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Using Nutrition Clinical Decision Support Systems in low resource settings

A case from Rwanda

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Abstract

Rwanda's Ministry of Health (MOH) is currently working to eliminate malnutrition and stunting in children less than five years. The backbone of this project has been the development of the Rwandan Fortified Blended Foods programme, which oversees and manages the delivery of care and food for children in the poorest families in country. To support this effort, the MOH identified the need for a growth tracking application (app) to facilitate the detection of and intervention in cases of anomalous child development.

This thesis explores the process of developing, implementing and user-testing a nutrition and growth tracking app in Rwanda, as well as the potential benefits of using a Clinical Decision Support System (CDSS). It looks at the different challenges and opportunities that might arise for developers and health workers in the implementation and use of the app. The app calculates Z-scores based on anthropometric measurements, which represents deviations from normal growth, and uses growth charts to present the results. The app gives health workers Clinical Decision Support (CDS) during patient consultation, presenting a health status of the child based on the calculated Z-scores. Additionally, based on user feedback, another app prototype was developed to help health managers aggregate and synthesize growth data. The overarching goal of the thesis is to improve our stock of knowledge about the use of CDSSs in low-resources settings. CDSSs are characterized by a lacuna of research, although it is suggested that they may significantly improve patient outcomes in developing countries.

The study is based on an action research framework that both generated empirical data and enabled field testing of the app. The results of the research shows great potential for the use of CDSSs in Rwanda compared to the existing paper based system. Based on feedback from health workers, experts and managers, it was found that the growth tracking app shows potential for lessening workload and improving workflow, reducing calculation errors, and improving patient feedback. However, because of limited time to field test the app, collect user feedback and implement improvements, the results of this study should only be considered indicative. Further, iterative development and testing of the app throughout Rwanda will be required in the future.

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Contents

List of Figures

List of Tables

Abbreviations

Chapter 1

Introduction

In developed countries, growth monitoring is an essential part of child care, while in developing countries, health workers also use growth monitoring to detect and intervene in areas that experience issues with growth and nutrition. The use of growth charts to present such assessments are common practice in pediatric care worldwide [55]. In 2006 the World Health Organization (WHO) implemented a new and broader set of child growth standards to replace the original standards that were implemented in the early 1990s. These standards facilitate assessment of child growth by defining how children should grow, and any deviations from this standard is evidence of abnormal growth. The deviations from the normal growth standard is represented by a range of Standard Deviation (SD) that describes how far from the normal growth a child is [94, p. 1-2]. The growth standards are meant for global use, regardless of ethnicity, socio-economic status and feeding mode. In 2011 a global survey covering 178 countries found that 125 countries had adopted the new standards, another 25 countries were considering or in he process of adoption, while 30 countries had not, citing preference for local references, and lack of resources as the main reasons for non-adoption [52].

This thesis looks at the development and implementation of a Clinical Decision Support System (CDSS) for healthcare in low resource settings, through a nutrition and growth tracking app developed as a module of District Health Information System 2 (DHIS2). DHIS2 is a Health Management Information System (HMIS) that helps governments and health organization manager operations, monitor process and improve communication [6]. It also examines the potential benefits using Clinical Decision Support Systems (CDSSs) may have in healthcare for developing countries. The growth tracking application calculates Z-scores based on anthropometric measurements, which represents the deviations from normal growth, and uses growth charts to present the results. The application gives health workers Clinical Decision Support (CDS) during patient consultation, presenting a health status of the child based on the calculated Z-scores. The health workers can then use the information to make educated decisions on further treatment for the patient. CDSSs shows promise for support in healthcare systems in developing countries, and gathers high interest among governments and Non-governmental Organizations (NGOs). However, mostly due to the lack of resources, large scale implementation is limited [74]. Additionally, there is a lack of studies exploring the impact these systems may have on patient outcomes, health workers, or other parts of the healthcare system [64] [104].

A Clinical Decision Support System (CDSS) is a computerized Health Information System (HIS) that provides support for health workers in the decision making process in clinical cases. They aim to provide health workers with the information they require to make clinical decisions, in an understandable manner, before, during, or after patient consultation [104]. CDSSs can be a major support tool in areas with low resources, such as developing countries, by providing health workers with CDS where no doctors are available, or in tracking patients such as in growth monitoring of children [41]. The WHO developed an application called WHO Anthro [28], for tracking growth in individual children as well as national surveys, incorporating its own Child Growth Standards. However, it has since decided to discontinue further development of this software. Following the WHOs decision to discontinue WHO Anthro, the Rwandan Fortified Blended Foods (FBF) program has decided to implement a homegrown solution for growth tracking and consultation which is integrated with their HMIS. This provided an opportunity to study a growth tracking software similar to WHO Anthro and its potential impact.

This project is a part of an ongoing project in Rwanda supported by the Health Information Systems Program (HISP) group, which focuses on strengthening the country's Health Information System (HIS) [16]. The research team consisted of three people; the author of the thesis and a fellow master student as the developers, together with the head of the HMIS: Unit (HMISU) and project owner at the Rwanda Ministry of Health (MOH), Andrew Muhire.

The development of the growth tracking app happened throughout the entirety of the project. The development process is described in chapter 6. Most of the data collection was carried out over a two week period in Rwanda where the application was presented and tested with MOH managers, health workers from health facilities in Kigali, and health experts from various Non-governmental Organizations (NGOs), and other interested parties from the MOH.

1.1 Motivation

To reduce the mortality rates of children and increase life expectancy, as well as quality of life, the Rwanda MOH seeks to eliminate malnutrition in children under five years. This would also in turn increase their social and economic productivity later in life. In wake of the decision by the WHO to stop development of the WHO Anthro software, the Rwanda MOH has decided that there is need for a growth tracking application that can be integrated with their Health Management Information System (HMIS), DHIS2. Additionally, the MOH seeks to eliminate the use of paper registers that takes up a lot of storage space, and quickly deteriorates when stored in humid places.

There is also a lack of studies regarding Clinical Decision Support Systems (CDSSs) and their impact in low resource settings, such as development countries. This thesis contributes to the lack of knowledge by exploring the potential benefits and challenges of using a CDSS in a developing country, through the development and implementation of a growth tracking application for the Rwanda Ministry of Health (MOH).

1.2 Scope

The goal of this thesis is to look at the process of developing, implementing and user-testing the growth tracking application into the Rwanda HMIS. It looks at the different challenges and opportunities that might arise for developers and health workers in the implementation and use of the application in low resource settings. It also looks benefits and challenges of using a clinical decision support system for both health workers and managers.

1.3 Research question and objectives

The purpose of this thesis is to explore the different factors that influence the development and implementation of the growth tracker app in Rwanda, as well as the potential benefits of using nutrition clinical decision support systems in low resource settings.

The current research question and research area:

- Research aim: Explore the opportunities and challenges with using mobile technology and apps for nutrition and growth monitoring by health workers in real life settings in less developed economies.

- *Which challenges and opportunities influences the implementation and use of Internet technologies and apps for nutrition and growth monitoring by health workers in low resource settings?*

- *What are the potential benefits and challenges of using clinical decision support systems for nutrition and growth tracking in low resource settings?*

1.4 Chapter Overview

Chapter 2 Related Research: Gives an introduction to Information System (IS) and Health Information System (HIS), and presents related research about nutrition and growth tracking with a focus on developing countries.

Chapter 3 Conceptual Framework: Presents the concepts and characteristics of both Decision Support Systems (DSSs) and Clinical Decision Support Systems (CDSSs), and the components of a CDSS.

Chapter 4 Research Context: Gives an introduction to Rwandas current situation, including geography, economy, infrastructure, and health status as well as an introduction to the Health Information System (HIS) and Health Management Information System (HMIS).

Chapter 5 Methods: Presents the research perspective, methodology and methods, and the analysis process of collected data used in this thesis. This chapter also provides reflections upon methodologies used in the research and development of the nutrition tracker.

Chapter 6 App Development Process: Presents current and final product of the nutrition tracker. Describes the app functionalities as well as the Z-score formula for growth charts.

Chapter 7 App Demonstration & feedback: Presents the findings during the user demonstration and testing of the apps.

Chapter 8 Analysis of findings: Presents the analysis of the findings during development, with links to the conceptual framework, and deployment of the applications.

Chapter 9 Discussion & Conlusion: Discusses the findings and analysis in light of the related research and research questions of this thesis, as well as a reflection upon the methodologies used in the research and development of FBF Anthro. Lastly a summary conclusion, and thoughts and suggestions for future work is presented.

Appendix: Includes links to the github repositories for both apps, FBF Anthro and FBF Analytics.

Chapter 2

Related Research

This chapter presents related background research for the thesis. First, it gives a brief introduction to information systems and Health Management Information System (HMIS). Second, it gives an introduction and overview of the use of growth charts in pediatric care, and the use of growth tracking to fight malnutrition in developing countries. Finally, it also gives a brief introduction to Clinical Decision Support Systems (CDSSs), and an overview over their use in low resource settings, with focus on developing countries.

2.1 Introduction to Information Systems and Health Information Systems

Understanding the concepts of Information System (IS) and Health Information System (HIS) is important to this thesis as it helps explain the context for the application development part of this project. This helped when making decisions on how to approach the task of developing an application for DHIS2.

2.1.1 Information Systems

When developing and implementing Information System (IS) the context matters because it might change ones approach. This section gives a brief introduction to one of the main concepts in IS design; Information System (IS) as Social Systems.

According to BusinessDictionary.com, Information System (IS) are [4]:

> A combination of hardware, software, infrastructure and trained personnel organized to facilitate planning, control, coordination, and decision making in an organization.

IS as Social Systems

One approach to IS design is Socio-technical Systems Design (STSD), which takes human, social and organizational factors, as well as technical factors into consideration in the design of the systems. As Baxter and Sommerville states [37, p. 4]:

> It is widely acknowledged that adopting a socio-technical approach to system development leads to systems that are more acceptable to end users and deliver better value to stakeholders.

As IS consists of both social and organizational elements, and technical systems, the development process gets influenced by the context. The "...approaches to design and development of HIS must be broad-based and flexible enough to adapt" [43, p. xii].

Kling argues that technology is not sufficient to create any social or economic value on its own. He explains that few organizations design systems that facilitate people's work and also significantly underestimate the requirements of skilled work to extract value from computerized systems [68, p. 207]. Many organizations lose potential value to these factors when they computerize their systems. Thus, IS should be seen as complex networks where social systems and technological artifacts are interdependent. In other words IS should be seen as socio-technical systems where the technical aspects needs to facilitate the work people do and how they do it [100, p. 1182] [68].

2.1.2 Health Information Systems

The Oxford English Dictionary defines "system" as "a set of things working together as parts of a mechanism or an interconnecting network; a complex whole" [20]. In other words, a collection of components that work together to achieve a common objective. "Information" can be defined as a meaningful collection of facts or data. A Health Information System (HIS) is thus a collection of components that work together to improve health services management through optimal information support. Hubertubise (1984) describes them as "systems that provide relevant information to support the decision-making process at each level of an organization" [57, p. 2].

There are a wide variety of types of IS that supports health services, such as logistical information systems, laboratory report systems, patient records, epidemiological surveillance systems, and Health Management Information Systems (HMISs) [43, p. 10]. All of these can be combined as subsystems in a larger, unified HIS [57, p. 2-3]. An HMIS is "an information system specially designed to assist in the management and planning of health programmes, as opposed to delivery of care" [98, p 3]. This thesis focuses on expanding DHIS2, which is a modular HIS platform incorporating HMIS functionality, as well as clinical operations such as Electronic Health Records (EHR) and single patient case tracking for patient care [43, p. 153-163].

2.2 Understanding growth monitoring and growth charts

This section will give an introduction to the concepts of growth monitoring in children, and growth charts. Implementing a nutrition and growth monitoring application using growth charts requires an understanding of these concepts and their use.

Monitoring and assessing growth in children is common practice in pediatric care worldwide. Growth monitoring is an essential part of the healthcare follow ups of babies, while in developing countries, growth monitoring is used to detect and intervene when children experience growth faltering. Growth monitoring is also used at national level to detect and intervene in areas which experience over- or undernutrition [54] [55]. Shown in figure 2.1 is an example of paper growth charts used at a health clinic in Rwanda; one chart for boys and one for girls [94].

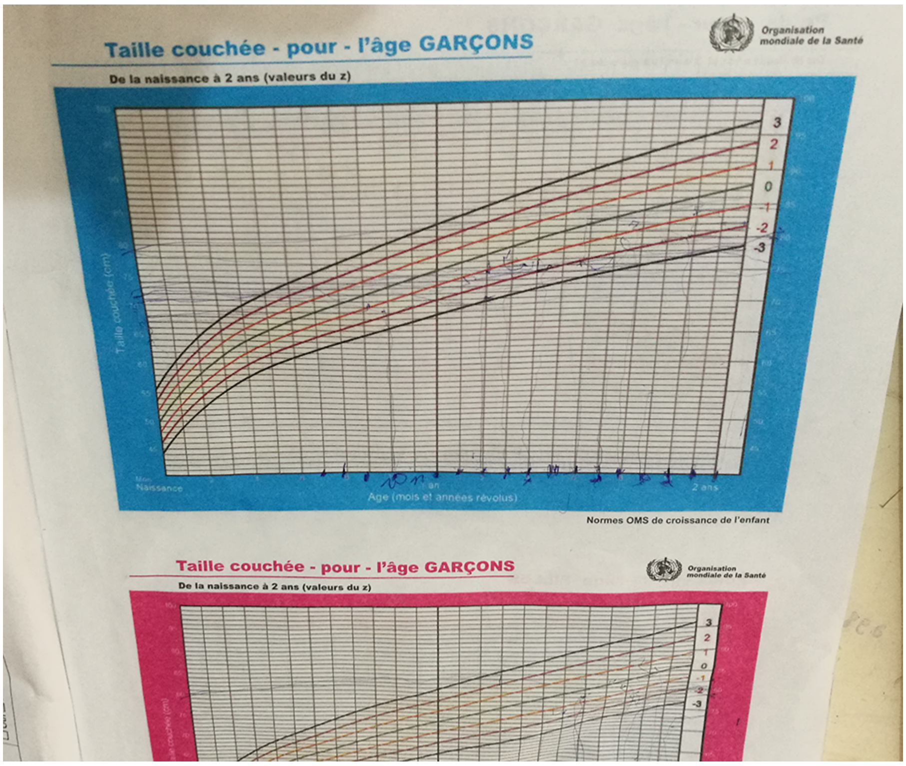


Figure 2.1: An example of the paper charts used to plot a child's growth indicators. (Note the many pen marks from previous use)

Growth monitoring in developing countries was started by David Morley in the 1950s, to prevent protein-calorie deficiency (malnutrition) in children

[77] [56]. He used weight charts as a way to track the weight gain of children under the age of 5 years. The charts also contained additional information such as when the child was weaned off breast-feeding or periods of sickness. The charts where overlaid with a "growth channel" which he considered a "... 'path' along which the village mother is encouraged to 'walk' her child" [77, p. 203]. These charts became a summary of a child's medical history, which, at a glance, could inform the user of a child's current state of nutrition. Further, he explains a traffic light model, see 2.2, which groups children into 3 groups based on their observed growth, namely: red (little or no growth), yellow (inadequate growth) and green (normal growth). This grouping makes it easier to see either progress or regress in individuals as well as in communities or nationally. His study shows that combining growth charts with a positive emphasis on achieving normal growth was the most satisfactory method of measuring growth and the state of nutrition [77].

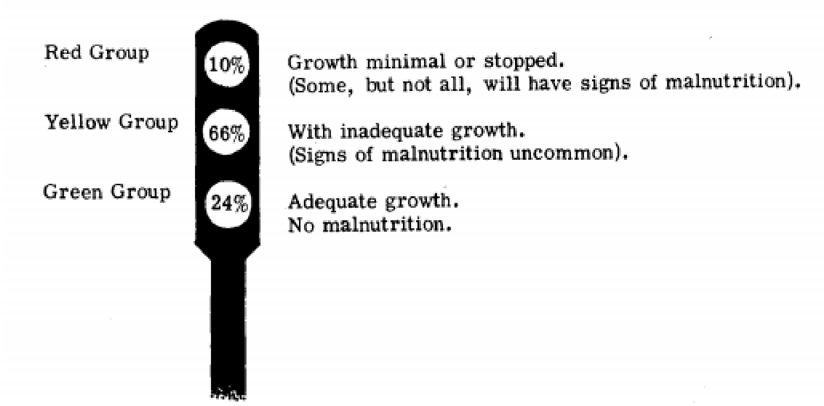


Figure 2.2: Traffic light groups for child growth and associated risks [77]

2.2.1 WHO growth indicators: consequences and implications

The growth charts are calculated based on a selection of anthropometric indicators. The WHO has developed an international reference guide for child growth standards in which they recommend a selection of indicators to use in growth monitoring of children under 5 years [29] [94]. As explained by Wang et al. racial or ethnic factors matters little for growth in children, in comparison to nutritional, environmental, and socio-economic status [110]. They can thus be used world wide, although there is insufficient evidence to disregard genetic factors as a factor in growth for older children [110]. The WHO Child Growth Standards serves as a reference for optimal growth in children. These indicators are used to measure malnutrition resulting in undernutrition (underweight, wasting, stunting) or overnutrition (overweight) [96, p. 1-2] [112, p. 5-12]. The WHO standards identifies children with measures below -2 SD of the Child Growth Standards median [96, p. 1-2] as malnutritioned, and children below -3 SD are diagnosed with Severe Acute Malnutrition (SAM). Children which suffer from SAM have shown an exceeding 9-fold risk of death compared to those with a weight-for-height above -1 SD [111].

WHO growth indicator definitions

The indicators and their corresponding measures are shown in table 2.1.

Malnutrition Indicators		
Indicator	Measurements	Definition
Underweight	weight for age	< -2 SD
Stunting	height for age	<-2 SD
Wasting	weight for height	< -2 SD
Overweight	weight for height	> +2 SD
Mortality	middle-upper-arm-circumference	< 11.5 cm

Table 2.1: All SDs are based on the WHO Child Growth Standards median [96, p. 1-2] [112, p. 5-12] [19].

Underweight, low weight for age:: Caused by undernutrition. Underweight is a difficult indicator to interpret however, because it can indicate either wasting, stunting, or both [96, p. 1-2] [112, p. 5-12].

Stunting, low height for age: Children who suffer from stunting is at a greater risk of illness and death. Stunting is the result of long-term nutritional deprivation and is a good indicator for poor environmental conditions or restriction of a child's growth potential. This long-term nutritional deprivation often results in delayed mental development and a lower intellectual capacity which in turn can affect the child's social and economic productivity later in life [96, p. 1-2] [112, p. 5-12].

Wasting, low weight for height: A symptom of acute undernutrition, usually from insufficient food intake or infectious diseases, such as diarrhea. Wasting impairs the immune system, increasing the severity, duration, and susceptibility of diseases. Higher risk of contracting severe diseases gives an increased risk of death [96, p. 1-2] [112, p. 5-12].

Overweight, high weight for height: A result of high nutrition intake which can lead to disabilities and noncommunicable diseases; such as cardiovascular diseases, heart disease or stroke, and diabetes, or musculoskeletal disorders, osteoarthritis (wear and tear arthritis) [96, p. 1-2] [112, p. 5-12].

2.2.2 Standard deviation classification system (Z-scores)

WHO recognizes 3 different systems for comparing children to the reference population: Z-scores (standard deviation), percentiles and percent of median. Z-scores is widely recognized as the best system for assessing anthropometric data in both populations and individuals. [51, p. 49].

The formula for calculating Z-scores is as follows:

Z-score (or SD-score) = (observed value - median value of the reference population) / standard deviation value of reference population

With this system anthropometric values are expressed through a number of standard deviations, or z-scores, below or above the reference median value. The Z-score system uses a linear scale with fixed intervals. This gives Z-scores "the same statistical relation to the distribution of the reference around the mean at all ages, which makes results comparable across ages groups and indicators". In addition, Z-scores is sex-independent, which permits the combination of sex and age groups when evaluating child growth. These characteristics gives Z-scores the major advantage of allowing population-based assessments, groups of Z-scores, to be summarized to create mean and standard deviations for a population, in addition to assessing the well-being of individuals [51, p. 48-51].

The Z-score formula is based on the LMS model by T.J. Cole and P. J. Green [46], with a cut-off at $\pm$ 3SD, after which the intervals has the same distance as between $\pm$ 2SD and $\pm$ 3SD. This removes the need for making assumptions about the distribution of data beyond these limits. After $\pm$ 3SD the Z-score distribution can depart from normality with minimal expected practical impact [94, p. 301-307]. The LMS parameters are the median (M), the generalized coefficient of variation (S), and the power in the Box-Cox transformation (L) [5] [46, p. 1306]. The mathematical formula and procedure for calculating Z-scores is described in 6.3 on page 60, with an example.

2.3 Clinical Decision Support & eHealth services in low resource settings

Electronic Health (eHealth) is an umbrella term for the use of Information and Communications Technology (ICT) for healthcare services, while CDSS is a computerized Health Information System (HIS) which aims to provide health workers with Clinical Decision Support (CDS). In other words, a CDSS aims to provide health workers with assistance in making clinical decisions during patient care [63] [36] [104]. This section gives an overview over the use of CDSSs in low resource settings, such as developing countries, while a detailed description of the concepts of Decision Support Systems (DSSs) and its components is given in chapter 3.

In developed countries, CDSSs have seen increased usage in the last couple of decades, and several studies on the characteristics of CDSSs have been made. Studies that have looked at the impact these systems have on patient outcome on the other hand are few, and even fewer show any benefits for the patient [65]. However, most of these studies have shortcomings in terms of sample size and time periods, and are not able to fully discover the effects a CDSS may have on patient outcome [64] [36] [104].

In developing countries several technologies, such as Mobile Health (mHealth) services, or eHealth services such as EHRs, and CDSSs, are emerging as promising tools to address healthcare challenges. They can be a major support tool for health workers providing healthcare in lower resource settings, such as where few or no doctors are available, patient tracking in health programmes like HIV-patient tracking, or inventory monitoring to reduce the risk of drug resistance [41] [104]. They can also provide support for managers in planning health sector operations [35] [53]. Because of recent advances in mobile technologies and applications, possibility of integration into existing eHealth services, and continued rapid growth in mobile network coverage, the WHO states that mHealth and eHealth services has the potential to transform the face of health services across the globe [97, p. 1]. Despite the promising outlooks and high interest for eHealth among organizations and governments, implementation has been fragmented and uncoordinated. Regardless of a country's development status, implementing eHealth services faces many challenges such as lack of economic resources, lack of trained human resources, lack of policies that addresses well-defined healthcare systems involving eHealth, resistance to the user of computers, or cultural aspects [49]. Thus, few programmes have aimed for larger scale implementations, rather focusing on single cases of healthcare delivery [74].

Evaluating the use and impact of eHealth services on patient care is difficult, and few rigorous studies have thus been made [104]. However, because of the lack of pre-existing well-defined healthcare systems, well-designed eHealth systems may prove to have a much higher impact in developing countries than in developed countries, with well-defined healthcare systems [41] [64] [65].

Chapter 3

Conceptual Framework

As explained in the previous chapter growth charts are used to support both mothers and clinicians to make decisions in regards to a child's growth and health. To implement this in a computerized system, or HMIS, one also requires an understanding of decision support systems; how they work and how to best facilitate the users needs. This chapter gives a description of key characteristics of DSSs and the subtype CDSSs, and a conceptual framework for describing them.

3.1 Understanding Decision Support Systems

> Managers want the right information, at the right time, in the right format, and at the right cost [50, p. 1541].

A Decision Support System (DSS) can be broadly defined as an interactive computer-based system that help people use computer communications, data, documents, knowledge, and models to solve problems and make decisions. DSS are ancillary or auxiliary systems; they are not intended to replace skilled decision-makers. In other words, DSSs are meant to provide decision support, not to automate the decision making process [50].

DSSs date back to the 1960's when the foundation for building DSSs were made at the Massachusetts Institute of Technology (MIT). In the early 70's research demonstrated the feasibility of DSS and by the late 70's, multiple companies had developed interactive systems to help managers analyze semistructured problems. DSSs ability to support decision-makers throughout an organization were recognized early on and today there widespread use of both off-the-shelf systems as well as custom-designed systems [50]. There are three major characteristics for DSSs [50, p. 1540]:

- DSSs are designed specifically to facilitate decision processes.
- DSSs should support rather than automate decision making.

- DSSs should be able to respond quickly to the changing needs of decision-makers.

These characteristics is a guideline to help managers and their support staff consider what information and analyses they need to support their business activities. Although, most managers only want or need transaction summaries, some need both detailed information as well as summaries. A computerized Information Management System (IMS) can provide this information to the managers. Nevertheless, the system should follow some basic characteristics, notably that information must be timely, relevant, accurate and complete. In addition the information should be presented in an understandable and readable format. A DSS is a subcategory of a IMS and should therefore adhere to these same characteristics [50].

3.2 Clinical Decision Support Systems

CDSSs represent a form of DSS specialized towards healthcare, specifically decision making about individual patients. Their purpose is to generate patient specific advice from patient data and present it in an timely and easily interpreted fashion. There are many factors that influence patient care outcomes, length of patient care, as well as cost of care. CDSSs have been shown to directly influence these factors with improvement in both patient outcomes and cost of care [47] [40]. They also have the potential to minimize human error by providing alerts or notifications to the physician about medication interactions, or other conditions that might affect the quality of care and patient outcomes [63] [36].

CDSSs should adhere to the same characteristics and guidelines as DSS; facilitate decision making, support not automate, respond quickly to changing needs during the decision making process. Kawamoto et al. discovered several characteristics that could improve clinical practice [66, p. 2], of these features 4 were shown to significantly improve clinical practice [66, p. 5-7]:

- Automatic provision of decision support as part of the work flow.
- Provision of decision support at time and location of decision making.
- Provision of recommendation rather than just an assessment.
- Computer based generation of support.

CDSSs should incorporate these features in addition to the baseline characteristics of DSSs. Of these four new features automatic provisioning of support should have the highest priority, given the close correlation between the feature and successful patient outcomes [66, p. 7]. Additionally, CDSSs can be categorized based on the the way they provide decision support; namely timing (before, during, or after decision making), active or passive support (actively provides alerts or not), and their ease of use. Another type of categorization is whether the system is non-knowledge-based, which make use of machine learning or statistical pattern recognition approaches, or knowledge-based, which utilizes a pre-compiled knowledge-base for support provisioning [38, p. 3-4].

Non-knowledge-based CDSSs make use of Artificial Intelligence (AI) and machine learning within an artificial neural network, similar to biological neural networks, to model human experts [39, p. 3]. This lets the system learn to reason, learn from previous experiences, recognize patterns, and change its own behavior without human input. This allows the system to produce diagnosis and clinical decisions without any human interaction. These systems are, however, very complex and the reasoning process behind the results is non-transparent. Physicians have therefore been hesitant to make use of these systems, even though they show promise in producing more accurate assessment than traditional systems [39, p. 5] [69].

This project developed an active, knowledge-based CDSS meant to be accessed during decision making, and is the focus of this study.

3.2.1 Knowledge-Based Clinical Decision Support Systems

Knowledge-based CDSSs were originally built around expert systems with the aim of simulating human thinking. In later years these systems have been adapted to assist the clinician in the decision making, rather than to have the system make the decisions. Instead of producing a solution or answer, the system provides useful information to help users reach their own decision. This lets the clinician be more involved in the system usage and the patient care process, rather than being a passive recipient and a broker of the computer determined output.

Most knowledge-based CDSSs contains three main parts, see figure 3.1; the knowledge base, inference or reasoning engine, and a mechanism to communicate with the user. The knowledge base consists of compiled information such as if-then rules (IF blood test results are in THEN alert physician), probabilistic associations of signs and symptoms with diagnoses, or known drug and food interactions. The second part is the inference or reasoning engine, which contains the formulas for combining or calculating the rules or associations in the knowledge base with patient data. The last part is the communication mechanism, which is responsible for inserting patient data into the system and presenting the output of the system to the end user, who will make a decision based on the presented data [38, p- 4-5].

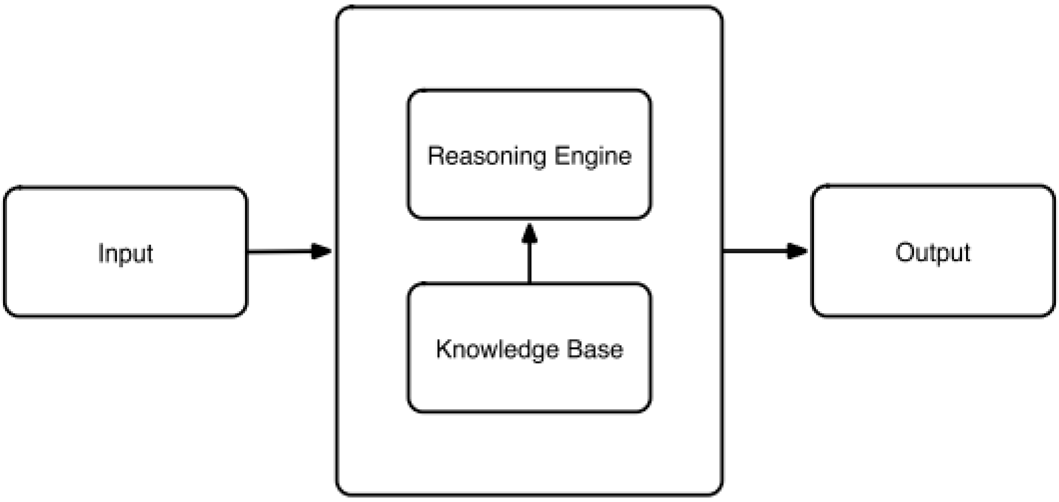


Figure 3.1: The components of a CDSS [39, p. 32]

Knowledge base

The knowledge base contains all the data the system uses for the decision making process, and thus is an essential part of any CDSS. The knowledge encoding has to match the design of the inference engine. The process of encoding the knowledge so that it matches the design is time consuming as the data often is of varying quality and format. Once the knowledge base is created and populated with data, it has to be regularly maintained. With the varying quality of data received and the precision needed to keep the data relevant and safe to use in clinical cases, this process is very resource heavy. Knowledge-acquisition and maintenance is therefore seen as a bottleneck in CDSSs [39, p. 36].

Inference or reasoning engine

The inference engine combines the input and other data in accordance to a logical scheme. These logical schemes are usually non-transparent, although, the user usually has no need to know how the results are achieved. There are several different solutions to creating an inference engine, such as a Bayesian network that relies on the probabilities of an event to occur, given other events that have or haven't occurred, or a production rule where rules of predicate logic specify how the statements are combined to achieve a result. A popular way of constructing the logical scheme is to use a cognitive model based on a physician's reasoning. Such a model can consist of "frames" that contain information about a disease or other medical conditions. These frames can then be combined to a searchable network, which may then be queried based on particular criteria. The physician can then decide what frames, or condition, fit best with the patient data [39, p. 34-35].

Communication mechanism

The communication mechanism is controlling the input and output of the system.

Input: The queries or information entered into the user interface of the CDSS has to follow the specific format for each system. The format systems require vary and one query might work in one system but not another. For example "Symptom: joint swelling" in one system, might be forced to be the more specific "Finding: arthritis" in another. This form of input restriction, where input is restricted to a finite set of terms, is common in CDSSs, and there is no standardization. One set of terms might give very different meanings if the timing are different. For example "five year history of chest pain radiating to the left arm" and "sudden onset, 20 minutes ago, chest pain radiating to the left arm" have two very different meanings. The temporal factors for symptoms is difficult to express in such a controlled vocabulary of terms, because expressing time in various ways may have completely different meanings, depending on the symptoms. One way of simplifying this problem is to use broader categories of time such as acute, sub-acute, or chronic. Other solutions may be explicit time models by describing temporal relationships between events (event A happened before event B), or implicit time models where the time information is built into the input, such as adding "a history of" to the input to describe the timing of the symptom or condition (patient has a history of symptom A) [39, p. 32-34].

There are many different ways of formating and restricting input, and it all depends heavily on the context and type of medical information the CDSS is required to operate with. While some input formats might perform well in some cases, it might not work in others. Thus, there are no "one system fits all" for CDSSs.

Output: The output of a CDSS is usually a ranked list of possibilities, depending on the criteria the results are evaluated on. For example unlikely diseases might be ranked higher on the list because a misdiagnoses might could have catastrophic consequences. Most physicians are not interested in the very obvious answers either, because they already have that information, but rather the more unlikely diagnoses [39, p. 36-37]. However, like for system input, the output is very context dependent.

Chapter 4

Research Context

This chapter gives a brief overview of the geographic, economical, and infrastructure situation in Rwanda, as well as an overview of the general health status of the population, and lastly an introduction to its healthcare system and Health Management Information System (HMIS).

4.1 Overview

Rwanda is situated in central Africa, bordered by the Democratic Republic of Congo to the west, Burundi to the south, Tanzania to the east and Uganda to the north, making Rwanda a landlocked country; see the map below 4.1 on the next page.

Rwanda is divided into four provinces and one city: Eastern, Northern, Western, Southern, and the city of Kigali. Each province is again divided into districts, for a total of 30 districts, which control the local economical development and public services.

Rwanda is a small mountainous country, extending 26.338 km^2 with an estimated population of 11.610.000 in 2015 [91], which makes it the most densely populated country in Africa (470/km^2) [34]. Rwanda's population had an estimated growth rate of 2.53% and an estimated birth rate of 33.3 births per 1000 population in 2016 [34]. The population is young, with approximately half (41.53%) of Rwanda's population aged 0-14 years old and a third of the population aged 25-54 years old (32.93%) [34].

Economically Rwanda's Gross Domestic Product (GDP) has seen a steady increase with an average growth of 7-8% since 2003 and a GDP per capita of $1,900 as of 2016 [34]. According to government statistics, estimates shows that just over a third (39%) of the population lives below the poverty line, improving steadily compared to over half (56%) of the population in 2006 [34]. For comparison, Norway had a GDP per capita of $69,300 as of 2016 [34].

Figure 4.1: Map of Africa /w Rwanda highlighted [87]

Rwanda's fragile economy was decimated by the 1994 genocide that severely impoverished the population and temporarily dampened the attraction of external private investors. The Rwandan government has made substantial progress in rehabilitating the economy towards the pre-1994 levels. The economy is predominately based on agriculture, with 90% of the population engaged in subsistence agriculture. Agriculture account for about one third (34.5%) of the GDP, services accounts for about half (50.3%) and industry, such as mining and processing, accounts for the remainder (15.1%) of the GDP. Rwanda's main sources of export are coffee, tea, hides, and tin ore. Exports, however, only accounts for about 13% of the GDP [34].

VISION 2020

In 2000, the Government of Rwanda launched its VISION 2020 plans, which is a framework that outlines a set of indicators with the aim to transform the country from a developing country into a middle-income country by 2020 [80]. The plan is based around six pillars, or main targets:

1. Good governance and a capable state
2. Human resource development and a knowledge-based economy
3. A private sector-led economy

4. Infrastructure development
5. Productive and market-oriented agriculture
6. Regional and international economic integration

These pillars outlines the need for fair and stable governance, universal education and health services, a thriving private sector, a well developed infrastructure, increased agricultural productivity, and an established integration with regional and international economic markets.

4.2 Infrastructure

The mandate of the Ministry of Infrastructure (MININFRA) is to oversee policy development and supervision of four major infrastructure areas, namely transport, energy, water and sanitation, and urban planning and housing. In addition, the ministry oversees the efficiency and effectiveness of infrastructure projects and it facilitate, promotes and engages the private sector to invest in infrastructure [84].

Water and sanitation

Rwanda faces many challenges with general infrastructure such as water and sanitation, electricity, roads, and ICT. Water and sanitation is a major contributor to increasing the health status of the population, as over 80% of diseases that affect Rwandans are waterborne. In 2000, 64% [86] of the population lived without access to an improved water source. In 2015 this had increased to about 76% [34] of the population, mostly those living in urban areas. In total around 24% of the population, with as much as 28% in rural areas, live without access to safe drinking water. This is an improvement from 2000, but it is still behind Rwanda's Millennium Development Goal (MDG) to halve the population that don't have access to safe drinking water. Over 90% of the population had access to sanitation in 2000, but only about 60% had access to improved sanitation like enclosed latrines [86]. Estimates for 2015 shows that this has remained more or less unchanged [34].

Electricity

The many challenges in the power sector in Rwanda is a major constraint for the VISION 2020 plans. The target is 100% access to electricity by 2020. The currently installed power generation capacity is at just over 200MW while the 2020 target goal is around 500MW. Since 2008 the power capacity has grown from 45MW, yet only 30% of the population has access to on-grid electricity, while another 11% has off-grid access. This leaves 60% of the population without access to electricity. The main challenge lies in an old and underdeveloped electrical grid that causes frequent short rolling blackouts [106] [42] [14].

Internet

In Africa as a whole, Internet has historically been scarce and unreliable, with an average international Internet bandwidth of 51 kbit/s per user in 2016, compared to Europe's 178 kbit/s [17]. As seen in figure 4.2, the average Internet bandwidth per user in developing countries is at 53 kbit/s, which is almost three times lower than in developed countries, at 140 kbit/s. According to the World Bank, Rwanda had an average Internet bandwidth of about 9 kbt/s per user in 2016 [33]. This places Rwanda about five times lower than the average in Africa as a whole. In 2013 the government of Rwanda signed a deal with Korea Telecom Corporation to implement and increase the 4G LTE coverage to 95% [83]. In 2017, Korea Telecom: Rwanda reported that they would reach said goal of 95% coverage by the end of the year [70] [78].

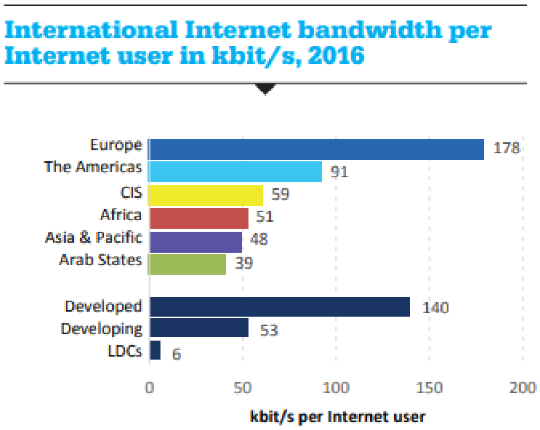


Figure 4.2: International Internet bandwidth coverage per Internet user in kbit/s, 2017 [17]

4.3 Health Status

Life expectancy and mortality

In the decade after the 1994 genocide, life expectancy at birth in Rwanda almost doubled, from 27.5 years for men and 30,5 years for women, to 52.6 years for men and 54.8 years for women in 2004. Over the last two decades the life expectancy at birth has further improved to 62.9 and 66.8 for men and women respectively [61] [60]. Projections from 2017 show that life expectancy at birth has increased to 66,6 years for both sexes [85]. A major factor has been the decline in childhood mortality rate. According to the United Nations (UN) Inter-agency Group for Child Mortality Estimation, the mortality for children under five years has been reduced from about 200 deaths per 1.000 live births in 2000, to about 50 in 2013. [92] This sets Rwanda in line with their Millennium Development Goal (MDG) 4 (to reduce child mortality) of 52 deaths per 1.000 live births by 2015 [86]. Another factor is the improvement in the full immunization coverage of children increasing from about 70% to about 90% in the same period.

Over the last three decades, the Maternal Mortality Ratio (MMR) has declined steadily from about 1300 in 1990, to about 290 in 2015 [93] resulting in a 77% decline. This substantial reduction puts Rwanda ahead of the Sub-Saharan region and in line with the country's MDG 5a (improve maternal health) with a maternal death reduction of three quarters [86].

Nutrition

Improving nutrition for children under five years is a key factor contributing to the increase in life expectancy and quality. Between 1992 and 2015 the rate of underweight children decreased from 24% to 9% of children [58, p. 12-14] [107]. In the same period, however, the rate of stunting in children under five remained steady between 40 and 50%, only showing a decrease towards the end, being at 38% of children in 2015. However, the rate of stunting varies dramatically based on location and social status, from 41% of children in rural areas to 24% in urban areas. In the poorest population quintile, 49% of children were stunted, while in the wealthiest quintile 21% of children under five were stunted in 2015 [58, p. 12-14]. The higher rate of stunting in the poorest segment of the population correlates well with education levels as well, with 47% of children with an uneducated mother being stunted versus 19% of children where the mother has secondary or higher education [58, p. 12-14].

In 2013 the MOH alongside the Ministry of Agriculture and Animal Resources (MINAGRI) and Ministry of Local Government (MINALOC) developed the National Food and Nutrition Strategic Plan (NFNSP) 2013-2018 [76, p. 14]. This strategic plan aims to implement the updated 2013 revision of the National Food and Nutrition Policy (NFNP). The objectives of the policy is to "improve the household food security and nutritional status of the Rwandan people, to substantially reduce chronic malnutrition in children under two years of age and to actively identify and manage all cases of acute malnutrition". To achieve this the NFNSP seeks to follow some key objectives [76, p. 38]:

- Reduce prevalence of underweight children under five years from 11% (2010) to 6% by 2018.
- Reduce prevalence of wasting from 3% (2010) to 2% by 2018.
- Reduce prevalence of chronic malnutrition in children under 2 years from 44% (2010) to 24,5% by 2018.

With the additional help of the World Food Programme (WFP) and their country programme [62], the MOH started delivering FBF and Ready-to-Use Foods (RUF) to children under 24 months old [32]. To manage the growth tracking and food delivery the MOH created the FBF Nutrition programme. The food is given to the families that are classified as very poor, and for the poorest of these families, the mother is also given FBF both during pregnancy and after birth. The foods contain calorie and protein rich ingredients such as precooked and milled cereals, soya, and beans, and are fortified with micronutrients (vitamins and minerals) [32], see figure 4.3.

Figure 4.3: Nutritional info in the FBF packs for children

Health sector financing

Other contributing factors are financial aspects like total expenditure of health services. The total expenditure on health has increased from just under $21 per capita in 1995, to about $125 in 2014 [91]. For comparison, the Democratic Republic of the Congo had a total expenditure of health per capita of $32 in 2014 [89]. This sets Rwanda well ahead of Congo, but the expenditure is still very low, especially when compared to a developed country such as Norway, which had a total expenditure of $6.347 in 2014 [90]. This is about 50 times higher than Rwanda. In 2014 Rwanda also used about 7% of GDP while Norway for comparison used about 9% of GDP [34].

HIV/AIDS and malaria

The National Strategic Plan on HIV and AIDS for 2013-2018, sets the goal of halving the number of HIV-related deaths from an estimated 5.000 deaths per year in 2013 to 2.500 in 2018 [79]. 2015 estimates for HIV/AIDS related deaths is at 2.900 deaths per year [105]. This reduction is well in line with the goal of 2.500 deaths in 2018. The reported deaths from Malaria has also gone down, from 3.167 deaths in 2002 to 496 deaths in 2014 [88]. This is a significant 84% reduction in deaths from Malaria in just over a decade. This in addition to the reduction of HIV/AIDS related deaths per year, has been a major contribution factor to the increased life expectancy as well.

4.4 Health System

4.4.1 Structure

In Rwanda the MOH operates a universal healthcare system. The healthcare system is based on a community-based health insurance scheme, with the most common insurance being *Mutuelle de Santé*. Residents pay premiums to a local health fund, in which they can draw from when in need of medical care. Premiums are based on a sliding scale, adjusted based on income, where the poorest members of society are entitled to free service and the wealthiest pay the highest premiums. Membership in the insurance scheme is voluntary, but it is estimated that about 80% of the population is covered by the Mutuelle insurance. The insurance, however, does not cover private healthcare services [73].

Nearly all (77%) of healthcare services in Rwanda are public. About half, 55%, of these are operated by the Government of Rwanda (GoR), and 20% are operated by private organizations. The remaining facilities are operated by communities, 2%, and parastatal organizations, 1% [73].

The public healthcare system is a decentralized, multi-tiered system tailored to the local administrative level structure in the country (see figure 4.4 on the following page). The system consists of five levels of care, namely village, sector, district, province, and national level [101], visualized in figure 4.5 on page 27.

The health system hierarchy levels is as follows [101]:

- The *village* level provides the most basic of services. Community Health Workers (CHWs) work at health posts in the villages with the focus on mother and child health, vaccination, hygiene and sensitization. This work by the CHWs play an important role in improving health status in households.
- The *sector* level provides primary healthcare services at health centers. The health centers are run by nurses who provide the most basic services like simple tests, or health checkups of mother and child. This includes private clinics and dispensaries, as well as public and community owned health facilities.
- The *district* level provides district hospitals, as well as private clinics and hospitals. They serve the role of supervising district health

centers and as a referral point for cases too complicated for primary healthcare facilities.

- The *province* level provides provincial hospitals, which hosts advanced clinical service and serve as a referral point for district hospitals in cases that are too complex for them to handle.

- The *national* level provides national referral hospitals as well as specialized hospitals. They consists of advanced, specialized clinics and serve as a referral point for province hospitals when specialized services are required.

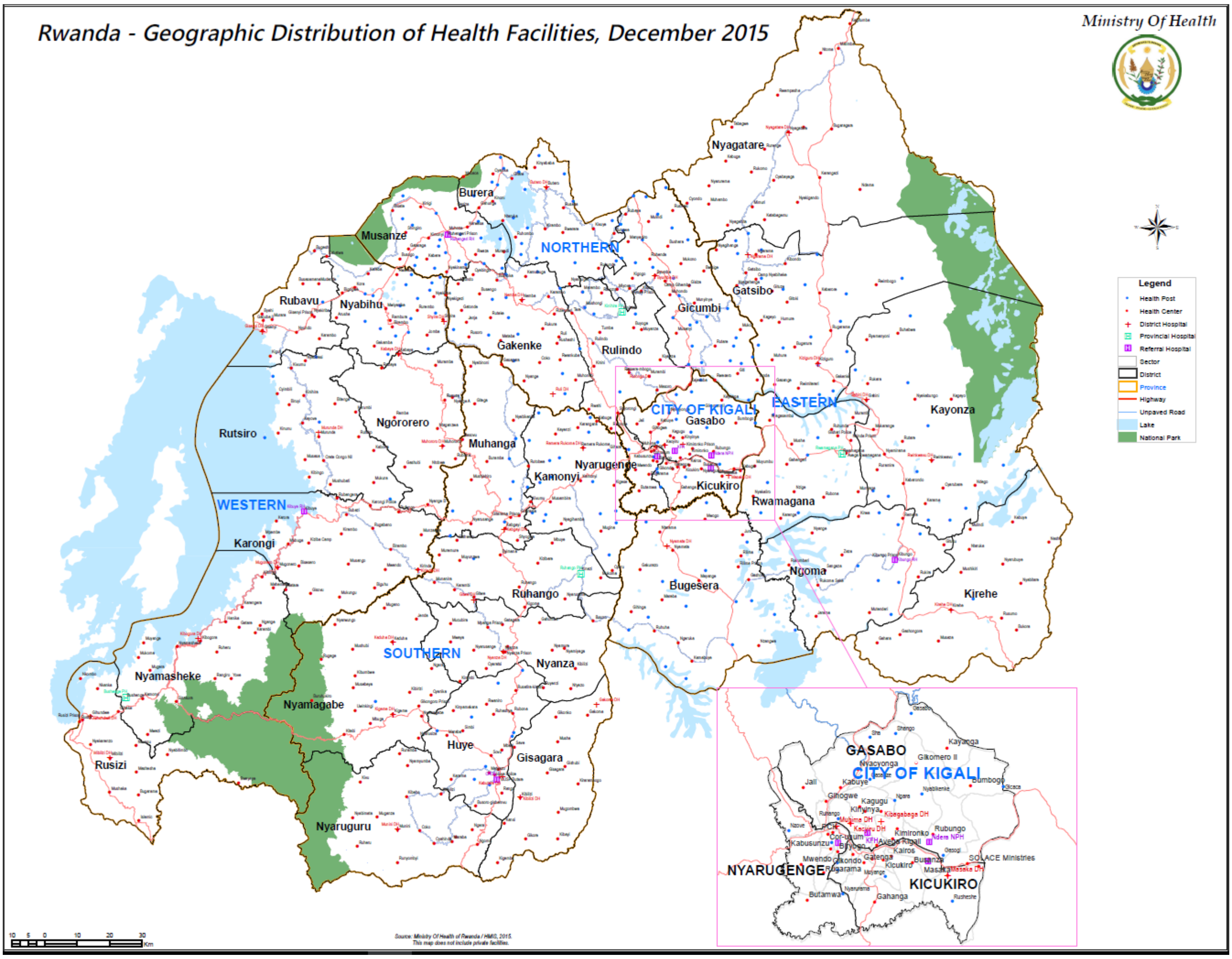


Figure 4.4: Map showing the distribution of health facilities in Rwanda as of 2016 [81]

4.4.2 Health Management Information System in Rwanda (RHMIS)

According to the WHOs guidelines a "sound and reliable information is the foundation of decision-making across all health system building blocks" [95, p. 44].

The WHO further states that the key functions of a HIS is "data generation, compilation, analysis and synthesis, and communication and use" [95, p. 44]. The HIS is in other words the overlying structure that supports every aspect of a health system such as data collection from health and other relevant sectors, data analysis to ensure data quality, relevance and timeliness, and data presentation for health-related decision-making [95, p. 44]. The HIS also supports specialized health related systems such as the HMIS, and patient management systems, or health related logistics systems such as medical supplies.

Rwanda's HMIS follows these guidelines by encompassing data collection, reporting, and processing and use of said information to improve the effectiveness of the health services and improvement of the nation's health status. The HMIS is built around a five level hierarchy as described in section 4.4.1 and visualized in figure 4.5 below.

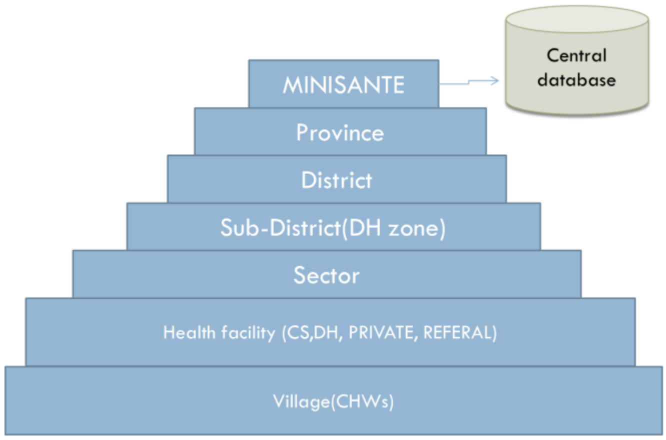


Figure 4.5: The healthcare system structure in Rwanda [101, p. 2]

The information flow starts at the villages where data is collected by CHWs in paper records. The reports are then brought to health centers, or district and provincial hospitals where it is digitalized by Data Managers who enter the data into DHIS2. Reports are then generated and sent regularly by quarter, month, weekly or even on case by case basis through DHIS2. These reports are accessed by the HMIS Unit and other units at the MOH, or by provincial and district hospitals [101, p.4-5]. District or health center based reports are also generated and displayed by managers at health centers to involve the general population (figure 4.6).

The HMIS Unit at the MOH is "in charge of coordinating the activities of collecting, storing, analyzing, interpreting and reporting key health-related routine data" and their mandate is to ensure the availability and

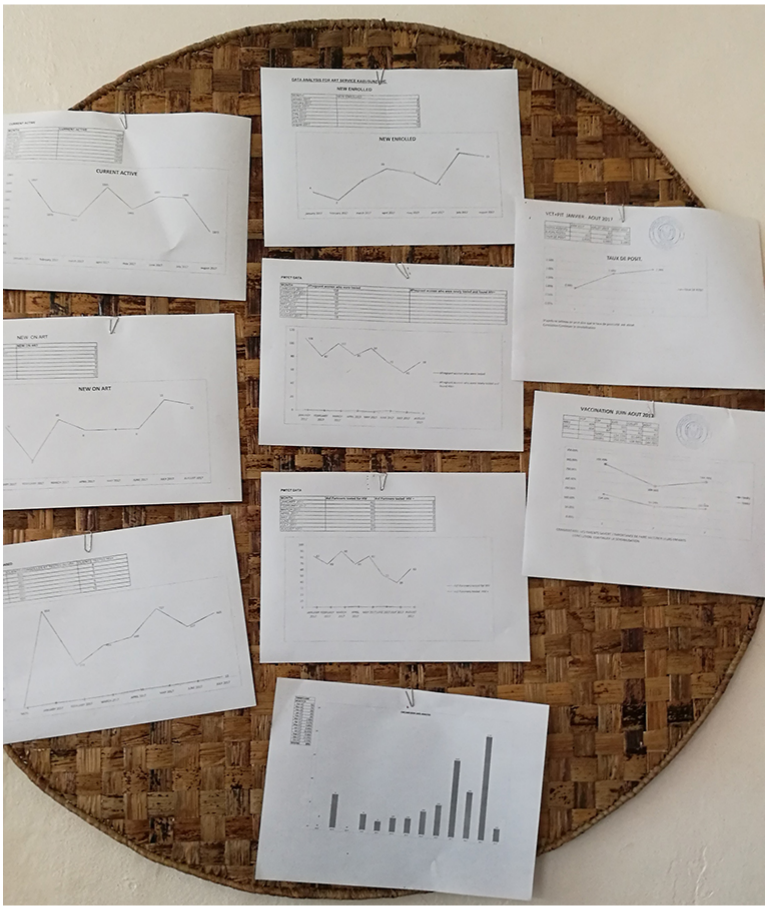


Figure 4.6: Health reports for everyone to see on a notice board at a health center.

data quality of the HMIS. To fulfill this mandate, the HMIS Unit began the development of the GESIS software in 2007, a standalone application that had to be manually installed on every PC [82]. It was quickly realized that this system was very inflexible and the developer stopped providing system support and updates. These issues with the GESIS software happened to coincide with an increased investment in Internet coverage in Rwanda, which brought with it the opportunity for the country to operate their own web servers. The HMIS Unit began to prepare requirements of a system to replace the failed GESIS software. Their objectives were to find software that was both open source and web based in addition to being able to handle data collection and reporting. This lead to the discovery of DHIS2, which was found to comply with most of their needs [101, p.1]. In 2012, DHIS2 was chosen as the software to use for the country's HMIS and countrywide roll-out was achieved only 4 years later [13] [82].

This short roll-out period was achieved by giving health workers thorough training in DHIS2 simultaneously with the implementation of the system. In addition, the pre-existing computer and network hardware from the previous system where utilized, which saved both time and resources.

The Rwandan HMIS (R-HMIS) is currently divided into eight different instances. These are HIV, Individual Records (eTB), eIDSR (Integrated Disease Surveillance), Data Warehouse, SISCOM (Community Health Worker System), PBF, and FBF System, as seen in figure 4.7. Each covers a specific area within healthcare, and users are restricted to use only the instance they have user access rights to.

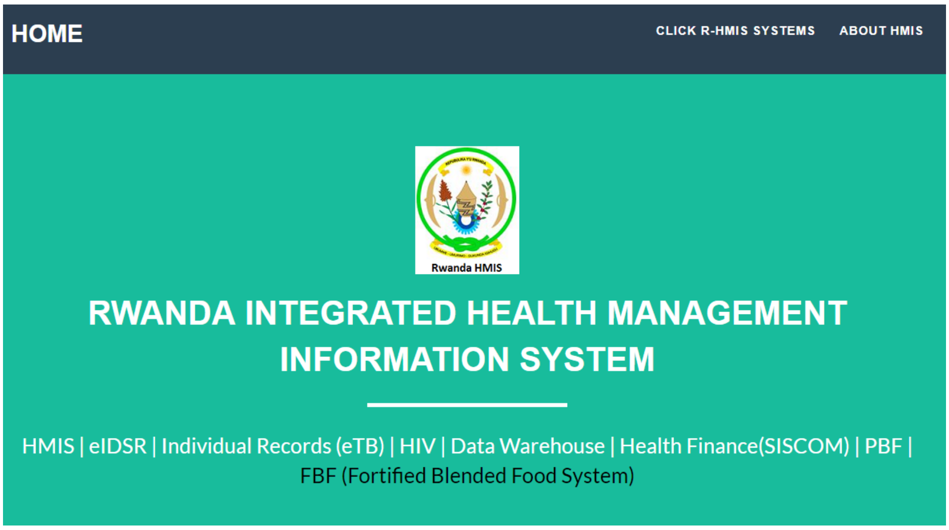


Figure 4.7: The frontpage for the RHMIS showing the different DHIS2 instances [24].

4.5 Summary

Rwanda is faced with many challenges when it comes to improving its health sector. One of those challenges is the prevalence of malnutrition in children under five years old. The current situation for tracking specific patients and their development throughout the NFNP based FBF programme faces many challenges in form of large and cumbersome paper records and multi-use paper growth charts. The use of paper records can be major source for human error as handwriting can be difficult to read, especially if corrections have to be made, in the small boxes alloted in the records. The multi-use paper growth charts can also be a common source for errors as they become very hard to read, and plot when covered in old pen marks.

This thesis explores the potential for nutrition CDSSs in healthcare in development countries. To help this research the project includes the development of a growth tracking CDSS application to help clinicians and managers solve some of the mentioned problems or difficulties in tracking and managing the health status of malnutritioned children, as well as furthering the research on nutrition CDSSs in low resource settings.

Chapter 5

Methods

This chapter describes the research methodologies and methods used in this thesis. The chapter describes the research perspective and paradigm, methods used in the app development and the methods used in the research data collection and analysis for this thesis. Lastly a reflection on the research methodology and development approach is presented, as well as a reflection on the shortcomings and limitations of this thesis.

5.1 Research Perspective

This section describes the research perspective used in the thesis while the following sections will, in more detail, describe the methods used. In the article "Qualitative Research in Information Systems" Meyers argues that even though research methods can be classified in various ways, the most common distinction is between qualitative and quantitavive research [75]. The basis for this distinction lays in the data the methods is based upon. Quantitative research is based on numerical data analyzed statistically, whereas qualitative research bases itself on non-numerical data such as human interpretation [75, p.3-4]. Quantitative research methods are often used to study natural phenomena, with methods such as surveys, laboratory experiments, and mathematical modeling. Qualitative research methods are used to study cultural phenomena, with methods such as participatory and passive observation, interviews, documents and texts, and the researcher's own impressions and reactions.

The data sources in this project are mainly based on fieldwork through observations as well as interviews and the researcher's own impressions. This fits with the definition of qualitative research methods and is therefore the chosen method for this project. Such data cannot be analyzed easily using mathematically based methods. According to Meyers' qualitative research methods:

"... are designed to help researchers understand people and the social

and cultural contexts within which they live [75]."

Following this description, using qualitative methods is the appropriate choice, as the growth monitor app is designed and developed for the users of DHIS2. Understanding the thoughts and needs of the users are imperative for developing a successful application.

Within the qualitative research field there are three philosophically distinct paradigms; positivistic research, critical research, and interpretive research [109]. In positivist research, reality is objectively given and can be described by measurable properties, which are independent of the observer. The aim in positivist studies is to test theory to understand a phenomena. In critical research social reality is assumed to be historically constituted and produced and reproduced by people. One can consciously act to change one's social and economic status but one's ability to do so is constrained by social, cultural and political forces. The aim of critical research is to eliminate oppositions, conflicts, and contradictions in contemporary society. In interpretive research reality is accessed through social constructs such as language, consciousness and shared meanings. Interpretive studies seek to understand phenomena through the meanings people assign to them. In Information System (IS), interpretive studies seek to produce an understanding of the context of the IS and how the IS influences or is influenced by the context [75].

Because of the nature of the data sources with human thoughts and opinions as feedback for the development, implementation, and use of the apps for this thesis, the paradigm that best fits the research is interpretive research. The research in the thesis is colored by our interpretation of health workers thoughts and perceptions of using an application to calculate and create growth charts during a patient visit. Our interest was in researching how a growth tracking app can influence the workflow during a patient visit, and potential benefits or challenges as experienced by health workers and managers in Rwanda.

5.2 Action Research

> Action research aims to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration within a mutually acceptable ethical framework - Rapoport, 1970 [75].

The focus of Action Research (AR) involves solving organizational problems through intervention while at the same time contributing knowledge to the science community [75].

The goal of this project is to generate knowledge for the science community, while at the same time trying to contribute to solving the malnutrition problem the Rwandan MOH is facing. This makes the use of AR appropriate and also the method we chose to use for the project. For practical reasons most of the user testing phase of the application and partly the app development took place in Rwanda.

The AR process is cyclical and consists of five steps. As seen in figure 5.1, the steps are as follows:

- 1. Diagnosing (Identify or define a problem)
- 2. Action planning (Consider courses of action)
- 3. Action taking (Selecting & implementing the course of action)
- 4. Evaluating (Study the results of the action taken)
- 5. Specifying learning (Identify the general findings)

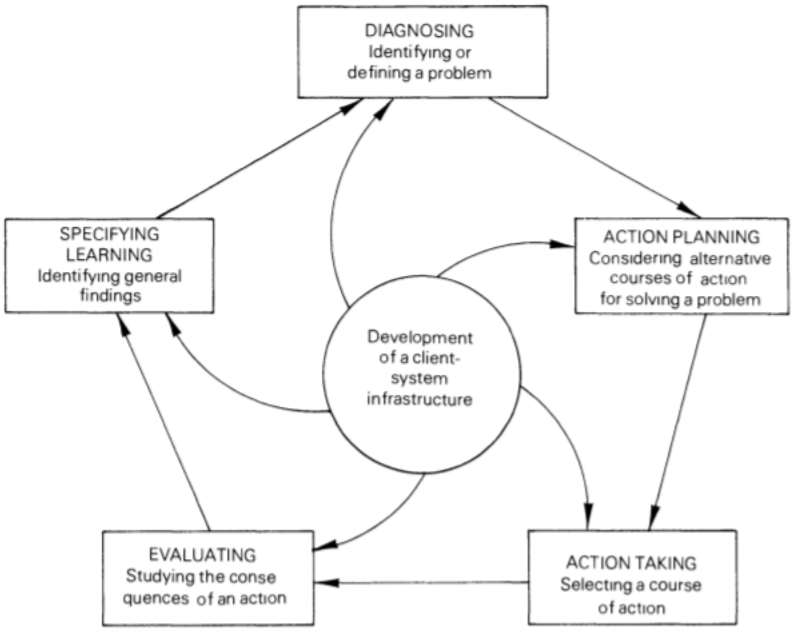


Figure 5.1: The cyclical process of action research, Susman et al. [103]

One of the many challenges the Rwanda MOH faces is a high percentage of malnutrition in children below 24 months. The idea behind the growth tracker is to simplify the patient consultation for nutritionists and data managers at health facilities. Since the applications is aimed at solving the needs of both local health workers and regional and national managers, the involvement of the local organization was a key factor for the development process. Their feedback directly influenced the design decisions and let us, as researchers, experience and observe situations and needs that we otherwise would not have discovered.

Action Research cycle steps

The main cycles of this project is visualized in figure 5.2 on page 35. The prototypes produced within each cycle is described in more detail in section 6.5 on page 63. The Action Research cycle steps in this project is as follows:

1. Diagnosing: The need for a new anthropometric measurement tool was identified after the cancellation of WHO Anthro. The measurement tool would preferably be integrated into the DHIS2 as this is the chosen HMIS platform in Rwanda. In addition this turned out to be an opportunity to study the potential for using CDSSs in developing countries.

2. Action Planning: This step consisted mainly of the development of the application. The development took place mainly in Norway, but also partly in Rwanda. An initial prototype were developed according to the requirement specifications given by the MOH during an initial meeting in Oslo. The application were developed using agile development as the project required openness for changing requirements from the stakeholders. For example, early on during the stay in Rwanda the need for an extra application that could do aggregate analytics were discovered and a proof of concept was developed.

3. Action Taking: The main source of data collection. This step took place in both Norway and Rwanda, but mainly in Rwanda. The data collection is described in the data collection section 5.5 on page 41.

4. Evaluation: The results from step 3 were evaluated continuously, and changes were made based on the findings. The feedback from stakeholders were crucial for the evolution of the applications.

5. Specifying Learning: After each cycle the process were documented and findings and further needs was discussed, and new requirements set.

	Cycle 1	Cycle 2	Cycle 3
When	Jan-Aug 2017	Aug-Dec 2017	Jan-Mar 2018
Where	Norway	Norway & Rwanda	Norway & Rwanda
Goals	• Re-engineer WHO Anthro in DHIS2 • Develop alpha version	• Gather feedback on alpha version • Implement requested features in beta version	• Test beta version • Gather feedback • Implement most critically required changes
Testers	• Developers	• MOH HMIS Unit	• MOH HMIS Unit • Local health workers &data managers • Hon. Minister of State
Learning	• The requirements for an anthropometric measurement tool • How to integrate into DHIS2	• The requirements for a decision support system for growth tracking	• Potential benefits of using decision support systems for health care in developing countries • The need for both consultation tools and aggregate applications

Figure 5.2: The main Action Research cycles of this project

5.3 Methods in software development

This section describes the methods used in the development of the applications, as well as some useful organizational tools.

5.3.1 Agile Software Development

Agile Software Development (ASD) is used as an overarching term for a set of development methods and practices, which is based on the principles expressed in the Agile Alliance's "Agile Manifesto". ASD has a goal of finding solutions through collaboration between small self-organizing, cross-disciplinary teams utilizing their collective knowledge [1]. The main target for ASD is dynamic projects where accurate estimates, and stable plans and predictions are difficult or impossible to get.

> True agile methods view the world as fundamentally chaotic. They assume change is inevitable. Their focus is to deliver value to the customer as quickly as possible, and not bother about extensive plans and processes that won't be followed anyway [108, p- 50]

Unlike traditional software engineering where the process is rigidly planned ahead of time, ASD promotes adaptive planning, frequent changes, collaboration, early and frequent delivery, continuous improvement, as well as encouraging rapid and flexible response to change [72] [108, p- 46-51].

The Agile Alliance suggests, through its Agile Manifesto, 12 principles that ASD projects should follow [2] [3], see figure 5.3.

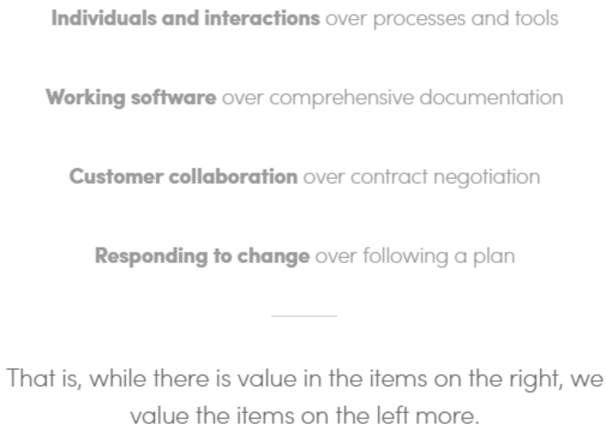


Figure 5.3: The Agile Manifesto [2]

As stated by the Agile Alliance, ASD is an umbrella term for several development methodologies. Most ASD methods break tasks into small incremental cycles, with no extensive long-term planning. At the end of each cycle new situations are reviewed, and the next cycle is planned. At the end of each cycle, the system is working and demonstrated to the stakeholders. "Agile methods are people-oriented, rather than process-oriented" [108, p- 51]. The human element in software development is emphasized, and each cycle often involves a cross-functional team performing all required functions; planning, requirements analysis, design, coding, unit testing, and acceptance testing.

This cyclic behavior strongly resembles that of evolutionary prototyping, however, the term prototyping suggests something temporary. "Working code" or "working system", on the other hand, carries a much more positive meaning, it gives something of immediate value, even if not yet perfect and final [108, p- 51].

ASD is, however, not free of risks as estimates can be hard to predict, making deadlines difficult to set. The openness to changes also provides a risk, as too many changing requirements may cause confusion and lead to breaking the system with bugs and tasks that do not meet the deadlines. Lastly, the agile principle of less documentation can lead to difficulties when developing new features or revisiting old code. These risks are easily avoidable by working efficiently and testing the software regularly, both new and old features, so that users can give valuable feedback. Making sure the code base is structured and easily readable is also important, as too much messy code is difficult or impossible to understand when revisiting the old code. The use of prototyping in addition to agile methods further increases the importance of structured code as quick, working solutions are favored. Revisiting old code to clean up 'hacky' solutions is therefore important during downtime.

5.3.2 Prototyping

One of the development methods used in this thesis is software *prototyping*. Software prototyping is the process of developing early, incomplete versions of a product to test features and get feedback to develop the product further. To support the research in this thesis we developed several prototypes to test functionality and concepts with potential users during the development process.

Creating a prototype begins with identifying the product requirements, in similar fashion of the first step of identifying a problem in AR. The most important part is to get the prototype working; details such as performance can be overlooked in the beginning. The next step is then to develop the prototype according to the basic requirements along with showcasing a functional version of the user interface. When the prototype sufficiently represents an early version of the system it can be presented to the stakeholders for testing. Feedback is collected and used to further develop and improve the product. The team then discuss the feedback to decide upon which changes that are feasible and important to implement, in accordance to time, technical feasibility, and budget. The agreed upon changes are then implemented into the next version of the prototype. This process is then repeated, creating a cycle, until either the stakeholders are satisfied with the product or the deadline is reached [25] [102].

This cyclic process resembles the cyclic nature of AR. The cycles starts with planning and action taking, and ends with an evaluation that produce new knowledge on the subject. This makes prototyping appropriate in this research setting; the Action Research (AR) seeks to enlighten the potential for CDSSs in the health sector in developing countries, while the prototyping seeks to specifically improve the development of the application.

Prototyping Variants

There are several different types of prototyping procedures, however, most, if not all are based on two major archetypes, namely Evolutionary and Throwaway Prototyping.

Evolutionary Prototyping

The aim with evolutionary prototyping is to, in a structured manner, build a working prototype of the product that can evolve with constant refinement along the development process. This allows for chances and additions of new, non specified features along the way [45].

Rapid Throwaway Prototyping

Rapid Throwaway prototyping refers to the process of creating a model based on the basic requirements, which are then discarded after it is reviewed by the users. After the prototype review, new requirements or clarification of existing clarifications are done, and the system is formally developed based on the newer requirements [48] [45].

Summary

The evolutionary prototypes are in various degrees functional systems, which can be used in some function, throughout the development process. Unlike in evolutionary prototyping where the prototype is a part of the final product, the prototype developed in the throwaway method is discarded, and not a part of the final product. The prototypes are not fully functional systems, but exists just to allow for a second look and refinement of the requirements before final development.

We opted to use evolutionary prototyping because it felt naturally to us to continue developing the prototype, which resembled the finished product throughout the project, instead of discarding the prototype after each cycle. Additionally, its evolutionary nature with continuous evolution and evaluation after each development cycle, fits well with the cyclic behavior of Action Research (AR). With a continuous prototype that resembled the finished product stakeholders could get used to the application, and give us more accurate and descriptive feedback throughout the whole development process, without having to relearn the application for each prototype.

Advantages and disadvantages with prototyping

There are both potential advantages and disadvantages to prototyping.

Advantages

Prototyping requires users to interact with the system throughout the process. This allows them to get a deeper understanding of the system, and provide more accurate feedback and specifications on the current implementation, as well as requests for new features. In addition, the user involvement provides the opportunity to change and improve the requirements and specifications throughout the development, which can result in shorter development time, and both higher quality and less expensive software [99] [48]. A working prototype may also prevent miscommunication and misunderstandings throughout the development, as the users can check out the product themselves and get a feel for how it currently works. A prototyped finished product is more likely to satisfy the customers, as the customer builds up a sense of ownership during the development process [108, p- 54].

Developing prototypes allowed us to show a working application to the stakeholders throughout the development, allowing rapid, frequent, and detailed feedback. This also allowed the users to become experienced with the finished product through the prototypes, which reduced the learning process for the final product.

Disadvantages or risks

When developing a prototype there is a risk of adding to much to the requirements and specifications, which can lead to spending too much time on the prototype. This can draw out the development type which might increase costs and complexity. Another risk is the risk of growing too attached to any one feature or the prototype as a whole. Users can become too attached to features that might not be a part of the final product and being discarded while developers can end up trying to convert a limited prototype into the final product. The risks may cause conflicts between developer and users, as well as with the time schedule. All of which can reduce the efficiency of prototyping, and the quality of the end product.

While the feedback generated through the use of evolutionary prototyping allowed us to increase the quality of the features implemented, it also generated suggestions and requests which we were not able to implement, within the time frame of this project. When one feature was implemented and given to the stakeholders for testing, the feedback generated even more suggestions forcing us to prioritize the most requested features, which would fit within the time frame.

5.4 Our approach to development methods

This section describes the methods used in software development and our approaches to them.

5.4.1 Prototyping

This project is based on the Rwanda MOH's wish to implement WHO's Anthro software [28] in DHIS2, but with no clear specifications for the look and feel of the new application. We used the prototyping method to quickly to quickly re-engineer and develop a working concept of the growth tracker. This let us quickly get a personal understanding of what is required in a growth tracker, and also to get feedback from the users and what they liked or disliked.

Throughout the development we could implement changes and new features upon the existing prototype, which could then be tested by the users to get new feedback, rinse and repeat. There was always a working version of the application available for testing, and new features could quickly be rolled out for testing and feedback. Following our AR cycles, we developed 3 major prototypes. The third prototype turned out to be the final version of the application, and thus, evolved to become the final product. The prototypes were made using the Evolutionary Prototyping method, as there was ever only one working version, which were continuously being changed and improved.

5.4.2 Agile Software Development

Agile methods proved to be the most suitable because of the limited pre-existing specifications, and new specifications and requirements arose during development of the growth tracker application. This made long-term plans hard to create and adhere to. Planning were, therefore, kept to a minimum, and specifications and requirements were organized in a digital scrum board, see 5.4.3 Trello. In addition, the ASD methods align well with AR, with the cyclic behavior of embracing and implementing ever changing requirements. After each cycle or iteration, the results were evaluated, new knowledge gained, and new requirements specified, thus beginning the cycle anew.

Project and cycle plans were made based on how feasible it was that a task would be completed within the given iteration or cycle. This planning depended heavily on existing software and knowledge. As agile methods is all about maintaining efficiency, ensuring that as many tasks as possible were including in each iteration, as to meet the end goal of each prototype, and to get valuable feedback from the users.

As stated in 5.3.1, the Agile Manifesto suggest 12 principles that ASD project should follow [3]. As this projects follows elements from ASD, all of these were relevant to our development project, but some were more relevant than others:

- "Welcome changing requirements, even late in development. Agile processes harness change for the customer's competitive advantage". The fact that requirements were changing as we got feedback on the growth tracking application, sometimes several times a day, this principle was important to follow, as to allow these new requirements.
- "Deliver working software frequently, from a couple of weeks to a couple of months, with a preference to the shorter timescale". Because of the limited pre-existing knowledge and specifications, and short time frame for development, this was an important principle to follow as it allowed us to get feedback on changed or new features quickly and often.
- "Simplicity, the art of maximizing the amount of work not done, is essential". This ties into the previous principle of frequent deliveries. The short time frame in Rwanda made it so changes would have to happen daily, or bi-daily, to maximize the on-site user testing and feedback process.

The development was split into 3 stages or prototypes. The duration of the iterations, or sprints, in each stage varied but were usually between 1 day and 1 week, sometimes up to a month. Things such as the complexity of each task, and remaining time until the development had to move on to the next stage heavily influenced the length of the sprints. The sprints during the first prototype development were weekly, and sometimes monthly if difficulties appeared. This ensured that the development had steady progress and followed the principles of steady efficient progress in ASD. The sprints during the final prototype, on the other hand, were done daily, or bi-daily. Due to the frequent and specific feedback we were getting while in Rwanda, in addition to the heavy time constraints due to the short stay in Rwanda. The daily implementation and feedback allowed us to move forwards at a quick and steady pace, ensuring that the end-users satisfactions were met.

5.4.3 Software Development Support Tools

Git

When multiple developers work on the same project keeping version control of the code is important, to prevent things from accidentally being overwritten or deleted, but also as a place of backup in case of hardware failure. The natural choice for version control fell on *Git* as both developers have had positive experience with it in other projects. Git "is a free and open source distributed version control system designed to handle everything from small to very large projects with speed and efficiency [15]." Git is a tool that allows developers to work independently on parts of a project, without having to worry about how it will be merged together with the work of others on the same project. Code can easily be created, merged, and deleted, as well as error correction, such as rollback, in case of errors during merging.

Trello

> Trello is a collaboration tool that organizes your projects into boards. In one glance, Trello tells you what is being worked on, who is working on what, and where something is in a process [26].

Trello is an organizational web-based tool that lets the user create and share digital boards in a fashion to scrum boards. These boards can be filled in with various notes, usually describing the status of project tasks, helping to show what needs to be done, and prevent duplication of work.

5.5 Data collection

When developing an application the opinions and impressions of the stakeholders are important. To end up with a finished product that they are happy with and able to easily make use of, a qualitative approach to the data made the most sense. We chose to use semi-structured interviews, group demonstrations and observations, and focus groups as the main methods to capture and collect relevant data. This approach fits with the characteristics of AR as well. The research was done in collaboration with the Rwanda MOH HMISU to get access to and an inside look at the current operations at health facilities and MOH.

Data Collection Methods:

The data collection employed consisted of:

- Observation of current health facility practices
- Demonstration of the application
- User-testing of the application
- Interviews and group interviews with users and managers

Due to time constraints on both the HMISU's end and ours, only four health facilities were visited during the stay in Rwanda, all in Kigali. We met the data manager and a nutritionist from each health facility, and they were later invited to participate in a demonstration and feedback session for the FBF Antro application. We had a total of 2 focus groups and feedback sessions. The first session were with the health workers at local facilities. The second group session were with health experts from various interested parties from within other parts of the MOH, as well as NGOs working in Rwanda such as UNICEF. The first meeting, with health workers, saw a total of 9 participants, while the health expert meeting had 16 participants.

Interviews and focus groups

> The purpose of the research interview is to explore the views, experiences, beliefs and/or motivations of individuals on specific matters (eg factors that influence their attendance at the dentist) [59].

There are three main types of research interviews; structured, semi-structured, and unstructured or in-depth interviews [44]. Semi-structured interviews was chosen for this project because of our limited knowledge with DSS and the medical field, and the nature of the information that was sought. This let us have a predetermined theme for the interviews, with a list of fairly open questions that we could build upon during the interview as we saw fit, depending on the responses given.

Semi-structured interviews is a combination of both structured and unstructured questions. They consist of several questions that define the area of interest, but lets the interviewer or interviewee diverge from the question in order to explore a response or area in more detail over other areas. Structured interviews on the other hand are much more strict and rigid in its form which is usually structured in a standardized manner and questions have mostly fixed choices. They only allow for very limited responses and are thus better suited for quantitative research which sees a wider use of questionnaires and surveys. Lastly unstructured interviews are even less structured than semi-structured interviews and may only cover a few issues, but in much more detail. The questions are very open with questions such as "Talk about your own health...". Open ended questions can become very time consuming as there are best suited when significant depth is required, with little to no time constraint [44] [59].

Focus groups share several features with less structured interviews. A focus group is a group discussion that lets the researcher ask a question to the group, and then let the participants discuss it between themselves. This method is useful to explore people's knowledge, and also the collective views and their meanings. The discussion is guided and monitored by the researcher or moderator [67] [59].

The number of participants, and our limited time scope dictated the use of focus groups when interviewing the health workers and health experts. Both focus groups and semi-structured interviews are qualitative data collection methods and share mostly the same goal. The main difference is the number of participants, where interviews are usually one-to-one and focus groups are usually 3-14 participants [59].

Interview and focus group purposes

The main theme for the interviews and focus groups were the usability and functionality of the growth tracking application. We were looking for areas of improvement in the user interface, to make it as simple to use for the health workers as possible. We were also looking for improvements and other changes to the functionality of the application that were needed, such as what information was important to the health workers during patient consultation. Lastly we were seeking information about their views on the effect this system could have on their daily workflow, both positive and negative.

The focus groups with health workers started with a demonstration and user-testing of the application, conducted by a member of the HMIS Unit. Language was a hard barrier for us and the health workers, so the discussions were conducted in their own language, and the HMIS Unit member took on the role as a translator. This let us, as researchers, focus on taking notes and observing the participants while they were discussing. The language barrier could, however, be cause for error in both questions asked and responses given, as neither researchers understood the language of Kinyarwanda, and English is not a widespread language in Rwanda.

Some of the questions asked include:

- How was it to use the application? Was it easily understandable?

- Is the information shown in the application useful, what could be improved?
- Would this system have a positive effect on the patients health status, or just reduce the health worker's workload?
- If the health workers had a laptop/tablet, would this be helpful during consultation and in what ways?
- Further suggestions?

As the focus of the project is two fold, seeking both to develop a usable application and explore the potential of using a nutrition CDSS in developing countries, the questions sought to gain knowledge of how the users experienced the application, and what their immediate thoughts were for how it would impact their daily workday.

The second group session with health experts were conducted in English. The session started with a demonstration of the application from a member of the HMIS Unit, which again let us observe and take notes. For this session, the HMIS member took the lead and acted as the moderator for the discussion. The health experts seemed to easily understand the use of the application, and quickly moved to more in-depth discussions and questions around more specific functionalities in the application. The questions were mostly directed towards us, the developers and researchers, as the experts quickly agreed on the usefulness of the application, and instead sought information about the more in-depth functionalities.

The semi-structured interviews were focused around the HMIS Unit members and what they were after and required in the app, as well as their impressions and feedback during demonstration and user-testing.

We used mostly audio recording with time stamps, however, as some interview participants expressed their wish not to be recorded, extensive note taking was also performed during the data collection process. Audio recording was chosen because taking notes while maintaining a conversation can quickly prove difficult and negatively effect the conversation flow. However, as the discussions with the health workers had to be translated, this let us focus on observing the participants and their body language during discussions, and focusing on taking notes when translations were given. This removed most of the effort of keeping the conversations flow.

5.6 Data Analysis Approach

Data gathered during interviews and observations were noted down and transcribed after the interviews. The notes and transcripts where later coded and categorized, see figure 5.4 below. The responses given in the group sessions and interviews gave us good feedback on the app, with fairly specific suggestions such as adding the total number of visits for a patient to the visit list. Other feedback such as questions about how a predicted scores feature worked, and confusion about its usefulness and accuracy led us to immediately realize that this feature would not be useful, and remove it. The direct and specific feedback turned out few but specific coding categories, with little room for ambiguity, such as "remove predicted visit", "fill colors between chart SD lines", or "makes our job easier" in regards to the digital growth charts with exact z-score numbers. With the limited amount of interviews and group sessions, the collected data was fairly limited in amount. This did not justify the use of complex and extensive data analysis software, and the coding was therefore done by hand.

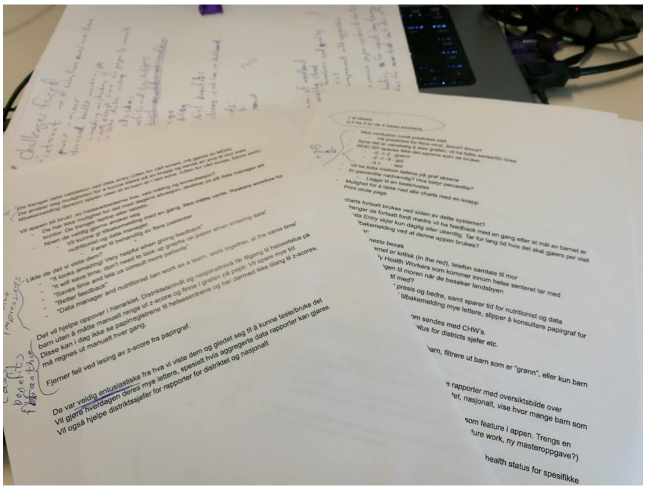


Figure 5.4: Coding example of interview notes.

As visualized in figure 5.5, the analysis went through three stages when analyzing the collected data, namely data familiarization, data categorization and connection of patterns and explanations. The first stage focused on reviewing the data, both notes and audio recordings, to get familiarized with everything. This helped us, afterwards, visualize the context the data were collected in when categorizing the data. The next stage focused on separating and categorizing data into topics and trends, such as identifying feedback for the different parts of the app, or feedback and opinions about the CDSS system in general. This allowed us to quickly identify the requested changes to FBF Anthro, and prioritize them, or identify requests that were outside of the scope of this project, such as general changes to the Tracker Capture (TC), or the HMIS in general. The final stage consisted of connecting the identified trends and opinions into patterns to form explanations, such as the impressions and opinions about what impacts the software might have on their usual workday.

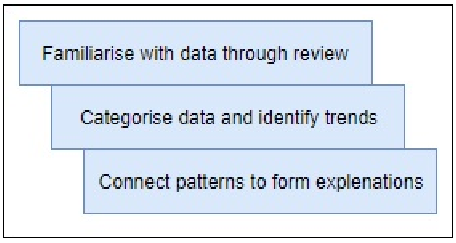


Figure 5.5: The stages followed during data analysis [71, p. 6-8].

The initial focus of the research was covering challenges and opportunities with developing the growth tracking app in Rwanda. During development the need to describe the building blocks of the application, such as the internal CDSS components, was identified, to facilitate explaining the challenges and opportunities faced during development and the final implementation.

Although most of the interviews and group sessions were focused around the app and its functionality for the health workers, we were also given an insight into how the app would help them do their daily job, and what effects it might have for their work, and potentially the patients. Their entirely positive outlooks on how the app might help them, led us to believe that this system would have a positive impact. The focus was therefore shifted from solely looking at what challenges might arise when developing such an app, but also to look at what impacts it might have on the health workers themselves, and potentially also their patients. This led to the addition of the second research question "What are the potential benefits and challenges of using clinical decision support systems for nutrition and growth tracking?".

A CDSS may have different impacts in a developing country without a fully computerized, well functioning healthcare systems, compared to a developing country such as Norway, which has a structured and well functioning healthcare system [41]. As Rwanda is a very poor country, with limited skilled human and financial resources, the study was narrowed down to focus on the impact in low resource settings such as that of the healthcare system in Rwanda.

During the data analysis we also identified the need they had for aggregated data for statistical analysis, which prompted us to create a second app as a proof of concept for this purpose, even though such an app would fall slightly outside the main scope of CDSSs and their impact on health workers, because the analytics app would be aimed more towards directors and managers.

5.7 Reflection on methodologies

5.7.1 Research approach

As described at the beginning of this chapter the research methodology opted for in this thesis was Action Research (AR), combined with the software development methods prototyping and agile development. As described, AR consists of a cycling process that can be broken down into five steps, namely diagnosing of problem, action planning, action taking, evaluation, and specifying learning. The cyclic behavior of AR fit well with prototyping, which also consists of a cyclic process. The development process took place over three AR cycles, resulting in three major iterations of the application prototypes. The prototyping process, described in section 5.3.2, functioned as a driving factor, moving the cycles forward, combining the prototyping and AR cycles into one larger cycle. The development took place in the diagnosing, action planning, and evaluation AR steps, while the demonstration and user-testing was done in the action taking step. Each cycle had some user-testing with Andrew in the HMIS: Unit (HMISU), however the largest acting taking step is arguably the demonstrations that took place in Rwanda.

All in all we believe that the combination of methodologies used in this project was sufficient to provide knowledge for further research within this field, as well as realizing the application goal with the growth tracker, allowing for further development and testing.

5.7.2 Development approach

When developing the application continuous and rapid iterations turned out to be very helpful for detecting bugs and other mishaps before displaying the apps to the end-users. This also enabled us to quickly get feedback for each changed or new feature in each iteration, with the feedback being focused on that specific feature, instead of a long list of features. This allowed us to quickly detect and resolve any potential issue that might have slipped under the radar during bug-testing.

Focusing on end-users when developing allowed features to be more tailored to their needs, allowing the users to quickly understand its usage during testing, and enabling the users to give more accurate feedback. When analyzing the feedback, it was important to consider everything that was said, in order to identify all possible feedback, even the more obscure suggestions. This allowed us to identify what features where most commonly requested, and what features that were feasible to implement before deadline.

When using prototypes as a development methodology, prioritizing getting the code working rather than structured and optimized was important, as getting feedback on new/changed features should take priority over having an efficient app early on. Having a well structured optimized app that loads slightly faster or well-documented code, is less important for the user when testing new features. Code optimization, formating, and re-structuring should happen once a feature is completed and the users are satisfied with its functionality. Formating old code is also important because new improved ways of doing things might have been discovered during development of newer features, making integration with older features difficult.

5.7.3 Study Limitations and Shortcomings

The methods used for data collection consisted of demonstrations with a following focus group discussion, interviews, observations, and user testing. The methods gave us a good insight into the health workers' daily workday, and how FBF Anthro would fit into their workflow, as well as their opinions regarding its use. However, this project is not without shortcomings, one being the small sample size of users we were able to demonstrate the app to. A larger sample size of end-users could have provided us with more insights and different opinions. The same goes for the number of health facilities we were able to visit in our short time in Rwanda. We would have liked to visit more facilities, especially those in more rural areas, outside of Kigali. This would have given us a better understanding of the current situation in Rwanda as a whole, not just in Kigali, where the facilities, presumably, have access to more resources and better infrastructure.

Figure 5.6: One of four health facilities visited during the stay.

Further, we would have liked to perform more user-testing, as we were not able to perform user testing with the finished product, after having implemented the prioritized change requests. The small sample size of end-users produced a fairly limited amount of data, which turned out to be quick to categorize, because of the unanimously positive responses and agreements on what changes were required to make the app more usable. It would also have been beneficial to revisit the health facilities, to let the health workers use FBF Anthro in a real life setting, outside of the controlled test environment at the MOH headquarters. This could have given the end users the ability to discover things related to real life use, as well as given us more data to identify more challenges or opportunities with the app. For FBF Analytics, we were not able to do any end-user-testing at all, because of the lack of time, with the main focus being FBF Anthro.

While in Rwanda, the focus was to identify the most commonly requested changes and features and implementing those. Categorization and analysation of the gathered data that was not directly linked to requests for changes and new features, were given lower priority, happening only when time allowed for it. This means that we were not able to come back with follow up questions regarding the findings.

We further made most use of focus groups because it felt most natural to us, and because it helped overcome the language barrier. Since the health workers spoke a very limited amount of English, we let them discus the app amongst themselves, watching their body language and enthusiasm, and then getting a translation afterwards. One could argue that having one on one semi-structured interviews with the health workers could have identified different and more opinions and views. Another possible limiting factor was that the new technology may have biased the end-users into being more enthusiastic, as it was something "new", possibly dictating the entirely positive responses.

With the approach of this research being a qualitative approach, with a very limited user sample, we cannot assume that the findings and conclusions are generalizable for every setting. The limited sample size and data amount, make it uncertain whether our findings reflect the opinions of the whole health sector in Rwanda. Nevertheless, in light of the related research on the use of CDSSs in low resource settings, described in section 2.3, such as developing countries, we felt that our findings were sufficient in order to identify potential benefits and challenges with using the growth tracker.

Overall, the major limitation to this project was the very limited time in Rwanda for field research. The schedules for both us and the HMIS: Unit (HMISU) were very busy, which limited the amount of health facilities and health workers we could observe and interview, as well as not allowing the time for end-user-testing the finalized products. Shown below is one of the four health facilities we visited, figure 5.6.

Chapter 6

App Development Process

This chapter aims to present the findings during development as well as the finished products. It will not cover reasons behind design decisions. Chapter 7 App Demonstration & feedback will cover implementation and user feedback which led to design and feature choices.

Since both applications were developed for the DHIS2 software system, the first section will give a general description of the system and elements that are relevant to the applications. The following sections will go more in-depth on the development of each application, the formulas used to calculate z-scores and percentiles, and the growth chart plotting. The last section will cover the technical solutions behind the applications.

6.1 Platform description: District Health Information System 2

The apps were developed for DHIS2, which is used as the HMIS software in Rwanda. DHIS2 is developed by HISP [16], with the primary objectives of data collection, validation, analysis, presentation aggregate and transactional. DHIS2 is the preferred HMIS in 60 countries and and 23 organizations world-wide [6]. The system facilitates decision making through all levels in a health sector hierarchy as well as supporting integration of fragmented health systems, and is tailored to integrated health information management. It is an open-source software that is accessed mainly through a web browser, but has great system interoperability making it able to be run on a wide variety of hardware such as mobile phones, tablets and computers. Data capture can be done offline in areas with poor connectivity, online through a browser based mobile client, or by a simple SMS [12] [11].

The functionality of DHIS2 is facilitated through apps or modules, which functions as an extension to the core system. The system can then be customized as required by adding or removing apps. These apps are located on the central web server, and is therefore accessible for all users, with user access rights, independent of location. The nutrition applications in this thesis is such an extension and is accessible through the application menu similar to other apps [8] [7], see figure 6.1.

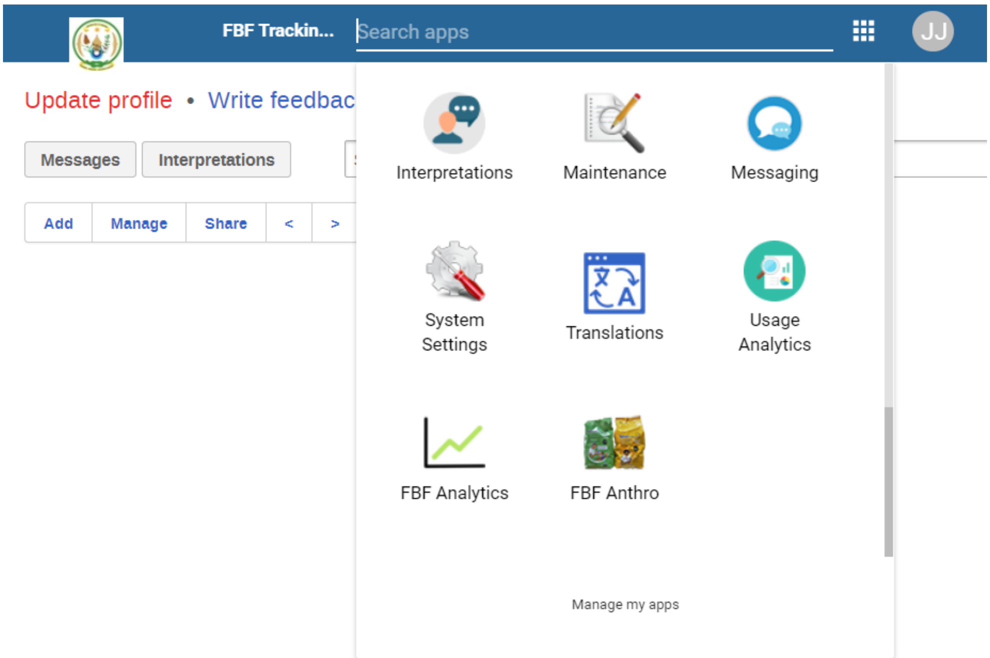


Figure 6.1: Accessing the FBF applications through the DHIS2 application menu

The customization options in DHIS2 makes it so no two implementations are identical. This thesis is based upon the RHMIS and as such it is natural to look at the Rwandan implementation of the system. The data structure is organized according to the hierarchy described in section 4.4.1. Captured data is stored on a central web server located at the MOH headquarters in Kigali. As both applications make use of captured data, and FBF Anthro is an extension of the core Tracker Capture app, the next section takes a closer look on this core app.

Tracker Capture in DHIS2

The Tracker Capture is an essential part of DHIS2 as this app facilitates both data capture through single and multiple events, such as patient visits. The Tracker Capture also supports reporting through program summaries, statistics, and upcoming and overdue events for either programs or individuals [10].

The app is based around widgets that serve different purposes such as, but not limited to, data entry, program enrollment, notes or profile. These widgets can be shown or hidden based on the users needs or preferences. Tracker Capture loads the data through Organization Units, which represents all of the facilities, districts, zones, as well as the national level. Users are restricted to view only the organization unit(s) that their access level permits [10].

Organization Units in DHIS2

Each organization unit holds a pointer to its underlying organization units. This forms a representation of the HMIS hierarchy; each zone has points to their underlying districts, and each district points to its health facilities. Each health facility contains pointers to data elements containing data about each patient registered to that specific facility [9].

6.2 FBF Anthro and FBF Analytics overview

Both the FBF Anthro and FBF Analytics application are web-applications customized for DHIS2. Their purpose is to track growth development, using collected data to calculate Z-scores and growth charts, in individual children, as well as aggregates at each level in the HMIS hierarchy, from facility to national level. They were implemented using ReactJS as a framework. They make use of existing data available in DHIS2, and thus will make use of local data in whatever implementation of DHIS2 it is installed. As both apps are integrated into DHIS2, which comes with credentials and security measures built in, they don't need to take care of security.

By being integrated, DHIS2 gives them access to the Application Programming Interface (API), which again gives access to the DHIS2 *Data Store*, further giving access to all organization units and data elements [7]. Data is acquired through HTTP requests to the DHIS2 API. Both apps calculated its scores locally and therefore does not need to send any HTTP requests for anything other than fetching data. The relationship between the FBF apps and DHIS2 can be seen in figure 6.2 on the next page.

6.2.1 FBF Anthro

FBF Anthro is the originally requested growth tracking app. It is based on the deprecated WHO Anthro software developed by the WHO, and the specifications were therefore initially based on its functionality. The app was requested to be a part of TC data collection app, and is therefore developed as a widget in TC. However, because the TC is a core app in DHIS2 we were not allowed to simply push our widget into the global TC. As a workaround, FBF Anthro is therefore implemented in a fully functional instance of TC, and functions fully as a stand-alone TC app with the widget included. The widget consists of two main screens; the circle page (frontpage) and the plot screen, as well as an additional options menu screen, which is restricted to administrators only.

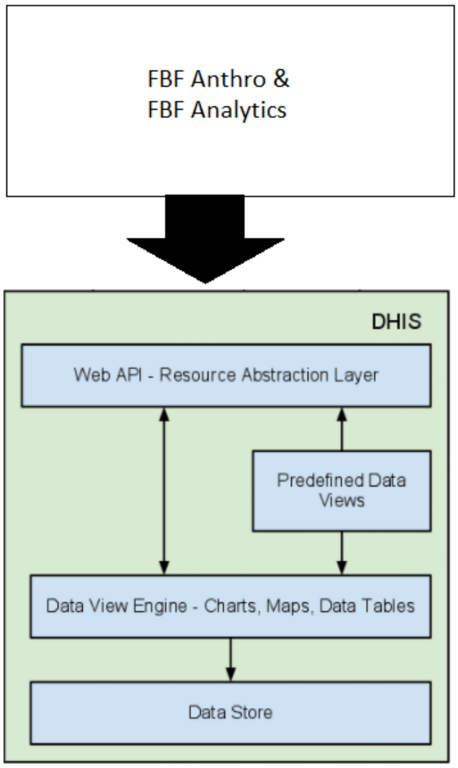


Figure 6.2: Diagram of the relationship between both apps and the DHIS2 instance.

Because FBF Anthro is a fully functional stand-alone instance of the TC it can also do data collection, however this is a side effect of the workaround. The growth tracking widget itself does not need HTTP requests for anything other than fetching data.

Circle page

The circle page serves as the landing page of the app. It serves to give a quick overview of a patients health growth and health status, see figure 6.3 on the facing page. The circle page consists of a list of visits (recorded events), and a circle for each growth indicator:

- Weight-for-Length
- Weight-for-Age
- Length-for-Age
- BMI-for-Age
- MUAC-for-Age
- Raw MUAC measures

The visits in the visit list is selectable and clicking on a visit will change the view to show the recorded data for that specific visit. The list defaults to the latest visit. The circles shows the calculated z-scores and percentiles for the patient, and the coloring will change depending on the calculated score. 0-2SD = green, 2-3SD = yellow, 3SD+ = red. The circles also functions as buttons to show the growth chart for each circles indicator. There is an additional alert message that is displayed above the circles if the scores reach certain thresholds. What indicators to show in the circles, as well as the coloring and animation, can be customized in the options menu screen.

Figure 6.3: The circle page, with alerts displayed.

Plot page

The plot page displays the calculated growth chart based on either Z-scores or percentiles, see figure 6.4. What plot type to display can be selected, as well as single or multiple points plot display, multiple points is default. The plot points points to their respective calculated scores, and is displayed over a representation of the WHO SD ranges. The selected visit from the visit list is highlighted. This page serves as the replacement of the paper graphs used during and after consultation. Clicking on a plot point changes the view to highlight the selected visit. On mouse over an info box is shown with more detailed information for the specific visit. From within the plot page for one growth indicator, one can select to display the chart for the other indicators. The Z-scores and percentile calculations are described in section 6.3 on page 60.

Figure 6.4: The plot page displaying weight-for-age growth chart in Z-scores and multiple points.

Options menu

The options menu is restricted to administrators only. The menu allows for customization of the various functions in the widget, see figure 6.5 on the next page. Customizable items are; the colors for the SD or percentile ranges, which information type the circles should display (percentiles and z-scores combined, or only either one), which indicator circles to display, alert messages and their SD thresholds and the size and animation of the circles.

- Colors: Customize which colors to use for the SD and percentile ranges.
- Display: Customize which information type the circles should display; percentiles over z-score, z-score over percentile, z-score only or percentile only.
- Indicators: Customize which indicator circles to display.
- Alert Messages: Customize what the alert messages should say, and at what score threshold they should appear.
- Size: Customize the size of the circles.
- Highlighting and Animation: Customize at what threshold the animation should appear at, animation speed and size.

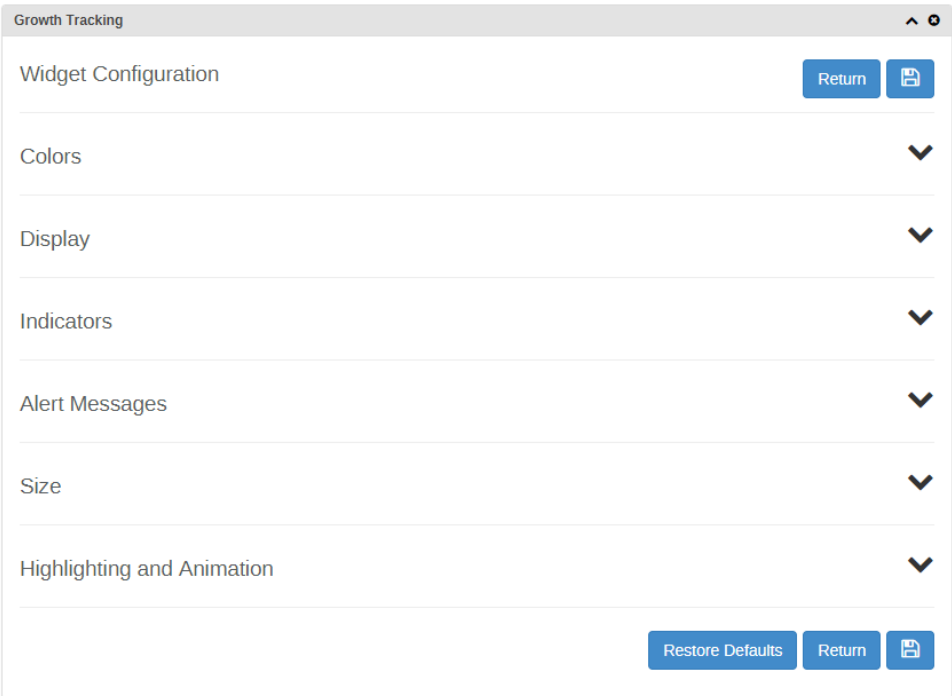


Figure 6.5: The options menu screen displaying the different categories of customization.

6.2.2 FBF Analytics

During our stay in Rwanda we quickly discovered the managers need and want for an app that could do analytics based on aggregated data. The FBF Analytics app is the result of this discovery. It was quickly pieced together, and functions mostly as a proof of concept because of its rough shape and functionality. FBF Analytics is based on the same calculations as FBF Anthro but uses only aggregated data from health facility level up to national level. It does not display individuals data. The app consists of 3 main screens; front page, summary screen, and comparison screen.

Front Page

This serves as a landing page when the app is opened. Here a time period and organization unit is selected; health facility up to national level. Shown in the figure below, 6.6.

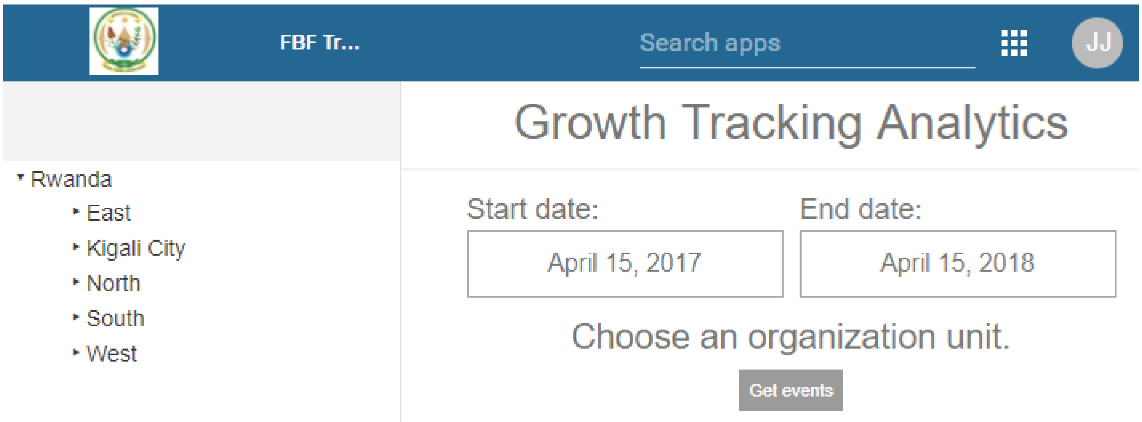


Figure 6.6: The front page for FBF Analytics.

Summary Screen

The summary screen serves as the main screen for the app. Here each indicator is displayed, with its corresponding SD intervals broken down displaying how many children fall within each category, both raw number and percentage. The average Z-score value for the selected organization unit is also displayed, see figure 6.7 on the facing page. In addition, a distribution chart and time line chart can be displayed. The distribution chart displays the SD interval breakdowns, and the time line chart displayed the Z-score values and how it fluctuates for each month in the selected period, shown below in figure 6.8 on the next page. Lastly the summary screen contains selectable filters for further breakdown of the analysis.

Comparison Screen

The comparison screen allows for comparison of organization units. The comparison screens functionality is the same as the summary screen, only split in two, allowing the display of two organization units side by side, see figure 6.9 on page 60.

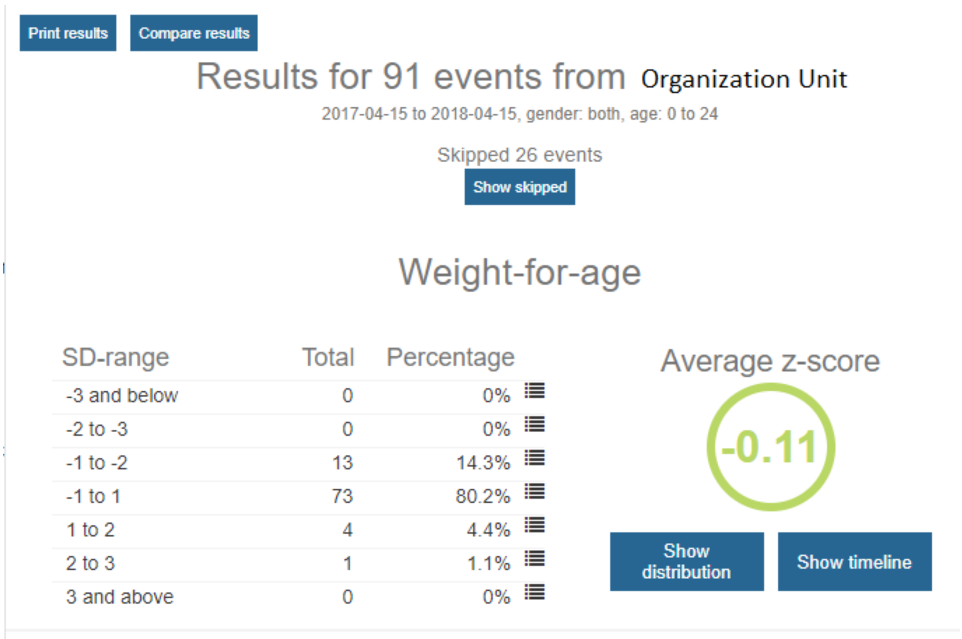
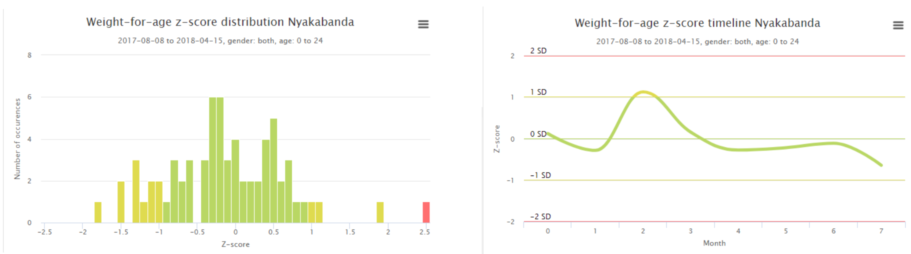


Figure 6.7: The summary screen showing each indicator and its SD interval breakdowns.



(a) SD interval distribution chart.

(b) Z-score time line chart.

Figure 6.8: Distribution and time line charts displayed in FBF Analytics.

6.2.3 Adaptability between DHIS2 instances

As described in 6.2.1 on page 53, FBF Anthro functions as a stand-alone instance of the TC, and could as such be installed on any instance of DHIS2. As FBF Analytics is a stand-alone app as well, it can also be installed on any instance of DHIS2. However, because of issues importing scripts URL's and data element ID's these had to be hard-coded. This makes it impossible to simply install it on a different DHIS2 instance than Rwanda's. To install the apps on a different instance these has to be changed to the corresponding instance's URL's and data element ID's.

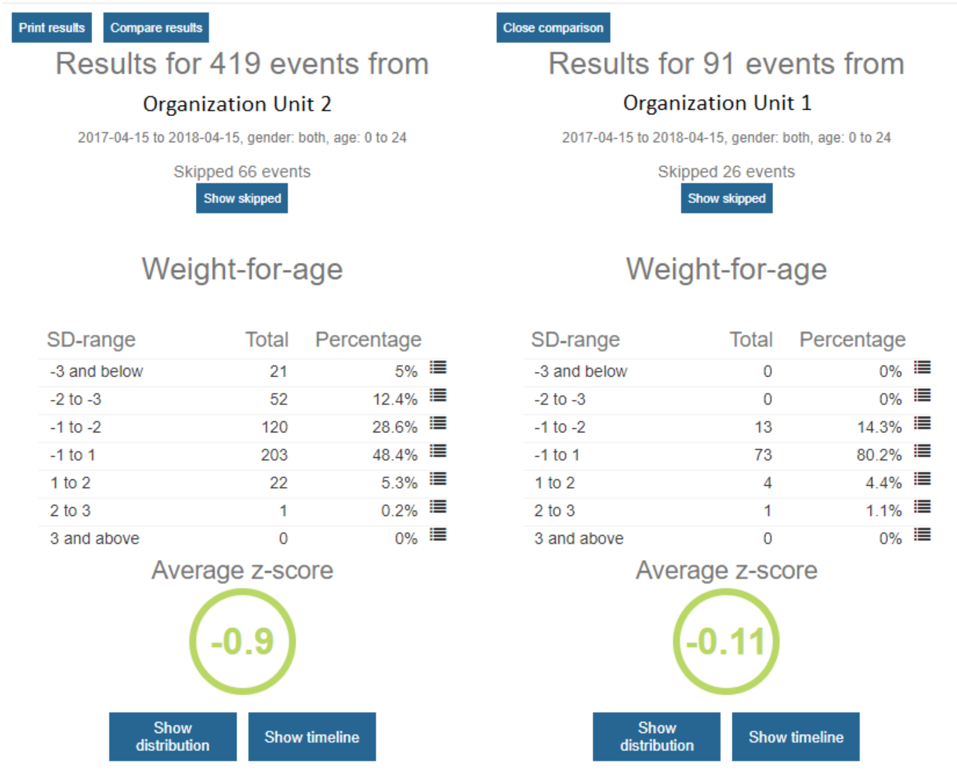


Figure 6.9: The comparison of two organization units.

6.3 Growth score calculations

This section describes the formulas used to calculate Z-scores and percentiles, as described in 2.2.1 on page 8, for growth charts. The formula for calculating percentiles for all indicators is as follows [94, p. 301-307]:

$$C_{100\alpha}(t) = M(t)\left[1 + L(t)S(t)Z_\alpha\right]^{1/L(t)}, \quad -3 \leq Z_\alpha \leq 3$$

Where:

- $C_{100\alpha}$ denotes the 100th percentile.
- (t) denotes age/length/weight.
- $Z\alpha$ is the deviate for tail area α.
- L denotes the tabulated fitted values of Box-Cox power, which normalizes skewed data.
- M denotes the median.
- S denotes the coefficient of variation.

For length/height-for-age the formula can be simplified by setting the Box-Coxs power to 1: $L(t) = 1$.

To calculate the Z-score for an individual child with measurement y at age/length/height t, the recommended formula as follows:

1. Calculate

$$Z^*_{ind} = \frac{\left[y \Big/ M(t)\right]^{L(t)} - 1}{S(t)L(t)}$$

2. Find the final Z-score $\left(Z^*_{ind}\right)$ of the child:

$$Z^*_{ind} = \begin{cases} Z^*_{ind} & if \quad |Z^*_{ind}| \leq 3 \\ 3 + \left(\dfrac{y - SD3pos}{SD23pos}\right) & if \quad Z^*_{ind} \geq 3 \\ -3 + \left(\dfrac{y - SD3neg}{SD23neg}\right) & if \quad Z^*_{ind} \leq 3 \end{cases}$$

where $SD3pos, SD3neg$ is the cut-offs, and $SD23pos, SD23neg$ is the difference between the cut-offs and ±2SD calculated at t by the LMS method:

$$\begin{aligned} SD3pos &= M(t)\left[1 + L(t) * S(t) * (3)\right] * 1/L(t) \\ SD3neg &= M(t)\left[1 + L(t) * S(t) * (-3)\right] * 1/L(t) \\ SD23pos &= M(t)\left[1 + L(t) * S(t) * (3)\right] * 1/L(t) - M(t)\left[1 + L(t) * S(t) * (2)\right] * 1/L(t) \\ SD23neg &= M(t)\left[1 + L(t) * S(t) * (-2)\right] * 1/L(t) - M(t)\left[1 + L(t) * S(t) * (-3)\right] * 1/L(t) \end{aligned}$$

An example could be a child of 28 months with a BMI of 12. Given the LMS values $L = -0.4850; M = 15.8667; S = 0.07818$, the Z-score calculations would be as follows:

$$Z^*_{ind} = \frac{\left[12.0 \Big/ 15.8667\right]^{(-0.4850)} - 1}{15.8667 * (-0.4850)} = -3.83 \qquad < -3$$

And then to find the non-skewed value for the Z-score:

$$\begin{aligned} SD2neg &= 15.8667\left[1 + (-0.4850) * 0.07818 * (-2)\right] * 1/(-0.4850) &&= 13.65 \\ SD3neg &= 15.8667\left[1 + (-0.4850) * 0.07818 * (-3)\right] * 1/(-0.4850) &&= 12.71 \\ SD23neg &= 16.64 - 12.71 &&= 0.94 \\ \Rightarrow Z^*_{ind} &= -3 + \left(\frac{12.0 - 12.71}{0.94}\right) &&= -3.76 \end{aligned}$$

Given the Z-score of -3.76, this child would be diagnosed with Severe Acute Malnutrition (SAM) according to the WHO Standard Deviation (SD) indicator ranges, see 2.1 on page 9.

6.4 Technical solutions

This section will give a brief description of the technical solutions that we made use of in the development of the apps.

6.4.1 ReactJS

> React is a declarative, efficient, and flexible JavaScript library for building user interfaces [22].

Unlike AngularJS that is the main framework used in DHIS2 and uses a Model-View-Controller (MVC) based paradigm, React is based around the "View" layer in the MVC model, with components and the state of each component. React is strictly for making web application interfaces, quickly and easily. The components tells React what to display on the screen at any time. When a component wants to update, React renders only the updated data, instead of reloading the whole page [23] [27].

In addition, React offers the JSX syntax for JavaScript that allows the use of Hypertext Markup Language (HTML) directly in the code. HTML is what describes what is generated on the screen. With React JSX, HTML can be quoted directly in the JavaScript code, removing the needed for large, and difficult to read HTML files [21] [27].

We chose to utilize React in this project because of our pre-existing experience with React, and its simplicity. In FBF Anthro the Tracker Capture (TC) fetches the data, so the growth tracking widget only has to tell TC what data to request. Without the need for a full framework with back-end data handling in our app, React was chosen because of its simplicity compared to AngularJS [23].

Advantages:

- Our pre-existing knowledge with React.
- Simplicity: Easy to start up and learn the concepts.
- Code re-usability: Components can be reused, and is preferred.
- Performance: Only renders whats changed on updates, saving time, computational resources, and data usage.

Disadvantages:

- Requires other frameworks to handle the Model and Controller part of MVC.
- JSX can be confusing at first because it is not pure JavaScript, nor pure HTML.
- Not used in DHIS2.

6.5 Prototypes

This section will present the 3 prototypes developed during the project, and how the evolution of the final product came to be. Lastly there will be a section describing the development of the second app, FBF Analytics.

During the stay in Rwanda it was made clear that the managers and health directors were in desperate need for aggregated statistical data for the same project. We therefore agreed to attempt to develop a second app, which could do statistical analysis on the aggregated Z-score data. Because of the complexity of Tracker Capture (TC), and it being outside the scope of FBF Anthro, implementing such features in FBF Anthro were deemed as not feasible, and a stand-alone app was therefore chosen.

6.5.1 Prototype 1 (Pre-Alpha)

The first prototype was developed exclusively in Norway during the spring of 2017. The sprints were often monthly as other university courses took priority during the early stages of the project. The development was based around re-engineering WHO Anthro [28]. The goal was to gain knowledge of the features needed for a growth tracking application, and create a functional proof of concept as a base for further development.

Planning

During the planning phase we tested the Anthro Software to quickly get a feel of the program and what it could do. We weren't given any specific specifications or requirements, and therefore decided to create a proof of concept based around re-engineering the relevant parts of WHO Anthro.

Development

The application started out as a stand alone application in DHIS2, with no data import, based on the WHO Anthro calculator tool, see figure 6.10 on the following page and 6.11 on the next page, with a rudimentary display of some Z-score values and a chart. We put most emphasis on making sure we understood the functionality of WHO Anthro. The main goal was to create a functional prototype with the most basic features included, such as calculating and displaying z-scores.

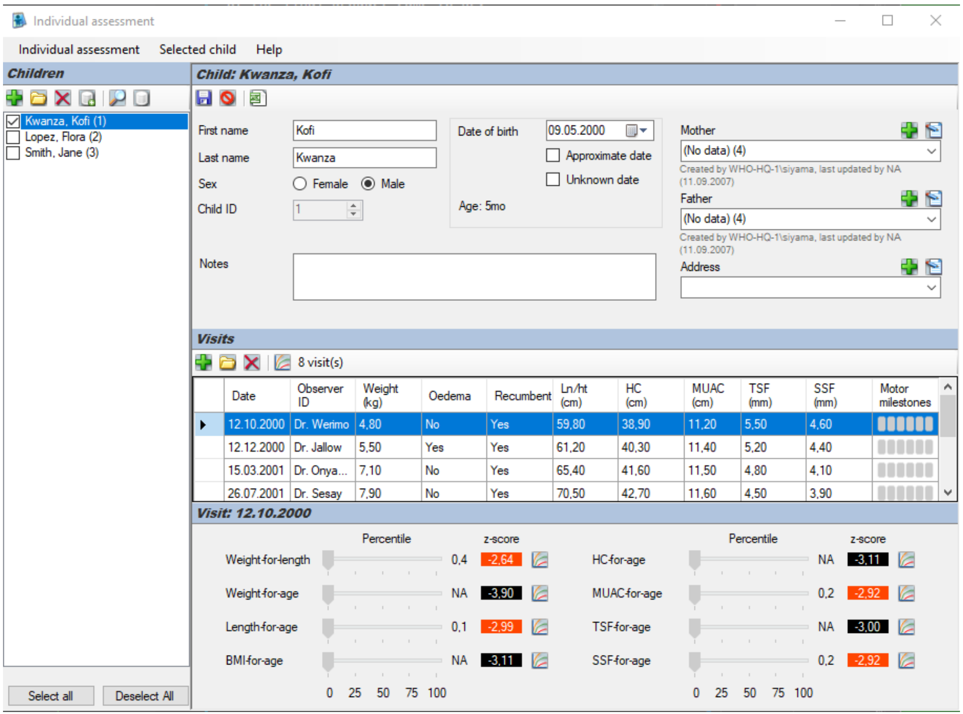


Figure 6.10: The individual child assessment tool in WHO Anthro.

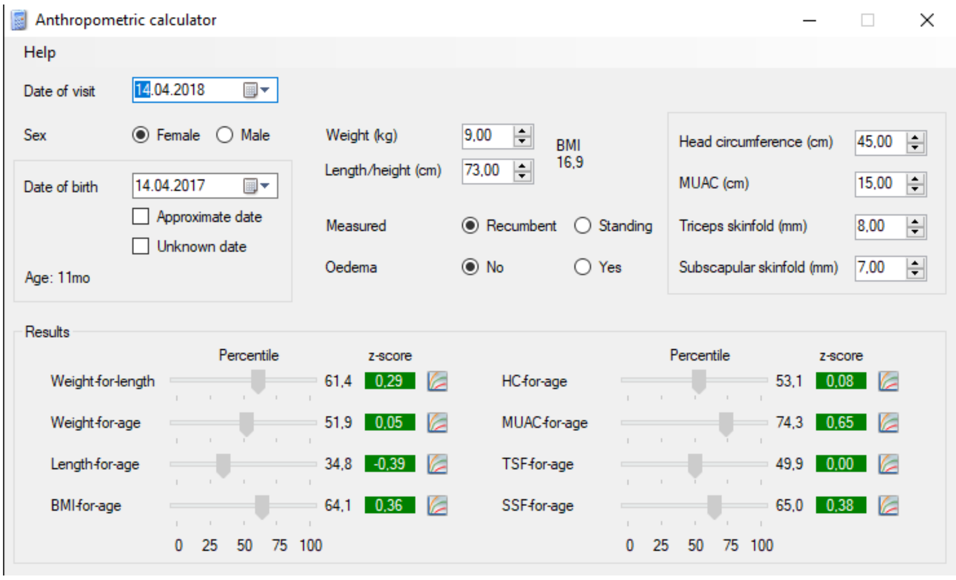


Figure 6.11: The Anthropometric calculator tool in WHO Anthro, displaying the default dummy data.

Testing

As this was a rudimentary proof of concept, and learning phase, we didn't do any user testing for the first prototype. We mainly did manual testing our selves, as developers, to make sure new features did not break existing features.

6.5.2 Prototype 2 (Alpha)

The second prototype was also developed in Norway, however, the sprints were down to a weekly basis as the project had our full focus; neither developers had any more university courses. The development of the second prototype was based on feedback given early in the second AR cycle, 5.2 on page 35, as well as feedback given continuously during the development. The goal for this prototype was to get a basic version of the application integrated into DHIS2, along with improvements to the growth tracking features developed in the first prototype.

Planning

At the start of August we had a meeting with a Andrew Muhire, leader of the Rwanda MOH:HMIS Unit visiting the DHIS2 conference in Oslo. We were given a brief introduction to the FBF Nutrition programme, and some wanted basic specifications for the application. In addition, we had a meeting with a DHIS2 developer to get information on how to integrate the application, as a widget, into the Tracker Capture (TC) application.

New specifications and features

- Integration with TC.
- Full interface with circle page, plot page, and options menu.
- Integration with the RHMIS data structure and API's in preparation for real data.

Development

We migrated the application from a stand-alone app to an integrated widget in the TC early in the cycle. This let us get familiar with the TC and how it worked. After some brief start up troubles getting ReactJS to communicate with AnuglarJS in TC, we were able to implement early versions of the widget screens described in section 6.2.1 on page 53, and seen below in figures 6.12, 6.13 and 6.14.

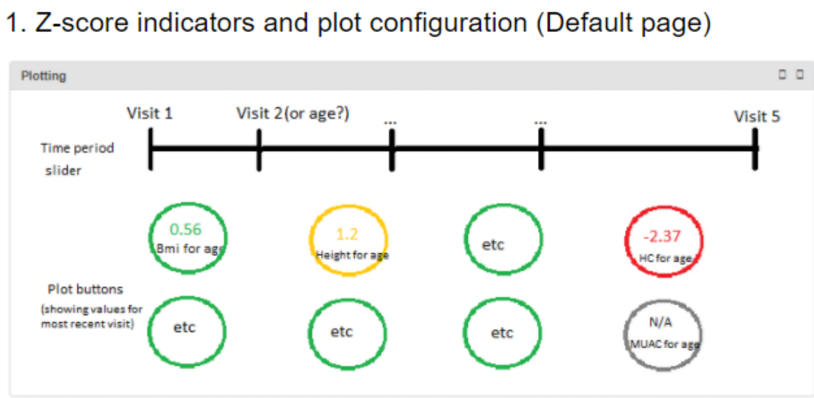


Figure 6.12: An early sketch of the circle page during development of prototype 2.

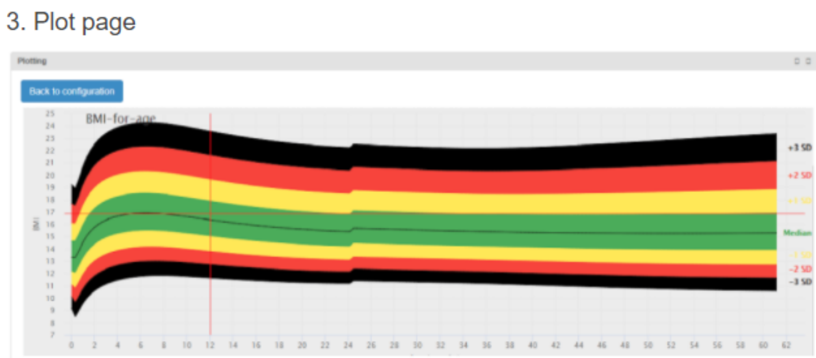


Figure 6.13: An early version of the chart feature during development of prototype 2.

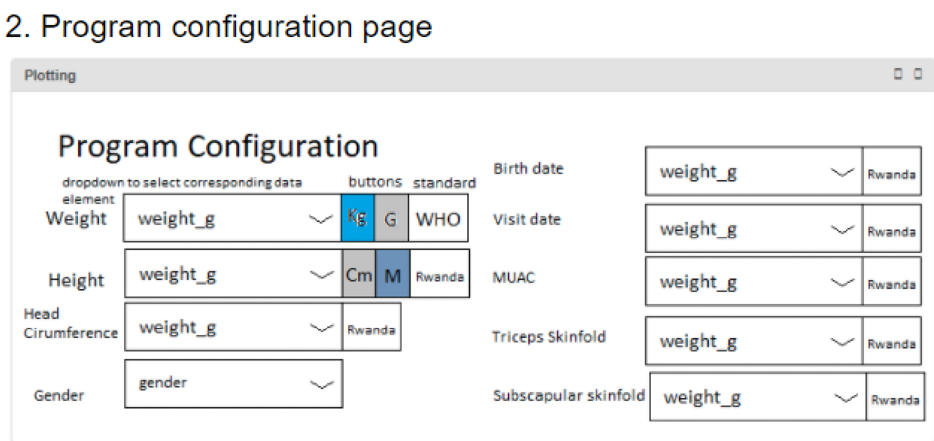


Figure 6.14: An early version of the options menu during development of prototype 2.

The early stages of the prototype 2 development process mainly consisted of getting the widget to work, with basic versions of the required features, such as calculating and displaying indicators, and displaying growth charts. Towards the middle of the cycle we got access to the R-HMIS which made us able to focus on getting the application integrated with the API's of the Rwandan DHIS2 instance so that we could upload the application and get feedback. Throughout the integration process we continued to refine the user interface, and fine tune the Z-score calculations to get them as close WHO Anthro as possible, while still keeping good performance in mind. With a functional, if not perfect, integration with the R-HMIS we could integrate their data structure as well, in preparations for field testing with real data in Rwanda in the last AR cycle.

Testing

Testing was done remotely with the HMIS Unit. After the full R-HMIS integration was completed we could upload our app directly to their DHIS2 instance for testing. The user testing mainly focused on the look and feel of the app, making sure the correct indicators were displayed.

6.5.3 Prototype 3 (Beta)

The third and final prototype was mainly developed during our stay in Rwanda, but continued some time after our return to Norway. Because of our short stay in Rwanda, the development sprints was mostly daily or bi-daily. The focus was to get real life testing of the application done to get feedback from health facility workers, and implement the changes requested. This version is based on the feedback and includes mostly visual changes, as well as the visit list, which also exists in the WHO Anthro software, see figure 6.10 on page 64.

Planning

Due to the short stay, long term planning was impossible, so plans were day to day based or skipped entirely to save time. During the first days in Rwanda we got feedback requiring a lot of visual changes:

Changes and improvements

- Fix the API script imports.
- Fix data fetching from TC
- Continue to fine tune Z-scores.
- Implement the visit list.
- Finalize display of indicators.

- Finalize growth charts.
- Implement alert messages at certain Z-score thresholds.

Development

The development was mainly done at the offices of the MOH in Kigali, Rwanda. To get a hands on understanding of current practices and the needs of clinicians and data managers we got a guided tour on four health facilities around Kigali. The development continued with feedback from the HMIS Unity on a daily basis.

(a) Data entry computer. (b) Stacks of old paper registers.

Figure 6.15: Data managers office (note the old deteriorating paper registers).

The API script imports turned out to be more difficult than first thought, and we ended up having to hardcode the script URL's to the Rwanda'n DHIS2 instance. This prevents the app from being easily transfered to different DHIS2 instances. To make it easier for the HMIS Unit to maintain the app in the future, we decided to place all data element ID's (program ID, event ID, and TEI ID) in a separate file for easy access, in case they change. We agreed to implement the visit list to the widget because it would make changing between selected visits easier, over using the event list already present in TC. The visit list filters out incomplete events, such as visits that were not properly completed for some reason. From the feedback sessions it was also made clear that some form of alert when a patient had Z-scores below certain thresholds were needed. An alert message would help clinicians make decisions about when to refer a child to a district hospital or other specialized facilities for better care. The alerts was implemented as a message that would appear above the circles on the front page for easy access. Both the thresholds and messages were made customizable, as we the developers, are not trained in any form of healthcare, and are thus not suited to give correct health advice. Another requested feature was live update of the growth charts upon data entry. We were, however, not able to make this feature work, and in the current state it requires a full browser page refresh to update the data. This is due to the integration with the TC; the app uses data stores on the server to calculate scores, thus a refresh is needed to fetch the newly entered data.

After our return to Oslo, it was requested that the age limits were increased from 24 months(2 years) to 60 months (5 years). We agreed to implement this as it was an easy fix of importing the expanded reference data from WHO. This was uploaded as separate versions of both apps, as this was requested by the MOH.

Testing

The HMIS Unit were testing new features and changes, and giving us feedback daily. In addition, the health workers from the facilities we visited were invited for a demonstration of the app, and to give feedback. In addition, a group of health and nutrition experts from various NGOs and other MOH groups were invited for a demonstration. From this we gained valuable feedback on visual changes that would ease their workflow, such as using multiple point charts as default, using raw values for MUAC instead of Z-scores, and changing the SD interval colors (new intervals seen in table 6.1).

Standard Deviation interval colors		
SD	WHO Anthro	FBF Anthro
SD 0-1	Green	Green
SD 1-2	Yellow	Green
SD 2-3	Red	Yellow
SD 3-4	Black	Red

Table 6.1: The SD intervals used in WHO Anthro and FBF Anthro

6.5.4 FBF Analytics Proof of Concept

The need for an app that could do statistical analysis of the nutritional health data was made clear to us early during the stay in Rwanda, by HMISU staff, as well as managers at the visited health facilities. Such an app would make it possible for directors and managers to manage resources, and in general get an overview over the FBF programme progress, from a health center perspective and up to the national level. When the most time consuming fixes for FBF Anthro was completed, fixing the script and data imports into the widget, we started implementing the FBF Analytics app.

Development

The app was developed over the course of 1 week during our stay in Rwanda and should be regarded as a proof of concept or prototype, rather than a finished product. The planning was mostly absent due to the extreme time schedule with developing both apps at the same time. The sprints were mostly daily, or as short as a few hours in some cases.

Testing

Testing was mainly done manually by ourselves, but also by the HMIS Unit on a daily or hourly basis.

6.5.5 Further development

Unfortunately there are several features we were not able to satisfactory implement into the apps within the limited timeframe of this project. Further development is therefore needed, and should at least include these features, as they were heavily requested by the Rwanda MOH:

FBF Anthro:

- Live update of data upon data entry: Getting live updated Z-scores and growth charts when data is entered was one of the most requested features from the health workers, we were, however unable to find a solution to this, as the Tracker Capture app only fetches data from the servers on a page refresh. Having a live update of this data would make their job easier, as having to refresh the browser every time can be confusing, as well as time consuming and data heavy, because all data is loaded each time the page is refreshed.

- Support for DHIS2 dashboards: A commonly request among the health workers were DHIS2 dashboards support. This was not a part of the features that was added in this project, but should be implemented in newer versions of the app. By being able to pin specific children to their dashboards, clinicians can much easier keep track of individuals that needs extra care.

- Offline support (this is more dependent on the TC): With the at times limited Internet connection in Rwanda, offline support is heavily requested. This would let data managers enter data even when there is limited or no Internet, instead of in large batches, which is very time consuming.

- More granularity in the alert messages, breaking them up in more intervals for more detailed alerts. Differentiate between those above and below the SD Median line, as the current version do not differentiate between alerts for over- or underweight children.

FBF Analytics:

- Count the number of children that have visited, instead of the number of total visits. This would give more accurate data, as some children may have more visits than others during the same period of time, due to unforeseen reasons such as sickness.
- Summary and percentage trends of the weight gain or loss at facility level up to national level. This would let managers quickly identify and intervene in areas where the average weight of the enrolled children decreased over the selected time period.
- Make the analysis download and printable.
- Map comparison: See a comparison of health facilities or districts etc. on a map, not just as a chart.

Chapter 7

App Demonstration & feedback

This chapter will present the research findings during the demonstration and user-testing of FBF Anthro and FBF Analytics. The development of the apps was conducted both in Norway and Rwanda. Two of the three development cycles took place in Norway, however, most of the research findings presented were gathered during the last cycle in Rwanda.

The demonstrations and user-testing was conducted over a two week period in January 2018 in Rwanda. The target for the demonstrations was local health workers, as well as managers in the MOH, and most of the gathered data originates from meetings at four health facilities in Kigali, as well as the MOH headquarters. These meetings included demonstrations and user-testing of the FBF Anthro, observing the users, and feedback sessions and discussions with the users.

This chapter is divided into two sections where the first section describes the existing infrastructure, and status of the data in the HMIS. The last section describes the reception during the demonstration and feedback sessions with local health workers, nutrition experts, and other interested parties.

7.1 Existing hardware- and software-base

The findings in this section focus on the existing infrastructure for operating a well functioning HMIS. Operating an HMIS requires many components to be present and functioning, such as software components, both server and client-side, infrastructural components, management processes, and accessibility and availability of timely and correct data. Most of the mentioned components were present and functional, although, not necessarily in perfect condition. Overall there were not many limiting factors facilitating the implementation of both apps, however there were some that will be presented below.

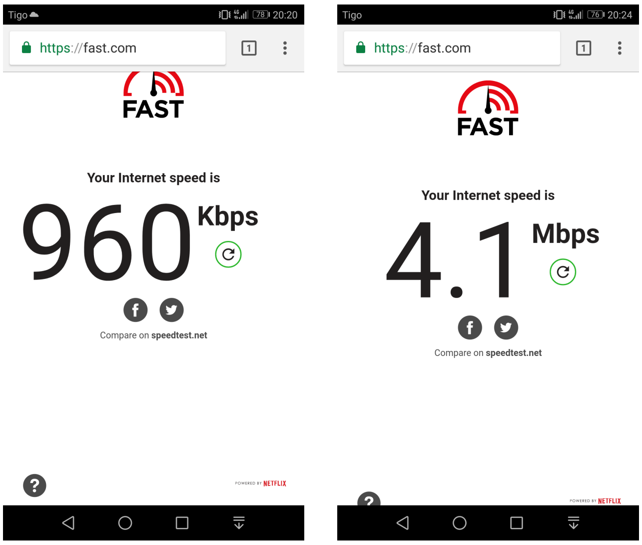
7.1.1 Infrastructure

Rwanda faces many infrastructural challenges, of which the most relevant for a computerized HMIS such as DHIS2 is Information and Communications Technology (ICT) and electricity.

Internet

As described in figure 4.2, Rwanda boasts a national 4G Internet coverage of 95%. Internet coverage in Kigali and immediately outside of Kigali was overall good, although, Poor in fringe areas where lower signal strength didn't manage to penetrate concrete walls. At the health centers we visited, we did not get any indication that the Internet coverage at those centers were bad, but it could be slow at times. We did, however, hear that some very rural health centers had to rely on using WHO Anthro for data collection, as it offers offline mode for data entry and synchronization. The slow Internet speeds could be caused by an overburdened 4G network, or low quality signal transmitters. Lack of Internet in rural areas can be caused by non-existant coverage, lack of operable network equipment, or unpaid Internet bills. At the MOH it was experienced that WiFi was interrupted by, to our knowledge, unpaid Internet bills. Shown below, figure 7.1, is two Internet speed recording only four minutes apart.

> There are some health centers using (WHO) Anthro, around the country. I've seen it. (Health Expert)
> If we have trouble solving offline mode, we will continue using (WHO) Anthro for synchronization. (Andrew Muhire)



(a) First speed test. (b) Second speed test.

Figure 7.1: The variations in Internet speed only 4 minutes apart.

Electricity

A functioning computerized HMIS also requires electricity. A stable and reliable power connection is paramount for operating computers and networking equipment. As described in section 4.2 the Rwandan power grid faces challenges with the reliabilty. Short rolling blackouts were frequently experienced in Kigali. These outages can be very damaging to sensitive electronics such as computers, shortening their lifespan, if not outright destroying the equipment [18]. To mitigate this issue, most desktop computers observed were placed behind power surge and outage equipment such as an Un-interruptible Power Supply (UPS), which secures power delivery for a short time during a blackout, see figure 7.2.

Poor or non-existant Internet, or unreliable power delivery makes the use of FBF Anthro and FBF Analytics impossible as they are only available through DHIS2, and requires an Internet connection to request data from the central server. At the health centers visited, this was not indicated as a common problem, although, slow Internet speeds did slow down or interrupt the workflow when loading data from the servers.

7.1.2 Accesibility to DHIS2

Having a stable access to the central servers when operating and using a computerized HMIS is vital, as several components requires access to either enter or request new data. The servers hosting the national DHIS2 instance was for the most part stable throughout the time spent in Rwanda. We did not face any server problems when deploying new versions of the applications to the servers or testing new features. However, the at

Figure 7.2: A desktop computer protected by an UPS.

times slow Internet speeds did interrupt or slow down the deployment or testing process quite frequently. The slow speeds caused connection requests to be refused, forcing the user to refresh the web page, which delays or interrupts the workflow of users of the system. During testing of FBF Analytics server crashes were also experienced when querying nationwide or comparing two provinces. This caused the FBF DHIS2 instance to become inaccessible until the server were restarted, halting any work requiring server access.

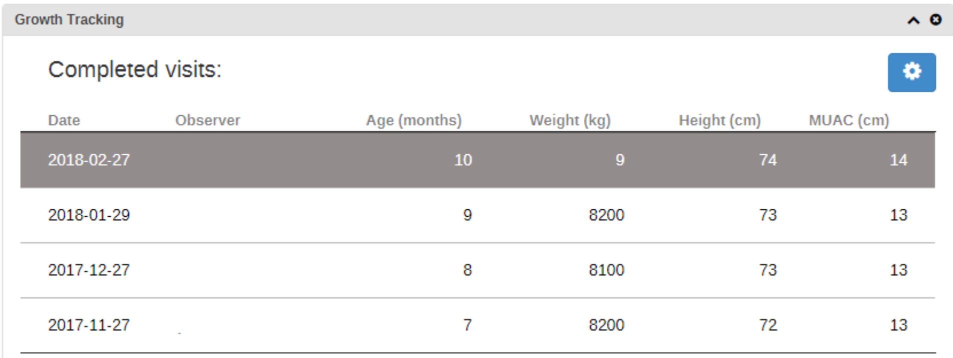
Another important factor for securing a well functional HMIS is well trained employees, with correct access and security credentials. As described in section 4.4.2 on page 27 health workers were trained in DHIS2 during the implementation period, and the health workers at the facilities visited seemed well versed in using DHIS2. During the demonstrations and user-testing the health workers quickly understood the usage of FBF Anthro without extensive guidance. However, a few of them struggled with remembering their DHIS2 passwords.

Restriction of data on the other hand seemed quite restrictive as it was observed that health workers has access to the data they specifically require in day to day work and nothing more. A data manager or director at a health facility doesn't have access to data outside of his or her specific facility. This hinders the access to data from for example a neighboring health facility, for comparison to their own facility. Having access to wider data sets could encourage the use of the data to improve his/her own facility, however, lack of aggregated data can cause privacy issues when data from individuals has to be manually aggregated to create statistics.

> I would like to compare my facility to others and hang them on the wall but i don't have access. (Health worker)

7.1.3 FBF Programme data quality

Having good data quality is also a crucial factor for a well functioning HMIS. The quality of the gathered data for the FBF programme was of varying quality. The programme requires weight to be in kilograms, however, it was observed that weight was being recorded in both kilograms and grams, varying from one visit to anther. It was observed that weight for one visit was entered in grams, and in the next visit it was recorded in kilograms. An example would be a child with the weight of 8200g, and during the next visit the weight was recorded as 9kg, see figure 7.3. The previous recorded weight is recorded as 8200kg in the calculations, which makes the output Z-scores unusable. The newly recorded weight of 9kg is correct, however, with the historical data the growth charts is unusable because of the incorrect data. Visits recorded with a date that comes before the date of the previous visit was also observed. This breaks the application as a recent visit cannot have happened before the previous visit.


Growth Tracking

Completed visits:

Date	Observer	Age (months)	Weight (kg)	Height (cm)	MUAC (cm)
2018-02-27		10	9	74	14
2018-01-29		9	8200	73	13
2017-12-27		8	8100	73	13
2017-11-27		7	8200	72	13

Figure 7.3: Example of poor data quality.

7.1.4 FBF Programme data collection & entry

To achieve good data quality good data collection and entry routines are important. At the health facilities visited patient data was collected before the consultation, often in groups, see figure 7.4 on the next page. The data collection was entered into large paper book registers. It was explained that every health center has a data manager with the responsibility of entering all collected data into the HMIS. The data managers are meant to enter this data daily, but because of high workloads it was explained that this could be delayed for as much as a week, or in extreme cases even longer.

It was observed that data entered in the paper registers could be hard to read, especially if corrections of mistakes was attempted in the small allotted space. When data managers was entering this data into the system, assumptions were made if the recorded measurement was difficult to read. The same goes for the paper growth charts. As they are reused, well used charts were often covered in pen marks from previous plots, see figure 2.1 on page 7.

Figure 7.4: Length measurement of a baby (this was done in a large room with 10-20 mothers waiting for their turn).

Data Validation

Well defined data validation is paramount for securing good data entry. It was observed that the data validation routines was unreliable. As weight is required in kg, entering data in grams, ex 8.000, should be prevented but wasn't. The patient profile also contains a "drop-out" function that serves to record if the patient is to be dropped out of the program for reasons such as death, patient has moved, or otherwise removed from the program before completion. It was experienced that this function has no validation rules. When "yes" is selected for drop-out, the data recorded for the currently selected visit is cleared from the system, with no confirmation or undo options. The HMISU staff seemed to be surprised by the lacking data validation rules that allowed for the poor quality of registered weight measurements.

7.2 Demonstration and user-testing feedback

This section will present and describe the reception of FBF Anthro during demonstrations and user-testing, and the following feedback sessions.

The heavily constrained time schedule throughout the short stay in Rwanda limited the amount end-user feedback we were able to collect. We were unable to get as many user-testing sessions as we wanted. During the demonstrations Internet was unstable with very varying speeds. Refreshing the page took several minutes at times because the Tracker Capture app is very data intensive. The health workers seemed used to this.

7.2.1 Health Worker demonstration and feedback

After visiting a selection of local health centers, the clinician and data manager from each respective center was invited for a proper demonstration, user-testing, and feedback session. They seemed overall versed in the use of DHIS2, although there were some complications when logging in because of forgotten passwords, or restricted access to the app.

After a short app demonstration, the health workers got to use the system. Feedback was given continuously throughout the testing. The health workers seemed very happy with the initial demonstration. During the session it was requested smaller changes such as making "multiple visits" the default view when displaying growth charts, over "single visit". Another feature was a "predicted visit" feature we thought would be useful, taking average values from previous visits and displaying a predicted value for the next visit. This turned out to be confusing for the health workers. They explained that mothers would not understand that it was a prediction, and not actual values. If a child was sick, this could also be incorrect because of weight loss due to the sickness. We decided to remove this feature, to remove any cause for confusion and misinformation. It was also brought to our attention that they don't use the same SD intervals as the WHO reference guide. Because of this the SD interval colors in the app was wrong. We agreed to accommodate this by changing the SD intervals in the app. Overall the users seemed happy with the usability of the app.

Regarding the process of decision making with the app, the health workers responses was overwhelmingly positive.

> "It looks amazing! Very helpful when giving feedback" (Health worker)
> "It will save time, don't need to look up charts on paper when entering data" (Data manager)

During a consultation, the paper graphs would still be used because mothers usually asks for feedback directly after measurements are taken. After the consultation the nutritionists makes more educated feedback that can be given at next visit, or if its critical it is sent by sms or with a Community Health Worker (CHW). The process of making educated feedback would be shortened and more accurate with the generated growth charts, less room for error when reading the charts. The general consensus was that the FBF Anthro app would save time throughout the whole process, especially if they were given extra computers or tablets so that they could use the app during patient consultation. This would lessen their workload as data entry could happen alongside the consultation. The feedback to mothers regarding their child would also be better, more timely and more accurate as they would get feedback quicker, and human error when reading from paper graphs would be removed. Human error when copying data from paper registers to the computer would also be removed.

> "Can give better feedback!" (Nutritionist)
> "Saves time and lets us consult more patients" (Nutritionist)

During the session, the focus often strayed away from FBF Anthro, and turning into a more general feedback session for the HMIS Unit. Several questions and requests was also directed towards us regarding features related to DHIS2 and TC in general, which is outside of the project focus. Questions regarding data validation or programme report summaries were among the unrelated requests directed towards us.

Additionally, it was requested, and made clear the need for aggregated data for health facility statistics, and managers higher up in the hierarchy.

7.2.2 Nutrition Expert feedback

The health experts session consisted of nutrition experts and other pediatric care experts from various MOH centers and NGOs invested in the FBF nutrition programme. The experts understood the point of the app very quickly and the focus of the session turned towards the underlying features of the app and potential outcomes.

The requests for different SD intervals was repeated, which underlined the notion that the Rwanda MOH uses different definitions for deciding when a child is suffering from malnutrition, and where the line for acute malnutrition lies. During the demonstration it was mentioned that Body mass index (BMI) wouldn't make sense for children because of rapid and uneven growth. Mid-Upper-Arm-Circumference (MUAC) was also mentioned in the same fashion, and it was requested that we changed MUAC from displaying the Z-score to showing the raw measurements. The accuracy of the Z-score calculations was also questioned, whereupon we demonstrated and compared calculations in WHO Anthro and FBF Anthro. The calculations depends on the accuracy of the reference data used. The experts found the accuracy to be within acceptable margins when we explained the balance between slightly less accurate calculations against performance of the app.

Overall the experts seemed very happy with the demonstration and showed interest in following the further development in the whole nutrition programme. The need for statistical analysis of aggregated data was again repeated in this session. The representatives from United Nations International Children's Emergency Fund (UNICEF) seemed especially interested as they said the app is something that could be used in other countries as well.

7.2.3 Other interested parties

Throughout the stay in Rwanda, we had informal talks with the members of the HMISU about features they had tested for feedback such as the daily meeting with Andrew Muhire, head of the HMISU and owner of the growth tracking app project. His and the rest of the teams feedback was crucial for the outcome of the apps. The feedback mostly related to feature changes such as reversing the visit list, changes to the displaying of charts like zoom levels, or what information to display in the chart legend. Their feedback was fairly similar to the wishes of the health workers and nutrition experts in the usability of the apps. After we started developing the FBF Analytics app their focus was primarily on that app as FBF Anthro was nearly finished at that stage.

In addition to the daily talks with HMISU members we had meetings with other stakeholders such as the Honorable Minister of State for Public Health and Primary Healthcare, and DHIS2 developers.

Honorable Minister of State

On the last day of the stay in Rwanda we got a short meeting with the Hon. Minister of State for Health in charge of Public Health and Primary Healthcare. A short demonstration of both apps were given, during which Honorable Minster continuously asked questions and came with requests for new features or changes he wanted to see. Most of the requests was directed at the FBF Analytics apps, such as map comparison of districts or the ability to show weight gain or loss trends over time through all levels of the health system hierarchy. The Honorable Minister seemed very happy with the apps, which he believed would make a big difference in the quality of the patient care for the FBF nutrition programme. He mentioned the same reasons as the health workers, such as being able to give better feedback and care to patients, and also consult more patients. However, he was mostly interested in FBF Analytics, which he said would let him, or managers in general, direct resources better and more quickly. Managers and directors would be able to compare facilities, districts, or provinces and see exactly where more resources was needed especially with the suggested feature of trend lines. He also explained that they eventually want to develop their own reference growth data, from birth and up to 18 years, because the WHO reference data is global and doesn't account for local variations.

DHIS developer

After the stay in Rwanda we also got a meeting with a developer of DHIS2. The focus of this meeting was the further development of the apps, and integration with the Tracker Capture in the core version of DHIS2. The developer was very interested in the app functionalities, especially the plotting features. He explained that this is something the developers have been wanting for a while. However, he further explained that they have better tools in the DHIS2 API to develop the FBF Anthro widget in Tracker Capture, and that the app would most likely be scavenged for the plotting features and Z-score calculations for an official version of a growth tracking widget. He also raised the question of further funding for the project.

Chapter 8

Analysis of findings

This chapter serves to present an analysis of the research findings in this project, while comparing the findings to the described conceptual framework for this thesis. It breaks down the findings during the app development, as well as the feedback and responses given during the app demonstrations, feedback sessions, and observations.

However, the observations took place at only four health centers in Kigali City, and thus we are not making assumptions about the rest of the country, especially in the rural areas where we were told that WHO Anthro was still in use because of lack of Internet at some facilities.

8.1 Development process

As described in 2.1.1, knowing the context matters when developing a software system. However, knowing the context of the system matters little if one does not understand what is required of a system in said context. Although Clinical Decision Support Systems (CDSSs) comes in many variants, as described in chapter 3, they all follow the same characteristics of focusing on displaying information to the user in a timely and easily interpreted manner. Focusing on the end user and their needs, in addition to studying WHO Anthro, allowed us to quickly gain an understanding of the requirements for a growth tracking system. This allowed us to develop a working prototype that was ready for testing, despite the limited pre-existing specifications. As shown during the app demonstration and testing, following the characteristics required of a CDSS with a user centric focus, let us design and implement an app that is simple to pick up and use with little to no guidance. The responses given in interviews and group sessions, suggests that following the steps of CDSS design, with a special focus on the needs of the end users, helped in developing a final product that the stakeholders were pleased with.

8.1.1 Clinical Decision Support System components

System input

As described in 3.2.1, a Clinical Decision Support System (CDSS) contains several components in order to support and give advice to end users. By being a widget integrated into Tracker Capture (TC), FBF Anthro utilizes the pre-existing patient data as input for the system. Not having to define the input format saved us time, as defining a suitable input format can be difficult and would require significant planning and consultation. The patient data for the FBF nutrition programme contains the collected anthropometric measurements, and the data usage in the app was thus structured around using the raw data, such as height or weight measurements. The patient data does, however, not contain any time parameters, thus allowing us to bypass the notion of time factors completely.

Inference engine

Because of the raw data format, the patient data could be used directly in the Z-score calculations. The described CDSS inference engine component is responsible for calculating and coming up with the advice for the user. During the development of said component, being able to study the WHO Anthro source code was crucial. As neither of us, the developers, had any medical or strong mathematical background, studying how WHO Anthro used the Z-score formulas (see section 6.3), allowed us to implement the calculations in FBF Anthro, and compare the output to WHO Anthro's output. Had the opportunity to look at the source code not been available, implementing the calculations would have been difficult, and taken far more time, with our limited pre-existing knowledge in the medical field.

Knowledge-base

A well functioning inference engine requires a well defined knowledge-base. As described in section 3.2.1, the knowledge-base is seen as a bottleneck in CDSS development. In this case, however, WHO has already created reference data for the Z-score calculations [29], and thus the knowledge-base for FBF Anthro was already existing. The reference data can be downloaded from the WHO, which allowed us to simply import it into the app. The knowledge-base for FBF Anthro is therefore both easily acquired, and simple to maintain.

System output

With the other components being fairly quick to define and implement, we were able to put more focus on the system output. The system output is responsible for displaying the generated information to the user in a manner that is quick and simple to interpret. The previously described CDSS characteristics, and knowledge gained from WHO Anthro allowed us to implement and display the required indicators and growth charts. The indicator-display and growth charts could then easily be changed to better suit the users' wishes, based on their feedback.

8.1.2 CDSS characteristics

Even though the characteristics of CDSSs, described in section 3.2, are mere guidelines, they are identified as features that significantly increase the usefulness of the system. These characteristics are; automatic provision of support, provision should happen when its needed, provide support not just an assessment, and it should be computer based. In FBF Anthro the support is by default computer generated as its an app integrated into DHIS2. The app is meant to be used during patient consultation, and the support provision is therefore provided at the time and location of the decision making. However, because the app using data stored on the central servers, the updated information is not provided automatically, as after new data entry, TC has to be reloaded for FBF Anthro to get new data and make new recommendations. Thus, the support provision is not fully automatic as the user is required to reload the app to get the new recommendations. Further FBF Anthro gives both an assessment, in the form of the Z-score circles and growth charts, and recommendations, in the form of customizable alerts to give recommendations for further referral or actions.

8.1.3 Infrastructure

Infrastructure can be a major hurdle for developing countries, and as described in section 4.2, and Rwanda is no exception. Although the situation in Rwanda has seen big progress the last two decades, electricity is accessible to less than half of the population. During the stay in Kigali we frequently experienced short rolling blackouts. The computers at the health facilities were protected by an Un-interruptible Power Supply (UPS) and surge protector, however the frequent loss of power increases wear and tear on any electronics. Even though the UPS continues to supply power to the computer during a blackout, if the blackout is a long one, the battery will eventually run out. Without power the access to the HMIS is lost, and with it the access to FBF Anthro. It was explained that every health facility has access to at least one computer, so we can thus assume that every health facility has access to power. Power blackouts was not experienced to be a major problem, however, we only experienced Kigali City, not the rural areas of Rwanda.

Internet is also a major hurdle in developing countries as the infrastructure relies on access to electricity. The experienced 4G coverage in Kigali was good, however the signal strength was of varying quality. The signal strength frequently dropped, especially when indoors. When the signal strength dropped, so did the connection speed. Fetching data from the server could go from taking seconds to minutes, or be timed out if taking too long. This was experienced throughout the stay in Rwanda, during development, health facility visits and the demonstrations of FBF Anthro. Because FBF Anthro needs to fetch data from the server to refresh the calculations and growth charts with newly entered data, this can be major disruption to the health workers' workflow.

8.1.4 Data quality

As described in section 7.1.3, the stored data varied in quality. Measurements were entered using both grams and kilograms, seemingly at random, even though its required to be entered in kilograms. The low data quality seemed to surprise the HMIS: Unit (HMISU) staff. We could have adjusted the input formatting of FBF Anthro to convert 8800g to 8.8kg, however we decided to keep it as is, as it served as display for the bad data quality. When interpreted by a human, the recored data can easily be corrected when plotting the growth chart for the patient. For a computer, however, this needs to be adjusted for as it cannot distinguish between 8800g and 8.8kg unless told to. The poor data quality can also be a sign of lacking health worker training, as it is varying between correct and incorrect from one patient visit to another. Correct data validation rules would remove the incorrect data as it would be impossible to enter values outside a set range.

8.2 Responses and feedback

During the stay in Rwanda, the health workers we met were open and friendly towards us, sharing their experiences and opinions with the current way of tracking growth, and the patient visit process as a whole. During the app demonstrations and user testing they also eagerly gave their responses and feedback. From the very start of the demonstration, the health workers seemed very positive and optimistic of what they were shown.

8.2.1 Health facility visits

The four health facilities visited were located in Kigali City. Each of the facilities where very busy at the time of our visit. In one of the facilities, there were at least 50 people in the waiting room, waiting for consultation. The waiting room was dark and full of visitors with little room to spare. It was explained that this was a fairly normal day at the health center. Not all visitors were there for the FBF Programme, but in general, it was pretty clear why data entry did not always happen daily, as it was supposed to. With a constant stream of visitors, the health workers had little time left for other duties. This could also be a source for the human errors we saw in the registers, as when one is stressed and overworked, errors are bound to happen. And without data validation rules that prevents unexpected data, these errors are not always picked up before the data is sent to the servers. Because these errors happen during the original registration of patient data, these errors are also likely to affect the feedback given from clinicians during consultation, and in the secondary feedback given at a later date. All of the health centers were busy, but the one described here more so than the others, at the time of visit.

> "Its very busy. Data entry should happen daily, but it happens weekly or later." (Health worker)

8.2.2 App demonstration feedback and responses

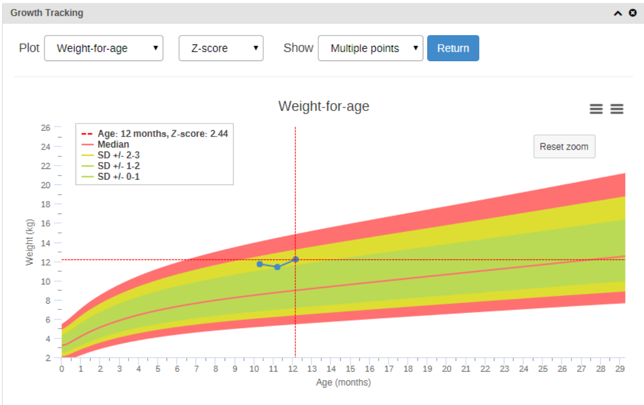
Local health workers

The responses during the app demonstrations and user testing were entirely positive. The feedback was mostly smaller changes about what, and how information was displayed. For example the way they suggested we change the standard deviation overlay in the growth charts, with different color intervals than the ones used in WHO's reference guide (see figure 8.1 on the next page). It was also suggested that we should remove BMI or use raw MUAC instead of Z-score in the circle page overview, as it was explained that this is not useful for children under 24 months. The health workers' responses suggests that FBF Anthro is something they want to use, and that it would make a big difference to their daily workflow in terms of less manual labor, giving more time to consult the patients, and the ability to give more accurate feedback. However, this comes with the caveat that it can be used during consultation, with a live update of growth charts and values during data entry. If not, it would still be of use, however it would not fully replace the paper growth charts and registers as it would still be needed during data collection and patient consultation.

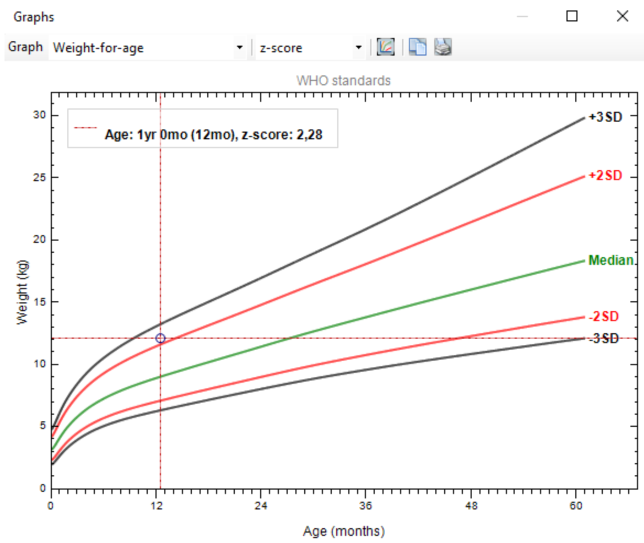
> "Data manager and nutritionist can work as a team, work together, at the same time" (Health worker)
> "This makes our job easier" (Health worker)

Health experts and other interested parties

The responses from the health experts were also positive, and feedback concerned the same changes in information display as the health workers. Having the same changes suggested by more than one source suggested to us that these were important changes, which we should focus on implementing. The requests for using different SD intervals, see figure 8.1, shows that the Rwanda MOH does not fully follow the WHO reference guides, and instead use them in ways that fit better for their local situation, as the WHO reference guides are for global use. As explained by the Hon. Minister of State "... a child from Sweden, does not necessarily grow the same as a child here in Rwanda. There are genetic differences. We need data for our local situation. Ultimately we want data from birth and up to 18 years".



(a) FBF Anthro Weight-for-Age.



(b) WHO Anthro Weight-for-Age.

Figure 8.1: Comparison of a Weight-for-Age chart with similar Z-scores. Note the difference in Standard Deviation color coding (FBF uses yellow, WHO uses red).

Chapter 9

Discussion & Conlusion

This chapter presents a discussion of the findings and analysis, linked to the related research and research questions of this thesis. Finally, a summary and thoughts on future work is presented. As a recap the research questions for this thesis were:

- *Which challenges and opportunities influences the implementation and use of Internet technologies and apps for nutrition and growth monitoring by health workers in low resource settings?*
- *What are the potential benefits and challenges of using clinical decision support systems for nutrition and growth tracking in low resource settings?*

9.1 Challenges and opportunities presented by the current situation in Rwanda

The observations were made in Kigali over a two week period, and does not necessarily represent the rural areas of Rwanda. Rwanda faces many challenges ranging from old and under-developed infrastructure to overworked health workers. The infrastructure has improved considerably since the 1994 genocide, and with the ambitious VISION 2020 plans, described in section 4.1, Rwanda is on a steady incline with further developments and improvements. Nevertheless, the Rwandan Government has quite a way to go before it reaches the ambitious goal of transitioning Rwanda into a middle-income country by 2020 [31]. The infrastructure challenges experienced did not cripple the app or the workflow, but did interrupt the flow of work sufficiently to cause inconveniences when demonstrating and testing the app during the stay in Rwanda.

9.1.1 ICT & Electricity

Internet

As described in section 4.2 the 4G coverage in Rwanda was impressive, however the signal strengths varied, and just going from one room to the other could interrupt the connection. The loss of Internet speed were at times interrupting the testing during development also, as loss in signal strength and speed brought uploading and retrieving data to a halt, making it impossible to test the apps. Overall the Internet coverage and speed in Kigali were good, ranging from 5-30Mbps. This was only experienced in Kigali, in rural Rwanda, we were told that some health facilities still use WHO Anthro, because of its offline mode synchronization. This situation could mean either unpaid Internet bills, lack of network equipment, or lack of Internet coverage.

Electricity

As described in section 4.2 around 60% of the population live without access to the power grid. The old and unreliable power grid, in addition to a low capacity, causes frequent and short power outages. It was explained to us that all health facilities has access to at least one computer, which meant that all health facilities has access to power. The computers we observed were protected behind an Un-interruptible Power Supply (UPS), and the short outages did therefore not cause any observed interruptions. However, if there is a longer power outage, this would become an issue as the batteries drain. The power outages did not cause any interruptions during the development, as we were using laptops, and the outages were short enough to not cause the laptop batteries to drain.

Server accessibility

The accessibility to the servers were relatively stable, when the Internet had suitable signal strength for the connection requests to be processed by the servers. The server crashes experienced when testing FBF Analytics, however, points to either server hardware, or a poorly installed database instance, which was unable to handle larger queries such as nation wide or province comparisons. When the server crashes, the FBF programme DHIS2 instance becomes unavailable for everyone until the server is restarted, which certainly puts an abrupt halt to any currently ongoing data synchronization.

9.1.2 Data quality & Data entry

The current situation with the paper registers and charts takes up a lot of time, resources, and storage space. Reading from paper registers and charts during patient consultation is time consuming, and a stressed person may easily make mistakes when reading from the registers or charts, especially when they are filled with old pen marks and corrections. This was expressed and observed during the health facility visits. The paper registers takes up a lot of space, and quickly degrades in humid areas (see figure 6.15b on page 68). With the limited space for each measurement, mistakes become difficult to correct. Hanwritten text that is hard to read may also cause wrongful assumptions when reading from the registers (see figure 9.1). Errors and mistakes will then easily transfer over into the HMIS as the data is first entered into the paper registers during consultation, before they are entered into the HMIS at a later time.

The erroneous weight measurements with recorded measures switching between kg and g, seemingly at random, on the other hand, points to lack of training of the users, or overworked and stressed health staff. If the data that is written into the paper registers are recorded in grams, a busy and/or not sufficiently trained data manager might overlook this and simply enter what is written in the registers. With validation rules that prohibit entering numbers outside of certain ranges, this would be eliminated completely, even if the incorrect paper register were used as a source.

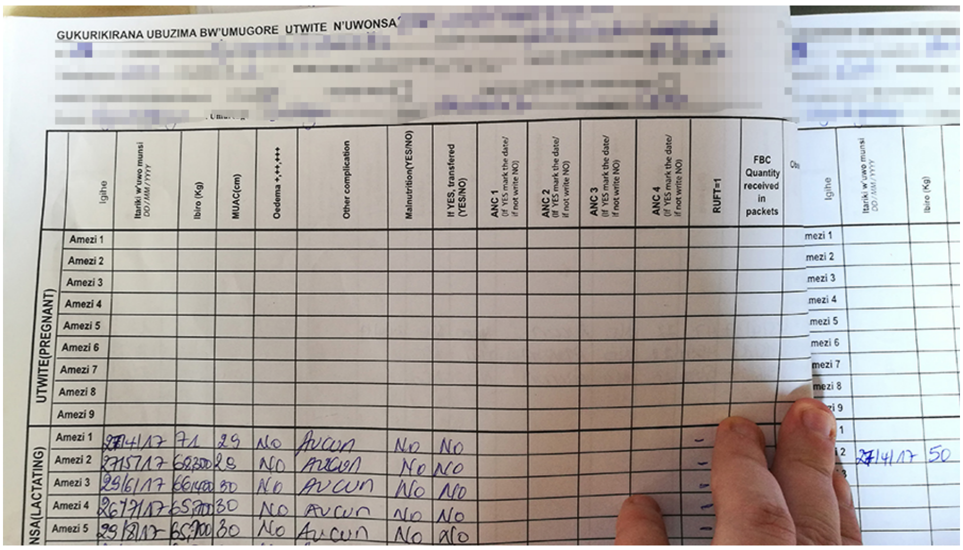


Figure 9.1: A paper register used at a health facility.

9.1.3 Data usage

Patient visits

In the early stages of the project, we were led to believe that a patient consultation included a data manager which entered data into the HMIS directly. This was not the case, however, as we discovered during the health facility visits. The health workers do not have access to a computer during consultaion. New data can thus not be entered into the HMIS when it is collected. Data entry into the HMIS was supposed to happen daily, but usually happens days or even weeks after collection. the data in entered into the database is thus not timely. During consultation the measurements that are recorded in the reception and waiting room is written into the register, and used to give parents or guardian an initial feedback on the growth charts. Later, the clinician makes a more educated decision based on the recorded data, which is then, if it is urgent, either sent by SMS or by a Community Health Worker (CHW) the next time one is visiting the patient's local community. If not urgent, the feedback is communicated at the next patient visit.

When manually plotting the charts, an older, cluttered, and well used chart can decrease the accuracy of the plot by more than 1 SD if one is not careful when tracing the axis in the charts correctly. As an example, in figure 9.2 below, plotting incorrectly may cause the child to be diagnosed with one or more Standard Deviation (SD)'s higher or lower. This may cause the clinician to make incorrect decisions, such as giving the child too few FBF food packs, if the child is identified as being less underweight than what is the reality.

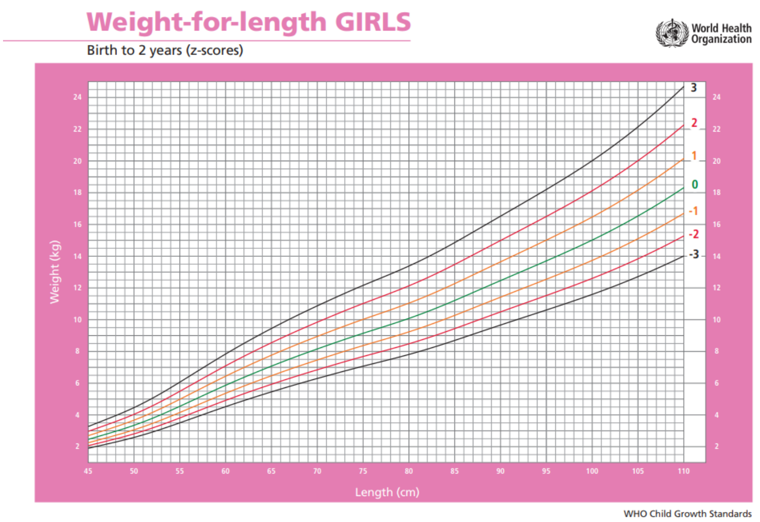


Figure 9.2: WHO Weight-for-Length growth charts for girls up to 2 years [30].

Growth charts, overlaid with the SD lines to act as a growth channel, can act as a motivator for the parent or guardian, visualizing the growth of her child [77]. Visualizing the growth can motivate the child's parent or guardian into making changes in their care for the child, and continuing to come back for regular check-ups. Currently though, as the paper charts are reused for every visit, children do not get a chart that follow them through the FBF programme enrollment. During a consultation the parent or guardian is only shown where on the chart her child is at that current moment. With FBF Anthro the growth chart can be generated with the whole growth curve, from the first visit until the latest. This would help visualize a child's progress for both health workers and the parent or guardian. The generated chart is also pin point accurate as its generated by the app.

Aggregated data analysis

Today, health managers and directors do not have access to aggregated data, at any level. This may cause decision making at higher levels to be extremely time consuming. To aggregate any data in the system, the currently only way is to manually trace growth charts to read out the Z-scores for every child, before summing up the averages. At the facility level, this is doable work, at district level or higher, however, this is not feasible. FBF Analytics would solve this problem by calculating the average Z-scores whenever they are needed, giving the managers statistics from single organization units, as well as comparisons. To save Internet data quotas, the data would not be stored on the server, however, as the calculations are done locally.

9.1.4 Summary

Developing and implementing the apps required a stable access to the HMIS. The varying reliability of the power grid and Internet connection gave temporary interruptions, but not so much as to cripple the development and implementation. The health workers trained in DHIS2 allowed the users to quickly pick up and use the apps. Health workers do not have access to a computer during the consultation, however, and data entry does therefore not happen immediately after the measurements are recorded, but days or weeks later. The data quality in the data base was also of varying degree, with measurements switching between kg and g at random. Strict data validation rules for data entry would have eliminated this problem. The lack of data aggregation creates major challenges for decision makers, as they have to manually aggregate data, which are extremely time consuming. The major factors identified to influence the development and implementation of the apps is summarized in table 9.1 below.

Challenges
Infrastructure (electrical & ICT)
Lacking data quality
Lacking data timeliness
No aggregated data for managers
No access to computers during consultation
Opportunities
DHIS2 trained stakeholders
Computers at every facility
Good data availability
No pre-existing aggregates potentially interfering with FBF Analytics

Table 9.1: The observed major influencing challenges and opportunities with the current growth tracking situation in Rwanda.

9.2 Potential benefits and challenges with FBF Anthro & FBF Analytics

The applications were tailored to the Rwandan HMIS, and the conditions and observations made during the stay in Rwanda.

9.2.1 Design

Designing the apps with the end-uses in mind, as described in section 2.1.1, gave good results when it came to keeping to the different guideline characteristics of Decision Support Systems (DSSs) and Clinical Decision Support Systems (CDSSs), as described in chapter 3. Designing the apps with a clean and simple user interface, focused around the information need of the users, was observed to simplify the process of learning to use the apps [37, p. 4]. Displaying a summary of the important indicators, with their corresponding SD color coding, on the FBF Anthro frontpage gives the clinicians an immediate health status report of the patient. With an additional alert message tied to each indicator, the clinicians explained that they would be able to know if extra attention was required at a glance. As the color coding is connected to the SD values, the indicator display represents an indication of where on the growth charts the child is. The colors follows the traffic light model (see figure 2.2 on page 8). Green indicates a healthy child, yellow indicates inadequate growth requiring attention, while red indicates little to no growth and immediate attention is required.

With each displayed indicator being a button to generate the specified growth chart, all the required information is within short reach, with minimal action needed from the users point of view. Hiding the growth charts from the frontpage also helped keeping the user interface clean and simple, only displaying them when requested. The ease of use experienced by the end-users suggest that designing the app with the end-users in mind contributed to creating an effective and simple application, which requires minimal knowledge and learning before use.

9.2.2 Usability

In the initial briefings of this project it was explained that every health facility had a computer, and that users were trained in using DHIS2. The focus of keeping the user interface of the application clean and simple made it easy for the users to understand the usage of the app. This allowed them to identify areas of improvements, such as filling the gaps between the SD lines, and also requesting the alert messages on the circle page, giving advice on further action. There was also feedback for improvements of the Tracker Capture (TC) in general, suggesting that they were fairly proficient in using DHIS2, even though this was outside of the focus of this project.

9.2.3 Benefits and Limitations

As described in section 2.3, CDSSs can be a major tool in developing countries, for example by supporting health workers in areas with no available doctors, or tracking patients such as in HIV programmes. The apps developed in this project was aimed towards tracking growth in children, and management of the Rwandan FBF nutrition programme. They were both well recieved during demonstrations and user-testing. After one of the FBF Anthro group sessions a health worker expressed their positive impressions: "This looks amazing! I look forward to using this".

Although, the focus of this thesis is CDSS and FBF Anthro, this section is divided in two as we ended up developing an extra app, FBF Analytics.

FBF Anthro

Benefits

The user feedback suggested that the need for a growth tracking tool was present. During our health facility visits the health workers were very positive to the brief description they were given of the project, and in the subsequent group session their impressions seemed to be reinforced by the demonstration they were given of the app. They were eager to test the app and discuss the impacts it would have for their daily workflow. Their responses were positive, explaining that the app would improve their workflow, such as by removing the tracing of growth charts to find the Z-score attributed to a child, simplified growth chart plotting, and tracking of a child's growth. All of these processes will be much easier for the health workers, as well as the parent's ability to follow their child's growth and well being. With FBF Anthro the current position on the growth chart would be calculated, along with the historical data, when the data is retrieved from the HMIS. The growth charts would also be more accurate than the paper charts, with a pin point accuracy on the chart, displayed in a clean chart with no old pen marks. This would allow the clinicians to make better, more accurate decisions, faster. With the download function of the chart, the feedback could also be visualized to the parent or guardian upon the next visit, or in the feedback sent with a Community Health Worker (CHW). Printing the generated growth charts would also give the parent or guardian an opportunity to see their child's progress, with a full progress curve overlaid on the SD lines. This could motivate the parent or guardian to making changes to improve care for their child, as described in section 2.2.

Because the parent or guardian wants immediate feedback on their child's well being, the health workers would still be forced to manually plot growth charts, as they do not have access to computers or tablets during consultation. A secondary educated feedback would therefore still be made, along with data entry into the HMIS. When asked about their opinions on having access to the app and a computer/tablet during consultation, the health workers' responses suggest that it would drastically improve their workflow, for both clinicians and data managers. The data could be entered directly into the HMIS upon collection, and the feedback given during consultation would thus be an educated decision as the growth chart would be accurately calculated there and then, not on data entry at a later date. The need for making a secondary decision after the patient visit would also be removed, thus lessening the workload for the clinician even further. The time saved during consultations would allow for more time spent on making the decisions for each patient, or potentially allowing for consultation of more patients. Another benefit would also be that the app would make paper registers and charts obsolete, freeing up much needed storage space and resources spent on purchasing and managing the paper registers, as well as removing the risk of having the registers destroyed by degradation or water and fire damage.

Challenges

The biggest challenge with the current patient visit process is that they would not have access to FBF Anthro during consultation. This is a large drawback as one of the core principles of a CDSS is to provide support where and when it is needed. Giving the Clinical Decision Support (CDS) long after the patient visit breaks the principle of timely reports as clinical decisions are required during a patient visit. On the other hand, installing a computer or tablet in the consultation rooms would be very expensive and a major investment from the MOH. A challenge with FBF Anthro is that when data is entered, the growth charts are not immediately re-calculated, as the Tracker Capture (TC) app does not update until data is retrieved to the server. As FBF Anthro is an extension of this app, it requires a full page refresh to fetch the updated data. In areas or periods with limited Internet access this could be a crippling if the Internet connection is not sufficient enough to refresh the page. This is tied in with the TC having no offline mode. Another challenge is that FBF Anthro does not have any dashboard functionality. This was one of the requested features we were unfortunately unable to implement as described in section 6.5.5. The dashboard functionality would allow health workers to pin certain children that requires extra care and attention to their DHIS2 dashboards. This would allow health workers to keep track of children that need special attention much easier, as they would not have to look these children up in the database.

FBF Analytics

Benefits

The FBF Analytics app did not get any extensive user testing outside of the HMISU. From their and the Honorable Minister of State's feedback, this app would drastically simplify the decision making process. Currently, the directors and managers have no access to aggregated statistical data, outside of manually calculating and aggregating the Z-scores for every child. This is extremely time consuming, inaccurate and and in reality not feasible for the whole population. Manually aggregating the data is also a privacy concern, as the patient data of individuals has to be read to aggregate it. With FBF Analytics, the managers would only see the calculated statistics, not individual patient data. The FBF Analytics app is designed to allow them statistics for every level in the hierarchy, from the national level and down to individual health centers at the click of a button. The app gives the average Z-scores for all the relevant indicators at the selected organization unit, as well as a chart displaying trends and SD distribution. This allows managers to quickly identify areas where more attention, and potentially intervention is required. As FBF Analytics is based on the same Z-score formula calculations as FBF Anthro, the accuracy is the same.

Limitations

The app is currently more in line with a proof of concept, as it has had no extensive user-testing, and several requested features are needed. The statistical data displays the average Z-scores, which was based on each recorded visit, and not on a per child basis. This would mean that the data would not be completely accurate, as it was explained to us that the rate at which the children visited a health center varied. For example over a 12 month period some children visited once a month, while others visited less, and some only a few times. Displaying trends, such as weight gain or loss, were also a request we were unable to implement with the short development time this app had. Another major challenge, and drawback, is that the current central web server does not manage to handle larger data queries such as retrieving data from the national level or comparison between two provinces. Given the large query size of fetching every patient visit throughout the given time period, the queries quickly grow in size. This could be mitigated by optimizing the app further, or upgrading the server, which can be very expensive. Another option could be to store the statistical data for each organization unit on the server, with regular updates. The app would then retrieve only the statistics, instead of every recorded visit from the server.

Summary

Both apps were met with entirely positive responses during demonstrations and testing, getting nothing but praise from their respective users. Based on the feedback and responses, both apps shows promise for improving the daily workflow for both health workers and managers.

FBF Anthro shows promise in lowering workload and improving the workflow for clinicians by removing the need for manual growth chart plotting. Access to a computer with the app during consultation would lower the workload even further. Clinicians would get accurate Z-scores and charts during consultation, and data managers or clinicians would be able to enter data into the HMIS continuously and immediately after collection. This would also help the child's parent or guardian by giving them a visual feedback, displaying her child's growth curve from the first visit and up until the current visit. This visual feedback could motivate the parent or guardian into making changes in thair care for child [77, p. 203]. FBF Anthro, especially if accessed during consultation, would remove the need for paper registers and paper charts. This would free up storage space and acquisition resources, as well as remove a source for data errors.

FBF Analytics offers managers quick access to statistical data, which is something they currently do not have access to, without manual data aggregation. Managers would get access to statistics such as average Z-scores, SD distribution and trends, and comparisons from the national level and down to individual health centers. This would allow managers to make accurate and timely decisions, as well as give them precise areas where attention or intervention is required. FBF Analytics would also remove potential privacy issues with manual data aggregation, as they would only see the aggregated results, not individual patient data.

There are not only benefits, however, as both apps requires a stable power and Internet connection to work, and for optimal use both would require potentially very expensive hardware investments. FBF Anthro would need access to a computer or tablet during consultation, and FBF Analytics may require a server with higher capacity to retrieve data from a. Additionally, the Z-score calculations requires very good data quality to not skew the data, making it unusable. There are also several feature requests that we were unable implement within the time frame of this project (see section 6.5.5). Shown below are summaries of the potential benefits and challenges for FBF Anthro 9.2, and FBF Analytics 9.3.

FBF Anthro
Benefits
Accurate Z-scores calculations and growth charts
No manual calculation errors
Instant consultation feedback (if accessed during consultation)
Quicker and more accurate feedback
Parent/Guardian gets visual feedback for the child's growth
Lessened workloads
Improved workflows
Timely data if entered during consultation
Paper registers and charts made obsolete
Challenges
No dashboard access
Requires computer/tablet during consultation for optimal use
Absolute requirement of good data quality
Requires stable Internet access to update growth charts

Table 9.2: The observed potential benefits and challenges with FBF Anthro.

FBF Analytics
Benefits
Full access to statistical data
Drastically simplified decision making process
Accurate and timely data for decision making
Drastically lessened workload
Comparison between organization units
No manual calculation errors
Facilitates timely decisions
No privacy invasion of patient data
Challenges
No dashboard access
Requires stable Internet access to update growth data
Absolute requirement of good data quality
Requires very good server capacity for top hierarchy level statistics and comparisons

Table 9.3: The observed potential benefits and challenges with FBF Analytics.

9.3 Conclusion

This section provides a summary of the discussion to answer the research questions, and finally provide suggestions for future work. This thesis have presented our work related to developing and implementing a growth tracking app in Rwanda, in light of the research questions. As a quick recap, the research questions for this thesis were:

- *Which challenges and opportunities influences the implementation and use of Internet technologies and apps for nutrition and growth monitoring by health workers in low resource settings?*
- *What are the potential benefits and challenges of using clinical decision support systems for nutrition and growth tracking in low resource settings?*

We identified several factors, both physical and in the Rwanda HMIS, influencing the implementation of the growth tracking CDSS FBF Anthro in Rwanda. Additionally, we identified some potential benefits and challenges with using CDSSs in low resource settings such as the healthcare system in Rwanda.

The enabling factors were that every health facility has access to one or more computers, along with staff trained in its use, increasing the access to the system, and reducing the amount of training required for testing the application. Developing the apps focused on the end-users' needs, along with a user-base already experienced in DHIS2, allowed the users to quickly grasp how to use FBF Anthro. This enabled them to produce more detailed feedback regarding the growth status and growth chart functionality of the app, rather than focusing on how to start up and use said app. This allowed us to focus on developing the most requested and important functionality, rather than unnecessary features potentially reducing usability.

The research participants saw potential benefits for the application, quickly mentioning lesser workload as one of the greatest potentials. They thought the automatic calculation of a child's growth status could save a lot of time per patient when making a secondary, more educated decision, after the consultation. They also thought it would allow them to make more accurate decisions for better feedback. More accurate data, and a shortened and simplified decision-making process would allow health workers to consult more patients and give them better feedback. These benefits would increase more, if the app would be accessible for the clinicians during patient consultation, as the data could be entered directly in the HMIS, and the parent or guardian could receive an accurate, educated feedback immediately, instead of days or weeks after the visit. This could potentially motivate the parent or guardian to improve her care for her child. This would again save even more time per consultation, as no secondary decision-making process would be needed, freeing time to see more patients, or allowing for less compact work days. This would in turn potentially improve the patient outcomes as well, with parents making greater efforts to improve their child's growth, as well as allowing more children to receive check-ups or higher quality check-ups with less overworked staff. Access to a computer or tablet during consultation would also make paper registers and charts obsolete, freeing up resources and storage space currently spent on re-supply and storage. This would however, require a large investment in new hardware from the Rwandan MOH, in addition to more stable power supply and Internet access. Extensive investments in computer hardware, could quickly prove to be too expensive for low-income countries such as Rwanda.

As for FBF Analytics, the participants thought it would make a huge change to their workload, by having direct access to statistics compared to having to manually calculate the data, from every citizens health record. This would allow the directors and managers to make timely, accurate decisions from the click of just a few buttons. FBF Analytics is a managerial DSS and is therefore not focused on Clinical Decision Support (CDS). FBF Analytics is therefore not a focus of this thesis. Because of the expressed great need for statistical data for decision makers, however, we decided to develop this app in parallel with FBF Anthro during the stay in Rwanda. The responses received, although minimal in sample size, shows that a statistical DSS can be of great help in the higher level decision-making process, where no such tool pre-exists. The great need and desire for aggregated data from higher level managers, however, could lead to more resources being spent on increasing managerial decision support in form of aggregates for national statistics, rather than also increasing CDS. Both CDS and management decision support is needed, to develop a well balanced healthcare system.

The challenges includes varying data quality, and a lack of timely data, making accurate decision-making based on data entered into the HMIS difficult. Data which switches denomination seemingly at random, can cause errors when calculating the growth status without being careful. Adding the factor of overworked and stressed health workers, this can cause a lot of errors being made without being noticed. In addition to this, data entry happened days after collection, and in some cases it was explained to be delayed by as much as several weeks. Additionally we found that electricity and Internet could cause interruptions in utilizing the HMIS, especially if Internet was slowed down to a crawl or interrupted.

Even though the WHO has discontinued the development of the WHO Anthro software, it was said that some health facilities still use this software because of poor or no Internet access. The discontinuation of WHO Anthro and subsequent need for a new growth tracking software is also the basis for this project. Additionally we were unable to find any studies regarding the impact and effects the WHO Anthro software has on growth monitoring.

The Rwanda MOH are also ultimately seeking to create their own reference data for growth monitoring that they can maintain themselves, and tailor to local genetic variations. As explained to us, their ultimate goal is for this reference data to range from birth and up to the age of 18 years. As described in section 2.2.1 the WHO Child Growth Standards and its associated reference data is constructed to be valid for international use. The reference data, however, are only available for children up to 5 years. The Rwandan MOH would therefore need their own data to track growth up the age of 18. Having local reference data, instead of the WHO international reference data could, however, interfere with the implementation of growth tracking tools worldwide as they would need to incorporate local data, in addition to the international WHO reference data. Having to cater to local variations in a worldwide distribution would quickly increase the complexity of such a software, such as FBF Anthro and FBF Analytics. As growth monitoring is a worldwide practice in pediatric care for monitoring individuals, as well as to detect areas that requires intervention [55], locally created reference data could skew the interpretation of growth indicators, with international organizations using the WHO references, and local governments using their own local data. This would also skew global growth statistics with different definitions of the Standard Deviation (SD) cut-offs in the Child Growth Standards developed by the WHO.

As explained in the related research, section 2.3, few studies have shown any benefits to patient outcome, and most of these have shortcomings such as small sample size and/or short time frames. This research project suffered from some of the same shortcomings with a limited sample size of user testing, and very limited time frame. This thesis is thus agreeing with recent research in that more large-scale and long-term research is needed to discover what impact Clinical Decision Support Systems (CDSSs) may have on patient outcome, health workers, and other sections of the health sector. As we were unable to find any studies regarding the WHO Anthro software and its impact, further development and study of FBF Anthro would also be an opportunity to study the effects of growth monitoring software.

9.3.1 Future work

In section 6.5.5 we identified several new features and improvements to both apps. These futures would generally contribute to the usability of the apps, increasing their support value to both managers and health workers. In the future both applications could also benefit from more extensive user-testing, especially FBF Analytics which saw no end-user-testing, preferably in a live environment such as a health facility. This could uncover information that may not be easily discovered in a controlled test-environment. Further, integration into the core Tracker Capture (TC) would benefit FBF Anthro heavily, as it currently is a separate instance of the TC, and thus will not receive any updates which is added to the TC. The script import routines for both apps could benefit from an overhaul as the URLs for each script is currently hard-coded to the Rwandan DHIS2 instance. This should make them universally available for every DHIS2 instance, unless local data structure differences mismatches with the Rwandan data structure.

Because of the very limited time in Rwanda, and short time frame for this project in general, further research is needed to clarify if the entirely positive responses were due to the bias of new technology, or genuine belief in the apps. Further, long term study is also needed to confirm or disprove the identified benefits to the workload and workflow for health workers, as well as to discover what impact a CDSS such as the growth tracker may have on the patient outcome.

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Appendix

Github repositories:

FBF Anthro:

- https://github.com/jonasbhe/growth-tracking-27

FBF Analytics:

- https://github.com/jonasbhe/growth-tracking-analytics