • Combine inventory data from multiple sources • View which obstetric emergency items are stocked out at an individual healthcare facility • View which obstetric emergency items are at risk of being stocked out at individual healthcare facilities • Print screenshot of the emergency-specific readiness screen for an individual facility • Navigate the system in an efficient manner
Facility Level	**Facility Level**
The individual will be able to identify if their facility is ready to manage obstetric emergencies	The individual will be able to identify if their facility is ready to manage obstetric emergencies

If not ready, the individual will be able to identify which supplies/medicine are needed	• View their own obstetric emergency readiness as well as other facilities' status • Print screenshot of their facility's overall readiness to manage the six most common obstetric emergencies • Navigate the system in an efficient manner If not ready, the individual will be able to identify which supplies/medicine are needed • View inventory data electronically • Combine inventory data from multiple sources • View which obstetric emergency items are stocked out at their healthcare facility • View which obstetric emergency items are at risk of being stocked out at their healthcare facilities • Print screenshot of the emergency-specific readiness screen for their healthcare facility • Navigate the system in an efficient manner

Note. The use cases were refined following interviews at the federal, regional, and facility levels

5.3.2 Design Features

After the use cases were refined, the author used the new functions to determine which features to include in the dashboard prototype. To create the initial prototype of the dashboards the author incorporated findings from Chapter 4 qualitative interviews, information from the existing dashboards, and followed best practices for dashboard development. During this development stage, four categories of features emerged. These included aesthetic features, filtering and sorting features, navigation features, and match with the real-world features. Table 5.3 displays the features that were incorporated into the original prototype as well as the source of information that supported the decision to include each feature.

Table 5.3: Dashboard Features Table

Design Specification	Interviews	Existing Dashboards	Best Practices
Aesthetic			
Use consistent icon design and style throughout the different dashboard views		X	X
Use bold fonts and white space to distinguish sections		X	X
Include titles, headers, and describe content		X	X
Follow a minimalist design			X
Use color coding to emphasize important data points		X	X
Use white space to create symmetry and lead the eye			X
Exclude unnecessary information from dashboard screens			X
Filtering and Sorting			
Provide different data views for different job types	X		
Allow user to tailor the level of detail visible within a dashboard screen	X	X	X
Use vertical drop-down menu style to view sorting options		X	X
Navigation			
Create a logical organization of the data	X	X	X
Provide clear back button			X
Match With the Real World			
Use words, concepts, and phrases that are familiar with supply chain employees	X	X	X
Use the same naming conventions and terminology on all dashboard screens			X

Aesthetic Features

There was limited information from the qualitative interviews to inform the visual appearance and aesthetic features of the dashboard. However, the author used the preexisting dashboards and followed current best practices to create the first version. This included titles and headers throughout the dashboard screens to describe the content and consistent icon design and style throughout the different screens, which follows the best practice of *visibility of system*. The author also incorporated the same color-coding strategy that was present in the existing dashboards in IPLS. For the comprehensive drug list, the IPLS used red, orange, yellow, green, and blue for stock quantities. The use of multiple colors that are easily distinguishable from one another and assist in getting a user's attention aligns with the principles of *consistency and standards* and *recognition rather than recall.* Finally, following the principle of *aesthetic and minimalist design*, the author attempted to exclude unnecessary information from crowding the screen and used bold fonts and white space to establish sections. Overall, these strategies helped to develop a simple dashboard style that used titles, colors, white space, and bolded font in a strategic way to promote comprehension of the data.

Filtering and Sorting Features

Interview respondents were clear that they wanted unique data views in the dashboard for different jobs and tasks. For this reason, when deciding how to sort the data the author created dashboard views that provided a regional overview of facility readiness and another that focused on individual obstetric emergencies. Participants also thought it was important to be able to tailor their data views so they could see the information that was most important to them. This same freedom to decide data views was present in the existing dashboards and supported by best practice of *orientation and help*. Because of this, the author included multiple options for sorting and filtering the data, such as by facility tier or months of stock available. The author then incorporated the vertical drop-down menus that were present within the existing technology.

Navigation Features

All three data sources supported a logical organization of the data within the dashboard views to assist in the ease of navigation. When deciding how to group the data and where to place items within the dashboards, the author developed logical groupings and simple ways to move between screens. Furthermore, following best practice of *user control and freedom*, a back button was added to several of the dashboard screens so that users would easily return to the main screen.

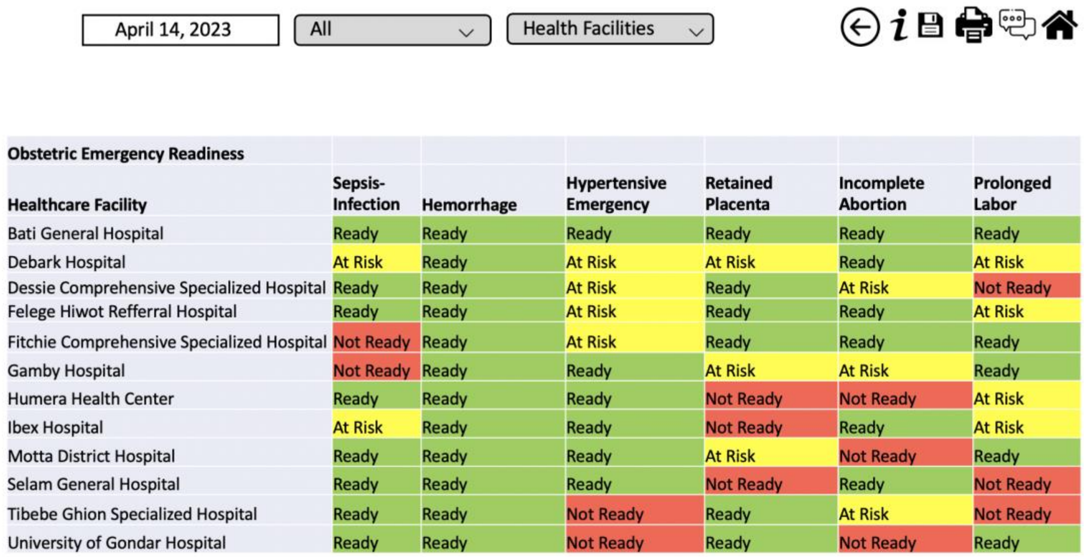
Match with the Real-World Features

To make sure users would be familiar with the content in the dashboards, the author used terminology that was already present in the obstetric emergency supply chain. To do this the author included terminology that was mentioned during the qualitative interviews and present in the existing dashboards. Using the same naming conventions throughout the different screens along with words and phrases that would be familiar to supply chain employees follows the best practices of *consistency and standards* and *match between system and the real world.*

5.3.3 Initial Dashboard Prototype

The initial dashboard components and prototype views are displayed in Figures 5.2-5.4.

Figure 5.2: Bar Chart Options to Represent Months of Stock Available



Obstetric Emergency Readiness						
Healthcare Facility	Sepsis-Infection	Hemorrhage	Hypertensive Emergency	Retained Placenta	Incomplete Abortion	Prolonged Labor
Bati General Hospital	Ready	Ready	Ready	Ready	Ready	Ready
Debark Hospital	At Risk	Ready	At Risk	At Risk	Ready	At Risk
Dessie Comprehensive Specialized Hospital	Ready	Ready	At Risk	Ready	At Risk	Not Ready
Felege Hiwot Refferral Hospital	Ready	Ready	At Risk	Ready	Ready	At Risk
Fitchie Comprehensive Specialized Hospital	Not Ready	Ready	At Risk	Ready	Ready	Ready
Gamby Hospital	Not Ready	Ready	Ready	At Risk	At Risk	Ready
Humera Health Center	Ready	Ready	Ready	Not Ready	Not Ready	At Risk
Ibex Hospital	At Risk	Ready	Ready	Not Ready	Ready	At Risk
Motta District Hospital	Ready	Ready	Ready	At Risk	Not Ready	Ready
Selam General Hospital	Ready	Ready	Ready	Not Ready	Ready	Not Ready
Tibebe Ghion Specialized Hospital	Ready	Ready	Not Ready	Ready	At Risk	Not Ready
University of Gondar Hospital	Ready	Ready	Not Ready	Ready	Not Ready	Ready

Figure 5.3: Regional Obstetric Emergency Readiness Dashboard

Individual Obstetric Emergency (Ex. Sepsis)								
Item	Serial Number	Status	Expiration Date	Monthly Consumption	Stock on Hand (SOH)	Months of Stock (MOS)	Ordered	Received
IV pole	X	Acceptable	XX/XX/XXXX		X	4		
IV tubing	X	Excess	XX/XX/XXXX		X	6		
Sphygmomater	X	Acceptable	XX/XX/XXXX		X	4		
Stethoscope	X	Acceptable	XX/XX/XXXX		X	4		
Thermometer	X	Acceptable	XX/XX/XXXX		X	4		
Lactated Ringers	X	Below Minimum	XX/XX/XXXX		X	1		
Normal Saline	X	Below Minimum	XX/XX/XXXX		X	1		
Ampicillin	X	Below Minimum	XX/XX/XXXX		X	1		
Cefotaxime	X	Stocked Out	XX/XX/XXXX		X	0		
Ceftriaxone	X	Stocked Out	XX/XX/XXXX		X	0		
Gentamicin	X	Below Minimum	XX/XX/XXXX		X	1		
Penicillin	X	Below Minimum	XX/XX/XXXX		X	1		

Figure 5.4: Emergency-Specific Facility-Level Dashboard

5.4 Discussion

The author leveraged and synthesized multiple data and information sources to create preliminary dashboards for monitoring facility readiness to manage obstetric emergencies in Amhara, Ethiopia. The interviews primarily informed features related to usefulness such as filtering and sorting, navigation, and match with the real world. Whereas, the literature and existing dashboards, which can be considered as representing the perspectives of experts, offered guidance for all features including those related to aesthetics. This is consistent with several studies in the HIT usability literature that note that users tend to focus on task performance while experts consider interface design as well (Cho et al., 2018; Yen & Bakken, 2009). The next step is to perform user-centered design sessions with targeted end-users at the regional and facility level. Garnering preferences and recommendations from these individuals will continue the refinement of the dashboard prototype.

Chapter 6: Usability Study Using Participatory User-Centered Design Sessions to Develop an Electronic Dashboard to Promote Facility Readiness

6.1 Introduction

Participatory design sessions are a collaborative design approach that leverages the preferences and expertise of end-users (Interaction Design Foundation, n.d.). The goal of this approach is to create technology, such as dashboards, that meet the needs of the targeted users and are compatible with the current environment that the dashboards will be integrated into (Elizarova, 2017; Patel et al., 2022). Furthermore, user engagement during the design phase can increase the probability of successful implementation and utilization of the technology (Shachak et al., 2011). Dashboards can be an incredibly useful tool for synthesizing large quantities of data and helping users accomplish their daily tasks in an efficient manner (Rabiei & Almasi, 2022; USAID, 2020). However, information needs, graphical representations, and interactivity preferences are highly contextual and influenced by the environment the dashboard is meant to be used in, the individuals interacting with the technology, and the tasks that will need to be accomplished (Helminski et al., 2022).

The purpose of this user-centered participatory design study was to iteratively refine an electronic dashboard prototype for monitoring facility-level readiness to manage obstetric emergencies in Amhara, Ethiopia. This study included individuals with real world experience in the supply chain processes in order to access their emic, or insider, perspective (Høstgaard et al., 2011; Yen & Bakken, 2011).

6.2 Methods

6.2.1 User-Centered Participatory Design Sample Selection

The planned sample for this study was 15 individuals who interact with the obstetric emergency supply chain and included some individuals who participated in Aim 3 (Chapter 4). The sample size was selected because the methods employed are considered discount usability inspection methods that allow for the exploration of the dashboard and the ability to identify the majority of usability issues (Nielsen, 1989). Moreover, the intent of the iterative participatory design process was to reach design saturation, the point at which users do not suggest further substantial changes to the design. The research team purposively sampled individuals who have firsthand experience working within the obstetric emergency supply chain in Amhara, Ethiopia at both the regional and local levels. Inclusion in this study required participants to be at least 18 years old. Study participants were Ethiopian citizens and full-time employees in one aspect of Amhara's current obstetric emergency supply chain including but not limited to hospital supply managers, regional hub employees, and pharmacists.

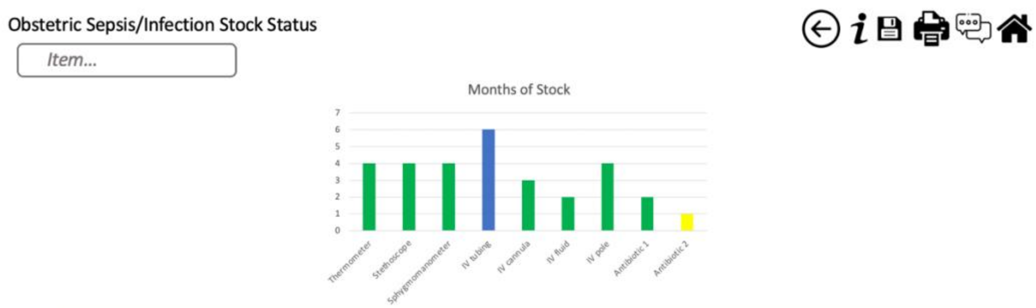
6.2.2 User-Centered Participatory Design Procedures

The Emory Ethiopia Partnership and Amhara Regional Health Bureau identified obstetric emergency supply chain stakeholders and reached out to determine if they were interested in participating in this study. The research team contacted interested individuals via phone call, email, and WhatsApp messaging to explain the study in detail and answer any questions. Team members then set a time to meet in person with the participant to obtain verbal consent and perform the research activities. Design sessions were conducted in English and Amharic, and data collection tools were available in both languages as well, since Amharic is the national language, and individuals working in Ethiopia's healthcare field received their training and education in English (Addis Ababa University, 2021a, 2021b). A team member who is fluent in both Amharic and English translated the study items.

The research team used preliminary dashboards created via PowerPoint to simulate the look and workflow that the dashboards would have when incorporated into the integrated pharmaceutical logistic system (IPLS). Figure 6.1 shows an early-stage version of one of the dashboard screens that was developed through the processes described in Chapter 5.

A research team member who is fluent in Amharic and English conducted the user-centered participatory design sessions. Prior to beginning data collection, the team member conducting the sessions met with the author virtually via Zoom to learn about the user-centered design process and practice performing a session with the author. Additionally, the first design session was conducted in English so the author could listen to the audio recording of the session and confirm that the data collector was conducting the design sessions correctly.

Design sessions lasted approximately 60 minutes and occurred in small groups within the healthcare facility or health bureau offices. During the design sessions participants were given printed copies of the prototype and asked to describe what they believed the graphics and dashboards were trying to convey. The participants explored the visualizations and information that are present in the preliminary prototype on their own and verbalized their thought process as they reviewed the images (Lai et al., 2008; Lucero et al., 2012; Vélez et al., 2014; Yen & Bakken, 2009). All design sessions were audio recorded and a member of the research team, YA, who is fluent in both English and Amharic translated and transcribed the audio files. YA also recorded field notes in English. The design sessions were an iterative process, and the research team incorporated changes recommended in the prior sessions into the designs presented in the following sessions.



Individual Obstetric Emergency (Ex. Sepsis)								
Item	Serial Number	Status	Expiration Date	Monthly Consumption	Stock on Hand (SOH)	Months of Stock (MOS)	Ordered	Received
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IV tubing	X	Excess	XX/XX/XXXX		X	6		
Sphygmomater	X	Acceptable	XX/XX/XXXX		X	4		
Stethoscope	X	Acceptable	XX/XX/XXXX		X	4		
Thermometer	X	Acceptable	XX/XX/XXXX		X	4		
Lactated Ringers	X	Below Minimum	XX/XX/XXXX		X	1		
Normal Saline	X	Below Minimum	XX/XX/XXXX		X	1		
Ampicillin	X	Below Minimum	XX/XX/XXXX		X	1		
Cefotaxime	X	Stocked Out	XX/XX/XXXX		X	0		
Cetriaxone	X	Stocked Out	XX/XX/XXXX		X	0		
Gentamicin	X	Below Minimum	XX/XX/XXXX		X	1		
Penicillin	X	Below Minimum	XX/XX/XXXX		X	1		

Figure 6.1: Preliminary Dashboard Prototype

6.2.3 Data Analysis

Analysis was concurrent with data collection with prototype modifications occurring after the initial two sessions and following the third and fourth sessions. Using the transcripts of audio recorded sessions and YA's field notes, the author extracted key preferences, identified poorly performing graphics and dashboard views, and revised the prototype based on participant feedback. The author maintained detailed notes on design decisions and the rationale for those decisions alongside the notes and transcripts, which functioned as an audit trail.

6.3 Results

Through the user-centered participatory design sessions, the author was able to ascertain targeted end-users' comprehension of the dashboard prototype and identify actions to take to improve the ease of use and usefulness of the dashboards. Design sessions began on May 19th and continued through June 27th, 2023. Unfortunately, recruitment and data collection ended prematurely due to civil unrest in Amhara which prevented the team from safely continuing the design sessions.

6.3.1 Sample Characteristics

Eleven individuals were recruited to participate in four sessions, and the author created two iterations of the prototype. Recruitment was paused at eleven participants due to civil unrest and safety concerns in the region. This sample includes six individuals who work within the regional health bureau or regional hubs for supply distribution and five individuals who work at individual healthcare facilities in Amhara. The age of participants ranged from 35 to 48. Table 6.1 presents the demographic data from the study participants.

Table 6.1: Demographics (N=11)

Population Characteristic	Number of Participants
Level of the supply chain	
Regional (ARHB)	6
Local	5
Age	
Less than or equal to 40	5
41 and older	6
Gender	
Male	10
Female	1

6.3.2 Evolution of Graphics and Dashboards

During the user-centered design sessions, two versions of the dashboard views were developed. These refined versions incorporated feedback from study participants. In the early design sessions participants were able to easily grasp the idea the dashboards were trying to portray related to facility readiness to manage obstetric emergencies. The users felt the dashboards, specifically, the regional view one, helped them to understand which facilities would be ready to handle the emergencies. One regional respondent stated, “This image [dashboard] demonstrates how they [individual healthcare facilities] would be able to handle each health issue considering the level of the supplies that each hospital has for these health problems. In general, we can conclude from this image [regional dashboard] that some hospitals are in good condition for these health issues and others are not in good condition for these health issues.”

Generally, the first two sessions focused on discussing individual graphic component preferences such as which type of charts they preferred to see the data presented and how they would want the data to be filtered and sorted. The third and fourth sessions reinforced a desire to see the data synthesized in visualizations. One facility-level respondent stated, “It would be beneficial if we could get a picture or visualization of the data in a way that would enable us to make wise decisions.” Additionally, the third and fourth sessions focused on confirming the terminology in the dashboards matched the words used in the supply chain and affirming design changes that were incorporated from the earlier sessions. These later sessions also helped to refine which individuals and job types should have access to which dashboards. A participant during the fourth design session stated, “This dashboard [emergency specific view] is essential for the dispensary unit as well. The store and supply officer bears most of the workload or duty in this workplace, but if the pharmacists and hospital managers have access to the data, it would be very good.” The figures in the following sections show how the initial designs lacked detail, labels, and keys, and were more difficult to interpret, while the final designs are more succinct, organized, and easier to follow leading to meaningful interpretation. Table 6.2 summarizes the changes that were incorporated during the design sessions as well as the session number, prototype iteration, and job level that the recommendations came from.

Table 6.2: Changes Incorporated in the Dashboard Prototype

Change	Prototype Version	Session	Respondent Employment Level	Quote
Aesthetic Design				
Changed to vertical, color-coded bar charts	1	1, 2	Regional	*"We need to have a color for overstock, stockout, optimal, and emergency" -Regional* *"I like the colorful one more" -Regional* *"The usual one is the vertical bars" -Regional*
Moved serial number column to be first	1	1	Regional	*"First serial number, then the product name" -Regional*
Added a key for readiness levels	1	1, 2	Regional	*"A key [needs to] be presented here that explains the meanings of 'ready,' 'at risk'" -Regional* *"The written word and color both contribute to the description." -Regional* *"Due to the ambiguity of using such general concepts like 'ready,' 'not ready,' and 'at risk' it can be confusing. These phrases should be operationally defined." -Regional*
Added a key for quantity status	1	1, 2	Regional	*"Key at the top would help." -Regional* *"The need for operational definitions is something else we are stating. It will be straightforward if there is an operational definition given for these terms." -Regional* *"There is no issue if the terms are there, but the levels should be noted" -Regional* *"Terms like excessive, acceptable, below, and others need to be explained clearly." -Regional* *"When we say 'maximum' in our case, for instance, we mean holding onto the stock for a minimum of two months and a maximum of four months. Therefore,*

				it's crucial to operationalize the terms so that you may specific the minimum and maximum levels." -Regional
Added a button to view comprehensive drug list in the facility-view dashboard	1	1, 2	Regional	*"I don't think we need that there; I believe there's no need for a batch number or expiration date to be present here."* -Regional *"You can get it from Vitas, we frequently utilize this tool. Everything that is here is also there."* -Regional
Removed the save button	1	1, 2	Regional	Designer decision following discussion with users about the tasks they would accomplish with the dashboards and data entry was not an included task
Removed request and received columns in the facility-view dashboard	1	1, 2	Regional	*"If we must use these columns then received must come around here (shows on image)."* -Regional *"You can get it from Vitas, we frequently utilize this tool. Everything that is here is also there."* -Regional
Greyed out the readiness classifications at the hub level for the emergencies they do not treat	2	3	Facility	*"There are services that are not provided by health posts. Since some of these services (such as sepsis infection) are not provided by health posts, in addition to the colors we use for readiness risk, we need to have a color that may show services not provided by health posts or we need to have a system that nay hide it."-Facility*
Increased font size for emergency-specific dashboard	2	4	Facility	*"It is difficult to read."* -Facility
Removed medical supplies from bar chart in the facility-view dashboard	2	3	Facility	*"This is a good one [bar charts]. However, it only works for supplies; it cannot be utilized for medical equipment."* -Hospital
Removed expiration date and months of stock data from	2	3	Facility	*Respondent 1:"It appears here a month's worth of stock, the status, expiration date, stock on hand, and prior month's consumption, and average month's consumption are all displayed…it is very good"* *Respondent 2: "This is an excellent one; however, it doesn't apply for medical equipment."* -Hospital

medical supplies in the facility-view dashboard				
Added additional medication strengths to the data table for the obstetric emergency specific	2	3	Facility	*“Ampicillin is correct, but the strength should be written, like is it 500 mg, 300 mg, 250 mg, an injection?”* -Facility
Filtering and Sorting				
Selected the option to sort supplies by categories and alphabetically	1	1, 2	Regional	*“This can be useful for inventory purposes…they can see alphabetically to make counts.”* -Regional *“The alphabetical order makers it simple to sort through the results and find what you’re looking for. It is one of the techniques for identification.”* -Regional *“It is beneficial and helpful to sort by category with level. The alphabetical order thus allows us to easily organize items. Consequently, it is beneficial if we employ both categories.”* -Regional
Provided a filtering option for supply quantities	1	1, 2	Regional	*“It is good if the dashboard also displays products at risk as well as overstock and understock.”* -Regional *“I think sorting option is better. If the products which products are overstocked so we can observe which products are in stock, then which products are at the emergency point.”* -Regional *“We can utilize the filter [drop down menu] here to see which products are overstock in order to avoid protracted discussion.”* -Regional *“We also need to prevent supply shortages; thus, it would be beneficial if we could immediately notice the at-risk item and they need to come first.”* -Regional
Provided a filtering option based on facility tier	1	1, 2	Regional	*“It would be better if we separated the primary, general hospitals from the health centers.”* -Regional *“If we choose a primary hospital, we will then have an additional 10-30 primary hospitals to concentrate on.”* -Regional

				"This one [health facility drop-down] would be useful for finding a summary report, such as a summary report for a health post or a health center." -Regional
Turned the facility tier into a column	1	2	Regional	*"Why don't we add a column for primary, general, and other health facility rankings so that we may conveniently filter and export for later use?"* -Regional
Allowed facilities to be able to view inventory data from other healthcare facilities in the region instead of only seeing the data from their facility	2	4	Facility	*"It is important for us to see other hospitals status like general and referral hospitals like [hospital] and…hospitals because they provide comprehensive care and give services like we do, and we can support one another. If you run out of supplies that are difficult to obtain, like dialysis catheters, you can get them from these facilities, which is crucial."* -Facility *"Keep in mind that the relationship between the health post and the health canter is quite strong because the health post receives supplies from the health centres. It is acceptable to suggest that the health post and health centre should appear in the dashboard as data or information."* -Facility
Match with the Real World				
Updated supply category terminology	1	1, 2	Regional	*"There are four categories at the Ministry of Health, and these are standard labels, and it is good if we use the standard labels that we have. Among the four, the first is 'pharmaceuticals', and medicine may be including IV fluids…the second group includes 'medical supplies'…the third one that we can use to label is 'reagents and chemicals'…then the fourth label, 'medical equipment.'"* -Regional *"If it is medical equipment, we refer to it as medical equipment; if it is pharmaceutical medication, we refer to it as medication; if it is chemical, we refer to it as chemical; if it is supplies, such as syringes, it is supplies."* -Regional *"These categories should exist. It will enable us to quickly pinpoint the issue. However, it is preferable if we stick to standard terminology."* -Regional
Added *emergency order point* category to supply quantities	1	2	Regional	*"Preferable to refer to stock using the phrase maximum, minimum, and emergency order."* -Regional *"Maximum, minimum, and emergency order are used to categorize status in our organization."* -Regional

Updated supply quantity categories	1	2	Regional	*"Yes, I advise you to take note on the terminology and the interfaces in that [drug list] dashboard" -Regional* *"The words we routinely use on a national level, such as 'okay,' 'overstock,' 'below minimum stock' and so forth." -Regional* *"I believe it is preferable if we use similar terms, such as stockout, as opposed to stocked out." -Regional*
Provided a definition for obstetric emergency	1	2	Regional	*"The phrase 'obstetric emergency readiness'…is unclear to me…I believe that it needs to be adequately described." -Regional*
Updated the definition of *below minimum*	2	2, 3	Facility	Designer decision to make sure there is no confusion in the definitions for *below minimum* and *emergency order*
Changed *IV pole* to *IV stand*	2	3	Facility	*"We must use conventional or standard terminology; for instance, you don't use the term 'iv pole'…it should say 'iv stand.'"-Hospital*
Changed quantity status terminology for medical supplies to *functional* or *nonfunctional* and updated the key to reflect this change	2	3	Facility	*"Instead of saying excess or minimal, we might state functional and non-functional for medical equipment while taking inventory." -Hospital* *"The only thing is how can we say medical equipment is excess, at risk, this naming is not a problem for pharmaceuticals, but such naming may not work for equipment. It might be challenging to assess whether medical equipment is excessive or not, but the best way to talk about them is to determine first whether the medical equipment is functional or non-functional." Hospital*
Provided different terminology options for regional readiness	2	3	Facility	"*In our case, we say 'normal' for what you described as the green 'ready'. Next, the others are stockout and below the emergency order point." -Facility*

Aesthetic Preferences

All participants in the first two rounds of user-centered design sessions preferred color-coded options within the dashboards. They reported that the colored bar charts, compared to the black and white version, promote understanding of the data, and the vertical presentation, compared to horizontal bar charts, is more common in the current technology available to these individuals. Participants also wanted at least four different colors to portray months of stock available at a healthcare facility. One regional-level respondent stated, "There could be one color for excess products, one color for maximum stock until minimum stock, one color for minimum stock level, which should have its own color, one color for below minimum stock, which is an emergency, and another color for stockout." This idea remained during the following two sessions and the colored-coded options were preferred, with one hospital respondent stating, "It's fantastic that we can comprehend that the green indicates a good stock status, the yellow indicates a risk, and the red indicates a lack of supply."

Participants in the first two design sessions identified several pieces of information they thought were important to include in the dashboard and pieces of information that were unnecessary. They did not think the columns for *ordered* and *received* were needed because this information could be found in other places within the IPLS. However, they found it important to include both monthly consumption and average monthly consumption in the obstetric emergency-specific dashboard view. Participants debated if lot/batch numbers for the supplies or manufacturer information should be included in the dashboards but ultimately decided against it because they did not think the information would be relevant for dashboards monitoring facility readiness to manage obstetric emergencies. A regional respondent rationalized this saying, "I believe there is no need for a batch number or expiration date to be present here since we have the status column. It should be necessary to include the batch number and expiration date when we distribute a product to customers or move [product] from one level to another…but in this instance, we show the product's status." However, to ensure users could find this additional information easily the author added a button in the second version of the prototype that would allow users to view the comprehensive drug list which is already available within the electronic components of IPLS.

Furthermore, the participants in the early design sessions also felt the order of the columns in the first iteration of the dashboards was not appropriate and recommended several changes so that the pieces of information they found most important appeared before information that was not critical for making inventory decisions. Later design session participants identified additional pieces of information they thought were unnecessary. For example, they did not think the dashboards should include months of stock or expiration dates for medical equipment since those items do not tend to expire.

Another aesthetic preference in the early design sessions was participants requesting to include keys in the dashboards that define the colors used as well as terms, such as *ready, at risk, not ready, normal, below minimum, excess, emergency order point,* and *stockout.* One regional respondent explained their rationale for this saying, "Due to the ambiguity of using such general concepts like *ready, not ready,* and *at risk* it can be confusing. These phrases should be operationally defined." Session three and four respondents agreed that the keys for readiness status, and stock quantities were useful. A hospital respondent said in relation to the keys, "This is good. This makes the information explanatory." Facility-level respondents from the later sessions also found it important to include the medication strengths of the drugs within the emergency-specific supply lists seen in the emergency-specific view. One respondent said, “Ampicillin is correct, but the strength should be written, like is it 500 mg, 300 mg, 250 mg, an injection?” The next version of the emergency-specific dashboard view included medication strengths.

During the third and fourth design sessions, the participants continued to refine the aesthetic look of the dashboards. This included increasing the font size for emergency-specific dashboard data. Participants also explained that not all health posts will manage certain obstetric emergencies, such as sepsis, so they should not receive a readiness classification for a clinical emergency that they will not handle. A hospital respondent explained, “There are services that are not provided by health posts. Since some of these services are not provided by health posts, in addition to the color we use for readiness risk, we need to have a color that may show services not provided…or we need to have a system that may hide it.” In response to these comments, the obstetrics emergencies not managed at a health center received a grey color so users could see that the specific emergency is not included in readiness classifications.

Finally, during design session three, facility-level participants thought that medical supplies should be left in the inventory table for the emergency-specific dashboard view, but their information should be removed from the bar chart. This is because the bar chart displays months of stock available, and it is hard to quantify months of stock for medical supplies because they can be reused multiple times. A hospital pharmacist who participated in the design sessions reported, “This is a good one [bar charts]. However, it only works for supplies; it cannot be utilized for medical equipment.”

Related to aesthetic decisions, design saturation was met with the smaller sample size. Participants in sessions three and four affirmed the design choices of the earlier sessions and provided only small recommendations for the overall look of the dashboards. Figures 6.2 and 6.3 show the aesthetic changes that were incorporated into the prototype during the design sessions.

Figure 6.2: Early to Midpoint Aesthetic Changes

Figure 6.3: Midpoint to Final Session Aesthetic Changes

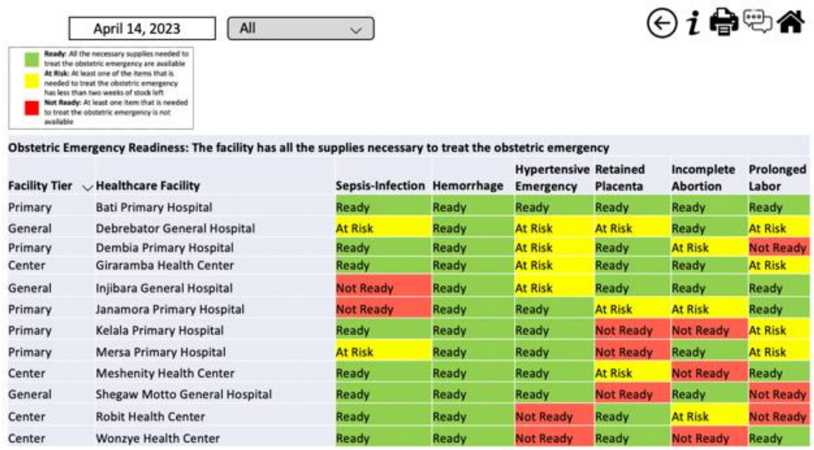
Filtering and Sorting Preferences

Participants in the early sessions wanted to ensure there was an easy way to filter the data so that they could view pieces of information that were most important to them. Overall, the majority of participants liked to see the data related to supply quantities presented in alphabetical order within the pre-determined categories that the Ethiopian Pharmaceutical Supply System already uses. These categories included *medical equipment, pharmaceuticals, chemicals and regents,* and *supplies*. One respondent stated, "The alphabetical order makes it simple to sort through the results and find what you're looking for." Additionally, they also thought it was important to be able to filter these supplies based on the quantity available. One regional respondent described the importance of being able to do this stating, "We also need to prevent supply shortages; thus, it would be beneficial if we could immediately notice the at-risk items and they need to come first." For this reason, the second version of the prototype provided a filter option so users could decide if they wanted to view items based on the quantity available.

Besides filtering by quantities early session participants wanted to be able to filter the data view based on what tier the health facility is within the healthcare system, including health posts, health centers, and primary, general, and referral hospitals. One regional-level respondent suggested, "Why don't we add a column for primary, general, and other health facility rankings so that we may conveniently filter and export for later use?" Following this recommendation the second version of the prototype included a column for facility tier with a drop-down menu that users could select to look at different types of healthcare facilities.

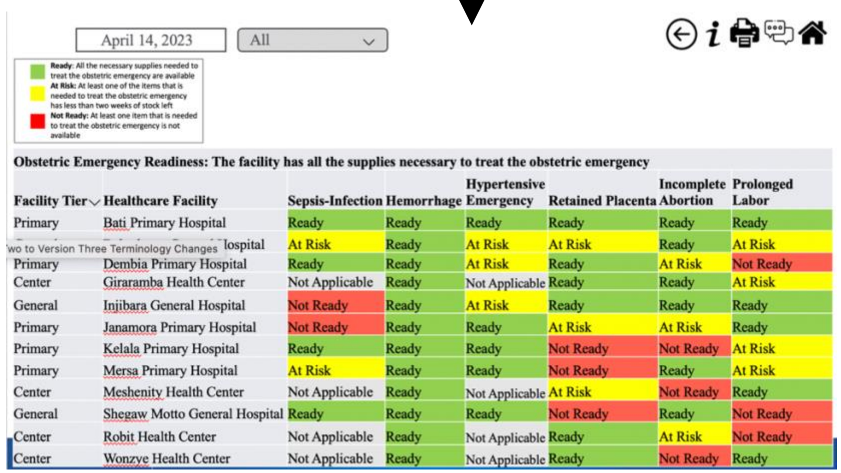
Participants during the third and fourth design sessions endorsed the filtering options that were included in the second version of the dashboards. When discussing the benefits of filtering based on supply quantity, one hospital respondent stated, "Using these options [excess, stockout] saves time because it allows us to quickly choose two items to buy in the event of an emergency rather than having to search for more information”. These facility-level respondents also wanted employees at individual healthcare facilities to be able to view inventory data at other facilities besides their own. They felt having access to this data could help with transferring excess supplies from one facility to another facility that was stocked out or at an emergency order point. A participant from design session four reported, “It is important for us to see other hospitals’ status like general and referral hospitals like…and…hospitals because they provide comprehensive care and give services like we do, and we can support one another. If you run out of supplies that are difficult to obtain, like dialysis catheters, you can get them from these facilities, which is crucial.” The author thus allowed the filtering option and ability to select different facilities from the regional view dashboard to be available for facility-level employees within the prototype. Since there was very little new information provided during the second two design sessions the author feels she met design saturation for filtering preferences even with the smaller sample size. Figures 6.4 and 6.5 show the filtering changes that were incorporated into the prototype during the design sessions.

Figure 6.4: Early to Midpoint Filtering and Sorting Changes



Obstetric Emergency Readiness: The facility has all the supplies necessary to treat the obstetric emergency

Facility Tier	Healthcare Facility	Sepsis-Infection	Hemorrhage	Hypertensive Emergency	Retained Placenta	Incomplete Abortion	Prolonged Labor
Primary	Bati Primary Hospital	Ready	Ready	Ready	Ready	Ready	Ready
General	Debrebator General Hospital	At Risk	Ready	At Risk	At Risk	Ready	At Risk
Primary	Dembia Primary Hospital	Ready	Ready	At Risk	Ready	At Risk	Not Ready
Center	Giraramba Health Center	Ready	Ready	At Risk	Ready	Ready	At Risk
General	Injibara General Hospital	Not Ready	Ready	At Risk	Ready	Ready	Ready
Primary	Janamora Primary Hospital	Not Ready	Ready	Ready	At Risk	At Risk	Ready
Primary	Kelala Primary Hospital	Ready	Ready	Ready	Not Ready	Not Ready	At Risk
Primary	Mersa Primary Hospital	At Risk	Ready	Ready	Not Ready	Ready	At Risk
Center	Meshenity Health Center	Ready	Ready	Ready	At Risk	Not Ready	Ready
General	Shegaw Motto General Hospital	Ready	Ready	Ready	Not Ready	Ready	Not Ready
Center	Robit Health Center	Ready	Ready	Not Ready	Ready	At Risk	Not Ready
Center	Wonzye Health Center	Ready	Ready	Not Ready	Ready	Not Ready	Ready



Obstetric Emergency Readiness: The facility has all the supplies necessary to treat the obstetric emergency

Facility Tier	Healthcare Facility	Sepsis-Infection	Hemorrhage	Hypertensive Emergency	Retained Placenta	Incomplete Abortion	Prolonged Labor
Primary	Bati Primary Hospital	Ready	Ready	Ready	Ready	Ready	Ready
wo to Version Three Terminology Changes	lospital	At Risk	Ready	At Risk	At Risk	Ready	At Risk
Primary	Dembia Primary Hospital	Ready	Ready	At Risk	Ready	At Risk	Not Ready
Center	Giraramba Health Center	Not Applicable	Ready	Not Applicable	Ready	Ready	At Risk
General	Injibara General Hospital	Not Ready	Ready	At Risk	Ready	Ready	Ready
Primary	Janamora Primary Hospital	Not Ready	Ready	Ready	At Risk	At Risk	Ready
Primary	Kelala Primary Hospital	Ready	Ready	Ready	Not Ready	Not Ready	At Risk
Primary	Mersa Primary Hospital	At Risk	Ready	Ready	Not Ready	Ready	At Risk
Center	Meshenity Health Center	Not Applicable	Ready	Not Applicable	At Risk	Not Ready	Ready
General	Shegaw Motto General Hospital	Ready	Ready	Ready	Not Ready	Ready	Not Ready
Center	Robit Health Center	Not Applicable	Ready	Not Applicable	Ready	At Risk	Not Ready
Center	Wonzye Health Center	Not Applicable	Ready	Not Applicable	Ready	Not Ready	Ready

Figure 6.5: Midpoint to Final Filtering and Sorting Changes

Match with the Real World Preferences

A feature that was a very important point of discussion in the early sessions was using appropriate terminology. Participants wanted to ensure that all the terms used within the dashboards aligned with the terms used within the IPLS. For example, the categories for products were updated along with the terms used to label stock availability. Examples include *overstock* changed to *excess, acceptable* changed to *normal*, *stocked out* changed to *stockout*, and adding *emergency order* as an additional category. Furthermore, the author updated the product categories *(e.g. medical equipment, pharmaceuticals, chemicals and regents,* and *supplies)* to match the terms used in the current supply chain.

This idea of matching the dashboard components to the existing supply chain continued to be an important discussion point in the third and fourth design sessions. Additional product names were changed, for example, *IV pole* was changed to *IV stand* in the second version of the prototype. The definition for *below minimum* was updated to ensure there was no ambiguity between *below minimum* and *emergency order.* Hospital-level respondents also did not think quantity terms, such as *excess* or *stockout,* were appropriate for medical supplies and recommended the dashboard use terms such as *functional* versus *nonfunctional*. One participant said, "Instead of saying excess or minimum, we might state functional and nonfunctional for medical equipment when taking inventory." This change was incorporated into the second iteration of dashboards designed during this study. Finally, participants during the third design session recommended that the terminology for facility-readiness for the regional dashboard view should be changed from *ready, at risk,* and *not ready* to *normal, emergency order,* and *stockout* so they would be the same as the terms used with the emergency-specific dashboard view. A participant's explanation for this was, "In our case, we say 'normal' for what you described as the green ‘ready’. Next, the others are stockout and below the emergency order point.” Following this recommendation, the author developed three versions of the readiness terms. The options included the original terms, the newly recommended terms, and a third option of *yes, no*, and *emergency order.* Since the author could not validate this change the three readiness options were presented to a domain expert to decide on the final terms to use. Since the author was unable to obtain user preferences related to this final change, design saturation was not reached for match with the real world. Figures 6.6 and 6.7 show the aesthetic changes that were incorporated into the prototype during the design sessions.

Healthcare Facility	Sepsis-Infection	Hemorrhage	Hypertensive Emergency	Retained Placenta	Incomplete Abortion	Prolonged Labor
Bati General Hospital	Ready	Ready	Ready	Ready	Ready	Ready
Debark Hospital	At Risk	Ready	At Risk	At Risk	Ready	At Risk
Dessie Comprehensive Specialized Hospital	Ready	Ready	At Risk	Ready	At Risk	Not Ready
Felege Hiwot Refferral Hospital	Ready	Ready	At Risk	Ready	Ready	At Risk
Fitchie Comprehensive Specialized Hospital	Not Ready	Ready	At Risk	Ready	Ready	Ready
Gamby Hospital	Not Ready	Ready	Ready	At Risk	At Risk	Ready
Humera Health Center	Ready	Ready	Ready	Not Ready	Not Ready	At Risk
Ibex Hospital	At Risk	Ready	Ready	Not Ready	Ready	At Risk
Motta District Hospital	Ready	Ready	Ready	At Risk	Not Ready	Ready
Selam General Hospital	Ready	Ready	Ready	Not Ready	Ready	Not Ready
Tibebe Ghion Specialized Hospital	Ready	Ready	Not Ready	Ready	At Risk	Not Ready
University of Gondar Hospital	Ready	Ready	Not Ready	Ready	Not Ready	Ready

Facility Tier	Healthcare Facility	Sepsis-Infection	Hemorrhage	Hypertensive Emergency	Retained Placenta	Incomplete Abortion	Prolonged Labor
Primary	Bati Primary Hospital	Ready	Ready	Ready	Ready	Ready	Ready
General	Debrebator General Hospital	At Risk	Ready	At Risk	At Risk	Ready	At Risk
Primary	Dembia Primary Hospital	Ready	Ready	At Risk	Ready	At Risk	Not Ready
Center	Giraramba Health Center	Ready	Ready	At Risk	Ready	Ready	At Risk
General	Injibara General Hospital	Not Ready	Ready	At Risk	Ready	Ready	Ready
Primary	Janamora Primary Hospital	Not Ready	Ready	Ready	At Risk	At Risk	Ready
Primary	Kelala Primary Hospital	Ready	Ready	Ready	Not Ready	Not Ready	At Risk
Primary	Mersa Primary Hospital	At Risk	Ready	Ready	Not Ready	Ready	At Risk
Center	Meshenity Health Center	Ready	Ready	Ready	At Risk	Not Ready	Ready
General	Shegaw Motto General Hospital	Ready	Ready	Ready	Not Ready	Ready	Not Ready
Center	Robit Health Center	Ready	Ready	Not Ready	Ready	At Risk	Not Ready
Center	Wonzye Health Center	Ready	Ready	Not Ready	Ready	Not Ready	Ready

Figure 6.6: Early to Midpoint Match with the Real World Changes

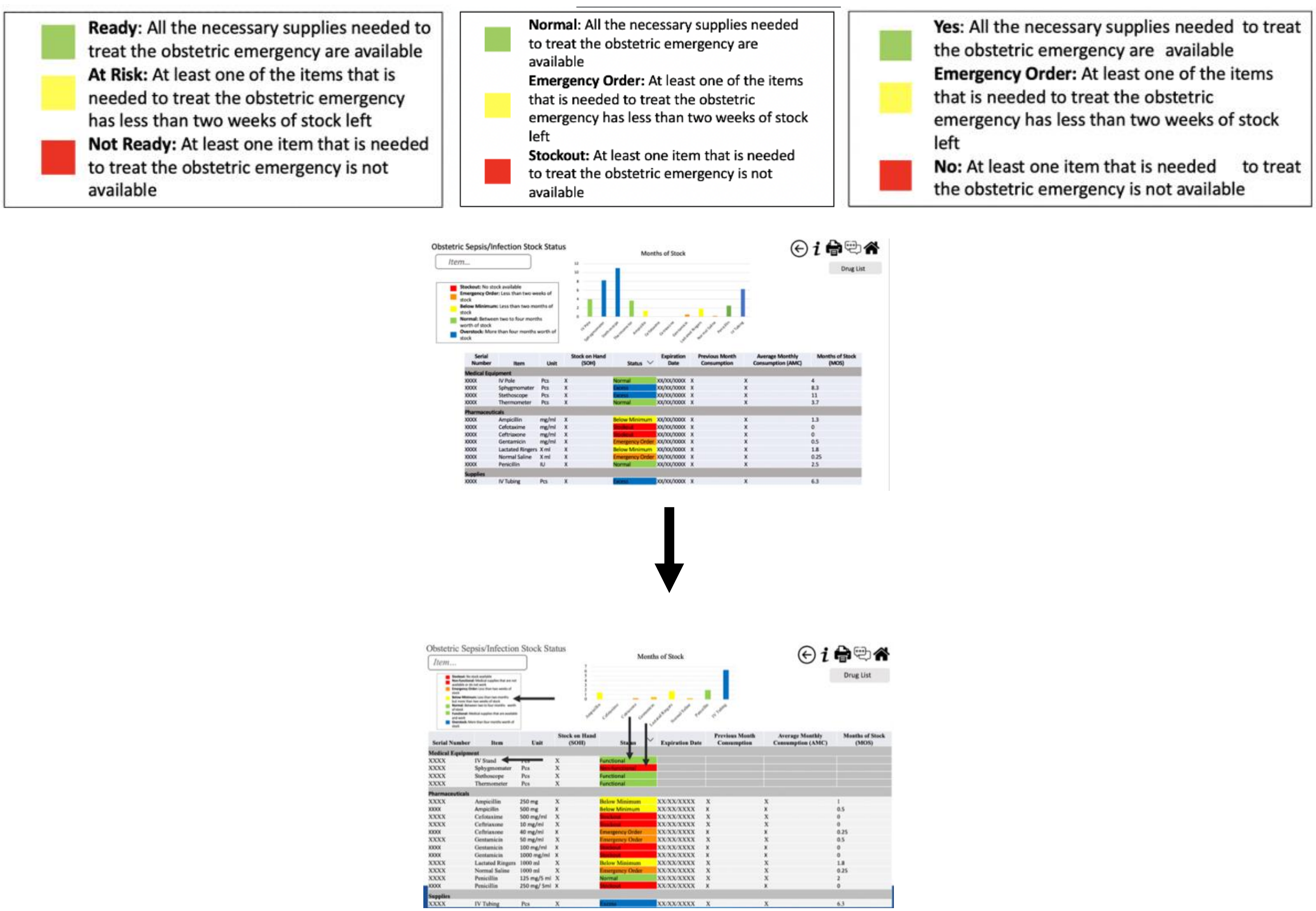


Figure 6.7: Midpoint to Final Session Match with the Real World Changes

6.3.3 Final Designs

Two different dashboard views were established, one that viewed obstetric emergency readiness at the regional level, and one that viewed it at the facility level. The regional-level dashboard view provides a summary of readiness for the six most common obstetric emergencies for all healthcare facilities in the region. The facility-level dashboard view focuses on one healthcare facility and one obstetric emergency at a time. Overall study participants viewed the dashboards positively, with one respondent from design session four reporting, “The hard copies [of the dashboards] you showed us today are beautiful and wonderful.”

6.4 Discussion

In this study, the research team worked with supply chain employees in Amhara, Ethiopia to design and refine an electronic dashboard prototype that would assist with monitoring facility-level readiness to manage obstetric emergencies. Garnering user recommendations and opinions is crucial to ensuring an appropriate fit between the technology and its future users (Martikainen et al., 2020). By including employees from both the regional and facility levels who interact with the obstetric emergency supply chain in Amhara, the author was able to obtain multiple viewpoints. This helped the author to ensure the dashboard would meet the needs of individuals from both levels of the supply chain, and that users with different backgrounds and experiences would be able to understand how to use the dashboards.

Furthermore, including targeted end-users in the early stages of HIT design allowed the author to tailor the prototype to the unique preferences and needs of the users. The author found the inclusion of stakeholders to be critical for ensuring images and terminology were easily recognizable and aligned with currently used paper forms and technology. These design sessions also provided the users the opportunity to voice their own opinions related to which pieces of information are critical for task completion and which pieces are unnecessary and merely take up space within the dashboards. Furthermore, the spontaneous interpretations of the individual graphics and dashboards as a whole underscore the participants' comprehension and reinforce the notion that the targeted end-users understand the data visible within the HIT prototype and comprehend the role of the dashboards. Obtaining these opinions helped to ensure that the author gained viewpoints from all the potential end-users of the dashboards which can help to prevent usability errors from occurring later in the piloting or implementation phase of HIT development. Ensuring that HIT, specifically electronic dashboards, are tailored to the unique users, environment, and for intended tasks can increase ease of implementation and promote consistent uptake and utilization by users (ISO; Lau et al., 2019). The next step for the development of the dashboards involves expert review of the refined prototype. This includes review by both domain and visualization experts as well as performing heuristic evaluations with human-computer interaction experts.

6.4.1 Limitations

Unfortunately, during the time of data collection, there was civil unrest in the Amhara region which prevented the research team from recruiting participants outside of the regional capital of Bahir Dar and from completing participant recruitment. Despite this limitation, design saturation was reached for two out of the three categories. Additionally, there was a lack of gender diversity among our participants. Only one participant was female, and the rest of the study participants were male. This was the result of the gender composition within the profession and geographical region. However, future research related to these dashboards, and facility obstetric emergency readiness would benefit from an emphasis on female opinions and participation. Additionally, there is a risk of social desirability bias. However, to combat this, the research team tried to create a low-stress, comfortable environment, emphasized their desire to obtain personal opinions and reiterated that all opinions would be blinded so no one would know who said what. Additionally, the research team chose to have an Amharic-speaking Ethiopian conduct the sessions rather than the principal investigator, who is from the United States and does not speak Amharic. The team took steps to ensure confidentiality and used indirect questioning techniques in an attempt to garner the participants' true opinions. Furthermore, the research team solicited opinions from all participants to prevent a situation where one individual was controlling the discussion or preventing other participants from contributing.

6.5 Conclusion

This paper describes an iterative visualization design process that leverages the preferences and opinions of individuals who would ultimately use the final product in their day-to-day tasks. This study created an electronic dashboard prototype that could be used to monitor facility-level readiness to manage obstetric emergencies. The research team recruited individuals at the regional and facility levels to participate in the design sessions since they are the targeted end-users of this HIT. The varied perspectives of the participants led to the evolution of the dashboard design and increased comprehensibility of the HIT, as seen by respondent comments. Well-designed HIT is critical to ensuring that technology can be used to its full potential. The design sessions discussed in this chapter highlight the importance of including end-users during the early stages of HIT development.

Chapter 7: Expert Review of a Novel Electronic Dashboard to Promote Facility Readiness in Amhara, Ethiopia

7.1 Introduction

Dashboards (i.e., computer interfaces that synthesize and communicate data in close to real-time) have been successful in improving health outcomes. Simple visualization tools (i.e., graphical representations of data), like dashboards, provide an opportunity to improve capacity surveillance of critical medical supplies (Ottih et al., 2018). For example, a simple dashboard was merged into the existing Integrated Pharmaceutic Logistics System (IPLS) in the Amhara and Oromia regions of Ethiopia which led to improved clinical readiness to treat tuberculosis by ensuring healthcare facilities had adequate supplies (Legesse et al., 2012). The development and use of similar dashboards in other fields, such as obstetrics, may lead to decreased occurrence of emergency supply stockouts and improve obstetric emergency care, in turn decreasing maternal mortality.

While dashboards can be an effective tool for improving health outcomes, researchers must ensure their dashboards are highly usable so that end-users can satisfactorily accomplish their tasks. Usability is defined as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" (International Organization for Standardization, 2013).

Usability is enabled by a user-interface design that supports a user to easily navigate and efficiently use technology. Simply engaging targeted end-users in the design process of HIT such as dashboards is not sufficient to ensure satisfactory user-interface design (Rahman et al., 2020). Researchers should also include domain and human-computer interaction (HCI) or user experience experts during the dashboard design process. There are multiple reasons for the inclusion of experts. First, this will help the developer to create a prototype that follows widely accepted principles and best practices for information visualization, or dashboard creation (Dowding & Merrill, 2018; Weijers et al., 2021). Second, effective user-interface design is built upon a set of broad principles that can be applied across all types of HIT (Nielsen & Molich, 1990). One common technique for ensuring effective user interface design is to conduct a heuristic evaluation based on Nielsen's ten usability heuristics (Nielsen & Molich, 1990). Additionally, other authors have proposed information visualization-specific user-interface heuristics for evaluating dashboards (Dowding & Merrill, 2018).

The purpose of this chapter is to describe the methods and results of two methods for engaging experts in the evaluation of low- and medium-fidelity dashboard prototypes: informal expert review and formal heuristic evaluation. Heuristic evaluation is a quick, affordable, and feasible way to investigate the ease of use of the dashboard prototype (Lai & Bakken, 2006).

7.2 Methods

7.2.1 Informal Expert Review

The author presented a low-fidelity, PowerPoint dashboard prototype to a domain expert and a group of individuals with expertise in information visualization, HCI, and user experience. The domain expert is an individual with six years of experience conducting research in Amhara, Ethiopia, evaluating the supply chain, and measuring facility-level readiness to manage obstetric emergencies. The author used Zoom screen sharing capabilities to display the various dashboards in the PowerPoint format and walked the expert through the prototype and displayed the various features of the dashboards. The domain expert then reviewed the dashboards at his own pace and provided recommendations and critiques to the author.

Additionally, the author leveraged the experience of a group of individuals with expertise in information visualization, HCI, and user experience to further refine the prototype. The author presented the same version of the prototype seen by the domain expert to attendees at a meeting of the Visualization Design Studio at Columbia University (Arcia, 2023). During the studio, the author walked the experts through the various dashboards, answered questions about the intended use of the dashboard, and obtained feedback and recommendations from the experts. Individuals with varying levels of expertise attend these open design studios to learn and gain advice on their current projects. The discussions at this design studio were led by PhD-level faculty. One of the discussion leaders is a nurse scientist with expertise in visualization design and evaluation, and the second is a human-factors engineer. Key contributions also came from another faculty member at the university who has training in the areas of nursing research and biomedical informatics. All have published in the areas of information visualization, HCI, and user experience. These expert recommendations were then used to develop a medium-fidelity prototype that was used in the heuristic usability evaluations.

7.2.2 Heuristic Evaluations

Sample Selection

This study included five HCI experts purposively sampled for heuristic usability evaluation. Previous research has found that 5-8 heuristic evaluators can identify over 80% of usability violations, which supports the small sample size for this study (Allen et al., 2006; Nielsen, 1992). HCI experts were eligible for inclusion if they had conducted research or published in the field of user interfaces and/or information visualizations.

Instruments

The checklist used in this study was guided by Nielsen's 10 usability principles of *visibility of system status, match between system and real world, user control and freedom, consistency and standards, error prevention, recognition rather than recall, flexibility and efficiency of use, aesthetic and minimalist design, help users with errors,* and *help and documentation* (Nielsen, 1992; Nielsen & Molich, 1990). The checklist consists of the 10 principles and a 5-item scale where experts rate the usability violation on a scale of 0 (not a problem) to 4 (catastrophic violation) (Allen et al., 2006; Lai & Bakken, 2006; Yen & Bakken, 2009). Table 7.1 defines the severity ratings of each violation. The original checklist was modified to fit the needs of a medium-fidelity dashboard model. Some questions were excluded from the checklist used in this study because they discussed advanced tasks that the prototype was not able to accomplish at this point of the design process. Questions for principles *error prevention, help users with errors,* and *help and documentation* were excluded. Additionally, three usability principles that related specifically to dashboards were also included. These principles included *spatial organization, information coding,* and *orientation* (Dowding & Merrill, 2018). They were important to include because while Nielsen's principles explore usability in general terms for all HIT, Dowding's explored usability through the specific lens of information visualizations. Table 7.2 describes each of the usability principles explored in this evaluation. A copy of the checklist used in this study can be found in Appendix I.

Table 7.1: Heuristic Usability Violation Severity Ratings

Usability Score	Explanation
0	I don't agree that this is a usability problem at all
1	Cosmetic problem: need not be fixed unless extra time is available on project
2	Minor usability problem: fixing this should be a low priority
3	Major usability problem: important to fix, so should be given high priority

4	Usability catastrophe: imperative to fix this before product can be released

Table 7.2: Heuristic Principles Explanations

Heuristic Category	Definition
1. Visibility of system status	The system should always keep users informed about what is going on through appropriate feedback within a reasonable time.
2. Match between system and the real world	The system should speak the user's language, with words, phrases, and concepts familiar to the user. The system should follow real-world conventions and ensure the dashboard fits within the existing workflow and technology system.
3. User control and freedom	Users should be free to select and sequence tasks and make their own decisions regarding the cost of exiting current work. Users should have clearly marked "emergency exit" to leave the unwanted state.
4. Consistency and standards	Users should not have to wonder whether different words, situations, or actions mean the same thing. Systems should maintain interface design choices in similar contexts and differ in different contexts.
5. Recognition rather than recall	The user should not have to remember information from one part of the dialogue to another. Objects, actions, and options should be easily visible, and instructions should be visible or easily retrievable whenever appropriate.
6. Flexibility and efficiency of use	The system should offer users several options for finding content. Users should be able to customize their interface and achieve their goals in an efficient manner, and the system should have the capacity to adapt to users' needs.
7. Aesthetic and minimalist design	The main dashboard should not contain information that is irrelevant or rarely needed. The system should present the largest amount of data with the least amount of ink.
8. Spatial Organization	The overall layout of a visual representation should make it easy for the user to locate an information element in the display.
9. Information Coding	The symbols and numbers used in the visualization should aid perception. The numeracy and graph literacy of the visualization should match the intended users' ability.
10. Orientation	The system should provide support for the user and help to orient them in their visualization.

Procedures

The author completed heuristic evaluations remotely using a secure and HIPPA-compliant videoconference platform, Zoom Pro. The team obtained a waiver of documentation of consent from the Columbia University Irving Medical Center Institutional Review Board. The author provided potential study participants with an information sheet and an opportunity to ask questions before obtaining verbal consent. The experts were compensated with a $50 Amazon gift card for their time to participate in the heuristic evaluation.

The author refined the dashboards based upon the informal expert opinions and implemented the prototype in Figma, which allowed the author to simulate the technology's current workflow (Figma, 2016). Figures 7.1 and 7.2 provide screenshots of the Figma prototype.

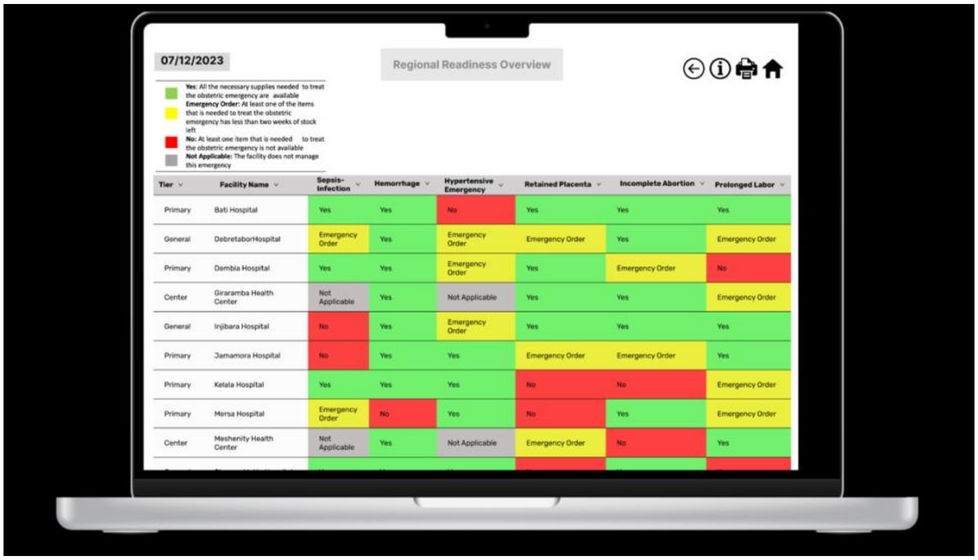


Figure 7.1: Screenshot of the Figma Prototype of the Regional Dashboard Screen

Figure 7.2: Screenshot of the Figma Prototype of Emergency-Specific Dashboard Screen

Using Zoom and its screen-sharing technology, the author asked HCI experts to complete several tasks (Table 7.3) related to the study use cases (Appendix J) within the dashboard prototype and encouraged them to explore other components of the dashboard. During their exploration the participants completed the heuristic checklist to identify and rate the severity of the heuristic violations and had the opportunity to expand upon usability violations they encountered (Allen et al., 2006; Nielsen, 1992; Yen & Bakken, 2009). Additionally, during the evaluations the HCI experts were asked to describe what they were thinking, feeling, and seeing while completing the various tasks. The sessions were videorecorded, and the author also took field notes during these sessions. At the end of the sessions, the HCI experts and the author discussed potential solutions for the identified usability violations.

Table 7.3: List of Tasks for Participants to Complete During Usability Evaluations

Heuristic Usability Evaluation Tasks
1. Filter the main screen to only view primary hospitals
2. Determine which healthcare facilities are not ready to manage retained placenta
3. Determine if [hospital name] is ready to manage hypertensive emergencies. If not, identify which items are missing
4. Determine if [hospital name] is ready to manage maternal sepsis/infection. If not, identify which items are missing
5. Determine what emergencies [hospital name] is ready to manage
6. For prolonged labor at [hospital name] filter the supplies table to see the items that are at the emergency order point
7. For prolonged labor at [hospital name] filter the supplies to see the items that are excess
8. Determine how many healthcare facilities are at risk for not being able to manage retained placentas

Data Preparation

The author transferred completed digital heuristic evaluation surveys into Excel for analysis. The research team used unique participant numbers to link the data to a confidential participant list.

Data Analysis

Data analysis included exploring the frequencies of usability violations and calculating the mean severity scores for each of the heuristic principles (using Excel), such as mean or mode severity ratings and standard deviations and range (Choi & Bakken, 2010). Furthermore, session notes, taken by the author, were used to corroborate quantitative findings.

7.3 Results

The recommendations from domain and visualization experts were used to refine the dashboard prototype. After incorporating those changes the newest version of the prototype, incorporated into Figma, was used for the heuristic evaluations.

7.3.1 Informal Expert Review

The domain expert's greatest contribution to the refinement of the prototype was his input on which terms to use to define facility-level readiness to manage obstetric emergencies, specifically for the regional view dashboard. During the last user-centered design session (Chapter 6), one of the respondents recommended changing the terms from *ready, at risk,* and *not ready* to *normal*, *emergency order,* and *stocked out.* However, the author was unable to obtain targeted end-user preferences on this change since data collection had to stop prematurely due to civil unrest in Amhara. To make the final decision on readiness classification terms the author presented the domain expert, who has several years of research experience calculating facility-level readiness, with three different options. These options included the original terms, the newly recommended ones, and a third option using *yes*, *emergency order*, and *no.* After reviewing all the options, the domain expert recommended the author use *yes, emergency order,* and *no*. The rationale for this decision was the yes and no choice was the simplest option, and he believed the end-users would be able to easily comprehend the meaning of these terms. The domain expert also affirmed the author's decisions to group data at the regional and facility levels and felt that no critical information was missing from the dashboards.

During the review by information visualization experts the majority of the recommendations centered around design features within the dashboard. The experts made recommendations in two areas: 1) aesthetics and 2) navigation. In terms of aesthetic design, the recommendations mainly focused on where to place different pieces of information or graphics to best grab the users' attention and/or prevent overcrowding on a screen. An example of this was when one of the experts recommended moving several columns of data to the right in the emergency-specific dashboard view. This would allow users to still scroll horizontally to see that information, but it would not be visible without scrolling so there would be less information crowding the page. Additionally, the experts recommended adding several more titles to different dashboard views to enhance clarity and advised on the location of different pieces of information within the dashboards so it would be easier for users to locate critical information. To improve navigation between the various dashboard views the experts during the design studios recommended adding additional filtering options, such as for emergency readiness categories on the regional view dashboard. This would increase flexibility when users wanted to customize the data they could see. The information visualization experts recommended adding an affordance feature to the prototype so that users would be able to see which items on the screen are clickable or not. These changes were incorporated when the prototype was moved from PowerPoint to Figma.

7.3.2 Heuristic Usability Evaluations with Human-Computer Interaction Experts

The heuristic evaluations took approximately 30 minutes each. The years of experience for HCI experts ranged from four to fifteen years, with the mean years of experience being 9.4 years. All of the HCI experts included in this study are female. Full details on participant demographics can be found in Table 7.4.

Table 7.4: Demographics Table for Heuristic Evaluations (N=5)

Population Characteristic	Number of Participants
Years of experience	
9 years or less	2
10 years or more	3
Age	
Less than or equal to 40	1
41 and older	4
Gender	
Male	0
Female	5

Overall, severity scores for HCI expert evaluations ranged from zero to three for the 10 heuristic principles, where scores closer to zero indicate high usability and agreement with the heuristics while scores closer to four indicate severe usability issues. The mean usability score for all ten heuristics combined was 0.82 (SD=0.98), with individual heuristic principle mean scores ranging from 0 to 1.4. The mode for the combined heuristic scores was zero with a range of three. For the majority of usability questions asked on the heuristic surveys, the experts gave the prototype a score of zero highlighting their belief that there was no usability concern with those items. Additionally, when a survey item did receive a score of three, a major usability problem, that score was only given to the question on the survey by one expert at a time. Table

7.5 shows the mean severity scores, mode, and range for each of the ten heuristic principles evaluated in this study. The principle with the highest severity rating was *match between system and the real world*, with a score of 1.4, which falls between a minor and cosmetic usability concern. Common issues identified for this principle included inappropriate color choices for both potentially color-blind users and colors that did not correspond to common expectations. Additional problems included the dashboards using concepts and phrases that were unfamiliar to the evaluators and some evaluators felt the section headings were not ordered in the most logical fashion. HCI experts identified issues with usability principles *visibility of system status, user control and freedom, consistency and standards,* and *recognition rather than recall* (M=1.2 for each), which again falls between a minor and cosmetic usability concern. Issues related to *visibility of system status* centered around inconsistent menu naming and complaints related to font size and color choices throughout the dashboards. While usability problems related to *recognition rather than recall* identified a need for more cues, prompts, and messages to assist the user in moving between dashboards and accomplishing tasks. Another area of concern was *user control and freedom,* this is because three experts, scores ranging from one to three, felt it was difficult to move between the different dashboards and that not all dashboard views were accessible to them. Furthermore, some of the HCI experts did not believe there were clear exits for every dashboard view and felt that the current design hindered their ability to efficiently navigate the system. Table 7.5 lists the common usability problems identified for each principle.

Table 7.5: Heuristic Usability Problems and Severity Scores

Heuristic Category	Problems	Mean (SD)	Range	Mode
1. Visibility of system status	• Title font is too small • Color choices may be inappropriate for color-blind users • Vertical bar charts make reading supply labels more difficult • Need hyperlinks to improve navigation	1.2 (0.84)	2	1 and 2

	• Menu-naming terminology is not consistent with the user's task domain			
2. Match between system and real world	• Color choices may be inappropriate for color-blind users • Section headings and subheadings are not ordered in the most logical way • Not all words, concepts, and phrases were familiar to the HCI experts • Some of the colors used in the dashboard did not correspond to common expectations about color codes	1.4 (0.89)	2	1
3. User control and freedom	• Need hyperlinks to improve navigation • Not a clear exit on each dashboard screen • Not all screens are accessible across the system • Users could not easily move forward and backward between fields	1.2 (1.3)	3	0
4. Consistency and standards	• Titles on the regional view dashboards do not update when the user filters the data • Abbreviations not clearly explained • Some colors are too similar to distinguish from other categories • Not enough or inconsistent visual cues to identify active screens	1.2 (0.84)	2	1 and 2
5. Recognition rather than recall	• White space is not optimized within the emergency-specific dashboards • Prompts, cues, and messages are not placed where the eye is likely to be looking on the screen	1.2 (1.3)	3	0
6. Flexibility and efficiency of use	• Need hyperlinks to improve navigation	0.6 (0.89)	2	0
7. Aesthetic and minimalist design	• Not all field labels are brief, familiar, or descriptive • Large objects, bold fonts, and simple areas have not been used to distinguish sections • There is not enough white space between color representation • Too much text is present in the keys which makes the screens look busy	0.8 (0.84)	2	0 and 1
8. Spatial organization	• Font size too small throughout the dashboards	0 (0.0)	0	0

	• Information does not follow a logical flow			
9. Information coding	• *No problems identified*	0 (0.0)	0	0
10. Orientation	• Measurement units are not displayed clearly • Users cannot control the level of detail they see in a representation	0.6 (1.3)	3	0

The experts provided several recommendations for how to remedy the problems identified during the heuristic evaluations. They believed adding hyperlink functions would improve users' ability to navigate between the dashboards, thus increasing usability scores for *visibility of system status, user control and freedom,* and *flexibility and efficiency of use.* Aesthetically, the experts believed increasing the font size of titles and data within the dashboards, as well as moving graphical components around to maximize white space would improve scores for *spatial organization, aesthetic and minimalist design, recognition rather than recall,* and *visibility of system status.*

HCI experts also made recommendations that disagreed with user preferences identified during the design sessions. These differences included the experts preferring horizontal bar charts compared to vertical bar charts. A reason the experts may prefer the horizontal bar chart is that the horizontal orientation allows the labels for the medical supplies to be read horizontally. However, during the user-centered design sessions (Chapter 6), the participants had a resounding preference for the vertical bar charts because they were more familiar with that format since some of their preexisting dashboards included vertical bar charts. Given the importance of the new dashboards to mimic the look of the existing ones, as well as the fact that the users explicitly preferred the vertical presentation, the author chose to retain the vertical bar charts. The color of the tables and graphs was also a point of disagreement between experts and users. The experts did not think the red, yellow, and green color choices were appropriate because if individuals are color blind these colors can be difficult to distinguish (National Eye Institute, 2023). However, the targeted end-users preferred those colors because those colors reminded them of traffic lights, and they could make assumptions related to the significance of the colors based on what those colors mean with a traffic light. When deciding the final color choices, the author looked at prevalence rates of color blindness for different ethnicities and found that African and African Americans had lower rates of color blindness compared to white individuals (Mashige & van Staden, 2019; Review of Optometry, 2014). For this reason, it is acceptable to assume that many targeted end-users would not have difficulty distinguishing between the colors and their preferences should be maintained in the final version of the prototype.

Beyond these recommendations, the reviewers cited several positive features of the prototype. This includes things such as the belief that the icons used throughout the dashboards were clear and easy to associate with their function. Additionally, the experts found the labels and keys to be clear and assisted with comprehension of the data. One respondent reported, "Your labels are quite clear. It's [the dashboard] very accessible and you have nice keys right here." Overall, the HCI expert felt the dashboards were designed well when looking at the information visualization specific heuristics. For example, the dashboards received mean usability scores of zero for spatial organization, zero for information coding, and 0.6 for orientation, which were some of the lowest scores assigned in the evaluation. Table 7.6 summarizes the changes that were incorporated into the dashboard following the completion of the heuristic usability evaluations, and Figures 7.3 and 7.4 display the final design.

Table 7.6: Summary of Changes Incorporated Following Heuristic Evaluations

Heuristic Category	Changes Following Heuristic Evaluation
1. Visibility of system status	• Increased font size throughout the dashboards • Added hyperlinks to the prototype

2. Match between system and real world	• Updated section headings to reflect filtering capabilities • Updated the terminology defining obstetric emergency readiness on the regional-level dashboard
3. User control and freedom	• Added hyperlinks to the prototype • Ensured exit buttons on every screen are activated • Activated more functions within the dashboard to make it a higher fidelity prototype
4. Consistency and standards	• Updated section headings to reflect filtering capabilities • Defined all abbreviations used in the dashboard • Changed the colors for *functional* and *nonfunctional* on the emergency-specific screen so that they are more easily distinguishable from the other colors used on the screen
5. Recognition rather than recall	• Added additional visual cues to identify active screens • Moved graphics at the top of the dashboard screens to optimize white space • Added additional visual cues to identify active screens
6. Flexibility and efficiency of use	• Added hyperlinks to the prototype
7. Aesthetic and minimalist design	• Shortened information in the keys to make them one line of text • Shortened data within the tables to make it one line of text • Used bolded fonts for all titles • Moved graphics at the top of the dashboard screens to optimize white space
8. Spatial organization	• Increased font size throughout the dashboards • Improved the navigation between screens to make it a higher fidelity prototype
9. Information coding	• *Not applicable*
10. Orientation	• Increased font size for measurement units • Activated more functions within the dashboard to make it a higher fidelity prototype

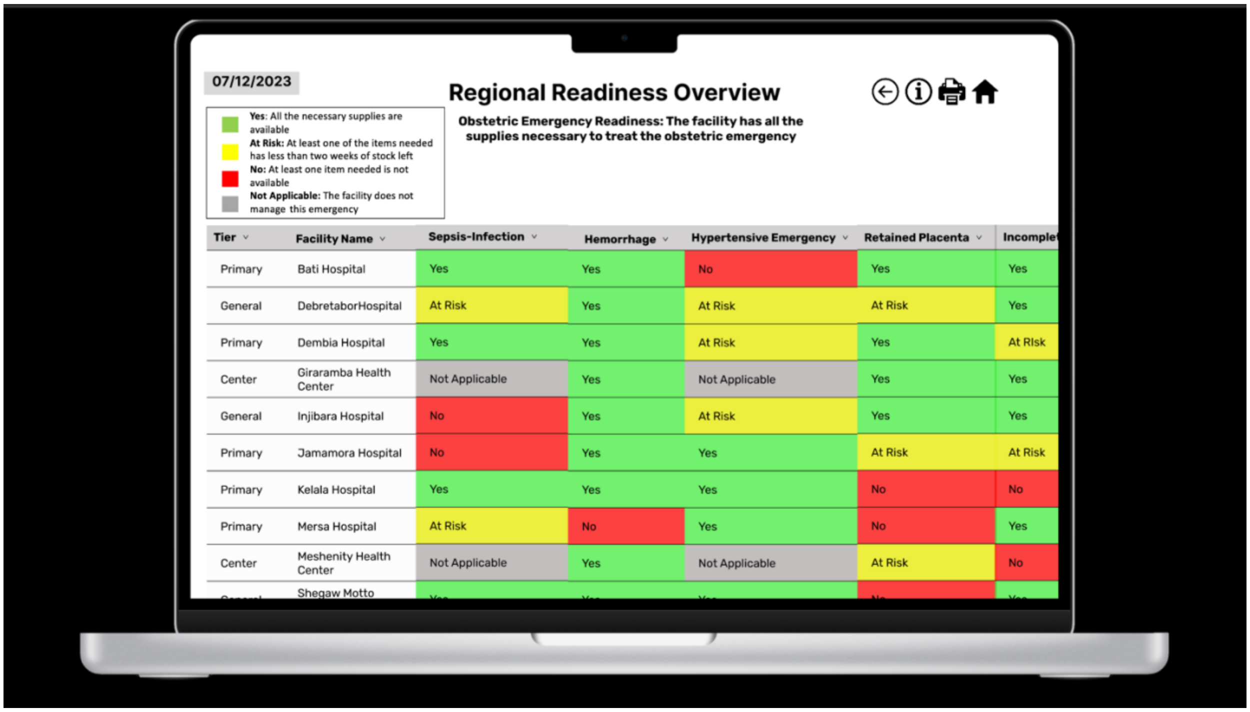


Figure 7.3: Screenshots of Final Regional View Dashboard

Figure 7.4 Screenshots of Final Emergency-Specific Dashboard

7.4 Discussion

7.4.1 Engaging experts in the evaluations of a medium-fidelity prototype

In this study, the author performed two different evaluations of a low- and medium-fidelity prototype designed to help monitor and manage facility-level obstetric emergency readiness. The author engaged domain and information visualization experts and leveraged their recommendations to refine the design of the dashboards. Additionally, HCI experts were recruited to identify usability concerns in the dashboards following the domain and information visualization expert reviews. Overall, the domain expert's recommendations helped the author to make final terminology decisions and ensure the data was grouped in logical and appropriate ways. The information visualization expert recommendations assisted in enhancing the clarity of the dashboards and providing users with a greater degree of freedom when using the technology.

The HCI experts found the prototype to be highly usable. With a mean score of 0.82 this means the usability issues fall between cosmetic and minor usability severity, and a mode of zero highlights the fact that the experts found no usability concerns with many of the questions asked in the heuristic survey. Additionally, the fact that no item received more than one score of three at a time shows that when a major usability concern was assigned by an expert the other four experts did not agree that it was that severe of a problem. Key areas of minor usability concern identified during this evaluation included issues related to *match between system and the real world* and *user control and freedom.* Common recommendations for modifying the dashboards included providing more messages and cues to assist users with navigation of the dashboards as well as increasing the font sizes of both titles and the data within the screens. These results also highlight a need to evaluate the color choices used throughout the dashboards. The findings from the heuristic evaluations underscore the importance of including experts in the evaluation of HIT to ensure the technology follows best practices and user-interface design requirements.

This study reinforces the notion that obtaining expert opinions and performing usability testing can be a low-cost, efficient method for exploring technology needs. Performing the evaluations with the domain expert and the information visualization experts took less than an hour for both groups. Furthermore, it took thirty minutes to complete each heuristic evaluation, for a total of two and half hours of data collection. Performing these evaluations does not take many resources or time and can easily be incorporated into the design process of HIT (Nielsen, 1994b).

Additionally, it is important to engage experts during the design and evaluation of HIT. The inclusion of these individuals can help researchers identify concerns that other groups, such as targeted end-users, may not see and provide a unique perspective to the evaluation (Cooke & Cuddihy, 2005; Manhartsberger & Zellhofer, 2005; Michael et al., 2003). Performing usability evaluations can identify problems and usability concerns that may not have been noticed prior to HIT implementation. Correcting usability concerns later in the development and implementation stages of HIT can be costly and time-consuming (Nielsen, 1992). The early and holistic evaluation and refinement of this prototype, by involving experts from multiple disciplines, helped to identify usability concerns early on, which can ultimately improve the ease of implementation and avoid costly technology modifications when these dashboards are incorporated into the existing integrated pharmaceutical logistics system (Cho et al., 2022).

7.4.2 Limitations

This study has several limitations. First, the sample of HCI experts was all female. While the incorporation of a female perspective is critical since the sample for user-centered design sessions was predominately male, it still may have led to the unintended exclusion of a male-specific perspective amongst HCI experts. Future research should incorporate a male perspective during an expert review of these dashboards. Additionally, the dashboard prototype reviewed in the heuristic usability evaluations was medium fidelity. This means the prototype was not able to complete all required tasks and certain usability heuristics such as *help and documentation* and *error prevention* were excluded from this evaluation, since their tasks were not applicable at this stage in the design process. Future research will need to explore all usability heuristics prior to implementation to ensure no new concerns arise once the prototype transitions from a medium- to high-fidelity model.

7.5 Conclusion

The domain and information visualization experts provided crucial information on how to enhance the design of the dashboards. The expert reviews confirmed that previous design decisions followed best practices and recommended additional ways to improve the prototype before conducting additional usability evaluations with end-users. HCI experts rated the dashboard prototype as highly usable. The heuristic evaluations provided a deep insight into the usability of the dashboards and helpful recommendations for further refinement of the prototype. Furthermore, this study underscores the importance of incorporating expert opinion during the design phase of HIT and performing usability evaluations prior to piloting or incorporating HIT into the existing electronic infrastructure.

Chapter 8: Discussion

The goal of this dissertation is to address two gaps in improving the obstetric emergency supply chain in Amhara, Ethiopia, through user-centered design processes: 1) identifying where the communication and information breakdowns are occurring in the obstetric emergency supply chain and 2) creating and evaluating a dashboard to improve information access and communication about obstetric emergency supply status as the foundation for monitoring real-time clinical readiness and obstetric emergency supply movement throughout the region. The dissertation comprises six studies; the first, a scoping review of the literature that critically analyzes and synthesizes usability evaluations of health information technology (HIT) in Africa; the second, a descriptive cross-sectional analysis of facility readiness to manage obstetric emergencies in Amhara, Ethiopia; the third, a qualitative sociotechnical analysis of the information and communication infrastructure and processes for obstetric emergency supply chain management in Ethiopia and user perspectives on the barriers and facilitators to use of the existing infrastructure and processes; the fourth, a descriptive analysis that synthesizes data from the qualitative sociotechnical analysis, literature regarding best practices (i.e., heuristics) for user interface design, and existing dashboards in the Integrated Pharmaceutical Logistics System (IPLS) to explicate the design goals, functions, and features for an electronic dashboard prototype to improve information access and communication about obstetric emergency supply status in Amhara; the fifth, a user-centered design study to continue the iterative design process of the electronic dashboards; and the sixth, expert usability evaluations including review by a domain expert and information visualization experts as well as heuristic evaluations with human-computer interaction (HCI) experts. This chapter summarizes the studies included in the dissertation, reviews key findings, synthesizes the theoretical, methodological, and substantive contributions to knowledge development, and discusses the implications of the findings for the IPLS, health system policy, and maternal health outcomes. Furthermore, this chapter explores future avenues of research.

8.1 Summary of Results and Key Findings

The first dissertation study involved a scoping review of the literature to critically analyze and synthesize usability evaluations of HIT in Africa (Dougherty et al., 2022). The review found that the majority of published usability evaluations occurred in later stages of the development process when HIT is deployed or close to being deployed for real-world use, such as during stage 4 of the System Development Life Cycle (SDLC). Through the use of the SDLC framework, the author was able to highlight a gap in the current literature, and also take steps during her own dissertation study to perform usability evaluations throughout the early stages of the development process. Furthermore, the review found that most of the HIT usability studies occurring in Africa do not include theoretical frameworks or models. This is a major concern because frameworks assist in providing a rationale for studies, can support the interpretation of findings, and develop a basis for establishing the contributions to scientific findings (Grant & Osanloo, 2015).

The second study was a prospective cross-sectional, facility-based analysis of readiness to manage obstetric emergencies that compared two methods of measuring facility readiness (Signal Functions tracer items method and Clinical Cascades method) amongst a sample of twenty hospitals in Amhara, Ethiopia (Dougherty et al., 2023). This study found that many hospitals in Amhara, be it primary, general, or referral, lacked critical commodities necessary to treat the most common obstetric emergencies. The analysis also found that the current method for measuring facility readiness (Signal Function tracer items) overestimates facilities' true capacity to treat and manage obstetric emergencies by 29.6% as compared to the Clinical Cascades methods.

The third study was a socio-technical analysis of the obstetric emergency supply chain in Amhara, Ethiopia. This exploration entailed qualitative semi-structured interviews with individuals who interacted with the supply chain. Prior to beginning the interviews, the author developed three use cases describing tasks that she believed the new HIT would need to accomplish to better support the obstetric emergency supply chain. Additionally, the author used screenshots of the currently available dashboards and reviewed the standards of practice handbook related to medical supply procurement in Amhara to gain a detailed understanding of the system and how it all worked together to supply healthcare facilities.

The Socio-technical Framework guided this study and the development of a priori codes for analysis of the qualitative interviews. The interviews focused on the dimensions that interact with HIT and influence its design, implementation, and utilization. The research team recruited seventeen participants for this study ranging from pharmacists at individual healthcare facilities (n=7) to regional health bureau and regional hub employees (n=5) and Ministry of Health employees (n=5). Through deductive coding, the author found several places within the current supply chain where the Ethiopian Pharmaceutical Supply System can intervene to improve the efficiency and performance of the system. Some of these locations involve interventions outside the scope of this study, including overcoming budget constraints and a lack of electronic devices and consistent internet.

However, this analysis also identified a need for greater data transparency and communication between regional hubs and individual healthcare facilities. When speaking with interviewees from healthcare facilities, they stated that they did not typically have quality consumption data and had to estimate their consumption and the forecasted future supply needs. These respondents described their desire to have electronic technology that they can use to monitor supply inventory data. Having greater access to this data would enhance their ability to forecast supply needs and theoretically prevent the facilities from experiencing critical commodity stockouts. Furthermore, regional, and facility-level respondents talked about how there is currently no technology available for regional hubs to view stock inventory data at healthcare facilities in close to real-time. Regional respondents believed that if they did have access to this data, they would be better prepared to monitor obstetric emergency readiness at the facilities under their jurisdiction and prevent facility-level supply stockouts.

The use cases that were developed prior to the interviews were continually refined as the author obtained more data from the interview respondents. The author used these findings to develop functions, built off the original use cases, that would meet the user needs described during the interviews. These functions included tasks such as displaying inventory data electronically, combining inventory data from multiple sources, and allowing users to view their overall obstetric emergency readiness as well as a granular understanding of their inventory status at the regional and individual healthcare facility level. Thus, pointing to an electronic dashboard as a HIT solution to meet those needs.

The fourth study used findings from the qualitative interviews, refined use case functions, and existing dashboards as well as best practices in the literature for HIT and dashboard development to create the first dashboard prototype. The synthesis of these sources resulted in four categories of design features for the electronic dashboard: aesthetic features, filtering and sorting, navigation, and match with the real world. After combining the data and recommendations from these various sources the author developed a low-fidelity prototype (PowerPoint) of the dashboards to monitor facility-level readiness to manage obstetric emergencies.

The fifth study involved user-centered design sessions with individuals who interacted with Amhara's obstetric emergency supply chain at the regional level and individual healthcare facilities. Eleven participants were involved in four design sessions. These findings guided the iterative refinement of the dashboard prototype. The author created two versions of dashboards during this study. During the user-centered design sessions, there were three categories of changes that were implemented: aesthetic (e.g., strong preference for color coding), filtering and sorting (e.g., desire for multiple options for filtering data), and match with the real world (e. g., utilize the same terminology present in the existing dashboards and paper forms).

The sixth and final study involved several different expert reviews of the prototype. These included reviews of the PowerPoint version of the dashboard by a domain expert and information visualization experts. The results of the expert reviews led the author to continue refining the dashboards and remedy the usability issues identified by both groups. The domain expert assisted the author in finalizing key terms that best represented the data in the dashboards while the information visualization experts provided recommendations on design features. At the conclusion of the expert reviews, the author developed a medium-fidelity dashboard prototype in Figma for usability evaluations (Figma, 2016). The HCI experts who completed the heuristic usability evaluations rated the prototype as highly usable, but also identified several usability problems with the dashboards. The severity of usability violations ranged from zero to three with a mode of zero; the mean heuristic violation scores ranged from 0 to 1.4. Overall, the HCI experts identified issues related to *match between system and the real world, user control and freedom,* and *flexibility and efficiency of use,* but found the dashboards fulfilled the information visualization specific principles for usability, such as *orientation* and *spatial organization*. Two discrepancies arose between user and expert preferences. The first was experts believed horizontal dashboards would be easier to read, while the targeted end-users reported they preferred viewing their data in vertical bar charts. Since one of the reasons the users had this preference was because existing dashboards already incorporated vertical bar charts the author chose to follow user preferences, since this would allow the new dashboards design to match the existing ones. Additionally, this choice would enhance users' familiarity with the data since it was presented in a familiar format. Additionally, experts cited concerns related to the use of red, yellow, and green color coding within the dashboards because these colors can be incredibly hard to differentiate for individuals with color blindness (National Eye Institute, 2023). However, upon further investigation, the author found that Africans have lower rates of color blindness compared to white individuals, so the original color choices were kept for the final design, which aligned with user preferences (Mashige & van Staden, 2019; Review of Optometry, 2014). All this work culminated in a dashboard prototype that follows usability standards and was designed to match the preferences and unique needs of individuals responsible for maintaining facility readiness to manage obstetric emergencies in Amhara, Ethiopia.

8.2 Theoretical Contributions

The use of a novel integrated usability framework incorporating Stead's SDLC and Bennett and Shackel's usability components in the scoping review of usability evaluations in Africa expands the body of literature surrounding this framework (Bennett, 1984; Shackel, 1991; Stead et al., 1994; Yen & Bakken, 2011). To the author's knowledge, the integrated usability framework has not been used to evaluate usability research conducted in low-to-middle-income countries (LMICs), or Africa specifically. The framework has only been used to evaluate studies in the United States (Yen, 2010). The incorporation of this framework in the scoping review in

Chapter 2 demonstrates the applicability of the integrated framework for use in an African context. Furthermore, it adds to the argument for its utility for research in LMICs.

Additionally, the author applied the Socio-technical Framework to these dissertation studies. The author's recommendation on the use of theoretical frameworks, especially those tailored for HIT, align with recommendations in the current literature (Fox et al., 2014; Godfrey et al., 2010; Sittig & Singh, 2010; Šmahel et al., 2018). Application of the Socio-technical Framework provided a streamlined way to organize and understand the obstetric emergency supply chain and the associated barriers and information and communication needs in Amhara Ethiopia. The findings from these dissertation studies align with the current literature that the Socio-technical Framework is a useful aid in determining how to create and evaluate electronic dashboards (Lentz et al., 2023; Sittig & Singh, 2010; Teo et al., 2023).

The current literature also supports the use of this framework to evaluate HIT in Africa, since it has successfully been used to evaluate electronic health records in South Africa (Mostert-Phipps et al., 2010). However, to the author's knowledge, these dissertation studies are the first time the Socio-technical Framework has been used to develop and evaluate HIT in Ethiopia. This framework has previously been used to explore supply chains and identify locations to improve their efficiency (Sabbagh & Kowalski, 2015). However, it has not been used to explore Ethiopia's medical supply chain. This dissertation expands upon the current literature surrounding the potential uses of the Socio-technical Framework.

8.3 Methodological Contributions

The dissertation studies provided novel methodological contributions. The first is a comparison of the Signal Function tracer items method and the Clinical Cascades method for assessing clinical readiness in Ethiopia. While this comparison has been performed previously in

Kenya and Uganda, the analysis in Chapter 3 provides additional evidence to support the argument that the Signal Functions tracer items method is not a sufficient method for measuring facility readiness to manage obstetric emergencies (Bridget et al., 2022; Cranmer et al., 2018; Dougherty et al., 2023). Furthermore, this analysis was the first to perform this methodological comparison with healthcare facilities in Ethiopia. Additionally, this analysis was the first to explore the role of protocols on Clinical Cascade readiness calculations, which provided a greater understanding of the role various supplies play in ensuring facility readiness.

This dissertation provides further details on how to adapt user-centered design session methods to meet the needs of the environment the research is occurring. When the author began the dissertation studies the original plan was for her to travel to Amhara and spend several months living in the community and performing the data collection. This included conducting qualitative interviews, user-centered design sessions, and usability evaluations with targeted end-users. However, due to civil unrest within the region, the author was unable to travel to Amhara to conduct the data collection. To accommodate this challenge, the author adapted well-known methods to meet the needs of the current situation. Instead of performing the data collection, the author rapidly and virtually trained a team member from another field in user-centered design methods. This ensured that the author could continue to work with the original population and use the same methods. This strategy also confirms what is found in the current literature, as other studies have shown Zoom and virtual training to be effective methods for teaching data collection strategies and monitoring data quality (Mazumdar & Donovan, 2020). One challenge to all these modifications was the fact that the research team had to submit institutional review board protocol modifications every time a change a made, and these modifications had to be approved by three separate review committees, one at Columbia University, one at Emory

University, and one at Amhara Public Health Institute. However, despite these additional steps the author and research team were able to modify study activities to accommodate travel barriers and civil unrest in their targeted geographic location.

Furthermore, this work supports the current literature that usability evaluations and data collection can successfully occur virtually and through platforms such as Zoom. From the beginning of this study, the author knew that she would be spending a substantial amount of time living and data collecting in Amhara, Ethiopia. However, she still wanted to be able to include HCI experts in the evaluation of the dashboard prototype. For this reason, the author planned to conduct the heuristic usability evaluations over Zoom so she could have experts in HCI, and information visualization evaluate the prototype. The current literature affirms the notion that usability evaluations can still be highly successful when conducted virtually (Moran, 2019). Performing discount inspection usability evaluations such as heuristic evaluation is a simple way to ensure the appropriate design of HIT, and these methods can easily be accomplished even in the face of barriers, such as geographic hurdles, that historically would have prohibited collaboration (Nielsen, 1992).

8.4 Substantive Contributions

This dissertation work highlighted major gaps in facility readiness to manage obstetric emergencies in Amhara Ethiopia. The current literature shows that maternal mortality (MM) rates have continued to decrease throughout Ethiopia over the last several decades (Tessema et al., 2017). Specifically, from 1990 to 2013 MM has declined from 708 to 497 per 100,000 live births (Tessema et al., 2017). However, a MM rate of 497 per 100,000 live births is still high, and these numbers alone do not tell the full story of Amhara’s ability to manage obstetric emergencies. For example, the quantitative analysis of facility-level readiness to manage obstetric emergencies found a large number of healthcare facilities do not stock critical obstetric emergency supplies. This analysis found that 65% of the facilities sampled were completely stocked out of aseptic gloves, and 95% of the sample facilities were stocked out of penicillin. This is significant because without these items, facilities will not be able to offer the highest level of care possible to the women coming to their facilities. This inconsistent availability of supplies was reinforced by supply chain employees during the qualitative interviews as they discussed the difficulties they experienced requesting the proper supplies and the barriers within the system that prevented them from receiving the supplies in a consistent and timely manner.

Through these studies, the author has shown how dashboards have the potential to overcome the communication barriers present in Amhara's obstetric emergency supply chain. The data visualizations in the electronic dashboards developed through user-centered design and expert review will help targeted end users comprehend inventory data and make appropriate supply request decisions which will ultimately improve maternal health outcomes in Amhara. The impact of data visualizations, specifically dashboards, is well-established in the literature (Helminski et al., 2022). The use of graphs and color coding is known to enhance the interpretability of data and aid in decision making (Helminski et al., 2022). The current literature affirms the notion that dashboards can be used to monitor performance trends, such as medical supply inventory status, and improve resource utilization which is strongly tied to improved health outcomes (Helminski et al., 2022; Lugada et al., 2022).

These dissertation studies offer substantial contributions to the development process of HIT in Amhara Ethiopia. There is little literature related to design and technology preferences for Amharans, specifically those working within the obstetric emergency supply chain. Findings from the qualitative interviews thus provided crucial information related to user desires and requests for new health technology to assist in monitoring facility readiness. This study incorporated currently available technology, user preferences and expertise, best practices from the literature, and expert recommendations to present novel information related to the process of developing dashboards to support facility-level obstetric emergency readiness. By creating dashboards that combines all necessary inventory data into one place and connecting the regional hubs and individual healthcare facilities this technology can enhance communication within the system and work to prevent critical supply stockouts. These dissertation studies fill gaps in knowledge related to the current state of obstetric emergency readiness in Amhara. Additionally, it provides a greater understanding of the process of developing HIT for supply chain needs in the region.

8.5 Implications for the Integrated Pharmaceutical Logistics System

Study findings suggest that the Ethiopian Ministry of Health and the Ethiopian Pharmaceutical Supply System should work together to implement and encourage one uniform system for ordering and managing obstetric emergency supplies. There is one process used to order supplies, the IPLS. However, healthcare facilities utilize the system differently; some facilities are completely digital and leverage the electronic components of IPLS to request supplies and monitor inventory levels, while some are completely paper-based, and others are a blend of paper and electronic. Additionally, some healthcare facilities have received technology, such as tablets, that allow them to interact with electronic components of IPLS and receive monetary support to pay for data, while other facilities do not receive hardware or funds to support data costs. Not having a uniform system for all healthcare facilities introduces the opportunity for breakdowns in communication and the presence of low-quality data, which is then shared throughout the supply chain, leading to stockouts and supply expiration (Balkhi et al., 2022). Encouraging one uniform system for requesting and monitoring supplies will help the supply chain to be more efficient.

Ensuring the obstetric emergency supply chain in Amhara functions efficiently is a crucial task if Ethiopia wants to have a substantial impact on MM rates in the region. This is because supply chains play an integral role in a health system's ability to offer quality care (Lugada et al., 2022). One important finding from these studies related to supply chain management is the need to review all components of the supply chain and explore how they impact one another. For example, while this dissertation focuses on the development of electronic dashboards to support data-driven decisions, it is also important to note that significant improvement within the supply chain will not be possible unless all barriers are addressed. For example, the supply chain needs all the structural components necessary to interact with the electronic IPLS to be in place before the users experience the full benefit of the HIT (Bogale et al., 2023; Sagaro et al., 2020). This means that all healthcare facilities need access to a computer or electronic device, so they have a point of entry and the ability to interact with the electronic IPLS components (Sagaro et al., 2020). Furthermore, these facilities will need a consistent internet connection and consistent availability of data or funds to purchase data to ensure that the system can be used to its greatest potential (Sagaro et al., 2020). All barriers identified in Chapter 4 must be addressed if stakeholders want to experience the full benefit of the electronic IPLS.

Additionally, communication must be open throughout the entire supply chain, from the federal level, through the regional hubs, and to the individual hospitals and healthcare facilities. If any part of the system experiences fragmented communication, this can introduce barriers to data exchange and transparency as well as complications within the supply chain leading to critical supply stockouts (Lugada et al., 2022). In Amhara, this breakdown was seen between the regional hubs and individual healthcare facilities. Supply chain employees need access to accurate and current supply inventory data so that they can make appropriate forecasting and supply ordering decisions. Furthermore, the findings from the facility-level quantitative analysis underscore the importance of making data, specifically detailed data related to obstetric emergency readiness and supply inventory available, so that individuals working within the supply chain can make informed decisions related to facility needs. The dashboard prototype from this dissertation is a first step to ensuring supply chain employees have the information they need to make data-informed decisions. Incorporating these dashboards into the current electronic IPLS can assist in streamlining consumption calculations, forecasting decisions, and promoting communication related to supply shipments between regional hubs and individual healthcare facilities.

8.6 Implications for Health System Policy

Study findings suggest that health policymakers should review the current practices for measuring facility readiness to manage obstetric emergencies. Currently, the Signal Functions is the gold standard for this (Whaley, 2020). However, the findings in Chapter 3 highlight a 29.6% facility readiness discrepancy between the Signal Functions tracer items method and the Clinical Cascades. This overestimate shows that when facilities are measuring their readiness with a less detailed tool, such as the Signal Functions tracer items, there is a greater chance that they will miss when critical items are at emergency stock points or completely stocked out. This overestimation can lead to the creation of an invisible need. This invisible need occurs when healthcare facilities that are classified as ready to manage obstetric emergencies are in reality missing some of the necessary supplies to handle these conditions. However, since the facilities are classified as ready, they may be unaware that they are stocked out, and thus be unable to provide care when a woman experiencing an obstetric emergency comes to their facility. Furthermore, this lack of awareness related to which facilities are truly prepared to manage obstetric emergencies makes it harder for regional health planners or regional hub employees to identify the problems within the healthcare facilities and rectify the stockouts. Policy planners should consider the possibility of modifying the Signal Functions tracer items method or replacing it with another facility readiness method, such as the Clinical Cascades, to prevent the invisible need from occurring. Careful consideration should be taken to determine if the Signal Functions method remains the best way to measure facility readiness.

8.7 Implications for Maternal Health Outcomes

Thaddeus and Maine identified three main delays in obstetric emergency care that greatly impact MM in LMICs (1994). These delays in care include 1) delay in the decision to seek care, 2) delay in arrival at the healthcare facility, and 3) delay in the provision of adequate care (Thaddeus & Maine, 1994). If any of these are present during an obstetric emergency, then maternal outcomes will suffer. While this dissertation primarily focuses on the third delay, a delay in one can influence other delays in receiving quality care for obstetric emergencies (Thaddeus & Maine, 1994). For example, if a mother knows healthcare facilities are far away and difficult to reach, it may take her longer to decide to seek care because she understands the transportation difficulties. Additionally, if mothers are aware that healthcare facilities do not provide good quality care or are frequently stocked out of critical medical supplies, this can also increase the amount of time it takes for them to seek care because they do not believe they will receive quality care even if they go to that healthcare facility (Barnes-Josiah et al., 1998; Thaddeus & Maine, 1994). Finally, the quality of maternal care decreases when critical obstetric emergency supplies are not available. A lack of obstetric emergency supplies can lead to delays in treatment, a need to transfer mothers to other facilities, or lower-quality care. Ensuring all critical obstetric emergency supplies are always available in healthcare facilities that perform deliveries will not only enhance the quality of care that mothers receive but will also help to combat the third delay in care. Several other studies support this notion (Mohammed et al., 2020; Tesfay et al., 2022; Thaddeus & Maine, 1994). The development of the dashboard prototype will assist in ensuring critical obstetric emergency supplies are consistently available and decrease the impact of type three delays.

Our findings that hospitals in the Amhara region are not prepared to manage the most common obstetric emergencies underscores the importance of continuing research to monitor stock availability and facility readiness. To address this issue of supply stockouts, facilities, and regional hubs require open channels of communication and high-quality consumption data. Substantial changes in clinical care cannot occur without strong data quality (Lugada et al., 2022). This data will help pharmacists more accurately calculate their monthly and average consumption rates, which is crucial information for forecasting future supply needs. If they can more accurately forecast supply needs, then facilities will be less likely to experience supply stockouts which will reduce delays in mothers receiving high-quality obstetric care. Additionally, when mothers know the facilities near them rarely have stockouts of critical supplies this will increase their confidence in the facility's ability to care for them and decrease the amount of time it takes them to decide to seek care. To combat the three delays in care, and have a profound impact on maternal health outcomes, the Ethiopian Ministry of Health needs to act to ensure facilities are consistently stocked with critical obstetric emergency supplies.

8.8 Implications for Future Research

Several implications for future research arise from these dissertation studies. Natural next steps include performing further usability evaluations and incorporating the dashboard prototype into Ethiopia's current IPLS electronic system. The next study should perform usability evaluations with targeted end-users since the author only evaluated the dashboards with experts. The reason these additional evaluations are important is that both experts and end-users can identify different issues and provide unique perspectives on how to improve the dashboards (Frith, 2019a; Khajouei & Farahani, 2020). Once this evaluation has occurred, the dashboards can be incorporated into the current IPLS. Researchers should perform some preliminary pilot testing to ensure the usability explored previously holds up when the dashboards are incorporated into a new environment. If this is successful researchers can begin implementing the dashboards into healthcare facilities and hubs in Amhara to see how they perform under real conditions. For these activities, the Socio-technical Framework can be used to measure performance and ensure there are no unintended consequences from the implementation of the technology (Sittig & Singh, 2010).

A future direction of research would be to explore the usefulness of the dashboards in healthcare facilities and hubs outside of Amhara. Before these dashboards are piloted in other regions in Ethiopia, researchers and the Ethiopian Pharmaceutical Supply System would need to perform similar usability evaluations with targeted end-users in the various regions throughout the country to ensure that the features of the dashboard are not Amhara-specific and that the dashboards are not difficult to use in areas outside the geographic scope of this dissertation.

Beyond exploring the utility of the dashboard, future research should also evaluate the Clinical Cascade's ability to predict maternal morbidity and mortality rates. While Chapter 3 displayed the large readiness discrepancy between Signal Function tracer items and the Clinical Cascades, research has not yet explored the Clinical Cascades' ability to predict maternal outcomes. Additionally, a future direction of research would be to explore if the Signal Functions tracer items method is truly the best way to measure facility readiness to manage obstetric emergencies or if it would be better to replace or modify this method.

8.9 Strengths and Limitations

These dissertation studies have both strengths and limitations. To our knowledge, this is the first study focused on designing HIT to support obstetric emergency readiness in Amhara, Ethiopia. The studies include data collection in both Amharic and English with the majority of data collection occurring with a native Amharic speaker who is fluent in English, which was a strength of the studies since participants were able to speak in whichever language they were most comfortable in. Furthermore, English translations were done by a native Amharic speaker, with over a decade of experience conducting health research in Amhara, which helped to ensure a proper translation. Another strength of this dissertation is that the author used a wide variety of methods to validate findings and obtain a thorough understanding of HIT needs and design requirements. The use of mixed methods in these dissertation studies provided a granular understanding of the obstetric emergency supply chain, and the current state of facility readiness in the region, as well as provided rich usability data to guide dashboard development. Current literature substantiates this claim since previous research has found that the most successful HIT is developed through a combination of different data sources and methods (Agency for Healthcare Research and Quality, 2018; Centers for Medicare & Medicaid Services, n.d.; Ghazisaeidi et al., 2015; Tariq & Woodman, 2013).

Two limitations of the literature review were that it excluded non-English articles from inclusion in the review and only searched three databases to identify eligible articles, which may have unintentionally omitted studies that met inclusion criteria. The user-centered design sessions, and usability evaluations are convenience samples, which limits the transferability of the study findings. Furthermore, the sample populations in the qualitative interviews and user-centered design sessions were predominately male, which aligns with the gender composition of the profession in the region, but also limits the generalizability of the findings, and as a result, the dashboard prototype may not meet the unique needs of female users. Additionally, the majority of data collected for the qualitative interviews and user-centered design sessions occurred in Amharic. While the individual performing the translations to English is a native Amharic speaker and has years of experience performing these kinds of translations, data quality errors may have still occurred.

Finally, while these dissertation studies were happening, there was civil unrest in the Amhara region which led to several changes in research activities. First, the author was unable to travel to the region for several months and had to transition data collection responsibilities to another team member living in Amhara. Furthermore, the majority of participants recruited for the qualitative interviews and user-centered design sessions came from the regional capital, Bahir Dar, or the surrounding area since it was not safe to travel farther into the region. Bahir Dar is a large city and there are many places within Amhara that are incredibly rural, so the author may not have obtained a comprehensive understanding of user preferences and needs for the region, since the team was unable to access participants outside the regional capital. Additionally, the user-centered design sessions had to end before the research team had recruited all of their participants. The team had a targeted enrollment of fifteen individuals but was only able to recruit eleven before data collection activities had to stop due to safety concerns for the team. This prevented the author from fully reaching data saturation with the design sessions. The final change that occurred was the author had to postpone targeted end-user usability evaluations. This was because the situation in Amhara became so unstable that members of the research team who were living in Bahir Dar were forced to relocate to Addis Ababa. While the author still intends to complete these evaluations in the future, due to time constraints, this evaluation had to be excluded from the dissertation, limiting the author's ability to fully evaluate the usability of the final prototype.

8.10 Conclusion

These dissertation studies aimed to create electronic dashboards to promote healthcare facilities and regional stakeholders' ability to monitor and manage facility-level obstetric emergency readiness in Amhara, Ethiopia. These studies assisted in identifying areas within the current supply chain where readiness to manage obstetric emergencies was lost. The dissertation culminated in the development of a dashboard prototype that was tailored to user-specific needs and followed usability best practices. This dissertation work highlighted the crucial role of early end-user involvement in HIT development. The findings from these studies identify future research possibilities such as determining the best way to measure facility readiness to manage obstetric emergencies and exploring the effectiveness and practicality of using the dashboards in healthcare facilities in Amhara.

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Appendix A: Population-Concept-Context Framework

Criteria	Concept	Search Terms
Population	African countries	Africa, Nigeria, Ethiopia, Egypt, DR Congo, Democratic Republic of the Congo, Tanzania, South Africa, Kenya, Uganda, Algeria, Sudan, South Sudan, Morocco, Angola, Ghana, Mozambique, Madagascar, Cote d'Ivoire, Cameroon, Niger, Burkina Faso, Mali, Malawi, Zambia, Senegal, Chad, Somalia, Zimbabwe, Guinea, Rwanda, Benin, Burundi, Tunisia, Togo, Sierra Leone, Libya, Congo, Liberia, Central African Republic, Mauritania, Eritrea, Namibia, Gambia, Botswana, Gabon, Lesotho, Guinea-Bissau, Equatorial Guinea, Mauritius, Eswatini, Djibouti, Comoros, Cabo Verde, Sao Tomo & Principe, Seychelles
Concept	Usability evaluation	Usability, technology acceptance, technology adoption, user acceptance, user satisfaction, ease of use, user-centered
Context	Health information technology	Health information system, mobile health, mhealth, digital health, integrated pharmaceutical logistic system, electronic health record, ehealth, telemedicine

Note. Population-Concept-Context Framework from Peters et al. (2015)

Appendix B: A Priori Protocol

Protocol item	A priori criteria
Review title	Scoping Review of Health Information Technology Usability Methods Leveraged in Africa
Review question	Based on the System Development Life Cycle when do health information technology usability studies in Africa occur, what are the methods used during these stages, and what components of usability are evaluated as based on Bennett and Shackel's usability model?
Searched	Searches will be completed in three databases: PubMed, Embase, Association for Computing Machinery
Types of studies to be included	Inclusion: 1) Quantitative studies 2) Qualitative studies 3) Mixed Method studies 4) Studies from Africa only 5) Studies that define health information technology as their main objective and describe the methods they used 6) Gray literature (e. g., conference proceedings) Exclusion: 1) Non-empirical literature (e.g., reviews, methodology) 2) Studies conducted outside of Africa 3) Studies that used health information technology to answer research questions but does not evaluate the technology
Participant/populations	Inclusion: African countries Exclusion: Any country that is not in the continent of Africa
Condition or domain being studied	Usability evaluations (the study of a user's experience when interacting with health information technology, exploring effectiveness, efficiency and overall satisfaction of the user related to their experience with the technology) Inclusion: 1) HIT usability is the primary objective of the study 2) Detailed information related to study methods included Exclusion: 1) Studies describing usability models or frameworks 2) Informatics studies that don't have usability as the main objective (e. g., information-seeking behaviors, computer literacy, evaluations of general or personal digital usage)

	3) Studies evaluating methods or models (HIT is not the focus)
Context	Health information technology (technology and electronic systems that are used to improve health outcomes) Inclusion: 1) Systems used by clinicians for patient care 2) Systems used by patients to manage care 3) Electronic/Medical health records 4) Systems used for public health and/or disease surveillance 5) Systems used for medication administration and/or management 6) Systems used to track the movement of medicine and medical supplies 7) Systems used for patient and clinician education Exclusion: 1) Systems used for research purposes 2) Systems used for bioinformatics 3) Systems used for economics, business, farming
Outcomes	The System Development Life Cycle stage that the study occurs along with the method(s) used at each stage, the usability interaction being evaluated
Frameworks used	Stead's System Development Life Cycle Bennett and Shackel's Usability Model

Note. Protocol adapted from the PROSPERO systematic review protocol registration form (University of York Centre for Reviews and Dissemination, 2016).

Appendix C: Search Strategy

Search Strategy

Electronic Database Search Strings and records retrieved 10/18/2021

PubMed (92 results): (((((((usability[Title/Abstract]) OR (technology acceptance[Title/Abstract])) OR (technology adoption[Title/Abstract])) OR (user acceptance[Title/Abstract])) OR (user satisfaction[Title/Abstract])) OR (ease of use[Title/Abstract])) OR (user centered[Title/Abstract])) OR (user-centered[Title/Abstract]) AND (((((((((health information technolog*[Title/Abstract]) OR (health information system*[Title/Abstract])) OR (mobile health[Title/Abstract])) OR (mhealth[Title/Abstract])) OR (digital health[Title/Abstract])) OR (integrated pharmaceutical logistic system[Title/Abstract])) OR (web-based health information system[Title/Abstract])) OR (electronic health record[Title/Abstract])) OR (ehealth[Title/Abstract])) OR (telemedicine [mh]) AND ((africa[Title/Abstract]) OR (africa [mh])) OR (nigeria[Title/Abstract])) OR (ethiopia[Title/Abstract])) OR (egypt[Title/Abstract])) OR (dr congo[Title/Abstract])) OR (democratic republic of the congo[Title/Abstract])) OR (tanzania[Title/Abstract])) OR (south africa[Title/Abstract])) OR (kenya[Title/Abstract])) OR (uganda[Title/Abstract])) OR (algeria[Title/Abstract])) OR (sudan[Title/Abstract])) OR (south sudan[Title/Abstract])) OR (morocco[Title/Abstract])) OR (angola[Title/Abstract])) OR (ghana[Title/Abstract])) OR (mozambique[Title/Abstract])) OR (madagascar[Title/Abstract])) OR (cameroon[Title/Abstract])) OR (cote d ivoire[Title/Abstract])) OR (niger[Title/Abstract])) OR (burkina faso[Title/Abstract])) OR (mali[Title/Abstract])) OR (malawi[Title/Abstract])) OR (zambia[Title/Abstract])) OR (senegal[Title/Abstract])) OR (chad[Title/Abstract])) OR (somalia[Title/Abstract])) OR (zimbabwe[Title/Abstract])) OR (guinea[Title/Abstract])) OR (rwanda[Title/Abstract])) OR (benin[Title/Abstract])) OR (burundi[Title/Abstract])) OR (tunisia[Title/Abstract])) OR (togo[Title/Abstract])) OR (sierra leone[Title/Abstract])) OR (libya[Title/Abstract])) OR (congo[Title/Abstract])) OR (liberia[Title/Abstract])) OR (central african republic[Title/Abstract])) OR (mauritania[Title/Abstract])) OR (eritrea[Title/Abstract])) OR (namibia[Title/Abstract])) OR (gambia[Title/Abstract])) OR (botswana[Title/Abstract])) OR (gabon[Title/Abstract])) OR (lesotho[Title/Abstract])) OR (guinea-bissau[Title/Abstract])) OR (equatorial guinea[Title/Abstract])) OR (mauritius[Title/Abstract])) OR (eswatini[Title/Abstract])) OR (djibouti[Title/Abstract])) OR (comoros[Title/Abstract])) OR (cabo verde[Title/Abstract])) OR (sao tomo & principe[Title/Abstract])) OR (seychelles[Title/Abstract])

Embase (30 results): ('usability evaluation':ab,ti OR 'technology acceptance':ab,ti OR 'technology adoption':ab,ti OR 'user acceptance':ab,ti OR 'ease of use':ab,ti OR 'user satisfaction':ab,ti OR 'user-centered':ab,ti OR 'usability':ab,ti) AND ('health information system':ab,ti OR 'health information technology':ab,ti OR 'mobile health':ab,ti OR mhealth:ab,ti OR ehealth:ab,ti OR 'digital health':ab,ti OR 'integrated pharmaceutical logistic system':ab,ti OR 'web based health information system':ab,ti OR 'electronic health record':ab,ti) AND ('africa':ab,ti OR 'nigeria':ab,ti OR 'ethiopia':ab,ti OR 'egypt':ab,ti OR 'dr congo':ab,ti OR 'democratic republic of the congo':ab,ti OR tanzania:ab,ti OR 'south africa':ab,ti OR 'kenya':ab,ti OR 'uganda':ab,ti OR 'algeria':ab,ti OR 'sudan south':ab,ti OR 'sudan':ab,ti OR 'morocco':ab,ti) AND 'angola':ab,ti OR 'ghana':ab,ti OR 'mozambique':ab,ti OR 'madagascar':ab,ti OR 'cameroon':ab,ti OR 'cote divoire':ab,ti OR 'niger':ab,ti OR 'burkina faso':ab,ti OR 'mali':ab,ti OR 'malawi':ab,ti OR 'zambia':ab,ti OR 'senegal':ab,ti OR 'chad':ab,ti OR 'somalia':ab,ti OR 'zimbabwe':ab,ti OR 'guinea':ab,ti OR 'rwanda':ab,ti OR 'benin':ab,ti OR 'burundi':ab,ti OR 'tunisia':ab,ti OR 'togo':ab,ti OR 'sierra leone':ab,ti OR 'libya':ab,ti OR 'congo':ab,ti OR 'liberia':ab,ti OR 'central african republic':ab,ti OR 'mauritania':ab,ti OR 'eritrea':ab,ti OR 'namibia':ab,ti OR 'gambia':ab,ti OR 'botswana':ab,ti OR 'gabon':ab,ti OR 'lesotho':ab,ti OR 'guinea bissau':ab,ti OR 'equatorial guinea':ab,ti OR 'mauritius':ab,ti OR 'eswatini':ab,ti OR 'djibouti':ab,ti OR 'comoros':ab,ti OR 'cabo verde':ab,ti OR 'sao tomo & principe':ab,ti OR 'seychelles':ab,ti)

Association for Computing Machinery (963 results): ([[Title: usability] OR [Title: technology acceptance] OR [Title: technology adoption] OR [Title: user acceptance] OR [Title: user satisfaction] OR [Title: ease of use] OR [Title: user-centered]] AND [[Abstract: usability] OR [Abstract: technology acceptance] OR [Abstract: technology adoption] OR [Abstract: user acceptance] OR [Abstract: user satisfaction] OR [Abstract: ease of use] OR [Abstract: user-centered]]) AND ([[Title: health information technology] OR [Title: health information system] OR [Title: mobile health] OR [Title: mhealth] OR [Title: digital health] OR [Title: integrated pharmaceutical logistic system] OR [Title: web-based health information system] OR [Title: electronic health record] OR [Title: ehealth] OR [Title: telemedicine]] AND [[Abstract: health information technology] OR [Abstract: health information system] OR [Abstract: mobile health] OR [Abstract: mhealth] OR [Abstract: digital health] OR [Abstract: integrated pharmaceutical logistic system] OR [Abstract: web-based health information system] OR [Abstract: electronic health record] OR [Abstract: ehealth] OR [Abstract: telemedicine]]) AND ([[Title: africa] OR [Title: nigeria] OR [Title: ethiopia] OR [Title: egypt] OR [Title: dr congo] OR [Title: democratic republic of the congo] OR [Title: tanzania] OR [Title: south africa] OR [Title: kenya] OR [Title: uganda] OR [Title: algeria] OR [Title: sudan] OR [Title: south sudan] OR [Title: morocco] OR [Title: angola] OR [Title: ghana] OR [Title: mozambique] OR [Title: madagascar] OR [Title: cameroon] OR [Title: cote d'ivoire] OR [Title: niger] OR [Title: burkina faso] OR [Title: mali] OR [Title: malawi] OR [Title: zambia] OR [Title: senegal] OR [Title: chad] OR [Title: somalia] OR [Title: zimbabwe] OR [Title: guinea] OR [Title: rwanda] OR [Title: benin] OR [Title: burundi] OR [Title: tunisia] OR [Title: togo] OR [Title: sierra leone] OR [Title: libya] OR [Title: congo] OR [Title: liberia] OR [Title: central african republic] OR [Title: mauritania] OR [Title: eritrea] OR [Title: namibia] OR [Title: gambia] OR [Title: botswana] OR [Title: gabon] OR [Title: lesotho] OR [Title: guinea-bissau] OR [Title: equatorial guinea] OR [Title: mauritius] OR [Title: eswatini] OR [Title: djibouti] OR [Title: comoros] OR [Title: cabo verde] OR [Title: sao tomo & principe] OR [Title: seychelles]] AND [[Abstract: africa] OR [Abstract: nigeria] OR [Abstract: ethiopia] OR [Abstract: egypt] OR [Abstract: dr congo] OR [Abstract: democratic republic of the congo] OR [Abstract: tanzania] OR [Abstract: south africa] OR [Abstract: kenya] OR [Abstract: uganda] OR [Abstract: algeria] OR [Abstract: sudan] OR [Abstract: south sudan] OR [Abstract: morocco] OR [Abstract: angola] OR [Abstract: ghana] OR [Abstract: mozambique] OR [Abstract: madagascar] OR [Abstract: cameroon] OR [Abstract: cote d'ivoire] OR [Abstract: niger] OR [Abstract: burkina faso] OR [Abstract: mali] OR [Abstract: malawi] OR [Abstract: zambia] OR [Abstract: senegal] OR [Abstract: chad] OR [Abstract: somalia] OR [Abstract: zimbabwe] OR [Abstract: guinea] OR [Abstract: rwanda] OR [Abstract: benin] OR [Abstract: burundi] OR [Abstract: tunisia] OR [Abstract: togo] OR [Abstract: sierra leone] OR [Abstract: libya] OR [Abstract: congo] OR [Abstract: liberia] OR [Abstract: central african republic] OR [Abstract: mauritania] OR [Abstract: eritrea] OR [Abstract: namibia] OR [Abstract: gambia] OR [Abstract: botswana] OR [Abstract: gabon] OR [Abstract: lesotho] OR [Abstract: guinea-bissau] OR [Abstract: equatorial guinea] OR [Abstract: mauritius] OR [Abstract: eswatini] OR [Abstract: djibouti] OR [Abstract: comoros] OR [Abstract: cabo verde] OR [Abstract: sao tomo & principe] OR [Abstract: seychelles]])

Appendix D: Description of Included Studies

Author (Schieve et al.)	Country	Study Design	Type of HIT	Sample size	Study Setting	Framework Used	SDLC Stage	Evaluation type
Abejirinde et a. (2018)	Ghana	Multiple Case Study	CDSS: providing patient specific recommendations	• 25 Maternal healthcare workers (HCW)	Multiple	Realist Evaluation	Stage 4, Stage 5	Type 4
Aw et al. (2020)	Kenya	Mixed Methods	CDSS: providing patient specific recommendations	• 1 Community HCW • 124 Community adults	Community	Not reported	Stage 4	Type 4
Azfar et al. (2014)	Botswana	Cross-sectional	Telehealth: Provider patient consultation	• 76 HIV positive adults	Clinic	Not reported	Stage 2	Type 2
Bagayoko et al. (2020)	Gabon	Observational study	Population-based system: Registry	• 2327 Physicians, nurses, midwives, healthcare facility managers, health administrators	Multiple	Information Success Model (ISSM)	Stage 1	Type 1
Barrington et al. (2010)	Tanzania	Pre-Post study	Logistics system: Medical supplies	• 129 Health facilities	Multiple	Not reported	Stage 4	Type 3
Benski et al. (2017)	Madagascar	Cross-Sectional	CDSS: providing patient specific recommendations	• 100 Pregnant women	Clinic	Not reported	Stage 4	Type 4
Brinkel et al. (2017)	Ghana	Qualitative	Population-based system: Disease control system	• 37 Mothers who had used the system for sick children	Hospital	Unified Theory of Acceptance and Use of Technology (UTAUT)	Stage 4	Type 3
Brown & Mickelson (2016)	Rwanda	Case study	Clinical Information System: EHR	• 8 HCW	Community	Not reported	Stage 4	Type 4
Byonanebye et al. (2021)	Uganda	Randomized Control Trial	Patient centered CDSS: focusing attention	• 274 Adults newly diagnosed with drug-susceptible TB	Multiple	Information, Motivation, and Behavioral Skills (IMB) Model	Stage 4, Stage 5	Type 4
Chirambo et al. (2021)	Malawi	Mixed Methods	CDSS: providing patient specific recommendations	• 3 Childhood illness coordinators	Community	Mobile App Rating Scale (MARS)	Stage 5	Type 3

				• 106 Health surveillance assistants				
Coppock et al. (2017)	Botswana	Mixed Methods	Logistics system: Pharmaceuticals	• 14 HIV treatment and research experts	Clinic	Not reported	Stage 3	Type 3
Crehan et al. (2018)	Malawi	Mixed Methods	CDSS: providing patient specific recommendations	• HCW (Sample size not reported)	Hospital	Not reported	Stage 3	Type 3
Crehan et al. (2019)	Malawi	Mixed Methods	CDSS: providing patient specific recommendations	• Development study: 46 HCW • Clinical usability study: 31 HCW	Community	Not reported	Stage 3	Type 4
Desrosiers et al. (2021)	Sierra Leone	Mixed Methods	Training system: Patient	• 8 Community HCW • 4 Supervisors • Community members (sample size not given)	Community	Grounded Theory	Stage 4	Type 3
El-Khatib et al. (2018)	Central African Republic	Mixed Methods	Population-based system: Disease control system	• 21 HCW	Clinic	Not reported	Stage 4	Type 3
Ellington et al. (2021)	Uganda	Qualitative	CDSS: providing patient specific recommendations	• 3 Administrators • 28 HCW	Clinic	Social Ecological Model	Stage 3	Type 3
English et al. (2016)	Uganda	Mixed Methods	CDSS: providing patient specific recommendations	• 30 Pediatric HCW	Multiple	Not reported	Stage 3	Type 3
Ezeanolue et al. (2017)	Nigeria	Mixed Methods	Clinical Information System: EHR	• 300 Pregnant women • 8 Maternal HCW	Multiple	Glasgow's Reach, Effectiveness, Adoption, Implementation, and Maintenance framework	Stage 3, Stage 4	Type 4
Feldacker et al. (2019)	Zimbabwe	Randomized Control Trial	Telehealth: Provider-patient consultation	• 722 Adult males who had a voluntary male circumcision • 8 HCW	Clinic	Not reported	Stage 3, Stage 4	Type 4
Finette et al. (2019)	Burkina Faso	Mixed Methods	CDSS: providing patient specific recommendations	• 163 HCW, ministry of health staff, child caregivers	Clinic	Not reported	Stage 4	Type 3

Fischer et al. (2021)	South Africa	Cross-sectional	Patient centered CDSS: Information management	• 168 Adults who had not had a HIV test in the previous 3 months and did not have a known HIV diagnosis	Community	Not reported	Stage 3, Stage 4, Stage 5	Type 3
Gallay et al. (2017)	Madagascar	Cross-sectional	CDSS: providing patient specific recommendations	• 56 HPV positive women	Clinic	Not reported	Stage 4	Type 2
Gbadamosi et al. (2018)	Nigeria	Mixed Methods	Clinical Information System: EHR	• Design phase: Implementation science researchers, public health consultants, computer scientists and programmers, health workers with HIV programmatic experience (Sample size not given) • 19 HCW with HIV treatment experience	Multiple	Not reported	Stage 1, Stage 3, Stage 4	Type 3
Ginsburg et al. (2015)	Ghana	Mixed Methods	CDSS: providing patient specific recommendations	• 7 Midwives, community health officers, and community health nurses	Clinic	Not reported	Stage 4	Type 4
Ginsburg et al. (2016)	Ghana	Qualitative	CDSS: providing patient specific recommendations	• 9 Health administrations • 30 HCW • 30 Caregivers	Clinic	Grounded Theory	Stage 3, Stage 5	Type 4
Ha et al. (2016)	Botswana	Mixed Methods	Population-based system: Disease control system	• 2 HCW • 378 Patient reports	Community	Not reported	Stage 4	Type 3
Habtamu et al. (2019)	Ethiopia	Cross-sectional	CDSS: providing patient specific recommendations	• 147 Adults with trachomatous trichiasis who received surgical treatment	Clinic	Not reported	Stage 5	Type 2

Heys et al. (2018)	Malawi	Mixed Methods	CDSS: providing patient specific recommendations	• HCW (Sample size not reported)	Hospital	Not reported	Stage 3, Stage 4	Type 3
Hicks et al. (2021)	Nigeria	Mixed Methods	Training system: Provider	• 328 frontline HCW • 34 Facility managers, policy makers, and frontline health workers	Clinic	Technology Acceptance Model	Stage 4	Type 2
Hollander et al. (2020)	South Africa	Mixed Methods	CDSS: providing patient specific recommendations	• 22 Patients anticipating TB treatment with injectable kanamycin or capreomycin • 4 Audiologists • 1 Software engineer • 1 Pharmacist • 1 Medical doctor • 1 Nurse	Hospital	Not reported	Stage 3, Stage 4	Type 4
Ide et al. (2019)	Malawi	Qualitative	CDSS: providing patient specific recommendations	• 28 Caregivers • 17 Health surveillance assistants	Clinic	Consolidated Framework for Implementation Research	Stage 5	Type 4
Ikwunne & Orji (2016)	Nigeria	Mixed Methods	Logistics system: Admission time	• 50 Patients and doctors	Hospital	Queuing Theory	Stage 1, Stage 5	Type 2
Janssen et al. (2020)	South Africa	Qualitative	Telehealth: Provider patient consultation	• 43 Adults who wished to complete HIV self-testing, nurses, medical officers	Clinic	Not reported	Stage 5	Type 2
Jarvis et al. (2019)	South Africa	Randomized Control Trial	Telehealth: Provider patient consultation	• 29 Cognitively intact, socially isolated, or lonely long-term care facility residents	Long-term care facility	Theoretical Framework of Loneliness	Stage 4	Type 2
Kabukye et al. (2017)	Uganda	Mixed Methods	Clinical Information System: EHR	• 12 Doctors, nurses, pharmacists, medical records officers, lab technicians	Hospital	Not reported	Stage 1	Type 1

Kawakyu et al. (2019)	Kenya & Mozambique	Mixed Methods	Clinical Information System: Information system	• 37 Nurse, nurse managers, health facility support staff • 11 Maternal child health experts	Clinic	Nielsen's Usability Framework	Stage 3, Stage 5	Type 3
King et al. (2013)	Ethiopia	Mixed Methods	Population-based system: Population survey	• Needs assessment: Volunteer computer scientists, epidemiologists, and public health program officers (sample size not reported) • 40 Households in Ethiopia	Not specified	Grounded Theory	Stage 4	Type 4
Klingberg et al. (2018)	South Africa	Mixed Methods	Telehealth: Provider patient consultation	• 24 Doctors • 4 Burn consultants	Multiple	Not reported	Stage 5	Type 4
Kruger et al. (2021)	South Africa	Mixed Methods	Population-based system: Registry	• 181 Patient files from a large academic public hospital	Hospital	Technology Acceptance Model	Stage 4	Type 3
Landis-Lewis et al. (2015)	Malawi	Case study	Clinical Information System: EHR	• 39 HCW	Hospital	Consolidated Framework for Implementation Research	Stage 5	Type 4
Liang et al. (2018)	Uganda	Observational study	Clinical Information System: EHR	• 28 HCW who had experience using the EHR	Hospital	Not reported	Stage 5	Type 3
Lim et al. (2015)	South Africa	Mixed Methods	CDSS: providing patient specific recommendations	• 38 Nurses and midwives	Hospital	Not reported	Stage 3, Stage 4	Type 3
Lodhia et al. (2016)	Kenya	Qualitative	CDSS: providing patient specific recommendations	• 8 HCW • 20 Patients receiving ophthalmic evaluations • 4 Community stakeholders	Multiple	Technology Acceptance Model	Stage 4	Type 4

Martin et al. (2020)	Sierra Leone	Mixed Methods	Population-based system: Disease control system	• 41 Electronic disease surveillance users	Multiple	Not reported	Stage 3, Stage 4	Type 4
Martindale et al. (2018)	Ethiopia	Cross-sectional	Population-based system: Disease control system	• 59 Health extension workers	Community	Not reported	Stage 4, Stage 5	Type 2
Mauka et al. (2021)	Tanzania	Pragmatic trial	Patient centered CDSS: focusing attention	• 25 Men who have sex with men • 35 Female sex workers	Community	Information System Framework	Stage 3, Stage 4	Type 4
Mawji et al. (2020)	Kenya & Uganda	Mixed Methods	CDSS: providing patient specific recommendations	• 15 Nurses working in the triage area of pediatric hospitals • 1500 Pediatric patient records	Hospital	Framework Method	Stage 3, Stage 4	Type 3
Morse et al. (2021)	Tanzania	Mixed Methods	CDSS: information management	• 21 Palliative care physicians and nurses • 10 Patients with poor prognosis and their caregivers	Multiple	Human-Centered Iterative Design Framework	Stage 3, Stage 4	Type 3
Muhindo et al. (2021)	Uganda	Mixed Methods	CDSS: providing patient specific recommendations	• 19 Nurses and midwives providing newborn care	Hospital	Proctor framework	Stage 4, Stage 5	Type 4
Musiimenta et al. (2018)	Uganda	Mixed Methods	Patient centered CDSS: focusing attention	• 63 HIV positive individuals • 41 Patient-identified social supporters	Community	Unified Theory of Acceptance and Use of Technology (UTAUT)	Stage 4	Type 3
Mwaisaka et al. (2021)	Kenya	Qualitative	Training system: Patient	• 15 Teenage males, 15 Teenage females from areas with the highest prevalence of teen pregnancy	Community	Not reported	Stage 5	Type 3
Ngabo et al. (2012)	Rwanda	Mixed Methods	Adverse event reporting	• 432 Community HCW	Multiple	Not reported	Stage 4, Stage 5	Type 2
Nhavoto et al. (2015)	Mozambique	Mixed Methods	Patient centered CDSS: focusing attention	• 3 Informatics students	Hospital	Design Science Research (DSR) Framework	Stage 1, Stage 3, Stage 4	Type 4

				• 2 Doctors with HIV and TB treatment experience • 5 Healthcare sites that provide routine HIV/TB care				
Nhavoto et al. (2017)	Mozambique	Mixed Methods	Patient centered CDSS: focusing attention	• 69 Patients diagnosed with TB • 72 Patients diagnosed with HIV • 40 HCW	Hospital	Not reported	Stage 4	Type 3
Nyumbeka & Wesson (2014)	South Africa	Mixed Methods	Clinical Information System: Information system	• 6 Dieticians	University/ Academia	Not reported	Stage 3	Type 3
Otu et al. (2021)	Nigeria	Pre-Post study	Training system: Provider	• 627 HCW	Multiple	Not reported	Stage 4	Type 3
Oyetunde et al. (2019)	Nigeria	Mixed Methods	Logistics system: Pharmaceuticals	• 326 Community pharmacists	Not specified	Technology Acceptance Model	Stage 5	Type 3
Oza et al. (2019)	Sierra Leone	Mixed Methods	Clinical Information System: EHR	• 16 HCW • 456 Ebola patient records	Hospital	Not reported	Stage 1, Stage 4, Stage 5	Type 4
Qin et al. (2013)	Kenya	Modified intraobserver concordance study	Telehealth: Provider patient consultation	• 102 Patients from a rural region in Kenya • Nurses (sample size not reported)	Community	Not reported	Stage 4	Type 2
Sabben et al. (2019)	Kenya	Randomized Control Trial	Training system: Patient	• 60 Adolescents • 22 Parents	Community	Technology Acceptance Model	Stage 4	Type 3
Sarfo et al. (2018)	Ghana	Prospective, single arm pre-post study	Telehealth: Provider patient consultation	• 20 Stroke survivors	Community	Not reported	Stage 4	Type 4
Shiferaw et al. (2016)	Ethiopia	Non-randomized controlled trial	CDSS: focusing attention	• 15 Maternal child health nurses and health officers • 514 Pregnant women • 1224 Pregnant women health records	Hospital	Not reported	Stage 4	Type 2

Thomas et al. (2020)	Tanzania	Pre-Post study	Clinical Information System: Information system	• 11 Healthcare dispensary workers • 9 HCW	Multiple	Diffusion of Innovation Theory	Stage 4	Type 4
Thomsen et al. (2019)	Ethiopia	Mixed Methods	Training system: Provider	• 56 Midwives, nurses, and health extension workers	Community	Not reported	Stage 5	Type 4
Underwood et al. (2013)	Kenya	Mixed Methods	Clinical Information System: Documentation system	• 95 Nursing students • 50 Nurses	Multiple	Not reported	Stage 3, Stage 4	Type 2
Van Heerden et al. (2013)	South Africa	Qualitative	Telehealth: Provider patient consultation	• 540 Pregnant women living with HIV	Community	Technology Acceptance Model	Stage 4	Type 4
Vanosdoll et al. (2019)	Uganda	Mixed Methods	Clinical Information System: Information system	• 32 Mothers with newborns • 12 Community HCW	Community	Community Health Worker-Coordinated Phone-Sharing Framework	Stage 3	Type 3
Vedanthan et al. (2015)	Kenya	Mixed Methods	CDSS: providing patient specific recommendations	• 5 Nurses	Clinic	Not reported	Stage 3, Stage 4	Type 4
Vélez et al. (2014)	Ghana	Mixed Methods	Clinical Information System: Information system	• 7 Midwives	Community	Not reported	Stage 3, Stage 4	Type 4
Velloza et al. (2019)	Kenya	Mixed Methods	Training system: Patient	• 74 Heterosexual HIV serodiscordant couples with immediate pregnancy desires • 5 HCW	Multiple	Not reported	Stage 4	Type 4
Weierstall et al. (2021)	Burundi	Mixed Methods	CDSS: providing patient specific recommendations	• 463 Burundi soldiers who had spent a year on a military mission in Somalia	Community	Not reported	Stage 4	Type 2
Zeleke et al. (2019)	Ethiopia	Randomized controlled crossover	Population-based system: Population survey	• 12 Data collectors • 1246 Community health records	Health Department/ Dataset	Not reported	Stage 4	Type 4

Appendix E: Availability of Critical Obstetric Emergency Supplies

Category	Type	Specific Tracer Item	%	n [a]
Consumables and **Durables**	Consumable Supplies	Gloves, Aseptic	35%	7
		IV Fluid [b]	95%	19
		IV Kit [c]	100%	20
	Durable Goods and Infrastructure	Manual Vacuum Aspirator (MVA)	100%	20
		Light source [d]	80%	16
Drugs	Uterotonic: First Line	Parenteral oxytocin	95%	19
	Uterotonic: Alternatives	Oral misoprostol	55%	11
		Parenteral ergometrine	80%	16
		Oxytocin or misoprostol	95%	19
		Any uterotonic [e]	95%	19
	Antibiotic 1: First Line	Parenteral ampicillin	95%	19
	Antibiotic 1: Alternative	Any parenteral penicillin[f]	5%	1
		Ampicillin or any parenteral penicillin	95%	19
	Antibiotic 2: First Line	Parenteral gentamicin	35%	7
	Anticonvulsant: First Line	Parenteral magnesium sulfate	100%	20
	Anticonvulsant: Alternative	Parenteral diazepam	45%	9
Protocols - Algorithms	Medical Treatments	Hemorrhage	35%	7
		Eclampsia	75%	15
		Infection-Sepsis	0%	0
	Manual Procedures	Retained Placenta	15%	3
		Incomplete Abortion	15%	3
	General	Obstetric Emergency Manual	60%	12

[a]n=20 facilities

[b]Either normal saline (NS) or lactated ringer's (LR)

[c]IV cannula

[d]functional electric lights and electricity or flashlights

[e]Presence of one or more of the following parenteral drugs: oxytocin, misoprostol, ergotomine

[f]Parenteral ampicillin or any parenteral penicillin alternative (benzathine, procaine or crystalline

Appendix F: Comparison of Emergency Readiness Using Signal Function Tracer Items and Clinical Cascades

Clinical Cascade	Signal Functions	Clinical Cascades	Overestimated Readiness
(Signal Function)	*% Readiness, Tracer Items*	*% Readiness, Stage 2*	*[Signal Function (-) Cascade]*
Medical Treatments			
Manage Sepsis- Infection *(Antibiotic)*	91%	50.0% (n=10)	41.0%
Manage Hemorrhage *(Oxytocic)*	96%	75.0% (n=15)	21.0%
Manage Hypertensive Emergency *(Anticonvulsant)*	98.8%	85.0% (n=17)	13.8%
Medical Readiness, Pooled Mean	**95.3%**	**70.0%**	**25.3%**
Manual Procedures			
Manage Retained Placenta *(Manual removal of retained placenta)*	90.7%	30.0% (n=6)	60.7%
Manage Incomplete Abortion *(Manual removal of retained products of conception)*	90.7%	65.0% (n=13)	25.7%
Manage Prolonged Labor (*Assisted Vaginal Deliver)*	90%	75.0% (n=15)	15.0%
Manual Readiness, Pooled Mean	**90.5%**	**56.7%**	**33.8%**
Overall Pooled Mean Readiness	**92.9%** *Signal Function Estimate*	**63.3%** *Cascade Estimate*	**29.6%** *% Overestimated Readiness by Signal Functions*

[a]n=20 facilities

[b]The total number and percentage of facilities out of 20 that do have the readiness to treat the specified emergency

Appendix G: Use-Cases

Use Case Number	1
Use Case	Local Level
Actor	Inventory manager
Description	1. The individual will be able to identify if their facility is ready to manage obstetric emergencies 2. If not ready, the individual will be able to identify which supplies/medicine is needed
Trigger	Current inventory data will be reported on IPLS
Normal Flow	1. IPLS will send the data to the prototype 2. Prototype will receive inventory data from IPLS 3. Prototype will calculate/ingest individual facility readiness for each of the 6 most common obstetric emergencies 4. Prototype will calculate/ingest overall facility readiness to manage obstetric emergencies 5. The individual will log onto prototype (either a standalone dashboard or incorporated into IPLS or the master facility registry) 6. The local individual will see the main screen 7. Main screen will provide a map overview of the Amhara region 8. The local individual can click on the map to enlarge areas or move around on the map 9. From the map the local individual can click on individual healthcare facilities 10. Clicking on individual healthcare facilities will provide the scores generated at steps 4 and 5 11. The local individual can click on a specific emergency to see individual supply levels 12. Individual supply level lists will be available for viewing 13. If supplies are missing or low the local individual will be prompted to order supplies 14. The local individual can also click on an item to order (if not prompted) 15. The prototype will direct the local individual to the IPLS for ordering supplies

Use Case Number	2
Use Case	Regional Level Distribution
Actor	Regional Health Planner/Distributor
Description	1. The individual will be able to identify the facilities in Amhara that are not ready to manage obstetric emergencies 2. If not ready, the individual will be able to identify which emergency and supplies/medicine are needed
Trigger	Current inventory data will be reported on IPLS
Normal Flow	1. IPLS will send the data to the prototype 2. Prototype will receive inventory data from IPLS 3. Prototype will calculate/ingest individual facility readiness for each of the 6 most common obstetric emergencies 4. Prototype will calculate/ingest overall facility readiness to manage obstetric emergencies 5. The regional individual will log onto prototype (either a standalone dashboard or incorporated into IPLS or the master facility registry) 6. The regional individual will see the main screen 7. Main screen will provide a map overview of the Amhara region 8. The regional individual can click on the map to enlarge areas or move around on the map 9. From the map the regional individual can click on individual healthcare facilities 10. Clicking on individual healthcare facilities will provide the scores generated at steps 4 and 5 11. The regional individual can click on a specific emergency to see individual supply levels 12. Individual supply level lists will be available for viewing 13. If supplies are missing or low the local individual will be prompted to ship supplies (or notify the health facility they are running low) 14. The regional individual can also click on an item to ship (or create a message to send to the facility) 15. The prototype will direct the regional individual to the IPLS for shipping supplies

Use Case Number	3
Use Case	Government/Ministry of Health
Actor	Regional or federal employee of the health ministry
Description	1. The individual will be able to identify overall regional readiness to manage obstetric emergencies 2. The individual will be able to pinpoint the emergency/area least prepared to manage obstetric emergencies
Trigger	Current inventory data will be reported on IPLS
Normal Flow	1. IPLS will send the data to the prototype 2. Prototype will receive inventory data from IPLS 3. Prototype will calculate/ingest individual facility readiness for each of the 6 most common obstetric emergencies 4. Prototype will calculate/ingest overall facility readiness to manage obstetric emergencies 5. The individual will log onto prototype (either a standalone dashboard or incorporated into IPLS or the master facility registry) 6. The ministry of health individual will see the main screen 7. Main screen will provide a map overview of the Amhara region 8. The ministry of health individual can click on the map to enlarge areas or move around on the map 9. From the map the ministry of health individual can click on individual healthcare facilities 10. Clicking on individual healthcare facilities will provide the scores generated at steps 4 and 5 11. The ministry of health individual will be able to print or create electronic copies of the readiness calculations displayed in step 10

Appendix H: Codebook

Code/Domain	Subcodes	Definition	When to apply	When not to apply
Hardware and Software	General	The digital infrastructure and equipment used to operationalize the clinical application explored	• When participants describe the physical equipment and digital programs needed to accomplish tasks related to monitoring facility readiness to manage obstetric emergencies	• When participants describe components outside of the digital infrastructure or physical equipment needed to monitor facility readiness to manage obstetric emergencies
	Facilitator		• When participants describe physical equipment and digital programs that make it easier for them to monitor facility readiness to manage obstetric emergencies	• When participants describe components outside of the digital infrastructure or physical equipment needed to monitor facility readiness to manage obstetric emergencies • When participants describe the digital infrastructure or physical equipment and how make it harder to accomplish their tasks
	Barrier		• When participants describe physical equipment and digital programs that make it harder for them to monitor facility readiness to manage obstetric emergencies	• When participants describe components outside of the digital infrastructure or physical equipment needed to monitor facility readiness to manage obstetric emergencies • When participants describe the digital infrastructure or physical equipment and how they make it easier to accomplish their tasks

Clinical Content	General	The categorical or numerical data and images that make up the "language" of the clinical application	• When participants describe the data, images, and labels needed to develop the language of the clinical application	• When participants describe things beyond the data, images, and labels needed to develop the language of the clinical application
	Facilitator		• When participants describe data, images, and labels that make it easier to develop and/or understand the language of the clinical application	• When participants describe things beyond the data, images, and labels needed to develop the language of the clinical application • When participants describe the data, images, and labels that make it harder to develop and/or understand the clinical application
	Barrier		• When participants describe data, images, and labels that make it harder to develop and/or understand the language of the clinical application	• When participants describe things beyond the data, images, and labels needed to develop the language of the clinical application • When participants describe the data, images, and labels that make it easier to develop and/or understand the language of the clinical application
Human-Computer Interface	General	All aspects of the digital application that the user can see, touch, hear, or manipulate	• When participants are describing the things that they can see, touch, hear, or manipulate within the digital application	• When participants describe components outside of those that they can see, touch, hear or manipulate
	Facilitator		• When participants describe how the components that they can see, touch, hear, or manipulate make it easier to accomplish their tasks	• When participants describe components outside of those that they can see, touch, hear or manipulate • When participants describe how the components that they can see, touch, hear, or manipulate make it harder to accomplish their tasks

	Barrier		• When participants describe how the components that they can see, touch, hear, or manipulate make it harder to accomplish their tasks	• When participants describe components outside of those that they can see, touch, hear or manipulate • When participants describe how the components that they can see, touch, hear, or manipulate make it easier to accomplish their tasks
People	General	The application users from the developers of the health information technology (HIT) to the end-users	• When participants describe the people who use or are expected to use the HIT	• When participants describe things unrelated to the people who use or are expected to use the HIT
	Facilitator		• N/A	• N/A
	Barrier		• N/A	• N/A
Workflow & Communication	General	The necessary steps that a user must accomplish to complete the task successfully and effectively	• When participants describe the steps they have to accomplish to successfully complete their tasks	• When participants describe things beyond the steps necessary to accomplish tasks successfully
	Facilitator		• When participants describe the steps that make it easier to complete their tasks	• When participants describe things beyond the steps necessary to accomplish tasks successfully • When participants describe the steps that make it harder to complete their tasks
	Barrier		• When participants describe the steps that make it harder to complete their tasks	• When participants describe things beyond the steps necessary to accomplish tasks successfully • When participants describe the steps that make it easier to complete their tasks
Internal Organizational Features	General	The policies, procedures, and culture within the specific organization using the technology	• When participants describe the policies, procedures, rules, and cultures within their own organization that relate to using HIT	• When participants describe things outside of the policies, procedures, rules, and cultures of their own organization that relate to using HIT

				• When participants describe the policies, procedures, rules, and cultures outside of their organization that relate to using HIT
	Facilitator		• When participants describe the policies, procedures, rules, and cultures within their own organization that make it easier for them to use HIT	• When participants describe things outside of the policies, procedures, rules, and cultures of their own organization that relate to using HIT • When participants describe the policies, procedures, rules, and cultures outside of their organization that relate to using HIT • When participants describe the policies, procedures, rules, and cultures within their own organization that make it harder for them to use HIT
	Barrier		• When participants describe the policies, procedures, rules, and cultures within their own organization that make it harder for them to use HIT	• When participants describe things outside of the policies, procedures, rules, and cultures of their own organization that relate to using HIT • When participants describe the policies, procedures, rules, and cultures outside of their organization that relate to using HIT • When participants describe the policies, procedures, rules, and cultures within their own organization that make it easier for them to use HIT
External Rules and Regulations	General	The policies, procedures, and culture within the larger geographical area where the HIT is located	• When participants describe the policies, procedures, rules, and cultures outside of their	• When participants describe things not related to the policies, procedures, rules, and cultures outside of their

			organization that relate to using HIT	organization that relate to using HIT • When participants describe the policies, procedures, rules, and cultures within their own organization that relate to using HIT
	Facilitator		• When participants describe the policies, procedures, rules, and cultures outside of their organization that make it easier to use HIT	• When participants describe the policies, procedures, rules, and cultures within their own organization that relate to using HIT • When participants describe the policies, procedures, rules, and cultures outside of their organization that make it harder to use HIT
	Barrier		• When participants describe the policies, procedures, rules, and cultures outside of their organization that make it harder to use HIT	• When participants describe the policies, procedures, rules, and cultures within their own organization that relate to using HIT • When participants describe the policies, procedures, rules, and cultures outside of their organization that make it easier to use HIT
Measuring and Monitoring	General	The evaluation process and method of measuring the effectiveness of HIT, including both intended and unintended consequences	• When participants describe the evaluation process for exploring the effectiveness and usefulness of HIT along with the intended and unintended consequences of the technology	• When participants discuss things unrelated to the evaluation process for exploring the effectiveness and usefulness of HIT including intended and unintended consequences
	Facilitator		• When participants describe useful evaluation processes for exploring the effectiveness and usefulness of HIT	• When participants discuss things unrelated to the evaluation process for exploring the effectiveness and usefulness of HIT including

			• When participants describe the positive intended and unintended consequences of the technology	intended and unintended consequences • When participants describe difficult or hard to use evaluation processes for exploring the effectiveness and usefulness of HIT • When participants describe the negative consequences of the technology
	Barrier		• When participants describe difficult or hard to use evaluation processes for exploring the effectiveness and usefulness of HIT • When participants describe the negative consequences of the technology, including those that were unintended	• When participants discuss things unrelated to the evaluation process for exploring the effectiveness and usefulness of HIT including intended and unintended consequences • When participants describe useful evaluation processes for exploring the effectiveness and usefulness of HIT • When participants describe the positive consequences of the technology

Appendix I: Qualitative Interviews Guide

PROTOCOL TITLE: Creation of an Electronic Dashboard to Enhance the Obstetrics

Emergency Supply Chain in Amhara, Ethiopia

The purpose of this interview is to explore the causes of obstetric emergency supply stockouts, Amhara's current health system approaches to restocking these supplies, and information flow dynamics that impact ordering and shipping of obstetric emergency medical supplies. We are interested in hearing your opinions and learning about your personal experiences. There are no right or wrong answers, we are interested in your honest opinion, and everything you say during this interview will be kept confidential.

1. What is your DOB?
2. What is your job title?
3. Years of experience working with Ethiopia's EPPS?

4. Can you describe your process for ordering (or shipping) obstetric emergency supplies? (Barriers and facilitators in the process, how often it occurs, who does this task, was there any training, decision making process)
5. What do you see as the major challenges to having the right supplies on hand to deal with obstetric emergencies when they occur? (Communication breakdowns, frequently unable to obtain certain items, computers available and/or consistent wifi)
6. What are your impressions of the paper-based supply request system? (Likes, dislikes, barriers and facilitators for use, areas of improvement)
7. Can you describe your experience using the IPLS system? (Likes, dislikes, barriers and facilitators for use, areas of improvement, training if it occurred)
8. What type of data would make healthcare facilities more effective at requesting the appropriate around of medical supplies?
9. What are the most important things to consider when determining where and how much supply you (federal/regional) ship out?
10. Do you find the current dashboards useful for your task completion? Please explain
11. Is there anything else that you'd like me to know about the topics that we've discussed today that I didn't ask about?

የጥናቱ ርዕስ፡ የነፍሰቱር እናቶች እና በማህጸን ውስጥ ያሉ ህጻናት ድንገተኛ የጤና እክል ህክምና የአቅርቦት ሰንሰለትን ለማሻሻል የሚረዳ የኤሌክትሮኒክ ዳሽቦርድ መፍጠር በአማራ ክልል፤ ኢትዮጵያ።

የዚህ ቃለ መጠይቅ አላማ የነፍሰጡር እናቶች እና በማህጸን ውስጥ ያሉ ህጻናት ድንገተኛ የጤና እክል ህክምና አቅርቦት ጋር በተያያዘ የክምችት እጥረት መንስኤዎችን እና የአቅርቦቶችን እጥረት ለማስተካከል የአማራ ክልል ወቅታዊ የጤና ስርዓት ሁኔታ ምን እንደሚመስል የሚያጠና ነው። በተጨማሪም ለእናቶች እና በማህጸን ውስጥ ያሉ ህጻናት ድንገተኛ ህክምና የሚውሉ ግብአቶች የአቅርቦት እዝ እና ማጓጓዝ ላይ ተፅእኖ ሊኖራቸው የሚችሉ ተለዋዋጭ የመረጃ ፍሰት ሁኔታዎችንም የሚዳሰስ ነው። የእርስዎ ልምድ እና አስተያየት ለዚህ ጥናት በጣም አስፈላጊ ነው። በዚህ ጥናት ትክክለኛ ወይም የተሳሳተ የሚባል መልስ የለም፣ የርስዎን ያመኑበትን መልስ ብቻ እንዲሰጡን እንፈልጋለን። በቃለ መጠይቁ የሚነሱ ማንኛውም ሀሳቦች በሚስጥር እንደሚያዙ ለማሳወቅ እንወዳለን። ለሚሰጡን ሀሳብም ከወዲሁ እናመሰኛለን።

1. የትውልድ ቀን ወይም የተወለዱበት ቀን እና ዓመተ ምህረት መቼነው?
2. የስራ ድርሻዎ መንድን ነው?
3. በኢትዮጵያ የፋርማሲዩቲካል አቅርቦት አገልግሎት (EPSS) ስር በመስራት የምን ያህል አመት የሥራ ልምድ አለዎት?
4. ለእናቶች እና በማህጸን ውስጥ ላሉ ህጻናት ለድንገተኛ የጤና እክል ህክምና የሚውሉ እቃዎችን የማዘዝ (ወይም የማጓጓዝ) ሂደቱን እስኪ ይነገሩኝ? (በሂደቱ ውስጥ ያሉ መሰናክሎች እና ምቹ ሁኔታዎች ምንድን ናቸው? ለምሳሌ መሰናክሎች ምን ያህል ጊዜ እንደሚከሰቱ፤ ይህ የማዘዝ (ወይም የማጓጓዝ) ስራ በማን እንደሚከናወን፣ ይህንን ስራ ለሚሰሩ ሰዋችስ ስልጠና ተሰጥቶ የሚያውቅ እንደሆነ፣ የዚህ ስራ የውሳኔ አሰጣጥ ሂደቱስ ምን እንደሚመስል)
5. የእናቶች እና በማህጸን ውስጥ ያሉ ህጻናት ድንገተኛ የጤና እክል በሚገጥምበት ጊዜ ከህክምናው ጋር በተያያዘ በትክክል የሚያስፈልጉ አቅርቦቶችን (ግባቶችን) በማቅረብ (በማግኘት) ሂደት ውስጥ ዋና ዋና ተግዳሮቶት ምን ምን ናቸው? (የመገናኛ ዘዴዎች ብልሽት፣ የአንዳንድ እቃዎች ገበያ ላይ ሁሌ ያለመገኘት፣ የኮምፒውተር አለመኖር እና/ወይም ወይም ዋይፋይ በቋሚነት አለመኖር)
6. በወረቀት ላይ በተመሰረተውን የግባቶች የአቅርቦት ጥያቄ ስርዓት ላይ ምን አይነት አመለካከት/አስተያየት አለዎት? (በወረቀት ላይ በተመሰረተውን የግባቶች የአቅርቦት ጥያቄ ስርዓትን በተመለከተ የሚወዱት ነገር መንድን ነው፣ የማይወዱት/ያልተመቾትስ ነገር ምንድን ነው፣ ተግዳሮቶቹ እና መሻሻል ያለባቸውስ ነገሮች ምንድን ናቸው)
7. የተቀናጀ የፋርማሲዩቲካል አቅርቦት አገልግሎት ስርዓትን (IPLS system) በመጠቀም ያልዎትን ልምድ ቢገልጹ? (IPLS system ወስጥ የሚወዱት ነገር መንድን ነው፣ የማይወዱት/ያልተመቾትስ ነገር ምንድን ነው፣ ተግዳሮቶቹ እና መሻሻል ያለባቸውስ ነገሮችስ ምንድን ናቸው ፤ የወሰዱት ወይም የተሰጡ ስልጠናዎችስ አሉ)
8. በትክክል የሚያስፈልጉትን የከህክምና ግባቶችን አቅርቦት መጠየቅ ጋር በተያያዘ የጤና ተቋማትን የበለጠ ውጤታማ የሚያደርጉት ምን ምን አይነት መረጃዋች ናቸው ብለው ያስባሉ?
9. እናንተ (የፌዴራል ወይም የክልል ተቋማት) የህክምና ግባቶችን መቼ እና ምን ያህል መላክ እንዳለባቸሁ ስትወስኑ ከግምት ማስገባት ያለባቸሁ በጣም አስፈላጊ ነገሮች ምንድን ናቸው?
10. አሁን ያሉት ዳሽቦርዶች ስራዎን በአግባቡ ለመከወን ጠቃሚ ናቸው ብለው ያስባሉ? እባክዎን ያብራሩ?
11. እስካሁን በተነጋገርነው ርዕሰ ጉዳዮች ላይ ያልተነሱ ብለው የሚስቡት ተጨማሪ ሀሳብ ካለ እባክዎ ያክሉ?

Appendix J: User-Centered Design Session Guide

Obstetric Emergency Dashboard Design
Session Guide

Good morning/afternoon/evening. Thank you for being here today. My name is __________ and my role in this project is ________. This is my colleague ____________. S/he will be making notes about our conversation. We are studying ways to create a visualization dashboard to monitor obstetric emergency readiness at the regional and individual healthcare facility level. This study is funded by the National Institute of Nursing Research and Fulbright US Student Program.

For group sessions:
Our discussion should last between an hour and a half and two hours. I will be helping to guide the discussion and make sure everybody has a chance to speak but every person does not have to answer every question. As described in the information sheet that you all reviewed, we will be audio-recording our conversation to make sure that we fully capture the opinions that you express.

For individual sessions:
Our discussion should last between an hour and an hour and a half. I will have a series of questions for you but if there's anything you don't want to discuss, we can skip it. As described in the inform sheet you reviewed, we will be audio recording our conversation to make sure that we fully capture your opinions and reactions.

We will show you a series of images and ask you a few questions about them. In general, we are interested in knowing

1) what you think we are trying to communicate with the images,
2) what parts of the image helps you understand what we are trying to convey?
    - Probes: colors, length of bars, familiarity with the icon, display order
3) which images you prefer and why,
4) how the images can be improved, and
5) what actions you might take as a result of seeing the images.

There are no right or wrong answers to the questions that we will ask. We want your honest opinions. If something is confusing or you don't like it – that's exactly the kind of thing we want to know so that we can make it better. We want you to feel comfortable expressing your opinions. To help make that possible, can we agree to keep everything that is said here confidential? I'm going to start the recording now.

For groups sessions:

Let's start off with introducing ourselves. You can use your real name or a fake name, whichever you like. Take a moment to write down the name you would like to use on the name card in front of you and then tell it to the group. As we get started, please remember not to interrupt anyone and try to give everyone a chance to speak.

For individual sessions:

For this discussion, you can use your real name or a fake name, whichever you like. What would you like me to call you?

For each image:

- What information do you think we are trying to convey with this image? What does it mean to you?
- What is your reaction to seeing this information? If this was your information, what would you think or do?

After small groups of similar images:

- Which of the images do you prefer? [Use a voice or hand vote for groups]
- Why is that your preference?
- How can the images be improved?

Closing

- Is there anything else we should have asked you?

I would like to remind you that we agreed to everything we heard here today confidential. Thanks again for joining us today!

በእርግዝና ወቅት ለሚከሰቱ ድንገተኛ የጤና ችግሮች የዳሽቦርድ ንድፍ የጥናት መጠይቅ

እንደምን አደራችሁ/ዋላችሁ/አመሻችሁ፡ ለጊዜዎ ከወዲሁ እያመሰገንኩ ስሜ_   ሲሆን በዚህ ፕሮጀክት ውስጥ ያለኝ የስራ ድርሻ ---------- ነው፡፡ አብራኝ/አብሮኝ ያለችው/ያለው የስራ ባልደረባዬ የቃለ መጠይቁን ጭብጥ በማስታወሻ መልክ በመያዝ ያግዙናል፡፡ በክልልሉ እና በክልሉ ስር ባሉ የጤና እንክብካቤ ተቅዋማት ውስጥ በእርግዝና ወቅት ለኢከሰቱ ድንገተኛ የጤና ችግሮች ዝግጁነትን ለመከታተል ይረዳ ዘንድ የእይታ ዳሽቦርድ ለማዘጋጀት የተለያዩ መንገዶችን እያጠናን እንገኛለን፡፡ ይህ ጥናቱም በብሄራዊ የነርሶች ጥናት እና ምርምር ተቀምና በፋልብራይት ዩኤስ ተማሪዎች ፕሮግራም የሚደገፍ ነው፡፡

ለቡድን ውይይት

ውይይታችን ከአንድ ሰዓት ተኩል እስከ ሁለት ሰዓት ሊወስድ ይችላል። ውይይቱን በመምራት እኔ አብሬያችሁ የምቆይ ሲሆን ሁሉም የውይይቱ ተሳታፊ የመናገር እድል እንዳለው አረጋግጣለሁ ነገር ግን እያንዳንዱ ተሳታፊ ለእያንዳንዱ ጥያቄ መልስ መስጠት አይጠበቅበትም። በተመለከታችሁት መጠይቅ ላይ እንደተገለጸው እርስዎ የሚገልጹትን አስተያየት ሳይሸራረፍ በሙሉ ለመያዝ ይረዳ ዘንድ መቅረጸ-ድምጽ እንደምንጠቀም ከወዲሁ ለማሳወቅ እንወዳለን፡፡

ለግለሰብ ውይይት

ውይይታችን ከአንድ ሰዓት እስከ ግማሽ ሰዓት ሊወስድ ይችላል፡ በቆይታችን ተከታታይ ጥያቄዎችን የማነሳ ሲሆን መመለስ የማይፈልጉት ማንኛውም ጥያቄ ካለ መዝለል ይችላሉ፡፡ በመጠይቁ ላይ እንደተገለጸው እርስዎ የሚገልጹትን አስተያየት ሳይሸራረፍ በሙሉ ለመያዝ ይረዳ ዘንድ መቅረጸ-ድምጽ እንደምንጠቀም ከወዲሁ ለማሳወቅ እንወዳለን፡፡

ተከታታይ ምስሎችን በማሳየት ስለምስሎቹ ጥቂት ጥያቄዎችን እንጠይቅዎታለን። በዋነኛነት እኛ ማወቅ የምንፈልገው :-

በእነዚህ ምስሎቹ ምን አይነት መልክት ለማስተላለፍ እንደፈለግን ይገማታሉ6?

1) የትኞቹን ምስሎች እንደሚመርጡ እና ለምን እንደመረጡ ቢገልጹ?
2) ምስሎቹን እንዴት ማሻሻል ይቻላል?
3) ምስሎቹን በማየት ምን አይነት እርምጃዎችን ሊውሰድ ይችላሉ?

ለምንጠይቃቸው ጥያቄዎች ትክክለኛ ወይም የተሳሳቱ የሚባሉ ምላሾች የሉም። ከልብ የመነጨ አስተያየቶችዎን እንዲሰጡን እንጠይቃለን። በመሆኑም በመጠይቁ ውስጥ ግራ የሚያጋባ ወይም ያልተመችዎት ነገር ካጋጠምዎ እኛ በዋነኛነት ይሂንኑ አይነት ነገር ስለምንፈልግ ነው ምክንያቱም የኛ የትኩረት አቅጣጫ እሱን የተሻለ ማድረግ ስለሆነ፡፡ አስተያየትዎን ለመግለጽ ምቾት እንዲሰማዎት እንፈልጋለን፡ ይህ ይሆን ዘንድም በቃለ መጠይቁ የሚያነሱትን ማንኛውንም ሀሳብ በሚስጥር እንደምንይዝ ለማሳወቅ እንወዳለን። አሁን ቃለመጠይቁን በመቅረጸ ድምጽ መቅረጽ እጀምራለሁ:-

ለቡድን ውይይት

እራሳችንን በማስተዋወቅ እንጀምር: የፈለጉትን ማለትም እውነተኛ ወይም ሀሰተኛ ስም መጠቀም ይችላሉ። ጊዜ

ለተናጠል ውይይት

ለዚህ ውይይት፣ የፈለጋችሁትን ትክክለኛ ወይም ሀሰተ ስም መጠቀም ትችላላችሁ። ማን ብዬ እንድጠራዎ ይፈልጋሉ? በመውሰድ ለመጠቀም ያሰቡትን ስም በካርዱ ላይ በማስፈር ለቡድኑ ያስተዋውቁ ፡፡

ለእያንዳንዱ ምስል:

- ከዚህ ምስል ጋር በተያያዘ ምን አይነት መልዕክት ማስተላለፍ የተፈለገ ይመስሎታል? ምስሉ ለርስዎ ምን እንድምታ/መልዕክት ምላሽ ሰጡ? ይህ የእርስዎ መረጃ ከሆነ ምን ያስባሉ ወይም ያደርጋሉ?

ከጥቂት ተመሳሳይ ብድኖች ምስሎች በኋላ:

- ከምስሎቹ ውስጥ የትኛውን ነው የሚመርጡት? [ለቡድኖች የድምጽ ወይም የእጅ ድምጽ ይጠቀሙ]
- ለምንድን ነእ ያ ምርጫዎ የሆነው?
- ምስሎችን እንዴት ማሻሻል ይቻላል?

መዝጊያ

- ተጨማሪ ልንነጋገርነት የሚገባ ለሚሉት ሀሳብ ካለዋት እባክዎ ያክ?

በዚህ ጥናት ስለተሳተፉ እያመሰገንኩ በቃለ መጠይቁ የተነሱትን ሀሳቦች ሁሉ በሚስጥር እንደምንይዝ ለማስታወስ እንወዳለን፡፡

Appendix K: Heuristic Usability Survey

1. Visibility of System Status

The system should always keep user informed about what is going on, through appropriate feedback within reasonable time.

I. Please select your response for the individual items related to this usability factor:

#	Usability Factor	Response	Comments
1.1	Does every screen have a title or header that describes its content?	• Yes • No • NA	
1.2	Is there visual feedback in menus or dialog boxes about which choices are selectable?	• Yes • No • NA	
1.3	Is there a clear indication of the current location?	• Yes • No • NA	
1.4	Is the menu-naming terminology consistent with the user's task domain?	• Yes • No • NA	
1.5	Does the system provide *visibility*: that is, by looking, can the user tell the state of the system and the alternatives for action?	• Yes • No • NA	

II. Please select the overall severity rating for this usability factor:

No usability Problem	Cosmetic Problem Only	Minor Usability Problem	Major Usability Problem	Usability Catastrophe
0	1	2	3	4

III. If you have other comments, please specify.

2. Match between System and the Real World

The system should speak the user's language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.

I. Please select your response for the individual items related to this usability factor:

#	Usability Factor	Response	Comments
2.1	Are the section headings and sub-sections in each screen ordered in the most logical way?	• Yes • No • NA	
2.2	Is there a natural sequence to the menu choices for a data item?	• Yes • No	

		• NA	
2.3	Are all the words/concepts and phrases used in each screen familiar to users?	• Yes • No • NA	
2.4	Are icons concrete and familiar?	• Yes • No • NA	
2.5	Do the selected colors correspond to common expectations about color codes?	• Yes • No • NA	

II. Please select the overall severity rating for this usability factor:

No usability Problem	Cosmetic Problem Only	Minor Usability Problem	Major Usability Problem	Usability Catastrophe
0	1	2	3	4

III. If you have other comments, please specify.

3. User Control and Freedom

Users should be free to select and sequence tasks (when appropriate), rather than having the system do this for them. Users will need a clearly marked “emergency exit” to leave the unwanted state without having to go through an extended dialogue. Users should make their ow decisions regarding the costs of exiting current work.

I. Please select your response for the individual items related to this usability factor:

#	Usability Factor	Response	Comments
3.1	Is there a clear exit on each document screen?	• Yes • No • NA	
3.2	Are all screens accessible across the system?	• Yes • No • NA	
3.3	Can users easily move forward and backward between fields?	• Yes • No • NA	

II. Please select the overall severity rating for this usability factor:

No usability Problem	Cosmetic Problem Only	Minor Usability Problem	Major Usability Problem	Usability Catastrophe
0	1	2	3	4

III. If you have other comments, please specify.

4. Consistency and Standards

Users should not have to wonder whether different words, situations, or actions mean the same thing.

I. Please select your response for the individual items related to this usability factor:

#	Usability Factor	Response	Comments
4.1	Have formatting standards been followed consistently in all screens within the system?	• Yes • No • NA	
4.2	Are abbreviations clearly explained?	• Yes • No • NA	
4.3	Are there salient visual cues to identify the active screen?	• Yes • No • NA	
4.4	Is vertical scrolling possible in each screen?	• Yes • No • NA	
4.5	Are there no more than four to seven colors, and are they far apart along the visible spectrum?	• Yes • No • NA	
4.6	Is the most important information placed at the beginning of the form?	• Yes • No • NA	
4.7	Are names consistent, both within each tab and across the system, in grammatical style and terminology?	• Yes • No • NA	
4.8	Is there a consistent icon design scheme and stylistic treatment across the system?	• Yes • No • NA	

II. Please select the overall severity rating for this usability factor:

No usability Problem	Cosmetic Problem Only	Minor Usability Problem	Major Usability Problem	Usability Catastrophe
0	1	2	3	4

III. If you have other comments, please specify.

5. Recognition Rather than Recall

Make objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.

I. Please select your response for the individual items related to this usability factor:

#	Usability Factor	Response	Comments
5.1	Are prompts, cues, and messages placed where the eye is likely to be looking on the screen?	• Yes • No • NA	
5.2	Is white space used to create symmetry and lead the eye in the appropriate direction?	• Yes • No • NA	
5.3	Have items been grouped into logical zones, and have headings been used to distinguish between zones?	• Yes • No • NA	
5.4	Is color highlighting used to get the user's attention?	• Yes • No • NA	
5.5	Is color coding consistent throughout the system?	• Yes • No • NA	
5.6	Can the user easily locate data?	• Yes • No • NA	

II. Please select the overall severity rating for this usability factor:

No usability Problem	Cosmetic Problem Only	Minor Usability Problem	Major Usability Problem	Usability Catastrophe
0	1	2	3	4

III. If you have other comments, please specify.

6. Flexibility and Efficiency of Use

The website should offer users a number of options when it comes to finding content on the site. Users should be able to achieve their goals in an efficient manner.

I. Please select your response for the individual items related to this usability factor:

#	Usability Factor	Response	Comments
6.1	Is navigation between screens simple and visible?	• Yes • No • NA	

II. Please select the overall severity rating for this usability factor:

No usability Problem	Cosmetic Problem Only	Minor Usability Problem	Major Usability Problem	Usability Catastrophe
0	1	2	3	4

III. If you have other comments, please specify.

7. Aesthetic and Minimalist Design

Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.

I. Please select your response for the individual items related to this usability factor:

#	Usability Factor	Response	Comments
7.1	Is only (and all) information essential to decision making displayed on the screen?	• Yes • No • NA	
7.2	Have large objects, bold fonts, and simple areas been used to distinguish sections?	• Yes • No • NA	
7.3	Are field labels brief, familiar, and descriptive?	• Yes • No • NA	
7.4	Is the visual layout well designed?	• Yes • No • NA	
7.5	Are there any unnecessary data elements in each screen?	• Yes • No • NA	

7.6	Is each lower-level sub-section/data item associated with only one higher-level section?	• Yes • No • NA	
7.7	Is data presented in a simple format?	• Yes • No • NA	
7.8	Is there white space between color representation?	• Yes • No • NA	

II. Please select the overall severity rating for this usability factor:

No usability Problem	Cosmetic Problem Only	Minor Usability Problem	Major Usability Problem	Usability Catastrophe
0	1	2	3	4

III. If you have other comments, please specify.

8. Spatial Organization

Relates to the overall layout of a visual representation and refers to how easily it is to locate an information element in the display and the distribution of elements in the representations.

I. Please select your response for the individual items related to this usability factor:

#	Usability Factor	Response	Comments
8.1	Are all information elements clear and visible?	• Yes • No • NA	
8.2	Does the information follow a “logical” organization?	• Yes • No • NA	
8.3	Does the information provide detail on the context and detail associated with the data element?	• Yes • No • NA	

II. Please select the overall severity rating for this usability factor:

No usability Problem	Cosmetic Problem Only	Minor Usability Problem	Major Usability Problem	Usability Catastrophe
0	1	2	3	4

III. **If you have other comments, please specify.**

9. Information Coding

Relates to the symbols or representations used to aid perception.

I. **Please select your response for the individual items related to this usability factor:**

#	Usability Factor	Response	Comments
9.1	Are the symbols appropriate for the data represented?	• Yes • No • NA	
9.2	Are realistic characteristics used to represent data or information elements?	• Yes • No • NA	

II. **Please select the overall severity rating for this usability factor:**

No usability Problem	Cosmetic Problem Only	Minor Usability Problem	Major Usability Problem	Usability Catastrophe
0	1	2	3	4

III. **If you have other comments, please specify.**

10. Orientation

Provision of support for the user to orient them in the visualization.

I. Please select your response for the individual items related to this usability factor:

#	Usability Factor	Response	Comments
10.1	Are the measurement units displayed clearly?	• Yes • No • NA	
10.2	Are there labels associated with each data field?	• Yes • No • NA	
10.3	Can the user control the level of detail they see in a representation?	• Yes • No • NA	

II. Please select the overall severity rating for this usability factor:

No usability Problem	Cosmetic Problem Only	Minor Usability Problem	Major Usability Problem	Usability Catastrophe
0	1	2	3	4

If you have other comments, please specify

Appendix L: Heuristic Usability Evaluation Guide

Obstetric Emergency Dashboard

Heuristic Usability Evaluation Guide

Good morning/afternoon/evening. Thank you for being here today. My name is ____________ and my role in this project is _________. During this session we are evaluating the usability of dashboard prototypes to monitor obstetric emergency readiness at the regional and individual healthcare facility level. This study is funded by the National Institute of Nursing Research and Fulbright US Student Program.

For human-computer interaction experts:

This session should last approximately one hour. I would like you to complete a series of tasks using the dashboard prototypes we have created. I ask that you describe your thought process out loud as you work your way through the tasks. After you have had time to work through the tasks, and using a Qualtrics form, I will ask you to rate the extent to which the prototype meet criteria for ease of use. As described in the information sheet that you reviewed, we will be audio recording our conversation to make sure that we fully capture your opinions and reactions.

We would like you to work your way through the dashboard prototypes and complete the following tasks.

1. Filter the main screen to only view primary hospitals
2. Determine which healthcare facilities are not ready to manage retained placenta
3. Determine if [hospital name] is ready to manage hypertensive emergencies
   If not, identify which items are stocked out

4. Determine if [hospital name] is ready to manage maternal sepsis/infection
   If not, identify which items are stocked out or not functional

5. Determine what emergencies [hospital name] is ready to manage
6. For prolonged labor at [hospital name] filter the supplies table to see the items that are at the emergency order point
7. For prolonged labor at [hospital name] filter the supplies to see the items that are excess
8. Determine how many healthcare facilities are at risk for not being able to manage an incomplete abortion

Closing

- Is there anything else you'd like to tell us about your experience using the dashboard?

Thank you again for participating in this work today!