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Improving Clinical Decision Support in Low-Income Regions

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Abstract

Improving Clinical Decision Support in Low-Income Regions

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The combination of lightly trained doctors, under-resourced hospitals, and complex treatment protocols can sometimes result in sub-standard care for HIV patients in low-income regions.

While previous work has shown that printed patient summaries with reminders improve the quality of care, reliable access to such decision support is limited. Moreover, even when summaries are available, there are no efficient mechanisms for doctors to correct serious errors found in the summaries. Supervisors of these systems also face challenges, such as depending on unreliable manual processes to monitor summary usage across geographically dispersed clinics.

This dissertation describes ODK Clinic, a mobile phone application that makes patient summaries with reminders available at the point of care, enables doctors to correct mistakes in a patient's record, and empowers supervisors with detailed usage data. Informed by the results of a 90-day deployment with over 13,000 patient encounters, I present evidence of how ODK Clinic has improved clinical decision support at one of the largest HIV treatment programs in Sub-Saharan Africa.

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Chapter 1

INTRODUCTION

Of the 33 million people globally who have the human immunodeficiency virus (HIV) [83], 22 million live in Sub-Saharan Africa where their clinical prognoses, once they develop acquired immune deficiency syndrome (AIDS), are worsened by strained healthcare systems [20]. Although Sub-Saharan Africa has 25% of the global burden of disease, it only has 3% of the world’s healthcare providers (e.g., doctors, nurses) — many of whom are lightly trained [93, 45, 46, 73, 24, 56]. Combined with the complexity of managing the chronic illnesses brought on by AIDS, it is no surprise that Sub-Saharan Africa accounted for 72% of the world’s AIDS-related deaths in 2008 [82].

There has been a push to use computing technology to help strengthen healthcare systems in low-resource settings such as those found in Africa. Broad categories of interventions include informing populations about health issues [25], providing medical consultation remotely [48, 85], and enabling better use of health data [47, 14]. In this latter category of health data usage, clinical decision support systems offer promising approaches to improving care.

1.1 Clinical decision support

Clinical decision support systems can improve the quality of care by combining observational data (e.g., patient demographics, lab test results, current medications) with health knowledge (e.g., a trained doctor’s expertise, accepted standards of care) to enable better clinical decisions. Decision support is particularly powerful when delivered as patient-specific summaries (e.g., a one-page overview of the patient’s data) and reminders (e.g., an alert about a deviation from the standard of care) at the time of a patient visit to a health facility.

Summarization is important for doctors in Sub-Saharan Africa because they must make decisions about a large number of patients, each with months of historical data, in a small

amount of time [89]. This heavy workload paired with the relatively little medical training found in these settings can result in low standards of care [51, 58]. Summaries with reminders are ideal because they provide an easy to understand format for patient data and can be tailored for the varying skill levels of healthcare providers and various care protocols found in these regions.

Decision support has been shown to improve clinical practice and the quality of care [51, 19, 75, 71]. Studies have also shown that for increasing the quality of care, using reminders is preferable to unassisted reviews of patient data [29, 55] or to using doctor-directed continuing education [26]. Extrapolating from the success of decision support in high-income regions, it is probable that such systems will change clinical behavior and improve the care of patients in low-income regions as well [58].

Early work in decision support for Sub-Saharan Africa used patient summaries with reminders on desktop computers or on printed sheets of paper given to doctors [11, 12]. Studies of such systems show that summaries with reminders improve compliance with care guidelines [91, 88] and thus lead to improved quality of care. Despite these promising starts, there are many challenges in providing this kind of decision support in Sub-Saharan Africa.

For example, patient data that is used for decision support in these settings is often inaccurate because it is manually entered from paper forms into computers by data entry clerks with no medical training [16, 22]. This inaccurate data can trigger reminders that are inappropriate to a particular patient and must be corrected by a doctor during a patient visit. Without these corrections, the value of decision support is greatly diminished. Decision support systems targeted for Sub-Saharan Africa must consider this and many other challenges.

1.2 Mobile devices

Mobile technology, which is now widely available in these settings, provides an opportunity to address many of these challenges. In 2000, there were 11 million mobile phone subscribers in Africa. In 2004, the number had grown to 53 million, and by 2008, there were 246 million subscribers [84]. Phones, tablets and other mobile devices are interesting because they provide portable computing and connectivity in places where there traditionally have been

none. And so, along with this rapid growth in availability, have come many examples of mobile device use in healthcare — especially for efficiently collecting and using patient data [43].

These trends suggest that a mobile clinical decision support system might address some of the challenges to providing decision support in Sub-Saharan Africa. In addition to enabling rapid correction of patient data at the point of care, these devices could also address the logistics of generating, distributing, and monitoring paper summaries for the hundreds of thousands of patients dispersed across rural areas [59].

Finally, as more health systems incorporate comprehensive chronic disease management (e.g., hypertension, diabetes, cancer) programs [34], there will be a greater reliance on decision support to help doctors comply with the various and complex care protocols [77, 80] specialized to each disease and their combinations. While desktop computers might be adequate for physicians at urban hospitals, enabling more disconnected and lightly trained care providers such as rural community health workers or dispensary nurses to access clinical summaries on phones and tablets is also an important need.

For these reasons, it has become increasingly important to study the viability of using mobile devices to address the challenges of providing summaries and reminders to healthcare providers in Sub-Saharan Africa.

1.3 Contributions

The thesis behind this work is that a mobile phone application can make patient summaries more available at the point of care, can enable doctors to correct mistakes in a patient's record, and can empower supervisors with detailed usage data. As evidence to support this thesis, my work contributes the following:

1. Identification of problems with paper-based decision support

I document an approach that builds on previous research, observations of clinical workflow, surveys of stakeholders, and tens of thousands of patient visits to determine causes of failure in a large-scale paper-based decision support system. The approach produces findings that guide the implementation of a mobile application that addresses

problems with availability, supervision and correction of summaries.

2. Design and implementation of phone-based decision support

I describe the design and implementation of ODK Clinic, a phone-based decision support application that enables greater availability of clinical summaries and reminders at the point of care. For doctors, the system enables direct entry of responses to reminders, corrections of patient medications and lab test results, and automated lab test ordering. Supervisors gain near real-time monitoring of various measures of system usage.

3. Deployment and evaluation at large hospital network

I present a deployment of ODK Clinic at one of the largest HIV treatment programs in Sub-Saharan Africa. Informed by the results of a 90-day deployment with over 13,000 patient encounters, I provide evidence of ODK Clinic's positive impact on the availability, correction and supervision of clinical decision support. I also provide evidence that suggests that while doctors prefer ODK Clinic to previous practice, supervisors must carefully consider the impact of this intervention on other parts of their clinical workflow.

1.4 Outline

The rest of this dissertation is organized as follows. Chapter 2 provides the necessary background while Chapter 3 explains the specific problems with clinical decision support at a large hospital network. Chapter 4 details the paper-based workflow I proposed to change with a smartphone and Chapter 5 describes the implementation of ODK Clinic, the application at the center of the new workflow I proposed and deployed. Chapter 6 describes results from initial usability testing of ODK Clinic, Chapter 7 details findings from a three-month deployment of ODK Clinic, and Chapter 8 summarizes feedback from doctors who used the application. Chapter 9 concludes this dissertation and provides a glimpse at future work.

Chapter 2

BACKGROUND

This chapter provides the necessary background and related work for HIV care, medical record systems, clinical decision support, and mobile phones to place the contributions of this dissertation in context.

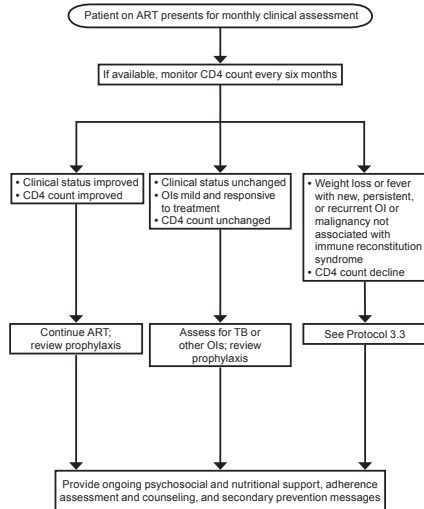
Section 2.1 discusses how HIV care is commonly practiced in Sub-Saharan Africa and how the very nature of the illness generates large amounts of patient data. Section 2.2 explains how some hospitals have moved from paper to electronic systems, and details electronic medical record use in low-income regions. Section 2.3 describes what clinical decision support systems enable, provides examples of their use in Sub-Saharan Africa, and explains some of the challenges of providing clinical decision support in low-income regions. Finally, Section 2.4 discusses the growth of mobile phone usage in developing countries and details how this new computing and communication platform could help solve some of the challenges with providing decision support.

2.1 *HIV care in Africa*

For many patients in Sub-Saharan Africa, human immunodeficiency virus (HIV) status is first determined in a clinical or community visit. In such visits, the patient is counseled about HIV and tested to determine status. If an HIV status test confirms that the patient is infected, a ‘cluster of differentiation 4’ (CD4) test is performed to determine how much damage the virus has already caused to the patient’s immune system.

Generally, if the CD4 count is under 200 cells/mm³, the patient is enrolled in antiretroviral therapy (ART) involving at least three antiretroviral (ARV) medications [40]. The medications suppress the virus and slow the progression of the disease.

Protocol 3.2 Immunological and Clinical Monitoring of Response to ART



Protocol 3.3 Switching to Second-Line ART Regimens

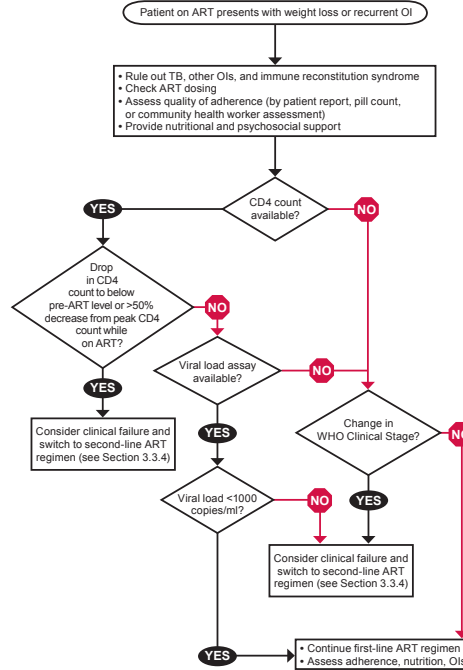


Figure 2.1: Care protocols from Partners in Health for doctors treating patients on ART medications [40]. If a patient’s CD4 count improves, the ART medications are continued. If CD4 count falls, especially when in concert with fever or persistent infections, patients are shifted to more powerful second-line regimens.

2.1.1 Antiretroviral therapy and monthly evaluations

ARV medications are not a cure for the disease, but instead control the HIV-1 RNA levels, or the viral load, in the body. The combination of medications must be taken daily for the rest of the patient’s life. As the virus evolves or opportunistic infections develop, doctors change the combination of medications to ensure patients stay healthy. Drug regimens also change if side effects from the medications become too much for the patient to bear.

Widely followed care guidelines specify that patients on ARTs be evaluated monthly for changes in CD4 count and viral load — the most important indicators for the health of

a patient with HIV. In the monthly evaluations, doctors must monitor and document lab results, medication changes, and any adverse events. An example of the protocols doctors use to evaluate progress is shown in Figure 2.1.

2.1.2 More diseases, more protocols, more data

If a patient's CD4 count improves, ART medications are continued. If CD4 count stays constant or opportunistic infections do not respond to treatment, medications are re-evaluated and patients are assessed for other infections. If CD4 count falls, especially when in concert with fever or persistent infections, patients are shifted to more powerful second-line regimens of medications.

While the care protocols described so far are simple, as patients develop other problems (e.g., tuberculosis, kidney stones, pancreatitis, diarrhea, meningitis), the set of relevant protocols grows more complex. Examples of more complex protocols are shown in Figure 2.2.

It is this compounding of diseases, protocols and data that makes the management of HIV care difficult. Historical case data for each patient must be regularly reviewed in order to ensure compliance with all care protocols. With a small number of HIV positive patients in a clinic, this data can be monitored cost-effectively using detailed paper records, but as the number of patients increases, the relevant data quickly grows to unmanageable levels. With search and retrieval limited to paper, critical information is not always readily available to doctors during a patient visit.

This situation is problematic because HIV care is primarily delivered by doctors with relatively little training — usually three to four years of undergraduate education and one internship year of practical medical training. Many of these doctors also work in hospitals that are under-resourced. For example, the health expenditure per capita in Kenya is \$37, whereas the United States spends more than 226 times that amount (\$8,362). France, a country known for efficient healthcare delivery, spends \$4,691 [96]. The combination of complex treatments, and lightly trained doctors and busy clinics (shown in Figure 2.3) can sometimes result in patients receiving sub-standard care.

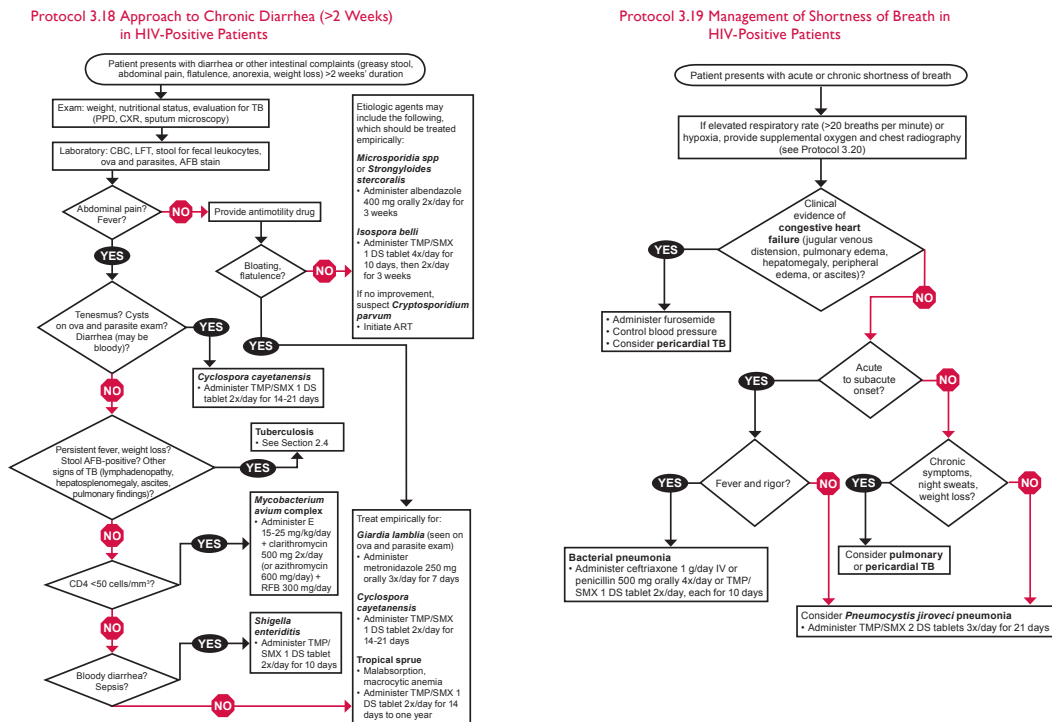


Figure 2.2: As HIV weakens the immune system, the patient can fall ill from a variety of diseases. Managing HIV is about managing this changing set of diseases. As shown from these protocols from Partners in Health, treatment steps can be quite complex [40]. Each additional disease adds to the complexity of the treatment plan.



Figure 2.3: In Sub-Saharan Africa, HIV care is primarily delivered by doctors with relatively little training. Many of these doctors work in hospitals that are under-resourced and busy. The combination of complex treatments, lightly trained doctors, and busy clinics can sometimes result in patients receiving sub-standard care.

2.2 *Electronic medical records*

When clinics realize the difficulties of paper-based record keeping (shown in Figure 2.4), they sometimes turn to spreadsheets or basic database programs (e.g. Microsoft Access). The switch rarely produces patient data management that is ideal, because the solutions are generally created by novices without training in software development or modeling relational patient data. The resulting system is often a patient database modeled on the paper forms the clinic uses. That is, for each field in the paper form, a corresponding column is created in the database. Each patient then becomes a row in that database.



Figure 2.4: An example of a well-organized records room in an HIV clinic. As the number of HIV positive patients increases at a clinic, the relevant data needed to maintain the quality of care quickly grows to unmanageable levels. With search and retrieval limited by paper, critical information is not readily available to doctors.

2.2.1 Limitations of basic databases

This simplistic design is problematic because medical data evolves rapidly. For example, the initial system may start by tracking a small number of patient demographics, various lab tests, diseases and medications. Each of these elements are generally represented as a column in a flat database table. As the number of tests, diseases and medications increases, additional columns will have to be added to the table. In addition, more columns will also be inserted for each new paper form the clinic uses, and the table will quickly reach the limits of basic database programs — for example, Microsoft Access can only manage 255 columns per table. Segmenting this data into many tables or separate databases is also not ideal because producing reports to answer basic questions about a clinic’s population (e.g., how many patients have a particular disease) becomes more difficult. For example, segmented data would require more complex database queries (involving joins of multiple database tables) than most hospital staffers can manage.

To properly store complex medical record data for hundreds of thousands of patients, one needs a far more rigorous abstraction for storing patient data. Electronic medical record systems (EMRs) provide this abstraction. An EMR stores a complete electronic representation of a patient’s record or chart. EMRs store all the encounters (e.g., visits, lab tests) the patient has had with a health system and the observations made by doctors and nurses during those encounters (e.g., symptoms, diagnoses, answers to questions). This includes lab results (or an interface with a laboratory system), medications (or an interface with a pharmacy system). EMRs are generally designed to store this data systematically over time and in a normalized, flexible and scalable manner so that it is easy to extend, search and analyze.

2.2.2 Electronic medical records in low-income regions

EMRs are widely used in high-income countries, but simply transporting existing systems to low-income regions has not been shown to work. Many of these systems assume desktop computers and servers with high availability and are often tied to expensive and proprietary medical record systems that clinics in low-income regions cannot afford to install or

maintain [41].

Increasingly, EMRs that are more appropriate are being designed and used in low-income regions to help manage patient data and have had a positive effect [42, 79]. One study in Kenya showed that when EMRs are available, patient visits were 22% shorter, with doctor time per patient reduced by 58%, and patients spending 38% less time waiting in the clinic [70]. Other studies show improvements in legibility of clinical notes, prescriptions and lab tests [30], readily available patient charts [95], support for program monitoring [87], better management of chronic diseases [35, 21] and useful reminders and alerts about lab results and medications [39].

These benefits are not broadly realized, however. In many clinics where EMRs are available, the process of using patient data is still primarily paper-based. When doctors see patients, they complete paper forms that document the encounter. These forms are eventually added to the patient's folder. Every few days, the encounter form (along with laboratory data) is manually entered into an electronic system and then returned to the patient's record. Upon a return visit, the doctor reviews the patient's record on paper using past encounter data and lab results to guide decision making.

Instead of providing support in the form of patient-level recommendations and other decision support to doctors [17], many of these EMRs are used to report aggregate statistics to institutional stakeholders. This is unfortunate because healthcare in low-income countries is primarily delivered by lightly trained doctors in busy clinics who might benefit from assistance that could lead to improvements in care delivery.

2.3 Clinical decision support

In medicine, there are a wide range of interventions that could lead to improvements in clinical practice and patient outcomes [63]. One such intervention is a clinical decision support system that can give doctors patient-specific information at appropriate times to enhance care [61]. Decision support systems can include clinical guidelines, diagnostic support, clinical workflow tools, patient summaries, and computerized alerts and reminders [62, 15]. Summaries, alerts and reminders can serve to automate clinical practice guidelines, and in low-income regions, show promise for improving the quality of care.

Summaries are needed for doctors in Sub-Saharan Africa because of the large number of patients that must be seen in a small amount of time. With historical data spread across many sheets of paper, summaries can improve the efficiency of care. Reminders are important because they can be customized for the varying skill levels of health providers and the various protocols needed for treating patients in these regions.

2.3.1 Reminders as decision support


Clinical alerts and reminders were created in the late 1970s to support a doctor's imperfect memory and thus ensure the highest quality of care [51]. This notion of the "non-perfectability of man" has not changed much in decades, with current systems still providing these suggestions at the point of care [72]. Reminders are now available on computers in consultation rooms where doctors see patients. Printed reminders added to a patient's chart also remain a popular alternative [94, 60].

Reminders are particularly critical for HIV care where doctors must frequently monitor patient status and intervene with various treatments [32]. As the care is highly algorithmic, it is amenable to decision support [53]. One study found that HIV clinical reminders delivered at the time of care were associated with more timely initiation of recommended practices. For example, the study found that patients were significantly more likely to undergo screening for syphilis infection ($p < .0001$) [44]. Another study concluded that when alerts and reminders were linked to a patient's record, adherence to HIV practice guidelines increased. In that study, the median response time to alerts in the intervention group was 11 days whereas the control group's response time was 52 days ($p < 0.0001$) [71].

2.3.2 Summaries and reminders in low-income regions

When available in low-income regions, doctors do use and value summaries and reminders. In earlier work in Rwanda, I created a simple application to help doctors in a rural hospital more readily access patient data [11, 40]. The system features a search interface to locate a patient's record. Once a patient's record is found, a summary is dynamically generated for viewing or printing. The summary, as shown in Figure 2.5, includes reminders about gaps

in care (e.g., a missing lab result).



Bob Smith

Gender **Male**

Age **44 years** (~ Jun 01, 1964)

Last Visit **1 week ago** (Aug 14, 2008)

Dr. Alice, Rwinkwavu Hospital

TRACnet ID: 12345

Carte d'Identité: 1234567

Back
Print

IMB ID **12345678-A**

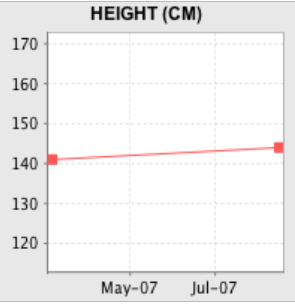
Alerts	Notes
<p>NO XRAY RESULT IN THE LAST 6 MONTHS</p> <p>NO CXR RESULT</p>	<p>No known allergies</p>

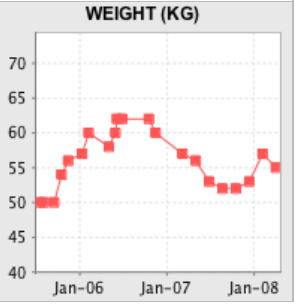
Recent Symptoms	Date
Hypersensitivity/allergic reactions, purple toes syndrome	Aug 14, 2008
Anemia, pallor, fever, rash, dermatitis, including bullous eruptions	Jul 01, 2008
Dizziness, loss of consciousness, taste perversion, and alopecia	Feb 27, 2008

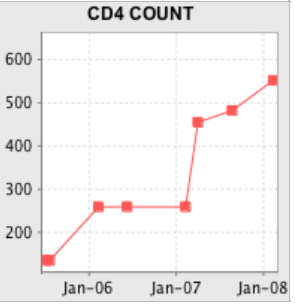
Drug Order	Dose	Frequency	Start Date	Stop Date	Notes
AZT+3TC	1.0 tab(s)	2/d x 7 d/w	Sep 13, 2007		
D4T	150 mg	1/d x 7 d/w	Aug 02, 2007		
Triomune-40 (stopped)	1.0 tab(s)	2/d x 7 d/w	Sep 01, 2007	Sep 13, 2007	Unexplained facial rash
EFV 600 (stopped)	1.0 mg	1/d x 7 d/w	Aug 02, 2007	Sep 13, 2007	

Lab Test	Result	Date	Notes
CD4	512	Aug 15, 2008	Ordered by Dr. Alice
CD4	259	Aug 01, 2008	
Viral load	515	Jul 28, 2008	Second test for verification of status
Viral load	200	Jul 27, 2008	Ordered by Dr. Eve

Graphs







Clinical Notes	Date	Clinician
Presenting History Suspect patient has malaria	Jul 02, 2008	Dr. Alice

Figure 2.5: This example of a printable summary used by Partners in Health in Rwanda has symptoms, medications, lab results, and reminders generated from patient data, and customizable graphs of important indicators [40]. This summary is representative and not from a real patient.

In 2011, this system was used by 20 doctors to access summaries for almost 8,000 HIV patients. Doctors were not required to look up patient data using the system, and had only been trained on usage in 2009. Doctors took the time to learn how to use the system and maintained that usage for at least two years. This indicates at least a perceived, but most likely a real value to the doctors.

Further evidence of the value healthcare providers derive from these systems can be found in Malawi where a touchscreen clinical workstation appliance with rudimentary decision support (shown in Figure 2.6) has been used in over 42,000 patient visits across six clinics [31].

The desire of providers to use summaries is promising because recent work in Uganda shows that such decision support improves HIV care in low-income regions by improving efficiency and quality of care through clinical summaries. After implementation of clinical summaries, doctors spent more time in direct care of patients (2.9 min vs. 2.3 min, $p < 0.001$) and the length of patient visits was reduced by 11.5 min. Doctors reported that clinical summaries improved care, reduced mistakes, and were generally accurate [91].

The authors of that work replicate and build on this success from Uganda in Kenya and show that summaries with reminders significantly improve compliance of doctors with CD4 testing guidelines. In the study's intervention clinic where summaries with reminders were printed, CD4 order rates were significantly higher when compared to the control clinic (63% vs. 38%, $p < 0.0001$) [88]. Despite these promising first steps, there are many limitations of existing decision support systems.

2.3.3 Limitations of existing decision support

Because of its cost, robustness and familiarity, paper has become the favored medium for collecting and delivering information in low-income regions [64]. And so, it is no surprise that much of the previous work providing decision support in Sub-Saharan Africa has focused on generating and printing paper summaries with reminders.

While such paper-based systems may work in small hospitals, they are difficult to scale. That is, the logistics of generating, distributing, monitoring paper summaries for the hun-

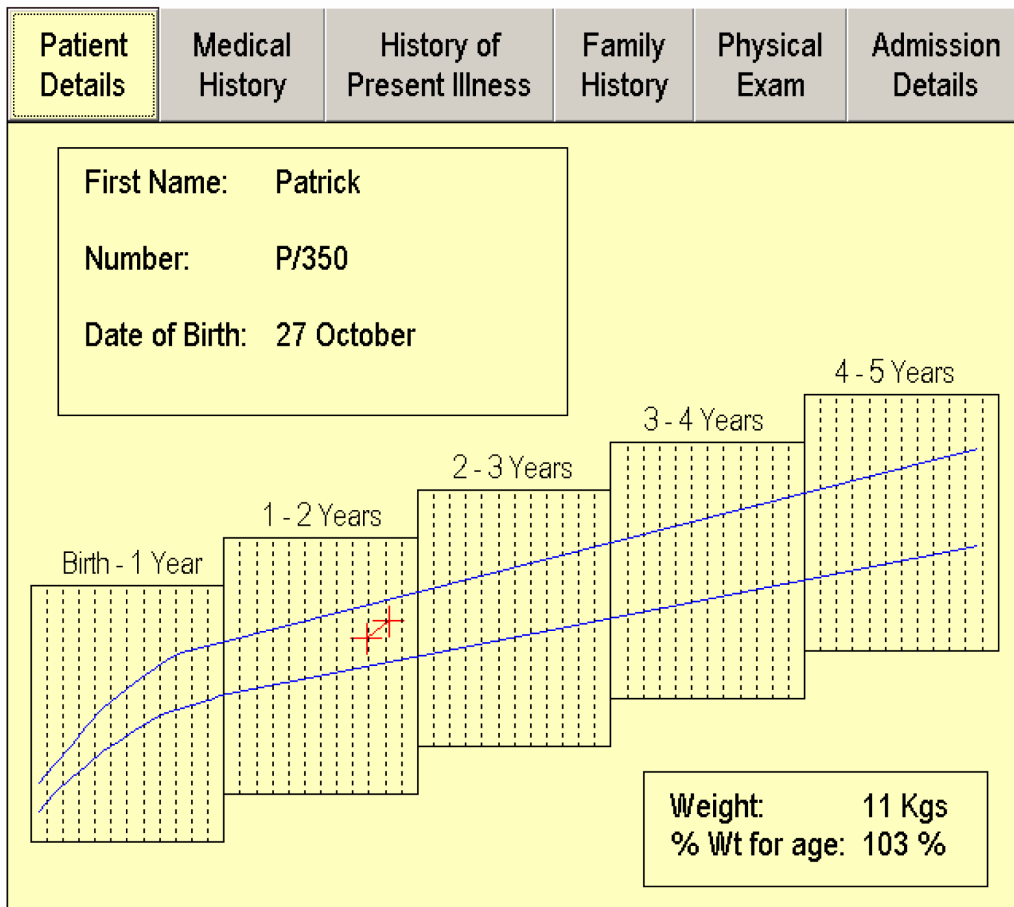


Figure 2.6: Screenshot of a touchscreen medical record system from Baobab Healthcare in Malawi. The system has some basic decision support. For example, it can recommend a patient be treated for malnutrition if body mass index is below a threshold [31].

dreds of thousands patients across geographically dispersed clinics are not trivial. The system from Kenya described earlier faced this very logistical challenge and the researchers urged alternative approaches to paper-based systems [59].

The difficulties experienced implementing clinician-directed decision support [on paper summaries] demonstrate that other approaches for delivering care suggestions need to be strongly considered when implementing clinical decision support

systems . . . reminders could also be displayed on a computer terminal or delivered to a mobile device.

Transitioning to a computer-based system solves some, but not all, the limitations of paper-based systems. For example, the decision support systems from Rwanda and Malawi that were described earlier target healthcare providers who are based in hospitals. These systems are more generally inadequate because the care for HIV-positive and other chronically ill patients is increasingly moving from large urban hospitals to smaller clinics and rural dispensaries near where patients live. This model of care reduces patient travel time and unnecessary visits to doctors whose time is a scarce resource. It is only when a chronic-care patient shows any signs of serious illness at a smaller site that they are referred to a hospital.

Because workers at small clinics and dispensaries tend to have less medical experience than doctors at hospitals, they need even more decision support to ensure a high standard of care. For this reason, summaries with reminders must also be available at smaller sites and in communities where desktop computers are difficult to deploy [86, 41], reliable connectivity is not always available [18, 49] and the human capacity for using and maintaining such computer-based systems is hard to find.

2.4 Mobile phone technology

The availability of mobile technology in these settings provides an opportunity to address many of the limitations of existing health information systems. Much of the related research in this space focuses on providing community health workers with access to low-cost phones. Examples of these include: HealthLine, a call-in system to hear health information [76]; CommCare, a patient management tool [52]; and persuasive messages and reminders about maternal health [69, 68, 28].

The technology choices in this related work are primarily driven by the cost. Basic phones are preferred because there are inexpensive (sometimes as low as \$20) and likely to be already owned and understood by healthcare workers. This can reduce initial capital and training costs of an intervention.

Unfortunately, in the case of decision support, basic phones are an insufficient technology. For example, most basic phones cannot easily store and synchronize the thousands of complex patient records needed to enable better summaries and reminders. A smarter phone is needed.

2.4.1 Why smartphones are ideal

Smartphones are mobile phones with features such as built-in cameras, GPS, and touch screens. Unlike their predecessors (e.g., basic or feature phones), smartphones are equipped with powerful operating systems, large amounts of memory, fast network connectivity, processors that approach the speed of laptop computers, and, fortunately, prices that continue to fall. For example, in Kenya, a basic smartphone (e.g., the Android-based, Huawei IDEOS) can be found for \$80-\$90. While a phone like the IDEOS is not affordable to all, the price is cost-effective for many organizations and middle-class Kenyans. In 2011, over 170,000 IDEOS were sold in Kenya [3].

Smartphones are an ideal device for decision support. Touch screens enable dynamic, customizable and user-friendlier interfaces for the variety of care providers who might interact with the system. Large amounts of memory can store the hundreds of thousands of patient records using flexible on-device databases. Powerful processors can manage the various and complex care protocols that doctors in these settings must contend with. Finally, smartphones can automatically connect to cellular networks that enable more timely access to more accurate patient data. In essence, smartphones are pocket-sized computers with the potential for Internet access.

2.4.2 Evidence of smartphone success

In my previous work, I was part of a team that designed an extensible, open-source set of tools to build information services for low-income regions. Open Data Kit, or ODK, shows that smartphones and ‘cloud’ servers can enable better mobile information systems in low-income regions [38]. In a population surveillance study with community health workers in rural Kenya, ODK Collect, a smartphone-based tool in the kit, was shown to be easier to

use, less error-prone, and more cost-effective than paper alternatives [67]. After the study, ODK Collect was used by hundreds of community health workers in over 650,000 patient encounters.

The success of Open Data Kit shows that it is possible to build and deploy a successful smartphone-based information system in these settings. Therefore, given the trends in clinical care, decision support, and mobile technology, it has become increasingly important to study the viability of using this technology to address the challenges of providing summaries and reminders to healthcare providers. In the next chapter, I present specific evidence of these challenges at one of the largest HIV treatment programs in Sub-Saharan Africa.

Chapter 3

CASE STUDY

In this chapter, I take a deeper look at the clinical decision support system that is used at AMPATH, one of the largest HIV programs in Sub-Saharan Africa in 2010. While not representative of small or medium-sized programs, AMPATH's size (over two million people in their catchment area) presents a unique opportunity to explore the problems of delivering decision support at scale.

To create the case study, I use a mixed-method approach that builds on previous decision support research, observations of doctors and staffers, interviews and surveys of stakeholders, and data from tens of thousands of patient visits at the case site. These varied approaches were used to triangulate results and to gain a more detailed and balanced understanding of the case [10].

Beyond explaining the context in which AMPATH works, the case study documents problems that hinder the scaling of AMPATH's summary system. These problems are: 1) physical movement of paper summaries is unreliable; 2) reminders expose incorrect data that slows clinic workflow; 3) feedback on availability and reminder response rates are not timely or reliable; and 4) surges of unscheduled patients can prevent paper summaries from being printed. These findings help explain why AMPATH struggles with the availability, correction and supervision of summaries.

This chapter is organized as follows. Section 3.1 presents background information on AMPATH and a description of how they scale HIV care through their electronic medical record system. Section 3.2 outlines the impact of paper summaries and reminders on the quality of AMPATH's HIV care. Section 3.3 presents the initial problems with AMPATH's paper summary system, and Section 3.4 reveals the problems faced when attempting to scale that system to many clinics. The chapter ends with Section 3.5 describing the problems of summary availability, supervision, and correction that could be solved by technology.

3.1 Scaling using electronic medical records

AMPATH (originally the Academic Model Providing Access To Healthcare) is the one of the largest HIV treatment programs in Sub-Saharan Africa and is Kenya's most comprehensive initiative to combat the virus. The program, started in 2001, is a partnership between the Government of Kenya, Moi University, Moi Teaching and Referral Hospital and a consortium of North American academic health centers led by Indiana University.

AMPATH's model is to "lead with care," but considers training and research equally important components to the short and long-term challenges of global health. AMPATH has trained about a thousand Kenyan and American medical students and thousands of Kenyan doctors. As of 2011, the program had more than 90 active projects, with research funding in excess of \$42 million, and over 170 publications resulting from these projects [1].

The AMPATH program provides care to more than 130,000 HIV-positive patients, with almost 2,000 new patients enrolled each month [78]. Care is provided at 55 urban and rural clinics (shown in Figure 3.1) in western Kenya, but AMPATH also interacts with patients in the community, including through the home-based testing and counseling (HCT) program for HIV. With HCT, AMPATH has reached over 650,000 people, has a greater than 98% rate of acceptance into homes, and has been able to lower mother-to-child transmission of HIV to below 3% [1]. Beyond HIV, AMPATH is also expanding into primary healthcare, management of chronic diseases, and specialty care.

Technology is one of the ways AMPATH can sustainably manage hundreds of thousands of patients. In particular, they have invested in an electronic medical record system to enable more efficient clinical care than paper-based systems could provide.

3.1.1 AMPATH Medical Record System

AMPATH uses the AMPATH Medical Record System (AMRS) to store comprehensive and longitudinal electronic medical records for all patients [78]. AMRS is built on OpenMRS, an open-source software platform that is widely used in resource-limited settings and enables design of a customized medical records system without requiring extensive programming expertise [50, 74].

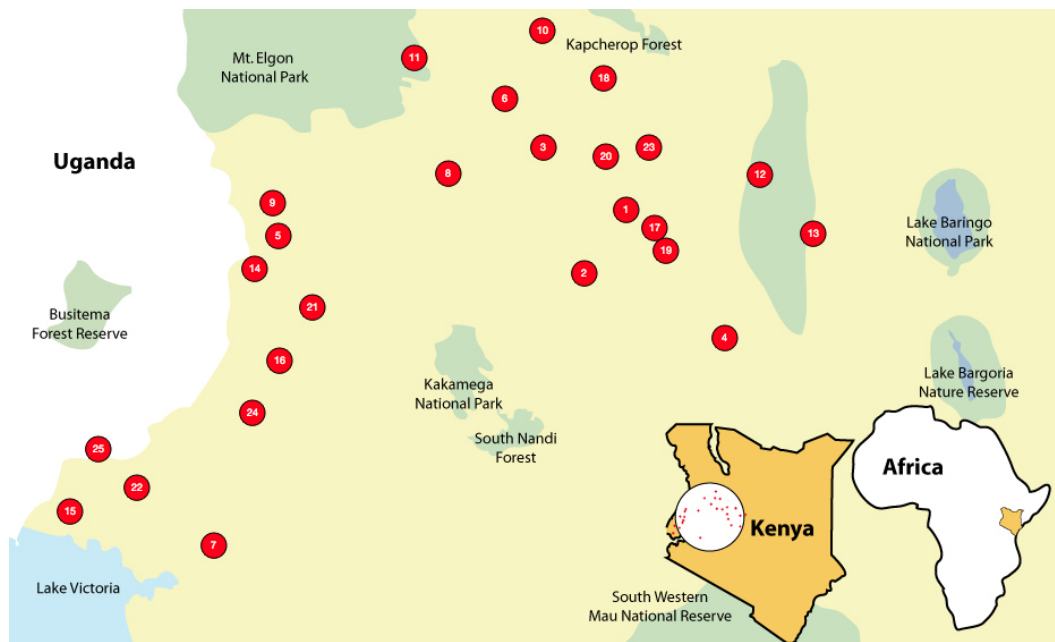


Figure 3.1: AMPATH provides care to over 130,000 active HIV-positive patients through 55 urban and rural hospitals and clinics in Western Kenya [1].

OpenMRS is designed around the principle that information should be stored for easy search, analysis and extension [90]. At the heart of this principle is the ‘concept dictionary,’ a mechanism that enables patient data (e.g., demographics, problems, diagnoses, medications, labs) to be stored in AMRS not as free-text, but as strongly coded values linked to ‘concepts.’ Concepts are the types of data that can be stored about a patient population. For example, the question “What is the patient’s blood type” is a concept. The set of answers (e.g., A, B, AB, O) are also individual concepts.

To enable this flexible mechanism of concepts, the database in OpenMRS uses the entity-attribute-value (EAV) model, a common approach for modeling entities with potentially large numbers of attributes. For example, OpenMRS’ underlying database has a single table describing every observation or piece of clinical knowledge about every patient. In this observation table, the entity is the patient (e.g., ‘Jenny Patient’), the attribute is the concept (e.g., ‘Blood type’), and the value is the numerical or textual result of that concept

for that patient (e.g., ‘AB’). This approach bypasses the expensive operation of changing the underlying database structure (e.g., creating more columns) when adding new concepts.

In addition to enabling more flexibility in the underlying database, the concept dictionary also enables data sharing and comparisons across different OpenMRS installations — as long as each installation’s dictionary has the relevant concept, patient data can be compared directly. Concepts tend to be very specific to enable this precise analysis. For example, instead of an ‘Age’ concept, the dictionary would have ‘Age in months’ and ‘Age in years.’

OpenMRS’ modular and extensible architecture allows functionality to be added or removed from the system at runtime. These modules have complete access to OpenMRS’ extensive application programming interface (API) and can modify much of the behavior of the system. For example, the Sync Module enables synchronization of all data between other OpenMRS installations, while the XForms Module exposes an API to process XForms (a type of form-based document) sent to the server from mobile devices. Modules enable hospitals to choose functionality that is appropriate for their needs without changing how core patient data is managed.

3.1.2 Clinical workflow and AMRS

Doctors at AMPATH do not enter data directly into AMRS but instead complete highly structured paper encounter forms as shown in Figure 3.2. These forms contain questions and answers that map to concepts in AMRS. For example, a question like ‘Is the patient pregnant’ maps to a ‘Patient Pregnant’ concept, while the possible responses, ‘Yes’ and ‘No,’ are also concepts. Because of AMRS’ focus on highly structured data, there is very little free-text in the forms.

After the patient visit, data clerks with minimal computer skills and little medical knowledge enter visit data from the encounter forms into AMRS. A data quality clerk also reviews the encounter data to ensure mistakes are not made in the transcription process. The paper encounter forms are then placed in the patient’s chart, and made available to the doctor during the patient’s return visit. The doctor can then use the historical encounter forms to make decisions about patient care.


		ADULT RETURN VISIT FORM		Date: / /
1. Name:				
AMPATH ID:		Previous ID:		
National ID Number:		Hospital ID:		MTCT ID:
HCT ID:		pMTCT+ ID:		3. Category: <input type="checkbox"/> Pilot (PEPFAR) <input type="checkbox"/> MTCT-Plus <input type="checkbox"/> NASCOP <input type="checkbox"/> Research <input type="checkbox"/> Other: _____
2. Site / Satellite Clinic (Required):		Module# (If applicable): <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4		4. Member of Discordant Couple? <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Unknown
5. <input type="checkbox"/> Scheduled Visit <input type="checkbox"/> Unscheduled Visit Early <input type="checkbox"/> Unscheduled Visit Late				
6. Does patient have a disability? <input type="checkbox"/> Yes <input type="checkbox"/> No If Yes, specify: _____				
7. Does the patient have any interval complaints? <input type="checkbox"/> Yes <input type="checkbox"/> No Comments: _____				
8. Female Patients:				
8a. Is the patient pregnant? <input type="checkbox"/> Yes _____ weeks <input type="checkbox"/> No (Go to 8d)		If yes: On ARV-directed pMTCT <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Treatment <input type="checkbox"/> pMTCT only <input type="checkbox"/> unknown (CD4 pending)		
8b. LMP: / /		8c. Has she delivered since her last visit? <input type="checkbox"/> Yes Date / / <input type="checkbox"/> No (Go to 8d) Pregnancy outcome: <input type="checkbox"/> Live Birth, Child still alive <input type="checkbox"/> Live Birth with neonatal death <u>after</u> 7 days <input type="checkbox"/> Live Birth with neonatal death <u>within</u> 7 days <input type="checkbox"/> Miscarriage <input type="checkbox"/> Stillbirth		
How was the mother treated? <input type="checkbox"/> Total pMTCT <input type="checkbox"/> On ARV Therapy for clinical indication <input type="checkbox"/> NVP <input type="checkbox"/> Untreated <input type="checkbox"/> Unknown Infant received NVP? <input type="checkbox"/> Yes <input type="checkbox"/> No Infant received or receiving AZT <input type="checkbox"/> Yes <input type="checkbox"/> No If yes, _____ # days received Feeding Method? (nick all that apply) <input type="checkbox"/> Breast <input type="checkbox"/> Expressed Breast milk <input type="checkbox"/> Formula <input type="checkbox"/> Cow's/Animal milk <input type="checkbox"/> Water <input type="checkbox"/> Other liquids <input type="checkbox"/> Solid Food <input type="checkbox"/> Other: _____ Baby enrolled in Peds HIV Clinic? <input type="checkbox"/> Yes <input type="checkbox"/> No AMPATH Infant ID: _____ (If No, enroll infant in clinic today)				
8d. Does mother have any children less than 18 months? <input type="checkbox"/> Yes <input type="checkbox"/> No Breast feeding <input type="checkbox"/> Yes <input type="checkbox"/> No Have all children < 18 months been enrolled in Peds HIV clinic? <input type="checkbox"/> Yes <input type="checkbox"/> No AMPATH ID: _____				
9. Male and Female Patients:				
9a. Family Planning: <input type="checkbox"/> Yes <input type="checkbox"/> No If Yes, Method: _____				
9b. Condom Use: <input type="checkbox"/> Yes, always <input type="checkbox"/> Yes, sometimes <input type="checkbox"/> No <input type="checkbox"/> Not applicable (not sexually active)				
10. Has patient been hospitalized since last visit? <input type="checkbox"/> Yes <input type="checkbox"/> No If yes: Location _____ Diagnosis: _____				
11. Current Medications:				
11a. ARVs: <input type="checkbox"/> Yes <input type="checkbox"/> No Has this patient ever changed drugs for any reason? <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> NVP200/D4T30/3TC150 <input type="checkbox"/> NVP200/ZDV300/3TC150 <input type="checkbox"/> Nevirapine 200mg <input type="checkbox"/> Lamivudine 150mg <input type="checkbox"/> Zidovudine 300mg <input type="checkbox"/> Stavudine 30mg <input type="checkbox"/> 3TC150mg/ZDV300mg <input type="checkbox"/> Efavirenz600mg <input type="checkbox"/> Abacavir300mg <input type="checkbox"/> Aluvia (kaletra) 200mgLPV/50mg rit <input type="checkbox"/> Didanosine125mg <input type="checkbox"/> Didanosine200mg <input type="checkbox"/> Didanosine Enteric Coated(EC) 250mg <input type="checkbox"/> Didanosine Enteric coated(EC) 400mg <input type="checkbox"/> Tenofovir300mg <input type="checkbox"/> 3TC300mg/Tenofovir300mg <input type="checkbox"/> Truvada (Emtricitabine200/Tenofovir300) <input type="checkbox"/> Indinavir 400mg <input type="checkbox"/> Emtricitabine(FTC) <input type="checkbox"/> Aluvia (kaletra) <input type="checkbox"/> Other: _____				
11b. PCP Prophylaxis: <input type="checkbox"/> None <input type="checkbox"/> Septrin <input type="checkbox"/> Dapsone				
11c. TB Prophylaxis: <input type="checkbox"/> None <input type="checkbox"/> INH				
11d. TB Treatment: <input type="checkbox"/> None <input type="checkbox"/> Rifater (RHZ) <input type="checkbox"/> Rifair (RHZE) <input type="checkbox"/> Ethizide (EH) <input type="checkbox"/> Rifinah (RH) Start Date: / / <input type="checkbox"/> Rifampicin <input type="checkbox"/> INH <input type="checkbox"/> Pyrazinamide <input type="checkbox"/> Ethambutol <input type="checkbox"/> Streptomycin <input type="checkbox"/> 3-FDC(RHE) <input type="checkbox"/> Other: _____				
11e. Cryptococcus Tx: <input type="checkbox"/> None <input type="checkbox"/> Diflucan				
11f. Other Drugs: _____				
12. Adherence:				
12a. During the last month has the patient missed any medications? <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not applicable (Skip to 13) <input type="checkbox"/> ARVS <input type="checkbox"/> PCP Prophylaxis <input type="checkbox"/> TB Prophylaxis <input type="checkbox"/> Anti-TB Medication <input type="checkbox"/> Other drugs Drugs Missed: _____ Reason(s): _____				
12b. During the last seven days how many of his/her pills did the patient take? <input type="checkbox"/> ARVs: <input type="checkbox"/> None <input type="checkbox"/> Few <input type="checkbox"/> Half <input type="checkbox"/> Most <input type="checkbox"/> All Drug(s) missed _____ <input type="checkbox"/> PCP Prophylaxis: <input type="checkbox"/> None <input type="checkbox"/> Few <input type="checkbox"/> Half <input type="checkbox"/> Most <input type="checkbox"/> All Drug(s) missed _____ <input type="checkbox"/> TB Prophylaxis: <input type="checkbox"/> None <input type="checkbox"/> Few <input type="checkbox"/> Half <input type="checkbox"/> Most <input type="checkbox"/> All Drug(s) missed _____ <input type="checkbox"/> Anti-TB Medication: <input type="checkbox"/> None <input type="checkbox"/> Few <input type="checkbox"/> Half <input type="checkbox"/> Most <input type="checkbox"/> All Drug(s) missed _____ <input type="checkbox"/> Cryptococcus Tx: <input type="checkbox"/> None <input type="checkbox"/> Few <input type="checkbox"/> Half <input type="checkbox"/> Most <input type="checkbox"/> All Drug(s) missed _____ Reason(s) for missing pills in the last 7 days: _____				
13. Physical Exam: BP: / P: Temp: _____ Wt: _____ Height: _____ SaO ₂ : _____ Karnofsky Score: _____ Comments: _____				
14. WHO Stage: <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 Criteria: _____ New Stage? <input type="checkbox"/> Yes <input type="checkbox"/> No				

Figure 3.2: An encounter form from AMPATH. When a patient comes into a clinic, the doctor fills out this form to document the visit. The paper form goes into the patient’s folder and then during the patient’s return visit, the doctor reviews the previous encounter forms in order to make decisions about how to proceed. Data from these forms is also entered into the AMPATH medical record system by data clerks. The electronic data is used to generate patient summaries.

3.2 *Clinical summaries at AMPATH*

Rather than providing support in the form of patient-level recommendations to doctors, much of the electronic data at AMPATH was originally used for reporting aggregate statistics to institutional stakeholders [17]. This is unfortunate because healthcare in low-income countries is primarily delivered by lightly trained doctors in busy clinics who might benefit from this assistance.

Using recommendations from the World Health Organization [92], the Kenyan Ministry of Health [57], and its own clinical experts, AMPATH created a Clinical Summary module within AMRS. The module generates a printable, one-page summary that provides an overview of the most relevant patient data needed by doctors.

3.2.1 *Clinical Summary module*

The Clinical Summary module generates summaries with patient demographics (e.g., name, age, identifiers), HIV information (e.g., first encounter at clinic, disease stage), past problems (e.g., malaria, tuberculosis), recent ARV (anti-retroviral) and OI (opportunistic infection) medications, initial and last four lab results (e.g., weight, CD4, viral load), and results of last chest X-rays. An anonymized example is shown in Figure 3.3.

The module also appends patient-specific care reminders to the bottom of the summary. For example, if there has been a significant drop in CD4 count (an important indicator for HIV patient wellness), the reminder reads, “Consider checking CD4 or Viral Load. Last CD4 count down by 25% in pt on ARVs.” Alternatively, if the patient has had a chest X-ray that was not repeated after a month, another reminder would be appended reading “Please repeat CXR. Last CXR over 1 mo. ago, could not rule out TB.”

The algorithms for what appears in the summary are encoded by programmers as rules for OpenMRS’ Logic module to evaluate. The Logic module fetches the relevant data, evaluates them against the rules, and passes the data to the Clinical Summary module to generate summary and reminder text.

Summary data is cross-referenced from different sources (e.g., HIV status is determined using encounter forms, electronic lab data and medication history) and so tends to be

more accurate than basic data found only in the patient's encounter forms. Summaries can be generated on the fly, but as the process can be computationally intensive, they are usually generated every few days for all patients whose data has changed recently or who are expected to visit the clinic.

3.2.2 Summary distribution and usage

Generated summaries are available in PDF format on AMRS via desktop computers, but since most of the doctors do not have access to computers during patient visits, summaries are typically printed by nurses and included in patients' folders just before the visit.

To further increase data quality in AMRS, when a patient presents for care, the doctor must review summary data and handwrite any corrections (primarily medications or lab tests) in free-text on the printed summary.

Doctors must also write their responses to the reminders on the summary sheet. Responses to the reminders include: Ordered Today, Not Applicable, Previously Ordered, Patient Allergic, Patient Refused, I Disagree with Reminder and Other.

These responses take into account the fact that most recommendations are for ordering tests or referrals, or involve medications for the patient. In addition, the doctor has to handwrite a requisition form for any orders (e.g., labs, chest X-rays or medications). Summaries, once reviewed, are marked with a large diagonal slash by the doctor. Like the encounter forms, the marked summary is collected and any corrections that can be entered are added to the patient's record in AMRS. A summary with markings and corrections is shown in Figure 3.4.

If the summary is not available, doctors must rely exclusively on a time-consuming manual review of previously completed encounter forms and lab result sheets to find the relevant patient data.

3.2.3 Summaries with reminders improve care

Summaries with reminders are an important tool in improving care. In a prospective comparative study at AMPATH [88], printed summaries with reminders for overdue CD4 tests

Testarius Paul Kungu**014021634-2**Male 39 Years,10 Months (01/01/1971)
HIV STATUS: EXPOSURE TO HIV (06/12/2006)

4039MT-6

First Encounter	Highest WHO Stage	6 Months HIV Rx Adherence
31/03/2010		Perfect

Problem List*Remove resolved problems through encounter form*

1. MALARIA (01/06/2010 ...3 more)
2. BRUCELLA TEST (31/03/2010)

Immunizations

1. H.Flu B (1.0)
2. DPT (1.0)

Recent ARVs & OI Meds

1. TRIMETHOPRIM AND SULFAMETHOXAZOLE

ARV Side Effects

NONE

Maternal pMTCT: Med / Period / Doses Given / Rx Length

1. NEVIRAPINE / POSTPARTUM,ANTEPARTUM,INTRAPARTUM / [Unknown Dose] / 44.0 Weeks
2. LAMIVUDINE / POSTPARTUM,ANTEPARTUM,INTRAPARTUM / [Unknown Dose] / 44.0 Weeks
3. STAVUDINE / POSTPARTUM,ANTEPARTUM,INTRAPARTUM / [Unknown Dose] / 44.0 Weeks

Flowsheet (Initial + Last Four Value)

WT (KG)	HT (CM)	CD4	VIRAL-LD	HGB	SGPT	DNA PCR	ELISA	CREAT
6.0 <i>06/12/2006</i>	6.0 <i>06/12/2006</i>	(Test Ordered) <i>01/02/2010</i>		(Test Ordered) <i>01/02/2010</i>	(Test Ordered) <i>01/02/2010</i>	(Test Ordered) <i>01/03/2010</i>		(Test Ordered) <i>01/02/2010</i>
60.0 <i>01/02/2010</i>	60.0 <i>01/02/2010</i>	200.0 (No Order) <i>01/09/2010</i>				(Test Ordered) <i>16/03/2010</i>		
60.0 <i>01/03/2010</i>	60.0 <i>01/03/2010</i>	65.0 (No Order) <i>19/09/2010</i>						

Last 2 Chest X-Rays (check chart as needed for results prior to 14-Feb-2006)

No chest x-ray results available.

Reminders : (Write number next to each reminder)*1-Ordered Today, 2-Not Applicable, 3-Previously Ordered, 4-Pt Allergic, 5-Pt Refused, 6-I Disagree with Reminder, 7-Other(Explain)*

1. Please order HIV ELISA. Pt > 18 mo old with no valid ELISA result. (___)
2. Consider starting ARV Meds. Pt > 5 yrs with positive DNA PCR AND CD4 Count < 500 (___)

Last seen 31/03/2010 at MTRH Module 1 by The Super User
Encounter entered by The Super User on 01/03/2010
Next scheduled visit: 03/01/2007**014021634-2**

Figure 3.3: A one-page summary generated from AMPATH's electronic medical record system. The summary includes patient demographics, problems, medications, lab tests and patient-specific reminders to doctors about deviations in care. This summary is representative and not from a real patient.

were made available to an intervention clinic but not to a control clinic. CD4 tests determine how well a patient is responding to HIV drugs and without regular CD4 testing, it is difficult for doctors to deliver high quality care.

9. ANEMIA (05-Oct-2006)
 10. RESPIRATORY TRACT INFECTION,
 NOS (05-Oct-2006 ...1 more)

Maternal pMTCT: Med / Period / Doses Given / Rx Length
 NONE

Flowsheet (Initial + Last Four Value)

WT (KG)	HT (CM)	CD4	VIRAL-LD	HGB	SGPT	DNA P
20.0 <small>07-Jan-2010</small>	123.0 <small>07-Jan-2010</small>	846.0 (No Order) <small>16-Sep-2006</small>		8.6 (No Order) <small>18-Sep-2006</small>	15.7 (No Order) <small>16-Sep-2006</small>	
20.0 <small>01-Apr-2010</small>	123.4 <small>01-Apr-2010</small>	Test Ordered <small>16-Mar-2009</small>		Test Ordered <small>19-Aug-2010</small>		
19.5 <small>29-Apr-2010</small>	124.0 <small>29-Apr-2010</small>	464.0 (22.0%) <small>17-Sep-2009</small>				
20.0 <small>24-Jun-2010</small>	123.6 <small>24-Jun-2010</small>	464.0 (No Order) (22.0%) <small>17-Sep-2009</small>				
22.0 <small>19-Aug-2010</small>	125.0 <small>19-Aug-2010</small>	Test Ordered <small>19-Aug-2010</small>				

Last 2 Chest X-Rays (check chart as needed for results prior to 14-Feb-2006)

1. 16-Mar-2009 : NORMAL
 2. 16-Sep-2006 : INFILTRATE

Handwritten note: 602(39)

Figure 3.4: AMPATH doctors must write a large mark across the summary sheet after they have viewed it. When there is a mistake in the summary, they enter the correction directly on the sheet. In this image, the CD4 test result of 602 (or perhaps 1602) is in the patient's chart, but is not in the medical record system and thus not in the summary. The ambiguity in the value must be resolved by a data entry clerk.

In the study, the decision support system identified 717 patient encounters (21%) with overdue CD4 tests. In the intervention clinic, where summaries with reminders could be

printed, CD4 order rates were significantly higher when compared to the control clinic (53% vs. 38%, $p < 0.0001$) — this analysis considered all return visits in the intervention, whether the summary with reminders were printed or not.

When the comparison was restricted to encounters where summaries with reminders were printed, order rates in the intervention clinic were even higher (63%). Furthermore, a before and after comparison shows a 50% ($p < 0.0001$) increase in compliance rates with CD4 ordering guidelines at the intervention clinic when compared to the control clinic that had a negligible 8% increase from the pre-study baseline ($p = 0.51$).

3.3 Challenges with summary system

While there are clear benefits to summaries with reminders, implementing such decision support is challenging. Early work at AMPATH described several causes of failures that led to the collapse of a pilot system. Although progress was made addressing the failures, as the pilot system scaled, so too did the number and variety of challenges.

3.3.1 Problems found piloting summaries

In the pilot system, AMPATH added reminders about CD4 tests to summaries at an adult HIV clinic. Within a month, doctors had stopped complying with the reminders. In a study informed by stakeholder interviews, manual review of data and printed reminders, workflow analysis, dictionary maintenance and code review, assessment of doctors' knowledge, and examination of physical infrastructure, AMPATH researchers describe three primary causes of failure: unreliable generation of summaries and reminders, doctors ignoring accurate reminders, and generation of inaccurate reminders [59]. Their results are excerpted next.

Unreliable generation of summaries and reminders

There were multiple days when the summaries did not get printed because there was no power, the printer ran out of ink or paper, or a virus had infected the dedicated machine used to generate and print the summaries. On occasion, the nurse charged with printing the summaries was too busy performing other duties, and did not have time to print the clinical summaries. Over time, doctors simply

learned not to rely on having reminders available to them.

Doctors ignoring accurate reminders

On several occasions, doctors indicated that they simply did not agree with the reminders or did not want the computer to dictate to them what they should do. Some doctors had rote practice patterns which they were unwilling to change. Others were simply unaware of the approved algorithms for CD4 testing, and thought that the computer had made a mistake. This was paradoxical — the deficiency of knowledge among doctors, which was one of the main reasons for implementing decision support, turned out to be one of the main reasons why the reminders were subsequently ignored.

Inaccurate reminders

Doctors complained that in some cases the reminders generated were inaccurate. Our analyses revealed multiple factors that contributed to inaccurate reminders. First, generation of reminders relied on data stored in the EMRs. Unfortunately, on occasion, as was typical of laboratory results, there were delays in entering this information into the EMRs. Typically, laboratory results were sent in paper form to the doctor, and a copy also sent to dedicated data-entry clerks tasked with entering the result into the EMRs. The data-entry group was grossly understaffed and they were months behind in entering results into AMRS. As such, our CDSS [clinical decision support system] which queried the EMRs for CD4 results frequently found only older results consequently, reminders were generated based on inadequate data.

Second, our initial decision support module did not take into account pending test results. In cases where a result was not out, our system would still generate a reminder to check CD4 studies, even though the test had already been ordered. Third, we faced the problem of keeping up with concept dictionary changes that would affect what elements we needed to query. As an example, new concepts were sometimes created without the knowledge of CDSS developers who needed

these terms to develop the appropriate rules. Fourth, on several occasions inaccurate data had been stored in EMRs. Errors in the data stored in the system were due to (a) inaccurate documentation by doctors on paper encounter forms, and (b) errors by data-entry clerks in transferring information from encounter forms into AMRS.

3.3.2 Solving problems with pilot system

To address these causes of failure for the pilot, AMPATH increased the budget for paper and ink, implemented policies to ensure antivirus software is updated, and installed an uninterruptible power supply for the computers and printers used for generating the paper summaries. Instead of increasing the nurses' workload, assistants were hired to print the summaries.

To facilitate greater knowledge sharing, mailing lists and wikis are now used to coordinate the relevant teams. In addition, doctors are regularly trained, and reminder text has been modified to include the rationale behind each reminder.

The Clinical Summary module has been modified so it does not trigger reminders for pending tests and a laboratory information system has been created to automatically transfer laboratory results into AMRS. AMPATH has also added a manual data quality process so doctors can note all mistakes on the summary sheet. A dedicated data manager reviews the summary sheet, makes corrections and communicates all changes to doctors and data entry clerks.

3.4 Problems with summaries at scale

As decision support has grown and evolved, so too have the problems associated with it. What is noteworthy is that many of these problems are attributable to the scale at which AMPATH works. That is, while the solutions identified in the pilot system may work at a few clinics, they do not in every clinic. For example, hiring printing assistants for each site is not financially sustainable, and so printing, especially of unscheduled patients, still falls to nurses at many sites.

In addition, manual data quality has not scaled as doctors and data entry staff has fallen behind on correcting mistakes and entering the changes into AMRS. Preliminary analysis of data from an ongoing study at one AMPATH clinic finds that potentially significant data quality errors or omissions such as incorrect medications or missing laboratory results that had not been entered into AMRS.

Finally, given that there is no reliable connectivity between sites, some of which are very remote, it has become increasingly difficult for the decision support team to ensure that the most recent summaries and reminders are readily available during patients visits.

3.4.1 Methods

To better understand gaps in existing practice that affected decision support, I observed the clinical workflow at a number of clinics. We also gave self-administered anonymous surveys and semi-structured interviews to six doctors from a clinic with an average summary availability rate. We then surveyed and interviewed six members of the decision support team responsible for daily implementation of the system. The focus of these observations, surveys and interviews was to understand the challenges of implementing and using the existing system.

Doctors surveyed have three to four years of undergraduate education and an internship year of practical medical training. Most are between 30 - 40 years of age. They earn approximately \$6,000 annually (about \$1,300 more than a government doctor and \$3,500 less than a private doctor) and are thus in the lower end of Kenya's middle class income range (\$2,500 and \$40,000) [37]. Decision support team members earn approximately \$4,400 annually and have two to four years of undergraduate education. They are on average 30 years of age.

Additionally, from September 2010 to January 2011, I analyzed data on availability rates for summaries for patient return visits across 18 clinics. As shown in Table 3.1, Eleven of the clinics are rural, fifteen have reliable power, ten have computers and printers on site, and all eighteen have reliable cellular network connectivity (and thus some Internet access). This data was collected as part of routine care by decision support staff.

I define a summary as ‘available’ if for a return visit patient, the summary could be found somewhere in the clinic (though not necessarily in the patient’s chart). A summary is ‘marked’ if a doctor marked it as viewed with a large diagonal slash through the summary. As shown in Figure 3.5, for each clinic, n represents the number of established patients with recorded return visits by each clinic. This number is roughly correlated with average patient load — a small n generally reflects a more rural clinic with fewer patients and fewer doctors.

3.4.2 Results

For the study period, there were 51,186 return visits, 41,176 (80.44%) of these had summaries available. As many as 10,010 patient encounters did not have printed summaries available and thus may have received sub-optimal care. Availability rates did not depend on a clinic’s size.

In clinics analyzed more closely (five clinics, 15,135 return visits), doctors did not mark a third (4,999, 33.02%) of the summaries as viewed. This makes it difficult to confirm whether doctors even viewed the summary, but it reflects potentially sub-optimal care and potentially uncorrected errors in the patient records.

There were large variations in the rates with which doctors in different clinics marked summaries as viewed. This is reflected in Figure 3.6, where Clinics D, F, and N show much lower rates of summaries being marked when compared to Clinics Q and R. It is notable that clinics that are smaller and more rural tend to have lower rates of marking. This likely reflects an inadequacy of supervision or training at these sites.

When doctors were asked why they used the summaries, responses were unanimous.

“Saves time on clinical decisions [and provides] ready data for comparison.”

Doctors noted that while data accuracy in the summary was sometimes problematic, they found summaries were always available and always marked. Their responses regarding availability and marking rates did not match the quantitative data gathered from clinics.

To address this discrepancy, six staffers (again, self-administered and anonymous) responsible for implementing decision support were surveyed. When asked why summaries

	Rural Site?	Reliable Power?	Reliable Network?	On Site Printer?
Clinic A	Yes	No	Yes	No
Clinic B	Yes	Yes	Yes	No
Clinic C	Yes	Yes	Yes	No
Clinic D	Yes	No	Yes	No
Clinic E	No	Yes	Yes	Yes
Clinic F	Yes	No	Yes	No
Clinic G	Yes	Yes	Yes	No
Clinic H	Yes	Yes	Yes	No
Clinic I	Yes	Yes	Yes	Yes
Clinic J	Yes	Yes	Yes	Yes
Clinic K	No	Yes	Yes	Yes
Clinic L	No	Yes	Yes	No
Clinic M	No	Yes	Yes	Yes
Clinic N	Yes	Yes	Yes	Yes
Clinic O	Yes	Yes	Yes	Yes
Clinic P	No	Yes	Yes	Yes
Clinic Q	No	Yes	Yes	Yes
Clinic R	No	Yes	Yes	Yes

Table 3.1: Infrastructure of study clinics. Eleven of the clinics are rural, fifteen have reliable power, ten have computers and printers on site, and all eighteen have reliable cellular network connectivity (and thus some Internet access).

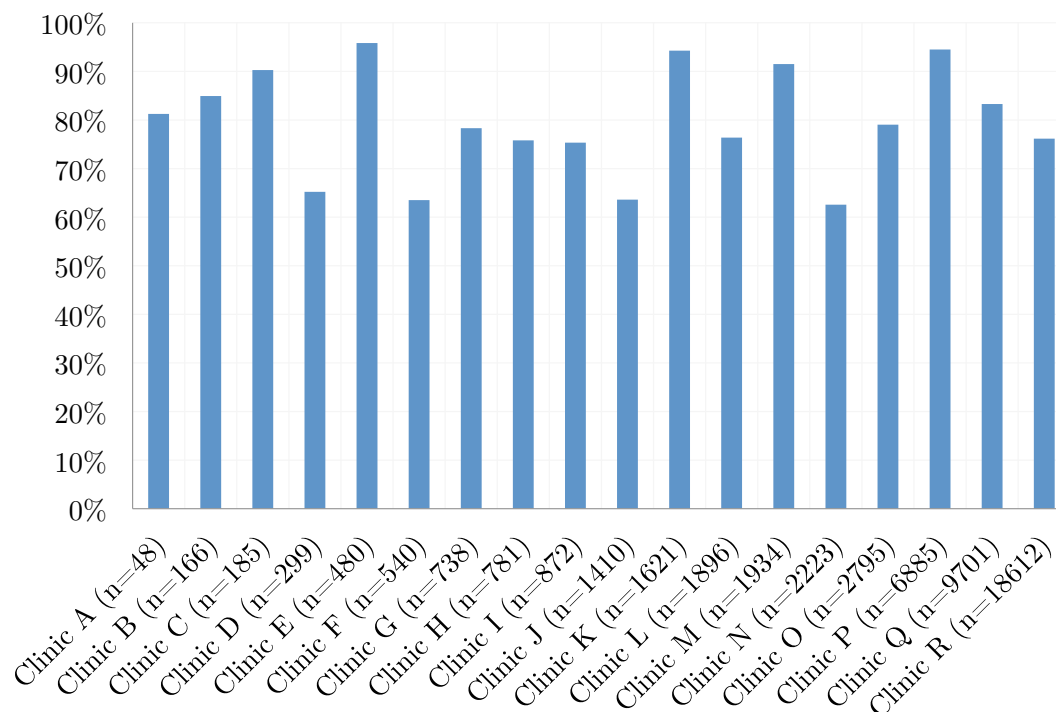


Figure 3.5: Proportion of patients with clinical summaries available (found somewhere in the clinic) during return visits. The gap between the top of each bar and 100% reflects missing summaries, and thus potentially sub-optimal care. Clinics are sorted by number of return visits (n) in the study period. As shown, availability varies by clinic and does not depend on number of return visits (and thus clinic size).

were not available or marked, staffers noted that failures were often driven by nurse workload.

“[Nurses] assume or neglect [printing] because they feel that it is an additional duty and not their work.”

“Nurses are sometimes overwhelmed by their work, so printing of unscheduled early patients summaries [is] not possible.”

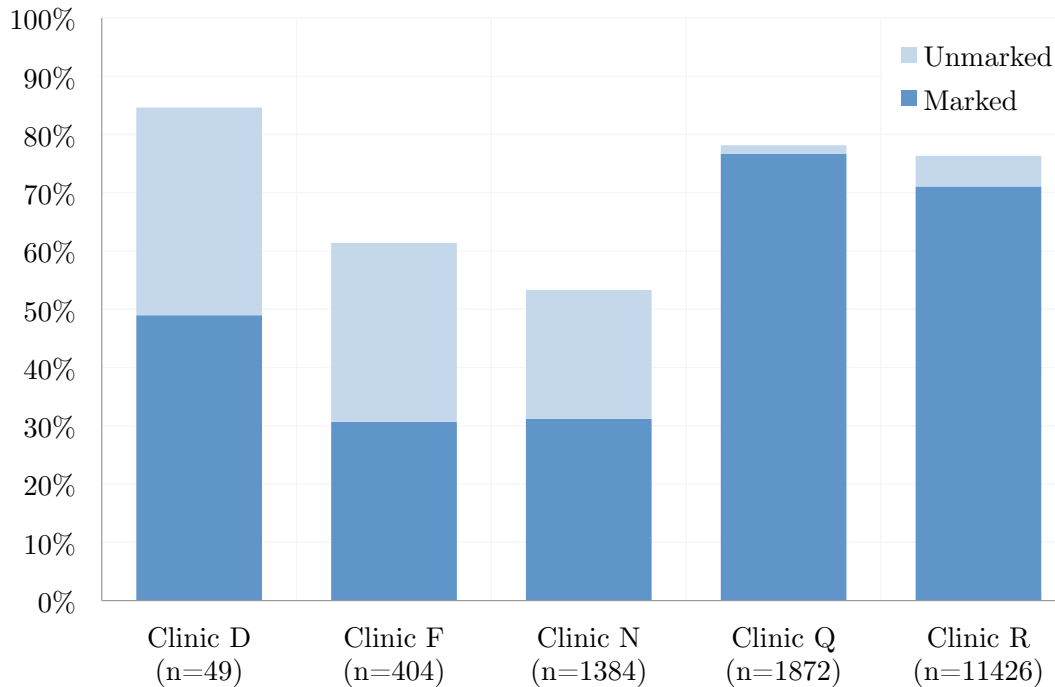


Figure 3.6: Proportion of patients with clinical summaries available (found somewhere in the clinic) and marked during visits from evaluated clinics. The gap between the top of the bars and 100% reflect missing summaries. Clinics are sorted by number of return visits (n) in the study period. It is notable that clinics that are smaller and more rural tend to have lower rates of marking. This likely reflects an inadequacy of supervision or training at these sites.

Although patients are scheduled to appear on a certain day, most do not. In some cases, they forget the exact date or simply cannot afford the trip at that time. Many of these patients, when they eventually present, tend to do so early in the week (and early during the day) and this causes surges in patient numbers that can be hard to manage.

Staff also cited problems with broken computers or printers, network outages and physical transportation of the summary data between clinics.

“Summary sheets for remote sites have not been reaching on time since there is



Figure 3.7: An AMPATH supervisor visits a clinic to ask doctors why summaries are not being corrected or marked as seen. With 55 clinics spread across Western Kenya, the manual monitoring and evaluation process AMPATH uses is inefficient.

no readily available transport.”

Due to connectivity challenges, remote clinics must have summary data of every patient copied to an encrypted USB key and driven from a central site every few days. Sites that

have no printers must also have summaries delivered. Once the vehicle arrives, previously printed and marked summaries are collected and driven back to the central site for data entry to capture corrections to patient data. Even with dedicated vehicles for the distribution and collection of summaries, shortages of transportation in other parts of AMPATH result in decision support vehicles being used for other purposes.

The survey of staffers also asked why doctors might not be marking summaries as seen or correcting mistakes they noticed on them. Staffers noted that doctors were busy and forgetful and sometimes saw correcting summaries as a burden that could be ignored.

“[Doctors] have been neglecting and not knowing the importance and seeing the pink sheet [the summary sheet] as an additional job.”

This neglect is likely the result of the long delay between when corrections are made on paper by the doctor and when they are corrected in the electronic records (and thus reflected in subsequent printed summaries). As all changes have to be entered and verified by a data clerk, delays in these corrections mean that doctors must correct the same mistake multiple times. Consequentially, the doctors tire and simply stop marking the summary. Staffers noted that doctors preferred to use the summary system when their changes were immediately reflected and when the summary had clearly actionable reminders.

When asked how to increase compliance, staffers wanted to reduce workload by hiring more doctors, nurses, or data clerks. They also suggested more training and more supervision of doctors and nurses as shown in Figure 3.7.

“[There should be] regular visits by the person in charge of summary sheets to ensure that summaries are printed and marked by doctors.”

Trained doctors and nurses are a scarce resource in developing regions. Furthermore, while more non-medical staff might increase the printing rate, these staffers would not solve the problems documented in the next section.

3.4.3 Findings

In addition to milder relapses of failures described earlier, the analysis reveals four additional problems: 1) physical movement of paper-based summaries is unreliable; 2) reminders expose incorrect data that slows clinic workflow; 3) critical feedback on availability and response rates are not timely or reliable; and 4) surges of unscheduled patients can prevent summaries from being printed.

Physical movement of paper-based summaries is unreliable

Every few days, AMRS generates summaries for all active patients. Due to unreliable power and network connectivity at remote clinics, the decision support team puts all the summaries in an encrypted format on USB keys to be transported via car to each remote clinical site. Once at the hospital, the data is synced to local machines where the summaries can be printed. If transport is not available, or the USB key sync malfunctions, updated summaries cannot be used until the next generation cycle.

Interviews with supervisors suggest the remote site process fails approximately half the time. When failure occurs, clinic staff sometimes fails to report the problem (see Figure 3.8) instead choosing to use outdated summaries. Without a more transparent monitoring system, it is difficult to correct these failures.

Reminders expose incorrect data that slows clinic workflow

Reminders use data in the electronic record that often differs from the data in the paper record. Discrepancies in this data become evident within the first few weeks of reminder creation. Each mistake then has to be corrected by a doctor and the change has to be verified and entered by a data clerk (sometimes by returning to a remote clinic to review the encounter form).

This correction process slows patient interaction for doctors and introduces a backlog of work for the data clerks. As the clerks process the backlog, frustrated doctors continue to see and are forced to continually correct the same mistakes on the forms. This process repeats each time new reminders are added to decision support.



Figure 3.8: In this view of a clinic (looking down from the ceiling), the nurse sits in the right chair, and the patient sits on the left. The patient's feet (or her young children) might accidentally disconnect the cables and disable summary printing. Because of a lack of technical ability and power dynamics at the clinic, weeks often pass before such problems are properly diagnosed and reported to supervisors.

While these errors tend to occur in the first few weeks of the creation of a reminder, the growing frequency of reminder creation introduces the potential for worsening the backlog

of corrections.

Feedback on availability and usage are not timely or reliable

Limiting the overall number of reminders, improving integration of reminders into workflow, adding the ability to document problems and receive feedback drives adoption of decision support [66, 65, 36]. The manual system with which AMPATH doctors currently interact makes reliable and timely feedback difficult to achieve.

For monitoring and evaluation, AMPATH must understand the availability of summaries at the point of care and response rates to individual reminders. Without this data, it is hard to properly staff clinics, incentivize doctors, provide extra training, correct unclean data, change unnecessary reminders, etc. Moreover, if this data is not available in a timely manner, supervisors cannot ensure only accurate and relevant reminders are shown to doctors. As a result, doctors grow frustrated and start to rely less on summaries and reminders.

Surges of unscheduled patients can prevent summary printing

Nurses print summaries for scheduled patients ahead of time, but patients often do not arrive on the day they are scheduled. If a surge of unscheduled patients arrives, the nurses cannot both manage patient care and print all the necessary summaries.

The study data shows 15.64% of return visits across all sites were unscheduled patients. Clinics with more patient visits showed higher rates, and the maximum rate of 33.47% across the study period was found at Clinic R (an urban clinic with the highest number of visits in the study).

3.5 Availability, correction, and supervision

Informed by the results of the case study, the problems of availability, correction and supervision emerged as broad challenges that, if solved, could “magnify the human intent and capacity” of AMPATH’s doctors [81]. The three problems are described next.

Summaries are not always available

It is often the case that the nurses in charge of printing summaries are overwhelmed with taking care of patients and are too busy to print the summaries. And so, when a patient presents for care, their summary may not be printed and placed in their patient folder. This is a problem because a patient visit without the help of summaries and reminders indicates that potentially sub-standard care was given.

Corrections are not added quickly to the record

The electronic data used to generate the summaries is not always correct. Doctors handwrite corrections on the summary, but these corrections take some time before they are entered into the patient's record. The summary has to be found in the clinic, transported to a central location, digitized by a data entry clerk, and then verified for accuracy. This delay results in doctors often correcting the same mistake multiple times. Doctors eventually tire of multiple corrections and stop using the system. This is unfortunate because AMPATH is potentially losing corrections of medication and lab data by medically trained professionals.

Summary usage is difficult to measure

When a doctor sees a patient's summary, they must write a large diagonal slash to identify it as viewed. Doctors do not always mark summaries, and even if they did, the current method of measuring usage is inefficient. Summary staff must visit all the geographically dispersed clinics in AMPATH's catchment area to count marks on sheets of paper. Without efficient and scalable monitoring, AMPATH has no insight into the effectiveness of a powerful tool that could improve care. Furthermore, this method is coarse-grained and does not provide information such as how long doctors looked at the summary and its various parts.

The problems of availability, correction and supervision of summaries stem from AMPATH's use of a manual, paper-based system. Any proposed intervention must be informed by this existing practice, and so in the following chapter, I describe this workflow in detail.

Chapter 4

SUMMARY WORKFLOW

This chapter describes how clinical summaries fit into the workflow at AMPATH. A detailed look at the workflow is important because it constrains the design of any intervention.

Section 4.1 provides an overview of the existing workflow at AMPATH and Section 4.2 describes how summaries are created from code, generated for use, and distributed to doctors. The chapter ends with Section 4.3, which looks at how the workflow could be transitioned to a mobile device and the principles that guide that transition.

4.1 Paper-based workflow

As shown in Figure 4.1, the process of creating and distributing summaries with AMPATH's workflow is complex. When a patient presents, a nurse locates that patient's chart and places it on the doctor's desk. During a patient visit, the doctor reads the old encounter forms and printed lab results that are in the patient's chart. The doctor completes a new encounter form with any observations, lab and medication orders. The doctor also uses the printed summary sheet to review patient data and to handwrite corrections and responses to reminders.

If there are corrections, the summary sheet is sent to a data clerk for entry. The clerk enters the corrections from the summary sheet and from the encounter form into AMRS, then moves the encounter form into the patient's chart. There is often a data quality check before the corrections are approved. In addition to writing the patient's lab and medication orders on the encounter form, the doctor also completes separate lab and medication order forms. These additional forms are delivered to the laboratory and pharmacy where a technician will immediately fill the order. The forms are then eventually entered into their respective electronic systems.

4.1.1 Multiple points of failure

The multiple systems and steps required to gather patient data contribute to inefficiencies at AMPATH. For example, due to use of multiple clerks and multiple systems, it is possible that medications that are entered from the encounter form into AMRS are different from medications that are entered into the pharmacy system from the drug order form. Since drug order forms might be entered after the medications are given to the patient, it is also possible that the patient is given entirely different medications.

The lab system has similar problems. For example, due to the unreliable connection between that system and AMRS, it is possible for AMRS to know about a lab order through the encounter form, for the result for that order to be printed and put in the patient's chart, but for the same result not to be present in the summary. It is only when the summary is printed, and a doctor sees the pill bottles the patient has come with that these discrepancies can be resolved. These problems are exacerbated at remote sites where this already unreliable manual workflow is used across large distances and under very little supervision.

4.1.2 Starting with summary sheet

While there are multiple places to intervene in the workflow, replacing just the summary sheet process is an ideal first step towards improving AMPATH's complex workflow. Because the summary sheet is important to doctors (e.g., makes it easy to review patient data) and administrators (e.g., corrections of bad data), these stakeholders are open to experimentation that could yield efficiency improvements. Unlike the other processes (e.g., patient chart, encounter forms) the summary sheet process is well contained and very similar across all sites. Moreover, any changes would not drastically alter the logistics of how care is delivered. Simply put, for AMPATH, replacing the paper summary with a phone-based summary is an important first step in understanding how to best to approach future interventions.

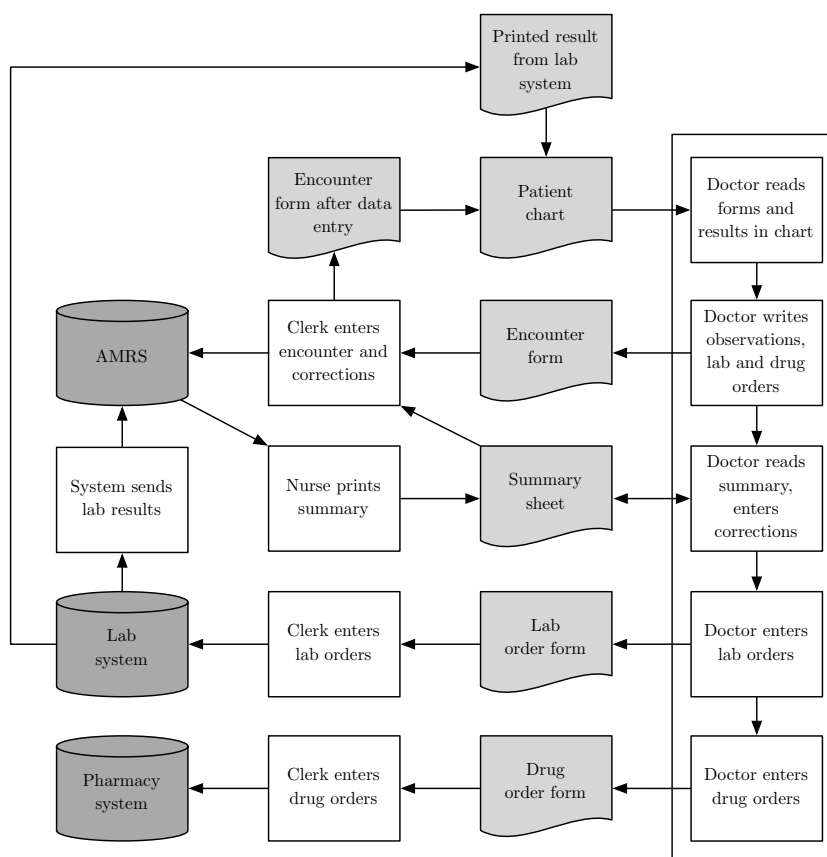


Figure 4.1: An overview of the clinical workflow. Doctors use the summary to review patient data, to enter corrections, and to respond to reminders. If there are corrections, the summary sheet is sent to a data clerk for entry. The clerk also enters the encounter data into AMRS, and then places the encounter form in the patient's chart. There is often a data quality check before corrections are approved. In addition to writing the patient's lab and drug orders on the encounter form, doctors complete separate lab and drug order forms that are delivered to the laboratory and pharmacy technicians then fill the order. The forms are eventually entered to their respective electronic systems. In the case of the lab system, while the system can communicate results electronically to AMRS there are software glitches in that link. For that reason, a printed result from the pharmacy that is placed in the patient chart is more reliable.

4.2 *Creating and distributing summaries*

Any intervention to the summary process must build on the existing Clinical Summary module that runs in AMRS. The summary module is where summaries are created and generated for use, and its design is described next.

4.2.1 *Creating summaries from code*

Summary creation starts with a Velocity template in the Clinical Summary module. Velocity is a templating engine that provides a lightweight language for referencing objects defined in Java code. The Velocity template defines the format of the data used for the summaries. As shown in Figure 4.2, the Clinical Summary module provides a user interface for programmers to view and change the template.

For example, to define a summary with the patient's name, the template would include:

```

1 <name>
2     ${ patient.getGivenName() }
3     ${ patient.getFamilyName() }
4 </name>
```

Within the module, there would also need to be Java code that passes in a Patient object to the Velocity engine in order to get the patient's full name. For example:

```

1 VelocityContext context = new VelocityContext();
2 context.put("patient", patient);
```

Velocity also provides support for logical iteration over Java objects, and thus patient data. For example, to include all of a patient's IDs followed by the summary name and date of generation, the template would include the following.

```

1 #foreach($id in ${ patient.getActiveIdentifiers() })
2     <identifier>${id}</identifier>
3 #end
4 ${ summary.getName() }
5 ${ fn.getCurrentDatetime() }
```

While a programmer can add many OpenMRS objects (e.g. an array of patient Encounter objects) into the Velocity context, doing so is not computationally efficient due to

all the complex queries required to generate such objects. Instead, to get more complex data added to the template, the OpenMRS Logic module is used.

The OpenMRS Logic module provides a unified service to evaluate rules against patient data and return the results. Rules are written in Java and once registered with the Logic module are available to any module.

Editing Template

Basic Information	Transformation
<p>Revision</p> <input type="text" value="70"/>	<p>Velocity Template</p> <pre><?xml version="1.0"?> <clinicalSummary> <currentDatetime>\${fn.getCurrentDatetime()}</currentDatetime> <moduleVersion>\${fn.getModuleVersion("clinicalsummary")} </moduleVersion> <templateRevision>\${summary.getRevision()}</templateRevision> <templateName>\${summary.getName()}</templateName> <id>\${patientId}</id> #foreach(\$id in \${patient.getActiveIdentifiers()}) #if (\$velocityCount == 1) <identifier>\${id}</identifier></pre>
<p>Name</p> <input type="text" value="Example Adult Template"/>	<p>XSLT</p> <pre><?xml version="1.0" encoding="UTF-8"?> <xsl:stylesheet version="2.0" xmlns:xsl="http://www.w3.org/1999/XSL/Transform" xmlns:fo="http://www.w3.org/1999/XSL/Format" xmlns:fn="http://www.w3.org/2005/xpath-functions" exclude- result-prefixes="fo"> <xsl:output method="xml" version="1.0" omit-xml-declaration="no" indent="yes" /> <xsl:template match="clinicalSummary"> <fo:root xmlns:fo="http://www.w3.org/1999/XSL/Format"> <fo:layout-master-set> <fo:simple-page-master master-name="simple"</pre>
<p>Description</p> <input type="text" value="Example on how to write a summary velocity template and the xsl to process them"/>	

Retire this summary
 Generate summary using the nightly task

Created By Super User - 14 August 2011 18:44:45 UTC

Figure 4.2: An example summary template in OpenMRS. The template defines all the data that will be used to generate the summary XML data.

For example, a programmer can define a rule called ‘HIV Status’ described earlier. While this rule can be evaluated against a single observation (e.g., the response to a question on an encounter form) that determines HIV status, the rule could also be evaluated against a more rigorous definition of HIV status that builds on multiple types of lab tests, medications prescribed, number of encounters, etc. This rigorous definition is particularly important because the manual data entry of encounters that AMPATH uses results in data with

mistakes. One way of improving the quality of data is by building summary data from independent sources.

Within the Clinical Summary module, a programmer can create and register a rule or use existing rules from other modules. Rules can be called from the Velocity context and they enable passing of complex query results into the summary template. For example, depending on the parameter passed into the ‘HIV Status’ rule from the template, the rule could return a simple (one or two lines of code) or rigorous (hundreds of lines of code) result for HIV status described earlier.

Reminders are created using these same rules. In the following rule definition, the ‘Adult Cluster Reminder’ rule is used to determine if a patient has CD4 results. If the patient’s record does not show any results, text reminding the doctor to order a CD4 test is added to the summary.

```

1 #set($params = {"reminderText": "Please check CD4. No CD4 tests
    in system."})
2 #set($reminderResults = $fn.evaluate($patient, "Adult Cluster
    Reminder", $params))
3 #foreach($reminderResult in $reminderResults)
4 <reminder>
5     <id>18</id>
6     <token>Adult Cluster Reminder</token>
7     <value>${fn.format($reminderResult)}</value>
8 </reminder>
9 #end

```

In this example, Line 1 is the reminder text that will be output into the summary. This is in the XML template to make it easier for non-programmers to change. Line 2 passes in the patient, the name of the rule to be evaluated by the Logic module, and the reminder text to be returned. The module always returns a list (often of one item) of results, and so the template must iterate through that list in Line 3. Line 7 outputs the result of each item in the list of results — generally the reminder text that was passed in.

If there are already numerous rules in AMRS, a doctor with some technical expertise can likely create a summary using the Velocity format. More commonly, a programmer

works with doctors to create the rules. Additionally, depending on the quality of the data, the rules generally have to be tested extensively to ensure they return expected values.

Once generated, summary data can be augmented with XSLT (a tool for transforming XML) and XSL-FO (a tool for styling XML) to generate printable PDFs, text or other XML representations. With XSLT and XSL-FO, a programmer can control both the look and structure of the resulting document. The XSLT can be changed at runtime and an example is provided next.

```

1 <fo:block font-size="8pt" font-style="italic">
2     <fo:inline>
3         1-Ordered Today, 2-Not Applicable(Explain),
4         3-Previously Ordered, 4-Pt Allergic, 5-Pt Refused,
5         6-I Disagree with Reminder(Explain), 7-Other(Explain)
6     </fo:inline>
7 </fo:block>
```

4.2.2 *Generating summaries for use*

Once created, summary templates are mapped to a patient's encounter. This mapping is necessary for summary generation. For example, for the 'Adult HIV Patient Summary' template, there is a mapping such that the summary is automatically generated when a patient has a recent (or any) 'Adult Return Visit Encounter.' Other programmer-defined encounter types can be used as well to trigger summary generation.

Summaries can also be generated on demand by location (e.g., Clinic A or Clinic B), by a patient's scheduled return date or identifier. More commonly, summaries are generated through scheduled tasks in AMRS.

Scheduled tasks are needed because of the computational complexity of queries and the size of AMPATH's data. For example, at AMPATH, there are about half a million patients and 125 million observations. Additionally, AMPATH's network can be unstable, going down for a few times a day for up to half an hour at a time. To manage this scale and unreliability, AMPATH separates patients into four groupings based on location and each group has summaries generated every four days. The combination of scheduled tasks results

in about 5,000-7,000 summaries generated over a six-hour period every evening.

There are two types of generation tasks at AMPATH. The first is based on a return date. Every evening, the Clinical Summary module searches through every location grouping for any patient who will have a scheduled visit within the next eight days. Each patient's summaries are generated in XML and PDF and stored on the AMRS server. For the second type of generation task, the module looks for patients with any new observations within the last five days for each location grouping — XML and PDF summaries are generated and stored for those patients as well.

Generation of summaries only happens on AMPATH's main server. The remote clinics do not have the computing power or all the patient encounter data needed to generate the summaries. Instead, these sites get pre-generated summaries delivered every few days.

4.2.3 Distributing summaries to doctors

At sites with computers and printers, summaries for patients are printed from PDFs generated the day before and placed in the patient's chart. In the busiest sites, there may be over a hundred patients a day. If a patient is unscheduled, printing must occur on demand.

To enable printing at remote sites, a site representative is given a USB key containing a week's worth of summaries as compressed and encrypted PDFs. The USB key is transported to the site, where its contents are uploaded and decrypted into a local instance of AMRS. From that instance, staff can print summaries for scheduled and unscheduled patients.

Sites that do not have computers and printers are given a week's worth of printed summaries. For these sites, the summary module tracks the first time the site received summaries. This initial printing provides a summary for every patient who has ever had an encounter at the site. Subsequent summaries are only generated when new data is available for a patient at that site. For large sites, this initial printing can be logistically difficult to implement.

4.3 Phone-based workflow

AMPATH wanted to explore the viability of a mobile and electronic replacement that would work well in sites with unreliable power and connectivity. Tablets were considered, but they

were not immediately viable because AMPATH wanted to try devices that were smaller, had ready connectivity to cellular networks, and were more locally available. Instead, a smartphone-based decision support system to help address availability, correction and supervision of summaries emerged as a better solution.

By equipping doctors with phones connected to AMRS, AMPATH could ensure summaries were more available at the point of care. Once doctors had summaries on a phone, they could correct serious mistakes, respond to reminders, and have their changes immediately reflected in AMRS. With doctors responsible for retrieving summaries, nurses could focus on other responsibilities when unscheduled patients arrived. Additionally, supervisors would be able to quickly monitor and evaluate the effectiveness of the decision support at AMPATH.

4.3.1 Extending the summary module

In order to provide phone-based decision support, the Clinical Summary module would need APIs added. The APIs would enable the download of patient summaries, and the upload of reminder responses, medication corrections and usage data.

There would also need to be a Search API that returned a list of patients with generated summaries who matched a name or identifier, and a Download API that downloaded the XML file of an individual summary given a patient identifier, location and summary type. The module would also have an Upload API that received responses to clinical reminders, medication corrections, and usage data.

For decision support staffers, there would need to be a user interface that showed what medication corrections have been made by a certain doctor over a configurable period. The interface would allow data quality clerks to approve or reject medication corrections. The module would also need to store reminder responses and usage data and expose it for reporting.

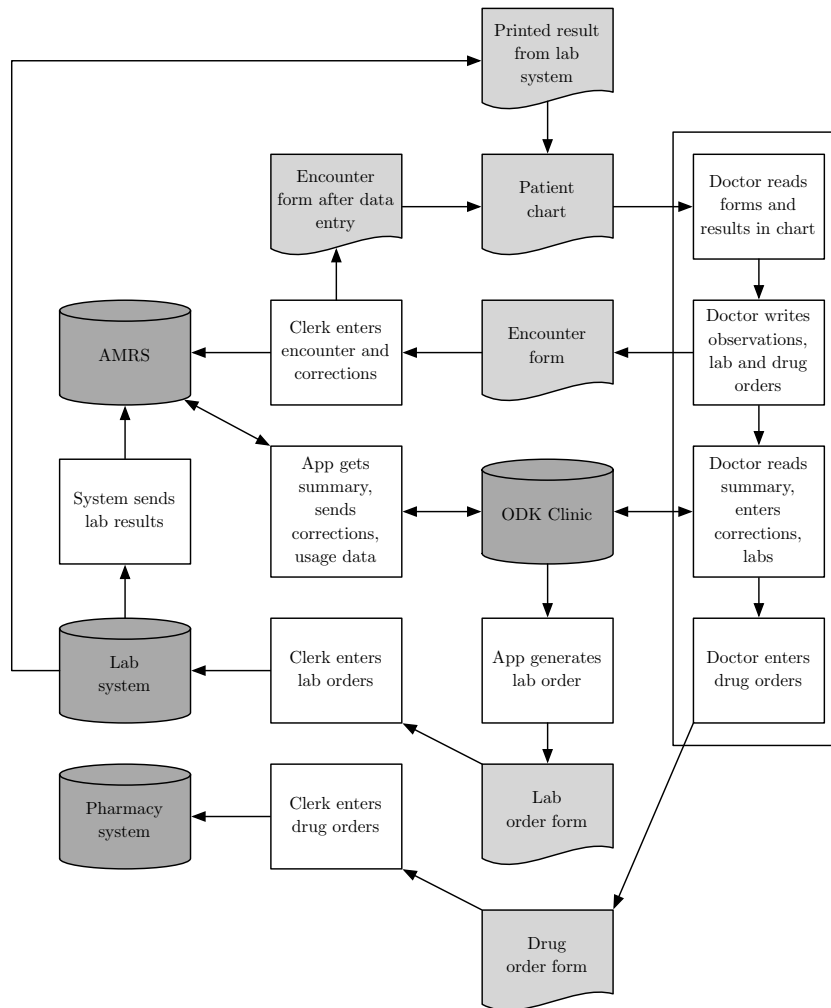


Figure 4.3: An overview of the clinical workflow with ODK Clinic. Doctors read summaries, enter corrections and order labs directly in ODK Clinic. Instead of a nurse printing the summary, ODK Clinic pulls the summary directly from AMRS. Instead of a data entry clerk entering the corrections, ODK Clinic sends that data to AMRS as well. Lab orders are printed from the phone and go through the original paper-based process. ODK Clinic could be modified to send lab, drug orders directly to their respective electronic systems and encounter forms directly to AMRS if AMPATH requests this additional enhancement. The previous workflow is shown in Figure 4.1.

4.3.2 Proposed workflow changes

To replace the summary sheet, a mobile application called ODK Clinic would need to be created. AMPATH envisioned ODK Clinic as an Android application that would connect to AMRS to download pre-generated XML summaries for offline use. Once summaries were downloaded into ODK Clinic, doctors could search for a particular patient, review data, correct summary data, order a lab test, and respond to reminders. Any corrections to the patient's record and usage data could then be uploaded to the summary module each time summaries were downloaded.

This proposed change in workflow is shown in Figure 4.3. Instead of the summary sheet (as shown previously in Figure 4.1), the doctor would use ODK Clinic to view the summary, enter corrections and order labs. Instead of a nurse printing the summary, ODK Clinic would pull the summary directly from the Clinical Summary module and make it available offline. Instead of a data entry clerk entering the corrections, ODK Clinic would send that data to AMRS, along with any usage data. Lab orders would be entered on the phone, printed wirelessly to a local printer, and the printed form would go through the original paper-based process. Although ODK Clinic could be modified to send lab and drug orders directly to their respective electronic systems, and encounter forms directly to AMRS, ODK Clinic would initially only be used for summaries. The lab order generation, while not entirely necessary, could explore the use of a hybrid phone-paper system.

4.3.3 Design principles

Building on the findings in the case study and an understanding of the workflow, three principles to guide the design of ODK Clinic emerged as important in addressing the problems of availability, correction and supervision. The principles are: 1) assume unreliable servers and offline use; 2) only reproduce functionality of the existing system and 3) collect data as a side effect of usage.

Assume unreliable servers and offline use

Because connections to AMRS (and AMRS itself) are unreliable, the application should ensure that summaries for patients that a doctor expects to see are always available on the phone. Moreover, because patients do not always present when they are scheduled, the application should make summaries of patients expected to visit within a few weeks also available offline. If a summary is not available on the phone when a patient presents, the application should connect to AMRS and download the summary. This design principle should help problems of availability.

Only reproduce functionality of existing system

Doctors use the summary to view patient data and correct medications and lab results. The application should mirror this and only this functionality. Introducing too many new features could result in a more involved (and thus expensive and difficult to scale) training of doctors. Instead, the application should make the functionality of the existing system more efficient. For example, instead of transporting summaries to a central location for data entry to capture corrections, corrections to the patient's record can automatically be sent to the medical record system via Wi-Fi or cellular networks. This design principle should help with corrections and help make the system more deployable.

Collect data as a side effect of usage

One of the gaps in AMPATH's existing system is the lack of visibility into how summaries are being used. The application should be extensively instrumented so that doctors' actions generate an implicit and detailed record of usage. As it is not clear exactly what data will be useful to decision making, this trace data should be automatically sent to AMRS whenever connectivity is available. Once in AMRS, supervisors will be able to monitor usage. This design principle should help with supervision.

This chapter provided an overview of the existing workflow at AMPATH, a description of how summaries are created and distributed, and an outline of a new workflow using ODK Clinic. In the next chapter, I describe the design and implementation of ODK Clinic, an application designed to help with the availability, supervision and correction of summaries.

Chapter 5

SYSTEM DESIGN

This chapter describes the design and implementation of ODK Clinic. ODK Clinic is an Android application that connects to AMRS (over secure Wi-Fi or the cellular network) to download pre-generated XML summaries for offline use. The Clinical Summary module, which runs in AMRS, generates the XML summaries and makes them available to ODK Clinic via an application programming interface (API).

Once summaries are downloaded into ODK Clinic, doctors can search for a particular patient, review data (e.g., see the latest lab results), correct summary data (e.g., mistakes in the list of medications), order a lab test, and respond to reminders or alerts. Any corrections to the patient's record and usage data (e.g., what parts of the summary were viewed) are uploaded to AMRS each time summaries are downloaded. This data is made available for analysis by supervisors.

Section 5.1 walks through the everyday usage of ODK Clinic with a fictional Dr. Alice and patient Bob. Section 5.2 describes in detail the functionality available in ODK Clinic and the chapter ends with Section 5.3 that outlines the architecture of ODK Clinic.

5.1 Usage scenario

Every morning, Dr. Alice gets her assigned phone from the locked storage room. The phone is marked with a sticker so she knows which phone is hers. She likes having her own phone that she can customize and take care of, but understands that after the pilot, AMPATH may go to a shared phone system to save money. This makes sense because some doctors go on leave for a month or two and their phone is left idle.

Alice turns on the phone, opens up ODK Clinic, and enters her PIN to unlock the application. She presses the refresh button to start downloading a batch of patient summaries. These summaries are for patients who visited the clinic last week and for patients scheduled



Figure 5.1: An AMPATH doctor in a consultation room. The green folder in front of her is the patient’s chart with historical encounter forms.

to visit a week after today. The storage room is strategically near a Wi-Fi access point and so the downloads of the hundreds of patients only takes a minute or two. When the download is done, Alice goes to her consultation room to begin seeing patients. Her first patient is Bob.

The head nurse generally puts the charts of patients who have checked in on Alice’s desk, so Bob’s chart is already there. When Bob enters the consultation room, Alice finds his

summary by typing his first and last name into the phone. Because Bob was scheduled for a visit, the summary is already on the phone and so it loads quickly. If Bob was unscheduled, she could search for his summary on AMRS. Alice's consultation room has very thick walls and so searches can be unreliable due to a weak Wi-Fi signal. Sometimes she has to go outside the room to do a search.

Alice opens Bob's summary on the phone and starts asking him questions about how he is feeling. She writes his answers in a new encounter form. Alice also asks Bob what medications he is taking. Bob shows her his bottle of Rifampin pills. Somehow, Rifampin is not listed in the summary, so Alice corrects that mistake on the phone. She also looks through the old encounter forms in Bob's chart to make sure all his lab results are in the summary. Luckily, they are, so she tries to close the summary. ODK Clinic does not let her do so, yet.

ODK Clinic reminds Alice that because the last doctor Bob saw did not order a CD4 test; he needs one during this visit. She responds to the reminder on the phone by selecting 'Ordered Today,' and the phone asks her if she wants to print a lab order form for the CD4 test. She says yes, and the lab order form with Bob's demographics is automatically generated and printed in the head nurse's office. Since there are no more reminders, ODK Clinic now allows her to exit Bob's summary. Before Bob leaves the room, a nurse brings the printed lab test form over for Alice to sign. She gives a copy to Bob to take to the laboratory where he will get his CD4 test, and bids him farewell.

Alice sees more patients throughout the day. If she is careful, the phone's battery can usually last over seven hours, but she also has an outlet near her desk if she needs a charge. When she goes for lunch, she takes the phone with her. ODK Clinic locks the screen after a few minutes, so she needs to re-enter her PIN when she comes back after lunch. At the end of the day, Alice takes the phone to the storage room. She presses the refresh button and sends the day's corrections to AMRS. Her usage data is sent as well.

ODK Clinic then downloads a new batch of patient summaries and stores it on the phone. With so many patients to see in the mornings, downloading the patient summaries now ensures that the most up-to-date summaries are on the phone in case AMRS is unavailable in the morning. After the download, Alice powers off her phone, stores it in the locked

cabinet, and heads home.

5.2 Mobile application workflow

When first installed, ODK Clinic takes the user, usually a decision support staffer, to a list of preferences. Doctors are not expected to configure their own phone because explaining the preferences takes up valuable training time and has very little bearing on how the application is used. The preferences have options for Server, User, Password, and PIN.

Server, User and Password provide the login details to connect to AMRS. While most doctors have accounts on AMRS and should know this information, they often do not because they rarely use AMRS directly. For that reason, this data must be entered by the decision support staffers. The preferences ask for a four digit PIN. This PIN is used by doctors to unlock ODK Clinic on startup and after the application times out due to inactivity.

There are also options for Summary ID and Location ID in the preferences. Summary ID is used to specify which summary (e.g., Adult HIV, Pediatric HIV) to download from AMRS. Location ID is used to specify the phone's home clinic. ODK Clinic uses Location ID to determine which set of summaries to download.

Finally, there are options to enable or disable lab order printing. In this section of the preferences, Provider Name, ID, and Site can be entered. This information is used to automatically complete a lab order form on the phone for printing to nearby printers.

Once the application is configured, it is ready for use by doctors. From this point forward, decision support team staff can enter an administrative code (entered at ODK Clinic's login screen) that is hard-coded into the application and do a long-press on the ODK Clinic logo to change preferences again. This choice was made to ensure only staffers could easily change phone settings that were critical to usage.

5.2.1 List of patient summaries

As shown in Figure 5.2, when a doctor powers up an assigned phone, they enter their PIN and are taken into the list of patients. The PIN screen will re-appear if the phone is left idle for longer than a few minutes.

The user interface has two major elements — a toolbar and an alphabetical list of patients. The toolbar has a button for barcode scanning (vertical stripes), a text box for filtering summaries by name or identifier, a search button (magnifying glass) for searching for a single patient summary on AMRS, and a refresh button (two curved arrows) that uploads and downloads data (e.g., summaries, corrections, and usage patterns).

The refresh button downloads a batch of summaries for patients who are expected to visit the phone's home location during the previous, current week, and next week. This feature was added because most patients do not present on their scheduled date. Moreover, if AMRS is ever unavailable, ODK Clinic will still have the majority of summaries of patients who are expected to visit. The period is adjustable on the server.

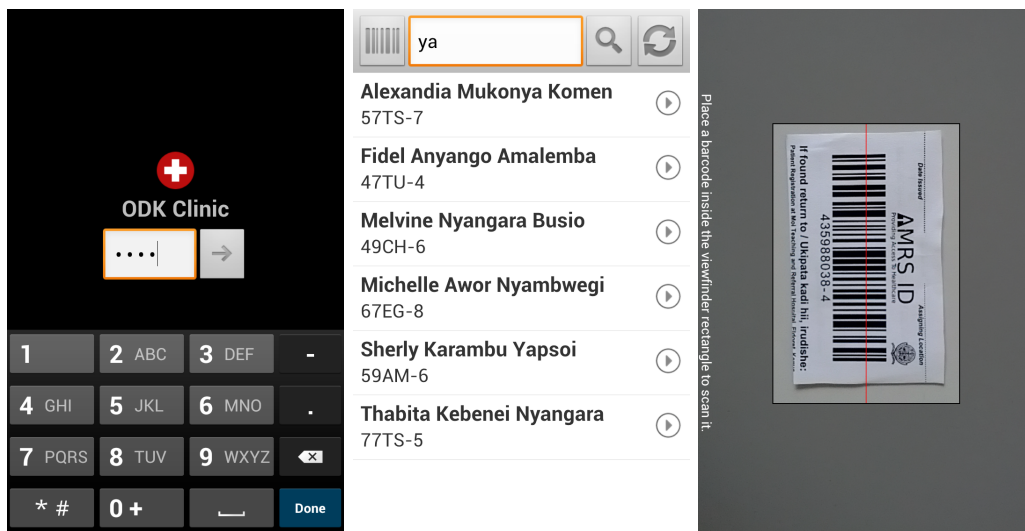


Figure 5.2: Once a doctor opens ODK Clinic, the list of summaries available on the phone are shown. The application also supports barcode scanning of patient ID cards.

The same refresh button also sends any local changes (e.g., reminder responses, medication corrections) to AMRS. Any usage data (e.g., button clicks, time spent viewing each summary) are also sent on refresh. The phone first sends all locally stored data, and if that submission is successful, the local data is removed from the phone and replaced with

data from the server. This algorithm means that if a doctor changes patient data and immediately refreshes, the changes will be sent to the server, and potentially stale summary data will be placed back on the phone. This process is intuitive to doctors because all data they enter on paper must go through a data quality review and a summary generation cycle before it appears as part of the record — ODK Clinic mirrors that process. Moreover, because the phone only replaces data if the server confirms receipt of local data, no local data is ever lost.

On refresh, the phone uses a multi-threaded and queued connection manager to create a thread for each summary being downloaded (usually a few hundred summaries). The number of active threads in the thread pool is limited to 29 (the maximum connections the Android phone allows), and each connection long timeouts to allow for high latency connections. This parallel approach ensures very fast downloads. Because doctors generally arrive at the clinic at different times, server and network load is not much of a problem.

Once the summaries are downloaded, they are shown below the toolbar. The patient's full name and identifier are displayed — these are the most relevant part of the record the doctor needs to see. Summaries are sorted in alphabetical order by patient name.

The input from the text box is used to filter the list of summaries for only matching names or identifiers. A doctor can also press the search button to initiate a search on AMRS for any patient whose summary is not found on the phone (e.g., an unscheduled patient). The search can also locate summaries for patients who do not belong to the phone's home clinic (e.g., any patient at AMPATH).

When a doctor initiates a server search, a list of all available summaries that match are displayed. Once a single summary is selected, the doctor can download that summary.

When a doctor presses the barcode scanning button, it launches an external application, that uses the phone's rear camera to capture a video stream and process it for any barcodes. If a barcode is detected, the scanner returns the textual result and inserts it into ODK Clinic's text box. The patient list will filter for that result. Doctors can also initiate a search on AMRS using this input.

Android's user interface does not make it immediately clear what items can be tapped and so novice users struggle with usage when first given a phone. Buttons that are 3D and

text boxes with orange borders are intuitive, but items in a list are not. For ODK Clinic's list items (e.g. the list of summaries), every element that can be tapped has a triangle with a circle through it. This tappable icon is used throughout the application.

5.2.2 Individual patient summaries

A doctor taps on a summary to open it. ODK Clinic then asks the doctor if they are completing a return visit form for the patient. This information is used to determine if the patient is physically present or if the doctor is merely reviewing a patient's record. If the doctor accidentally tapped on a patient's name, they can simply press the phone's back button to return to the patient summary list.

As shown in Figure 5.3, the summary on the phone heavily mimics the look of the paper summary. It has demographics, problem list, recent ARV medications, recent OI medications, a lab flow sheet with an initial and recent four values (e.g., weight, hemoglobin, CD4, viral load, creatinine, SGPT, VDRL), last two chest X-rays, reminders, and notes. The ordering is determined by AMRS — ODK Clinic just displays what it is given.

Each section in the summary has a header followed by the relevant data elements. Font size, style and spacing are used to help make the summary more legible. The size of all text is much larger than standard Android text sizes and ODK Clinic uses high contrast black text on a white background. Important elements are made bold or italicized and dates are slightly smaller than observational values. If there are multiple instances of an observation (e.g., multiple cases of malaria), those instances are collapsed into one summarizing value. Elements that reveal another screen (e.g., adding a missing ARV medication) have the tappable icon. The icon hints to a doctor that tapping on that element will reveal more (e.g., a list of medications)

AMPATH has found that the medications in a patient's record do not always match the medications the patient has been prescribed or physically has on their person when they present for care. For this reason, recent ARV and OI medications can be corrected in the summary with ODK Clinic. After a correction is made, it is immediately shown in the summary on the phone (but still goes through the data entry validation process).

Demographics	Recent OI Drugs
Aloice Beiywa Mukangu 38BF-4	<i>Add Missing OI Drug</i> ▶
47 Years - 18 Aug 1964	TRIMETHOPRIM AND SULFAMETHOXAZOLE ▶
Male	RIFAMPICIN ISONIAZID PYRAZINAMIDE AND ETHAMBUTOL ▶
14 Feb 2006 - First Visit	
WHO STAGE 3 ADULT	
Missing Adherence Data	
Problem List	
FEVER 11 May 2006 ... 2 more	
HUMAN IMMUNODEFICIENCY VIRUS 02 Mar 2006	
VOMITING 21 Mar 2006	
	Weight (KG)
	52.0 47.0 48.0 ▶ 02 Mar 2006 21 Mar 2006 26 Apr 2006
	Hemoglobin (HGB)
	ORD 9.1 3.9 02 Mar 2006 06 Mar 2006 24 Apr 2006
	CD4
	72.0 (%)

Change Drug

- Rifampicin Isoniazid and Pyrazinamide (○)
- Rifampicin Isoniazid Pyrazinamide and Ethambutol (○)
- Rifampin (○)
- Streptomycin (○)
- Trimethoprim and Sulfamethoxazole (●)
- Tuberculosis Defaulter Regimen by Using Streptomycin (○)

Save Drug Remove Drug

Figure 5.3: ODK Clinic’s summary mirrors the paper summary. It has demographics, problems, medications, lab test and reminders. The summary also allows for corrections of medications. This summary is representative and not from a real patient.

All medications in the application are strongly coded concepts in AMRS instead of free-text. The use of concepts means the corrections can be applied to the record without data entry and interpretation. It is important to note that medication corrections are not a change of a patient’s regimen. Instead, regimen changes, per AMPATH procedure, are recorded on the paper encounter form.

Lab results in ODK Clinic are shown with the earliest value first on the left and progressively later values heading towards the right. If there are more values than the phone can comfortably show in the summary (usually three in portrait mode, and four in landscape mode), the tappable icon is displayed. Tapping on the values then opens up a scrollable vertical list containing all the lab results. ODK Clinic does not graph any results because doctors would then have to be trained on how to read these graphs. Instead, results are displayed as numbers in columns, a choice that helps to control deployment costs.

5.2.3 *Reminder responses and lab orders*

As shown in Figure 5.4, reminders are displayed at the bottom of the summary. If there are no responses to a particular reminder, the reminder is highlighted with a bright orange color. Tapping on a reminder shows a list of potential responses (Ordered Today, Not Applicable, Previously Ordered, Patient Allergic, Patient Refused, I Disagree with Reminder and Other). If a doctor selects ‘Previously Ordered,’ they are given a chance to optionally add a free-text order explanation (e.g., the lab value that appears in the patient chart) and an order date in a structured format. This information is used by the data quality team to correct any incorrect or missing lab results in the patient’s record. If a doctor selects ‘Other,’ they are also given the opportunity to write a free-text explanation. After a response is given, it is immediately shown in the user interface.

In order to enable experimentation, there are two versions of ODK Clinic — enforcement and facilitation. The two differ on what happens when a doctor tries to leave a summary.

In the enforcement version, before a doctor can exit the patient summary, ODK Clinic requires responses to every reminder if the doctor said they were completing a return visit form for the patient (an indication that the patient was present). Doctors are also prompted to write all lab and medication orders, and referrals on the encounter form, in addition to noting it on the lab order form or referral form. This reminder is given because doctors often forget that this is standard operating procedure.

In the facilitation version, the application never requires a response to a reminder. Doctors can ignore reminders, but when they exit, ODK Clinic warns that ignored reminders are monitored by supervisors. In addition, if any reminder response is ‘Ordered Today,’ ODK Clinic asks the doctor if they want to generate the necessary paperwork to satisfy that reminder. The doctor is then present with a lab order section (shown in Figure 5.5) with a list of all lab tests. Like the patient summary section, this lab order section mirrors the paper lab order form. Under each test is an explanation that is identical to the paper lab order form. Each test has a checkbox, and there is an option for ‘Other’ where a doctor can enter an order for an arbitrary test.

Once a doctor is finished and tries to exit, ODK Clinic prompts the doctor for lab tests

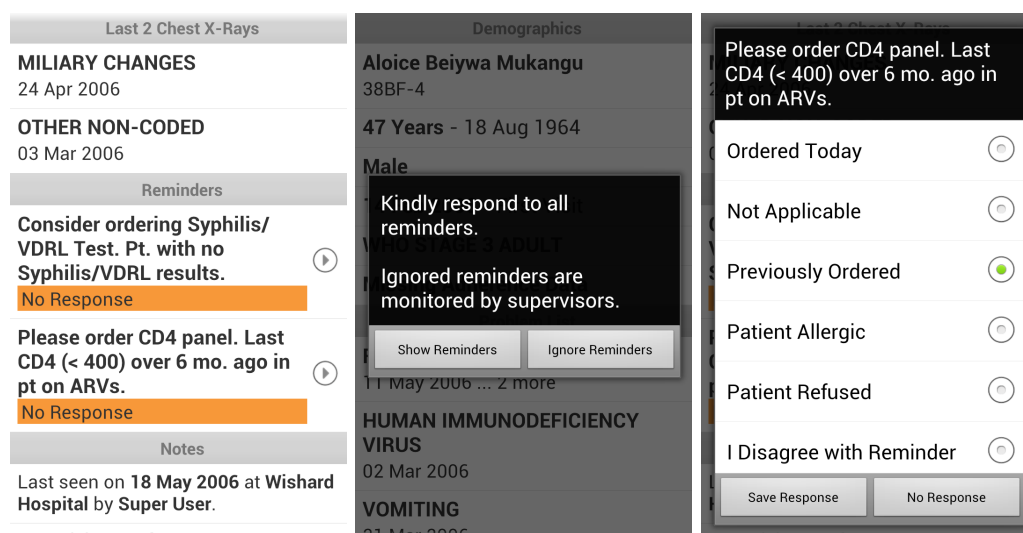


Figure 5.4: Reminders to doctors about deviations in care are shown at the bottom of the summary. If a doctor forgets to respond, ODK Clinic will prompt the doctor and prevent an exit of the application. Reminder response options range from ‘Ordered Today’ to ‘Patient Refused’ and ‘I Disagree with Reminder.’ This summary is representative and not from a real patient.

they might have forgotten. This prompt compares the list of selected lab tests with the reminders to which they answered ‘Ordered Today.’ If the reminder involved a chest X-ray, the doctor is also prompted to manually complete out a chest X-ray form. This prompt was created because the chest X-ray form is separate from the lab order form and requires an entirely different process. Because a doctor may prefer to use a paper lab order form instead of the electronic lab order form, ODK Clinic does not force the doctor to order a lab test even if the matching reminder was marked as ‘Ordered Today.’

If all the tests have been ordered (or the doctor decides they are finished), the lab test form can then be printed. ODK Clinic inserts patient and doctor demographics and lab order data into an electronic version of the lab order form. This electronic form is identical to the paper form. The doctor can pan and zoom to see all parts of the form before printing.

Upon printing, the patient, the doctor or the nurse can fetch the form from a nearby

SGPT

Adult Labs: On ARV, Over 1 Yr Visit

CD4
Yearly if last CD4 >400; Every 6-months if last CD4 <400

FHG
If patient is on AZT, repeat every 6-months; Otherwise only if clinically indicated. If Hgb is available locally, order instead of FHG and be sure to record results on chart

Creatinine
Only if patient is on Tenofovir; repeat every 6-months

Viral Load
Only if suspicion of failing ARV regimen

Adult Labs: On ARV, 6 Month Visit

CD4

FHG
May replace with HGB done locally

You may have forgotten to select: CD4, VDRL.

Print lab order forms before leaving summary?

Print Forms **Edit Forms** **Leave Summary**

SGPT

Adult Labs: On ARV, Over 1 Yr Visit

CD4

Figure 5.5: ODK Clinic can print a pre-filled lab order form to a nearby wireless printer. The form can be viewed by doctors before it is printed. The application also prompts doctors who may have forgotten to order a lab test.

wireless printer. The form is signed by the doctor, and given to the patient to take to the laboratory. While AMPATH has an electronic lab ordering system, it does not easily enable electronic transmission of the lab order. Regardless, ODK Clinic’s lab order printing does save doctors the time required to fill in all the required patient demographics when ordering.

After printing (or leaving the summary), ODK returns to the list of summaries. The patient whose summary was recently viewed is highlighted in green. This highlighting also serves as a visual cue for when a doctor has successfully sent this patient’s data back to AMRS — the green is removed only when the data is saved in AMRS.

5.3 Architecture of mobile summaries

ODK Clinic is an Android application and uses many of the recommended design patterns of that platform [2]. A description of how ODK Clinic is designed follows. Where relevant, a description of where and why the design differs from other Android applications is included.

5.3.1 *Activities*

In Android, each screen the user sees is an Activity. For example, the list of summaries is a single Activity, while a single patient summary is another Activity. The user interface for each of these Activities is composed using a MergeAdapter [4] that strings together a series of Views into a list. Views are the basic building blocks for user interface elements. The use of the MergeAdapter is needed because Android does not provide a simple mechanism for combining very different Views together into a list.

Users navigate in ODK Clinic Activities by scrolling vertically and tapping on the Views that are visible. For example, tapping on a patient's name (a single View) in the summary list Activity will launch that patient's summary — another Activity with a series of Views in a list. In the patient summary Activity, there is a View for each data element (e.g., each individual medication).

To switch between Activities, ODK Clinic uses Intents, a lightweight Android mechanism. Where appropriate, an Activity can pass data along with the Intent, or launch an entirely new application and wait for a response (e.g., for barcode scanning with Barcode Scanner [8]).

5.3.2 *Dialogs*

Activities in ODK Clinic encode much of AMPATH's procedures as blocking Dialogs to ensure doctors deliver standard care. Dialogs can vary in complexity. For example, if a user is exiting a patient summary without responding to all reminders, the Activity checks the patient's record to ensure that all reminders have been addressed. If not, the Activity shows a Dialog and prevents exit. A more complex Dialog that is used to respond to reminders includes a text box and a date picker.

All Dialogs in ODK Clinic display text that is never truncated and use a much larger font than Android's default. The large font is important because doctors sometimes have uncorrected vision and have difficulty with navigation. All Dialog content and ListView positions are persisted to memory to ensure users do not lose content or position on screen rotation (an action in Android that terminates the application). Android does not pro-

vide these mechanisms reliably across all versions of the operating system so ODK Clinic implements its own to ensure a good user experience.

5.3.3 Tasks

For any long-lived action that must run in an Activity, ODK Clinic uses Android's AsyncTasks and TaskListeners. When the Task is launched, it runs on a background thread, and posts updates to the Activity through a listener that the Activity implements. For example, when a user initiates a refresh of the summaries on the phone, that refresh starts a Task to first connect to AMRS and upload corrections, reminder responses and usage data. If that Task is successful, another Task is started to get the list of new summaries, and on completion, another Task downloads, parses and insert those summaries into an on-phone database.

5.3.4 Network

All network activity in ODK Clinic uses a multi-threaded connection manager over secure HTTPS, and each connection authenticates against AMRS. For example, when downloading a set of summaries, ODK Clinic spawns a thread for each summary download, but with thread pools and connection pools, to ensure only 29 threads and 29 TCP/IP connections are active at any time. This parallel technique ensures that summaries are downloaded as quickly as possible without overwhelming the phone or the server. As each summary is downloaded, it is parsed and stored in the phone's database by the downloading thread.

Each thread maintains an error stack that can be returned to the user. If any thread fails, the entire download or upload operation is rolled back. While Android has automatic garbage collection, ODK Clinic actively nullifies memory after each thread exits to ensure garbage collection does not happen at inopportune times (e.g., scrolling through a summary list) where it would cause user interface stuttering.

5.3.5 Databases

AMPATH's experience with smartphones suggests that user-accessible memory (e.g., an SD card) is at risk for theft. For this reason, ODK Clinic stores all patient data in the phone's internal memory (approximately 190 MB).

ODK Clinic uses the SQLite database functionality that the Android operating system provides to store data. Android does not provide ready mechanisms to encrypt data stored in its databases, and so encryption could not be implemented in the time allotted for development of the application. Android does provide some security for databases stored in internal memory and so patient data is not readable without 'rooting,' an unlikely attack vector in the environments where ODK Clinic will be used.

Patient data is stored in an observations table in ODK Clinic's database. An observation is a data element (e.g. Gender=Male) about a patient. Each row in the observation table stores the patient identifier, the concept (e.g., medication), the status (e.g., added, removed), the value (as text, date or number). In the case of an observation like a medication, the value is the medication name while the date is the date that it was prescribed. Reminders are treated as just another observation. Rows can be retrieved and formed into a corresponding Java object that can be passed to the relevant Activity. The entity, attribute, value structure that can be transformed into a Java object is identical to how AMRS stores data and has similar trade offs — while it is very flexible for storing many types of observations, it can also grow quite large in size and slow queries.

To display the data, ODK Clinic queries the database and passes all data through an ArrayAdapter. The Adapter examines the data from the query to determine what type of View to display (e.g., demographics, medications, reminders). For example, if the data is a medication, the application displays a View that is tappable to enable users to change each medication. Upon tapping the View, the appropriate Dialog is opened. As the underlying data changes (e.g., a user changes the response to the reminder), the Activity refreshes the Adapter to update the data. The Adapter also efficiently recycles Views that are displayed to ensure smooth scrolling on long lists of Views (e.g., a list of patients).

5.3.6 *Printing*

In ODK Clinic, printing is achieved through another Activity. The Activity shows a list of available lab tests, using the MergeAdapter and a series of custom Views. If a user chooses to print, a PDF creation Task is launched. The Task uses the iTextPDF [5] library to pass user selections and patient data into a fillable PDF template that is stored on the phone. The completed form is temporarily written to the phone's SD card and passed to PrinterShare [7] via an Intent. PrinterShare is a standalone application that sends that file wirelessly to any printer. The application sends the form to a nearby computer with a printer attached.

5.3.7 *Logging*

ODK Clinic monitors user actions that can be used to monitor usage of summaries. In particular, the application tracks barcode scanning, lab order printing, daily refreshes, patient searches, device timeouts, and lengths of summary viewing. Each event is time stamped and includes some relevant metadata. For example, for patient searches, ODK Clinic stores what the text of the query was, whereas for daily refreshes, the application stores how many summaries were downloaded and the duration of the download. Like observational data, logging data is stored in a SQLite database in the smartphone's internal memory and transferred over secure HTTPS to the server.

5.3.8 *Security*

For security, ODK Clinic maintains an Application singleton to store global state. The Application creates a thread that counts down from a configurable amount of time. When time runs out, ODK Clinic broadcasts an Intent to lock all Activities that show patient data. If a locked Activity is loaded, it will immediately close and require the user to enter a PIN to unlock. In each Activity, taps are forwarded to the Application to reset the counter that triggers the locking event. Each Activity also listens for any locking events from the user (e.g., if a user presses the power button to turn off the screen), and forces a lock at that moment. The application also enables ODK Clinic to lock even if it has been 'moved

to the background' by the operating system.

At AMPATH, computers and other devices are generally taken for their hardware value, and not for patient data. Moreover, with summary data already distributed with little oversight across a large geographic area, a phone with a subset of patient data stored in internal memory, protected with PINs and timeouts, and stored nightly in a secure location, is more privacy-preserving than current practice. To further reduce risk, future versions of ODK Clinic will encrypt all patient data stored on the phone.

This chapter described the design and implementation of ODK Clinic. I focused on many of the user interface choices made in the application, and in the next chapter, I report on the usability testing of ODK Clinic with six doctors at AMPATH.

Chapter 6

USABILITY TESTING

In this chapter, I describe the usability testing for ODK Clinic. The testing outlines findings that are important for implementers of mobile systems for healthcare providers in resource-limited settings. Specifically, I show that AMPATH doctors want to use phones for summaries, as well as throughout their clinical practice. Doctors in these tests were more concerned about holistic improvements in workflow than in decreasing time spent per patient. As expected, phone size and previous experience with smartphones affected how easily usability tests were for the participants, but overall, ODK Clinic was considered easy to use. The only expressed concerns from the doctors centered on the logistics of ODK Clinic's upcoming deployment.

This chapter is laid out as follows. Section 6.1 describes the methods used to perform the testing. Section 6.2 details the results and Section 6.3 discusses limitations of the findings.

6.1 Methods

Supervisors from two clinics where deployments of ODK Clinic were planned selected a convenience sample of six doctors (five doctors from one clinic, one from the other). The sample had two women and four men. The doctors chosen had three to four years of undergraduate education and an internship year of practical medical training and were between 30 - 40 years of age. Doctors at AMPATH earn approximately \$6,000 annually and are in the lower end of Kenya's middle class income range. Two of the doctors owned Android phones while the rest had basic phones.

Touchscreen smartphones with no physical keyboards were used for the testing. The phones ran Android OS 2.2 and were sourced in the United States. Two of the usability tests were performed on a Huawei U1850 IDEOS (528 MHz ARM 11 processor, 2.8" TFT screen) while the other tests were performed on an HTC Nexus One (1 GHz Scorpion

processor, 3.7" AMOLED screen).

Each test was designed to emulate a real patient interaction. The test began with a training session on the phone and a demonstration of ODK Clinic. There was then a guided walk-through of the functionality, a series of tasks for the doctor to complete, and a semi-structured interview. As the trials were held in consultation rooms between patient visits, the doctors could and did respond to interruptions from nurses and other doctors. Each doctor was evaluated separately. No direct comparisons with paper summaries were conducted.

Tests were approximately 30 minutes long. All doctors were asked to verbalize their actions during the entire test. Five of six doctors consented to have an audio recording of the interaction. Usability problems were noted as they occurred and doctors were prompted if they had difficulty proceeding through the sequence of tasks.

Each doctor was asked to unlock the phone, download new summaries, find a patient in the middle of a list of summaries, view a single summary, remove incorrect medications, add missing medications, view lab results, respond to reminders, search for a patient on the phone, search for a patient on AMRS, scan a barcoded ID card, and send medication corrections and reminder responses back to AMRS. The tasks emulated actions that each doctor would likely perform during patient visits. Rather than require the doctors to remember the entire sequence, they were reminded of each next step. The doctors were also asked to describe features they liked or disliked in ODK Clinic.

At the end of all the usability tests, all doctors (not just those who completed the usability testing) from the two clinics were invited to a group meeting to discuss a proposed deployment of ODK Clinic. The doctors were encouraged to voice their concerns about the application and the deployment. This session was recorded.

6.2 Results

All doctors who participated in the usability testing were able to complete the tasks with minimal prompting. Previous experience with smartphones and touchscreen size affected how quickly the tasks were completed. The doctors self-reported that they preferred using ODK Clinic to the current paper-based system. They also felt that the mobile system was

faster and easier to use than current practice.

Doctors wanted to be responsible for summary retrieval and patient data entry. They expected ODK Clinic to have only negligible effects on time spent with patients, and they wanted to use the phone throughout their practice. The primary concerns of the doctors were related to how the phones would be stored and distributed. Finally, doctors were concerned with the liability and security issues of patient data on expensive phones.

Given the small number of participants and uncontrolled setting, these results should be viewed as qualitative insights into how doctors perceived ODK Clinic and the proposed intervention. These insights are detailed next.

6.2.1 Doctors want to use phones for summaries

The doctors were particularly interested in being able to retrieve summaries without involving the nurses. They considered using nurses for summary printing a misuse of human resources. Additionally, despite backup computers in the clinic and extra training of staff, the doctors confirmed regular occurrences where the paper-based system had failed and they could not get summaries. They preferred ODK Clinic because it provided a more reliable and self-directed method of getting summaries.

“You can easily access data when in the room versus printing summaries. We have many people for that process; here I can do it on my own.”

This was a surprising result. Previous work with paper summaries suggested that doctors would not want to add more tasks (e.g., printing summaries) to their workload, but in these tests, the doctors wanted to try any technology that would potentially increase the quality of care. This was especially true if the technology was more reliable or easier to use than current practice.

“Whoever thought of this idea was thinking about us. This is a brilliant idea, which is going to go a long way in helping us deliver the best service to our clients.”

6.2.2 Importance of holistic improvements in workflow

Reducing time spent per patient was not considered by the doctors as important when compared to more holistic improvements to workflow. For example, one doctor liked ODK Clinic because he could find patient data without having to walk all over the clinic looking for paper records.

Doctors also expressed a desire to ensure that data they entered (e.g., medication corrections, reminder responses) reached AMRS quickly and accurately. The certainty of knowing data would go immediately and directly to the patient record without a potential data clerk error, was appealing and considered time saving.

When asked if using touchscreen phones with summaries would slow patient care, the doctors reported that although the first experiences with the phone would be slow, they would grow more adept at using ODK Clinic. Those who had recently learned how to use a smartphone or computer recalled their experiences struggling for a few days and then mastering the technology.

6.2.3 Desire to use phone throughout clinical practice

Many of the doctors requested more functionality than was currently available on the phone. One doctor asked if the phone could send images of X-rays to his supervisor for review. Another wanted to install an obstetric application to aid in estimating birth dates. A third wanted a calendaring application to schedule patients. Overall, the doctors were interested in replacing many of the paper-based systems at AMPATH with phones.

“Get rid of paper. This is what is actually eating us up. We are filling too many papers.”

To further explore the potential of a purely electronic patient interaction, the doctors in the group session were given the opportunity to complete a phone-based encounter form with ODK Collect’s single prompt per screen mode. The large number of elements in the form resulted in a slow form filling process that these doctors did not like. Based on these

observations, for long encounter forms, ODK Collect's multiple prompts per screen mode on a tablet-sized device might be preferable.

6.2.4 Limitations on replacing all paper

Regardless of the capabilities of the software and hardware or desires of doctors, it is important to note that as part of care, AMPATH doctors must always use a paper encounter form to document patient visits. AMPATH would like to maintain this existing practice so ODK Clinic does not implement any functionality (e.g., recording a patient's current blood pressure) that also exists on the encounter form. Moreover, AMPATH expects to use ODK Clinic exclusively for summaries and to continue using paper forms for documenting encounters. This is despite the availability of form filling in applications like ODK Collect.

Much of this decision is driven by the realities of care delivery in AMPATH hospitals. Encounter forms are at the heart of every patient encounter and changing this in-grained and well-understood mechanism, even for a pilot, is logistically impractical. Rather than consider this a limitation, AMPATH views replacing paper summaries with ODK Clinic as the first step in understanding how to replace the paper encounter forms with tools like ODK Collect. Two alternative approaches to improving paper encounter forms are Usher, a system for automatically improving data entry quality based on prior data, and Shreddr, a hosted paper form digitization service [23].

6.2.5 Phone size and previous experience matters

Two of the six doctors tested owned IDEOS Android phones. These two doctors were able to use ODK Clinic with very little training or prompting. Users not familiar with Android struggled with the responsiveness of the IDEOS touchscreen (especially the soft keys). Scrolling was difficult and the visual clarity and size of user interface elements on the small screen was a self-reported problem. Doctors who owned the IDEOS reported that while it was adequate, the larger form factor and higher quality touchscreen of the Nexus One made it much easier to browse summaries. The processing speed of the devices did not seem to affect task completion speed.

“The technique, the buttons, the hands. It’s a little tricky to start with, but it’s an issue of practice.”

Informal tests with an HTC HD2 (1 GHz Scorpion processor, 4.3” TFT screen) suggests that while some doctors would use this much larger phone, most preferred the Nexus One because the form factor worked better (e.g., easily stored in a pocket) as a personal phone. With the wide availability of the IDEOS, there was also an expressed interest in using a more “exclusive” phone. Given the impact on usability (and thus training and adoption), AMPATH has decided to deploy devices that can comfortably fit in a doctor’s lab coat (3.7” to 4.3” screen).

Future deployments will likely target tablet-sized devices because their larger surface area could be used to support richer functionality (e.g., to replace an encounter form) than is currently available on smartphones. Tablets were initially not considered because AMPATH wanted to try devices that were smaller, had ready connectivity to cellular networks, and were more locally available. As tablet use grows in popularity worldwide, the latter two concerns will likely become less important.

6.2.6 User interface considered easy to use

The doctors considered the user interface of ODK Clinic easy to use and understand. Moreover, the doctors were able to use the application with about 30 minutes of training. The user interface of the application was heavily influenced by early prototypes of mobile applications that I had iteratively designed at AMPATH [6], as well as my previous work using mobile devices in low-income settings.

That earlier work showed that the usability of touchscreens was impaired because users had calloused (and thus non-conductive) fingers and uncorrected vision. To counter these expected challenges, ODK Clinic uses minimal, large, high contrast user interface widgets. Important functions are always visible on the screen and are easy to tap. All tappable items have an icon that suggests that they are actionable. User input is channeled through two easily trainable interactions — i.e. scroll and touch. There is no use of pinch, swipe, or long press. Finally, ODK Clinic minimizes keyboard input when possible.

To ease training, ODK Clinic mirrors much of the existing paper summary's layout and content. For example, because doctors are trained to read lab values in columns, the application does not graph these values. Moreover, while ODK Clinic can display every value in AMRS, it only shows the same amount of data as on the paper summary. As the doctors grow familiar with the phone-based system, they will likely demand more data than the paper summary shows.

6.2.7 On-screen help and undo not used

AMPATH doctors are often interrupted (usually by other doctors asking questions) while seeing patients, so all error messages in ODK Clinic are blocking — the application will require some user input before it will proceed. No doctor disliked this method of displaying error messages.

To prevent these error messages from blocking a more fluid user interaction (and to make training of doctors more scalable), the usability tests tried using context-sensitive and transient help screens that would appear for a few seconds and then fade away. For example, AMRS requires three or more letters before searching for patient names or IDs, so in ODK Clinic, this requirement was displayed as the doctor typed the first two letters. The help information was then hidden when the third letter was entered. During the usability tests, it was clear that these help screens were ignored. This functionality was thus removed from the final version to further minimize the user interface.

All doctors struggled with the undo functionality (e.g., if a drug had been corrected accidentally, ODK Clinic offered a two-click undo) that had been included in these tests. The doctors also struggled with the user interface for correcting medications with unknown start dates. As both features were not necessary, they were removed after the tests.

6.2.8 Concerns center on logistics of deployment

In the group session, the doctors' concerns centered on the logistics of how phones would be deployed. Because phones would likely be assigned to (but not owned by) an individual, the doctors were interested as to how phones might be stored and retrieved easily, but securely.

The doctors also expressed interest in using the phones as personal devices in order to simplify deployment, get familiar with Android, review patient records when at home, and to avoid carrying two phones. They were also concerned with the financial and legal implications of losing an expensive phone with patient data.

“I like everything but the security of the phone.”

Phones alone cannot solve every problem with summaries. As the doctors’ concerns hint at, effective logistics play an equally important role. To secure against data loss, doctors must synchronize their phones with AMRS at the end of every workday. If a phone is misplaced, broken or stolen, spares should be available on site. In the rare instance when a spare phone is not available, patient charts are still adequate for care. Security of the data stored in ODK Clinic is also important. As such, user authentication, secure data transmission protocols and automatic time-outs are all used in the application.

6.3 Discussion

The usability tests at AMPATH found that doctors wanted to use phones for summaries. Doctors were more concerned about holistic improvements in workflow and as expected, phone size and previous smartphone experience affected how easily the usability tasks were completed. Overall, ODK Clinic was considered easy to use and the only expressed concerns from doctors centered on the logistics of ODK Clinic’s deployment.

The uncontrolled setting, small sample size, short evaluation period, and lack of usage in actual clinical practice limit these results. Additionally, the use of self-report and surveys can be unreliable due to a tendency for participants to wish to please the researchers [13, 27].

I address these limitations by conducting a longer-term deployment at two adult HIV clinics at AMPATH. I describe the findings from that deployment in the next chapter.

Chapter 7

DEPLOYMENT FINDINGS

In this chapter, I analyze the data from a 90-day deployment of ODK Clinic at two adult HIV clinics at AMPATH. Building on over 13,000 patient encounters, I provide evidence of ODK Clinic's impact on the availability, correction and supervision of clinical decision support. This chapter highlights findings that demonstrate the power of ODK Clinic's monitoring capabilities. While much of this data could be gathered by hiring and training staff, functionality that automatically gathers this data reliably and in real-time is particularly interesting to AMPATH.

Section 7.1 provides an overview of the deployment, while the rest of the chapter presents results that include evidence that ODK Clinic improves the availability of summaries, enables better reporting of usage and problems, and perturbs clinical workflow in unexpected ways.

7.1 Methods

The deployment was conducted at two adult HIV clinics at AMPATH in Eldoret, Kenya. Both clinics offer the same services in the same building, with 90% of the patient visits handled by nurses and clinical officers (equivalent to physician assistants) without the presence of a supervising physician. Enrollment at the clinics is based largely on the order of presentation, and there is very little patient crossover between clinics. There are no other meaningful differences between the clinics.

The clinics were selected because they have network access to the central AMRS server where electronic patient data is stored. The intervention targeted doctors caring for adult patients presenting for return visits. All patients, per AMPATH procedures, should have a patient summary available, and most summaries have reminders. All doctors in the study clinics were included in the intervention.

The study period is from September 18th, 2011 to December 18th, 2011 (91 days), approximately two weeks after doctors from two adult HIV clinics started use of ODK Clinic. The two-week period gave doctors a chance to grow comfortable with the tool. The analyses only use data that arrived in AMRS during the study period and ignores any data that was not time stamped on the device in that period.

In the study data, there are 20 users of the system. Of those, the analyses exclude eight users who had less than 500 logged events (e.g., scanning a barcode, opening a summary, changing a medication, etc.). The excluded users are either decision support staff testing the system, medical specialists who only see a handful of patients each week, doctors who started using the system and went on leave, or doctors who returned from leave near the end of the study period. Unless otherwise noted, the analyses only consider data where the doctor claims to be completing a return visit form. While it would be important to verify if a return visit form was truly completed, the study scope did not allow for it.

7.2 *Availability is better*

The results from the case study described earlier showed that across all clinics at AMPATH, 80.44% of patient visits had summaries. This rate was measured one year before ODK Clinic was deployed and updated availability numbers were needed. As the two clinics where ODK Clinic was introduced were relatively well-run and supervised, availability of summaries on paper were expected to be higher than the previously established average availability rate. ODK Clinic was expected to further increase the availability rate at these two clinics, but the data shows that availability is only slightly better.

7.2.1 Methods

Availability of summaries is defined as the ratio of the number of marked summaries to the number of patients who present. A patient is considered to be presenting if they are 'checked in' by a staffer located at the entrance of the clinic. For summaries on paper, a summary is viewed if there is a mark from a doctor when it is collected by clinical summary staffers. For summaries on phone, a summary is viewed if it is opened in ODK Clinic.

Device used	Paper	Phone
Study period	Jul 01 to Aug 31	Sep 18 to Dec 18
Patients present	9,802	13,518
Viewed summaries	8,877	12,381
% visits w/ viewed summaries	90.6%	91.6%

Table 7.1: Percentage of visits with viewed summaries at two AMPATH clinics. Before ODK Clinic, the percentage of visits with viewed summaries was 90.6%. After ODK Clinic was introduced, the percentage was 91.6%. The results suggest that at well-run clinics, availability of summaries stays the same.

The data only includes distinct summary openings (doctor, patient, week tuples) in the period. The analysis reports on the ratio of these aggregate numbers and not, for example, the percentage of patients who had encounter forms completed and also had summaries with marks. While the latter would be more a rigorous definition of availability, it is very difficult to measure.

7.2.2 Results

From July 01, 2011 to Aug 31, 2011, 9,802 patients presented at the two clinics. 8,877 printed and marked summaries were collected. The percentage of visits where the summary was marked (and thus viewed) 90.56%.

From September 18, 2011 to December 18, 2011, after the switch to ODK Clinic, availability of summaries was measured. During this period, 13,518 patients presented. The usage data of ODK Clinic shows that 12,381 distinct summary openings (doctor, patient, week tuples) occurred in that period. The percentage of visits with summaries opened (and thus viewed) was 91.58%.

7.2.3 Discussion

The results show that at well-run clinics, ODK Clinic performs better than current practice. It is likely that ODK Clinic would perform even better than baseline at more remote or less supervised clinics where availability tends to be worse due to reasons outlined in Section 3.3. This claim needs to be tested by another deployment at a poorly performing clinic.

7.3 Phone enables better reporting of usage

Usage is a metric that AMPATH supervisors must measure because a patient visit without the help of summaries indicates that potentially sub-standard care was given. In the paper-based system, usage was measured by marks written on the summary by doctors. ODK Clinic enables the more automated and fine-grained reporting (e.g., what times were summaries opened) that supervisors requested.

7.3.1 Methods

These analyses explore when summaries are opened while doctors said they were completing a return visit form. The analysis includes multiple summary openings for the same doctor and patient tuple, and discards the few openings on weekends and late evenings.

7.3.2 Results

In Figure 7.1, frequency of summary openings is shown on the Y-axis, while day and time are placed on the X-axis. As shown, Tuesdays have the most openings with 2,876 and Fridays have the fewest with 209 openings. Mornings (9-10h) have many more openings than early to late afternoons, with only 13 openings happening after 17h.

7.3.3 Discussion

The low numbers on Fridays are a result of where ODK Clinic is used. At the primary AMPATH location in Eldoret, doctors visit more remote sites on Fridays and thus do not see or schedule patients in Eldoret. For that reason, doctors do not open summaries on Fridays, and when they do, it is likely for an unscheduled patient.

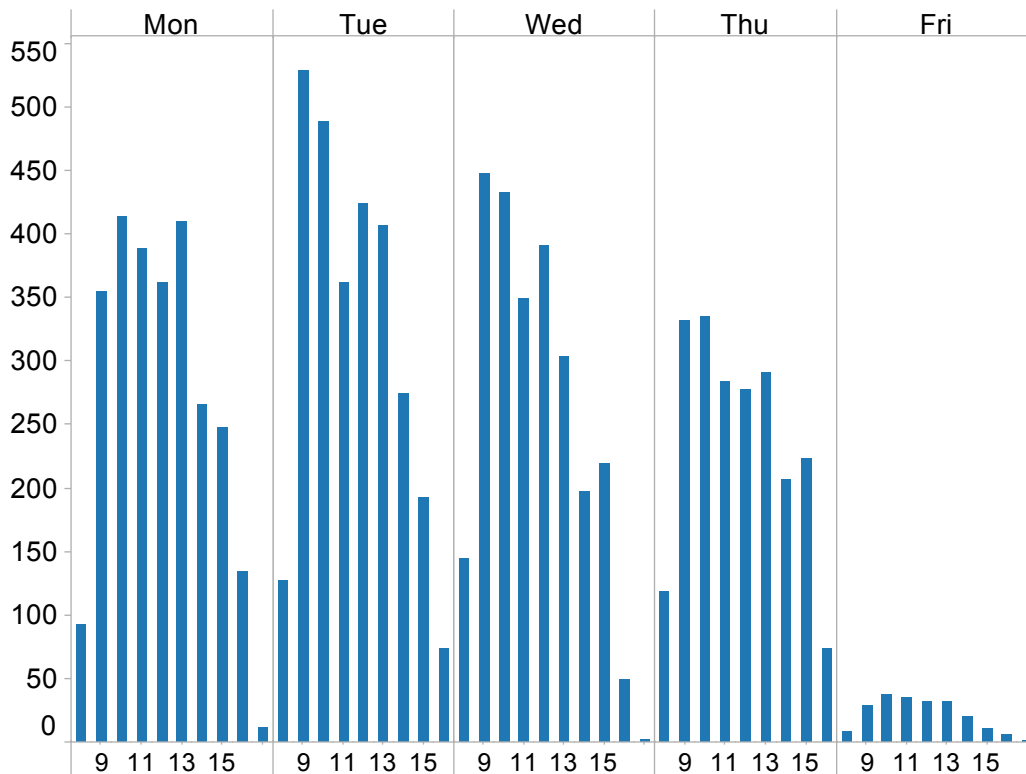


Figure 7.1: Frequency of summary openings grouped by day and time. Frequency is shown on the Y-axis, while day and time are placed on the X-axis. The majority of summary openings occur in the mornings. Fridays see a large drop in summary openings because patient visits are not scheduled on that day.

It is useful to understand when summaries are opened. For example, instead of the two to three week range that ODK Clinic currently uses, the range could be increased to four to five weeks on Friday mornings when even more unscheduled patients are expected. This functionality will be more critical as AMPATH scales to remote sites with even more unreliable connections to AMRS.

Of course, the tradeoff between the larger cohort size and the time required for downloading the patient summaries will have to be explored. A likely better alternative to increasing the range is a redesign of the download protocol such that throughout the week, the device continuously expands the number of summaries on the phone when there is network

connectivity.

Overall, opening of a patient summary provides insights that AMPATH can plan around. Summary openings when a doctor claims to be completing a return visit form are a good indicator of when patients are present in clinics. Administrators can use this information to ensure that all health providers (including nurses and pharmacists) are present and working during those times.

7.4 Barcode scanning is rarely used

Barcode scanning was expected to be an important feature for ODK Clinic. AMPATH patients are identified using full names and long patient ID numbers, and mistakes are often made when handwriting this data on paper forms. It was thought that ODK Clinic might magnify this problem of patient identification mistakes due to the difficulties of entering text on a QWERTY keyboard on a small screen. To help manage this problem, ODK Clinic uses a barcode scanning application on the phone to scan barcoded ID cards that patients carry. Instead of browsing through a long list of summaries on the phone or typing a long name or identifier to filter the list, doctors could instead scan a patient's barcoded ID card. The potential to quickly identify patients in this manner excited doctors and supervisors, but the data shows that doctors rarely used barcode scanning during clinical visits.

7.4.1 Methods

The analysis only considers summary openings where a doctor is completing a return visit form. This analysis also only considers barcode scans where a text or number has been returned to ODK Clinic by the barcode scanner.

7.4.2 Results

Figure 7.2 explores the ratio of successful barcode scans to summary openings across all doctors over time. On the Y-axis is the ratio of barcode scans to summary openings expressed in percentages. The X-axis of the graph shows each day in the study period. As shown in the figure, the percentage stays around 3% in late September and peaks at 6.36%

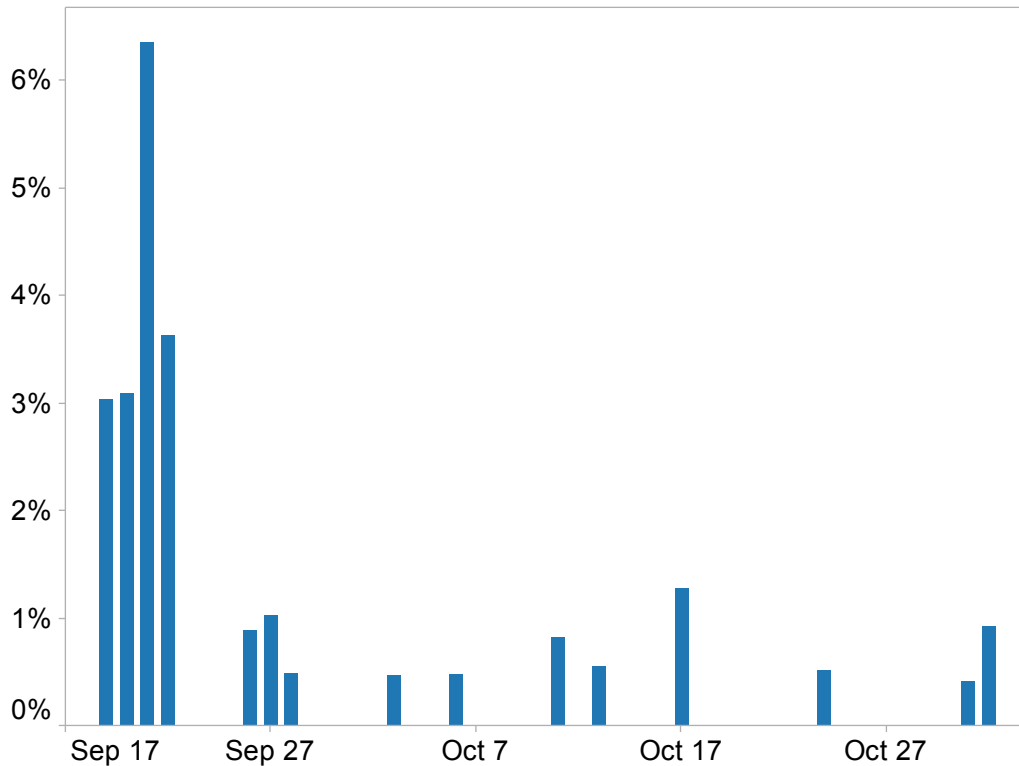


Figure 7.2: Ratio of barcode scans to summary openings over time. On the Y-axis is the ratio of barcode scans to summary openings expressed in percentages. The X-axis of the graph shows each day in the study period. The data shows that doctors do not use barcode scanning to find patient summaries. They instead manually enter a name, ID, or scroll through the alphabetical list of summaries on the phone.

(11 scans per 173 openings) on September 21st. There is occasional use until November 1st, when barcode scanning stops entirely. Clearly, the data shows that barcode scanning was not a highly used feature in this deployment. In fact, across the study period, only one doctor (out of 12) had a percentage above 2%.

7.4.3 Discussion

The lack of barcode scanning demonstrates how pressed for time the doctors are. The barcoded patient ID cards are valued by patients, and so they store the cards in a secure location on their person. When the patient is called by the doctor into the consultation room, the patient sometimes has to remove a layer or two of clothing to find the card. The doctor then has to position and scan the barcode (potentially multiple times) to get the identification number.

Doctors instead prefer to enter the patient's name or identifier from the patient's chart into the phone as they call the patient to enter the consultation room. ODK Clinic allows for live filtering, so after entering two or three letters into the phone, the patient can be identified from the now smaller list of patients. Even with mistakes, this process is faster than barcode scanning, and is thus preferred. For AMPATH, this finding could have significant cost savings. They may not need to purchase Android devices with cameras (or high quality cameras).

7.5 Viewing patterns vary across doctors

As ODK Clinic enables more fine-grained reporting, AMPATH supervisors also wanted to measure how much time doctors spent with the summaries open. The length of summary viewing correlates with the value a doctor associates with the summary. That is, a doctor will not use the summary for a long period if it provides no value. The data shows that viewing patterns varied widely across doctors.

7.5.1 Methods

A summary viewing is defined as a patient, doctor, and day tuple where the summary is opened and then closed either by exiting or by printing a lab order. If there are multiple opening and closings for a tuple, the analysis counts the total time the summary is open. If ODK Clinic exited the summary due to a timeout, that summary viewing is discarded in the analysis. The analysis also discards summary viewing times greater than 40 minutes — these were caused by a known software bug that affected the last patient seen by a doctor

each day.

7.5.2 Results

In Figure 7.3, the X-axis has one-minute bins of summary viewing times while the Y-axis has the frequency of those times. Summary viewing time spikes for fewer than one-minute viewings (1,038 viewings), then again spikes in the three to six minute viewing (2,059 viewings) range.

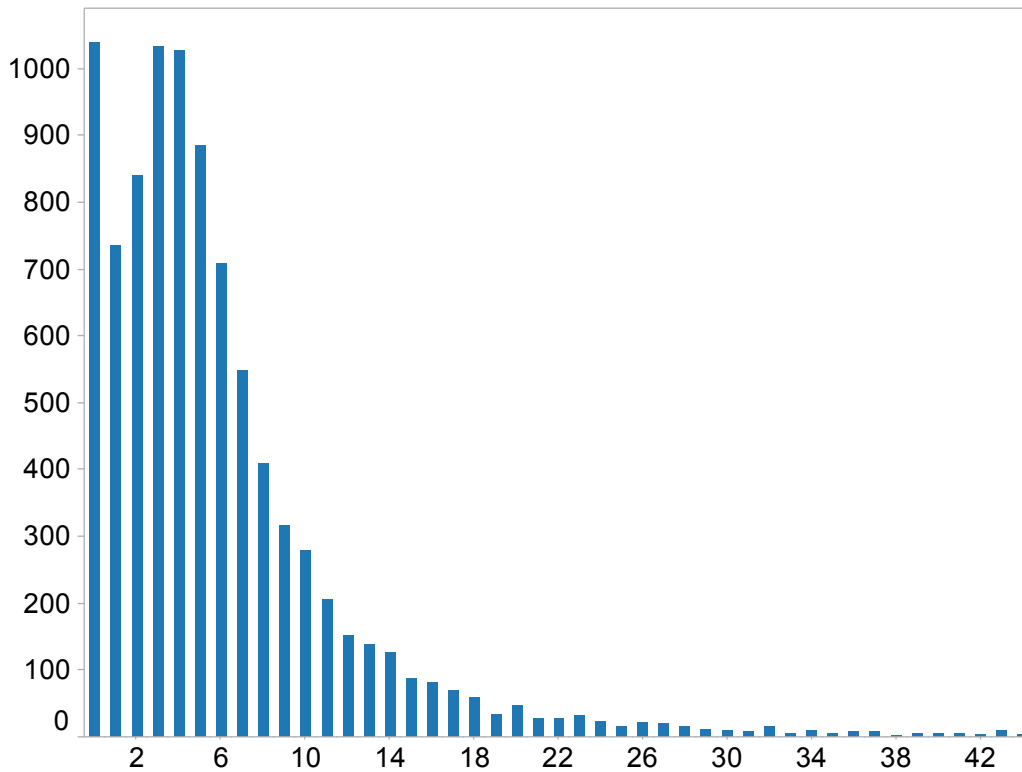


Figure 7.3: Frequency of length of time spent viewing summaries. The X-axis has one-minute bins of length of time, while the Y-axis has the frequency of those lengths. Summary viewing time spikes for fewer than one-minute viewings, then again spikes in the three to six minute viewing range. Short summary openings are driven by individual doctors.

The sub-minute viewings are driven by a handful of doctors. For example, Figure 7.4

shows two doctors with divergent viewing patterns. The figure has the doctors and frequency of summary viewings on the Y-axis. The X-axis has one-minute bins of summary viewing times. As shown, Doctor G tends to open summaries for a very short period, while Doctor A generally keeps summaries open for three to six minutes.

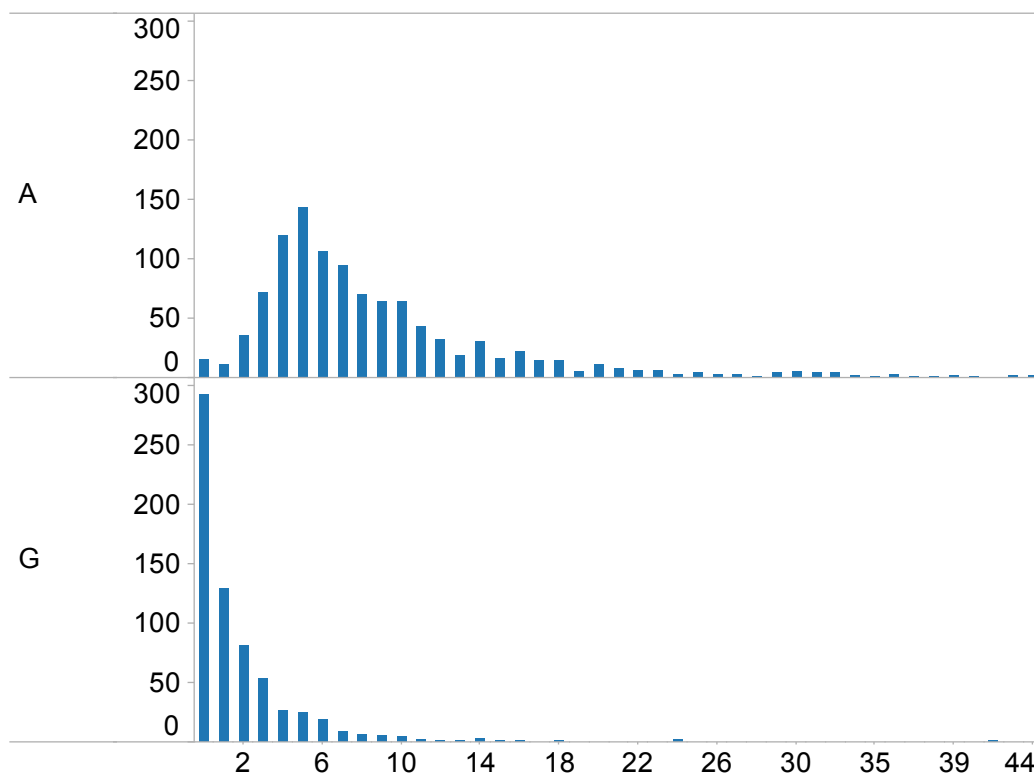


Figure 7.4: Distribution of summary viewing times of two doctors. Doctors and frequency of summary viewings are on the Y-axis. The X-axis has one-minute bins of summary viewing times. Doctor G's patterns require a supervisory follow up because they suggest surprisingly short patient visits.

Across the user population, summary viewing time distributions vary. Figure 7.5 shows the first, second, and third quartiles for summary viewing times. The number of minutes for each viewing is on the Y-axis, while the doctors are placed on the X-axis. The first quartile range is shown at the top (in dark green), and the third quartile range is shown in the bottom (in light green). The median (second quartile) is shown between the first and

third quartiles. The figure hides summary viewing times greater than 15 minutes, but those viewing times are included in the analysis. Across the population, the median summary viewing times is 4.87 minutes (Q1 is 2.6 min, Q3 is 7.13 min).

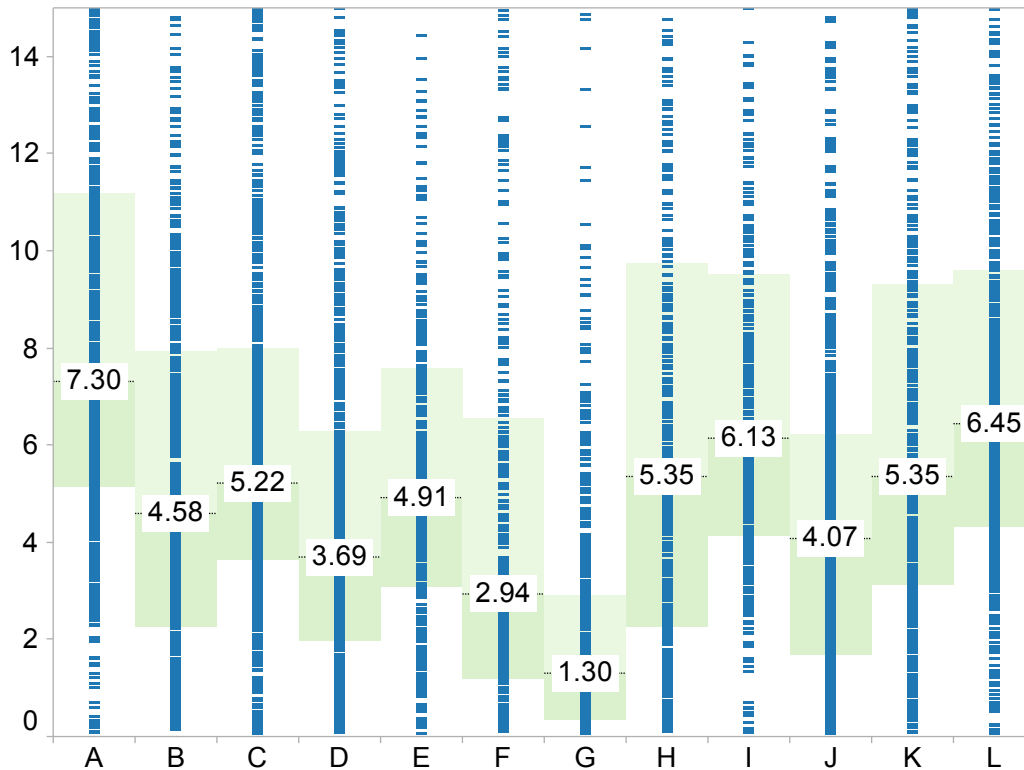


Figure 7.5: Distribution of summary viewing times grouped by doctor. Each dash is a summary opening. The number of minutes for each viewing is on the Y-axis, while the doctors are placed on the X-axis. The first quartile range is shown at the top (in dark green), and the third quartile range is shown at the bottom (in light green). The median (second quartile) is shown between the first and third quartiles.

7.5.3 Discussion

The data shows that doctors spend some time with summaries open, presumably looking through the information it provides. Moreover, the clustering of summary viewing times

suggests that this behavior is consistent across the population in this deployment.

The number of viewings under one minute for some doctors is problematic. In the case of Doctor G, much of it can be explained by that doctor's desire to review and correct patient records while not actively seeing patients. For the other doctors, a closer analysis shows evidence of accidental openings of summaries. There is also evidence of doctors reporting that they are completing a return visit form when they are not. This behavior should be accounted for in any conclusions one draws from this data.

Limitations aside, this data might help approximate patient visit length. A time motion study of paper clinical summaries at an adult HIV clinic in Uganda found doctors spent 6.4 minutes with patients [89]. This result is close to the median viewing length of 4.87 minutes in this data.

In a time motion study, an observer is tasked with measuring the length of every patient's visit by direct observation. Time motion studies are not ideal because the observation likely changes doctor and patient behavior (e.g., the Hawthorne effect [9]). For large hospital networks like AMPATH, running such studies can be quite costly. ODK Clinic enables AMPATH to measure proxies for patient visit times automatically, but further investigation is needed to understand how closely summary viewing times correlate with patient visit times.

7.6 *Phone enables better failure reporting*

One of the challenges of summary management is in understanding where and when problems are occurring. Quickly identifying these gaps helps ensure doctors continue using clinical decision support and thus continue delivering the highest standards of care. From a supervisory standpoint, the ability to find these gaps in an automated, transparent, and cost-effective manner is especially important for remote sites. In this deployment, ODK Clinic enabled better failure reporting.

7.6.1 Methods

Each summary contains a set of observations about a patient (e.g., Gender=Male, Age=25, CD4=500.5). Observations are downloaded and inserted into the doctor's phone. On any

given day, all doctors in a clinic will download the same number of observations because they are downloading the same set of patients. This action is defined as a refresh, and doctors are expected to refresh once in the morning and once in the evening.

7.6.2 Results

This analysis chooses two doctors with varying usage patterns to illustrate ODK Clinic's capabilities. Figure 7.6 places the total number of observations downloaded on the Y-axis and two doctors and the download date on the X-axis. Each circle represents a day's worth of observations downloaded.

As shown, Doctor D downloads over 90k observations on September 19th. That number falls to between 20-40k observations daily for the study duration. Doctor H has entirely different usage patterns. On October 21st, when Doctor H begins to use ODK Clinic, the phone fails to get more than a few observations. That failure continues until November 10th, when a normal number of observations are downloaded.

7.6.3 Discussion

The clustering in the 20-40k observations range is normal usage for a doctor refreshing summaries once or twice a day. Observations below that range show doctors with availability problems. Observations above that range are doctors who are downloading summaries multiple times a day. Both deviations from the norm are problematic.

Doctor D's usage on September 19th is an example of behavior that should be flagged for correction. Doctors who are improperly trained on ODK Clinic sometimes re-download a cohort of summaries throughout the day. This is an unneeded and expensive use of network resources. This is will be especially important as ODK Clinic moves to remote sites with expensive cellular connectivity.

Doctor H's usage starting on October 21st is an example of a network or phone problem preventing access to summaries. Decision support supervisors were alerted by staff about Doctor H's problems via email on October 24th, and the problem was reported fixed via email a few days before the data shows it was actually corrected. The staffers' documen-

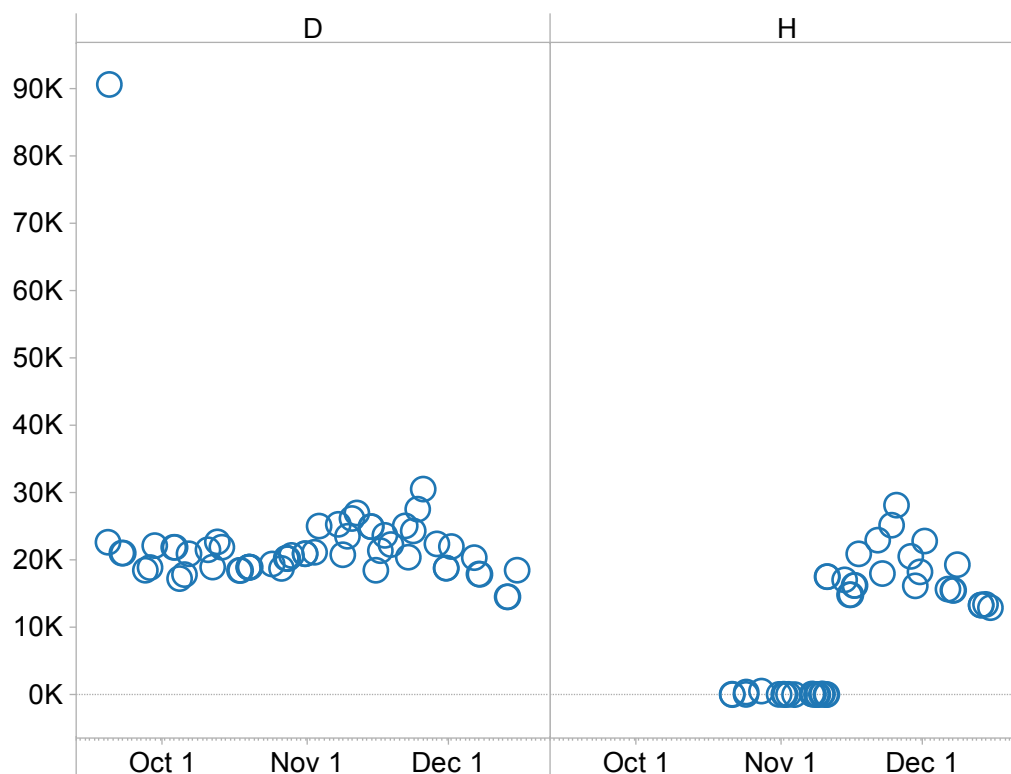


Figure 7.6: Observations downloaded by two doctors over time. The number of observations downloaded is the Y-axis and two doctors and the download date on the X-axis. Each circle represents a day's worth of observations downloaded. The figure shows Doctor H unsuccessfully attempts to get summaries for much of late October and early November.

tation of problems only report five days of outages for Doctor H's phone, when the data shows twenty days.

This analysis demonstrates that automated reporting can provide more reliable monitoring than staff can provide. Additionally, this data can also be operationalized such that supervisors and staff can identify problems without being always present in each clinic. It is easy to train a staffer to see that an unusually large number of observations suggests a training problem while an unusually small number of observations suggests a network problem.

One limitation here is that currently, this data is only revealed after the problem is fixed. That is, if the phone cannot communicate with AMRS, the failures logged with ODK Clinic are not available to supervisors. Future deployments should rely on a combination of phone and server side logging to provide even better failure reporting. For example, server side logging could show that Doctor H's phone has not refreshed in a few days and alert a staffer of the problem.

When electronic data from ODK Clinic and staff feedback are used together, supervisors can gain a richer understanding of the gaps in care. Identifying these gaps in a reliable and objective manner is critical to ensuring decision support scales across all sites.

7.7 Data quality problems with medications

In a survey of fifteen countries in Africa, South America and Asia, the quality of data collected in electronic medical databases was found to be unsatisfactory for many sites involved in the scale-up of antiretroviral therapy [33]. The authors cite insufficient trained staff to manage data as a primary reason.

At AMPATH, there is little work rigorously evaluating data quality. Research involving automatic data quality integrity checks found that data integrity problems in a small percentage of records (mean: .96%, range: 0.0-4.1%)[54]. That work explored fourteen quality checks (e.g., no date of birth, weight too heavy for a child, encounters after date of death) and was not evaluated against human reviewers. Moreover, the checks did not involve data that supervisors consider critical for care (e.g., incorrect medications). Given these limitations, and a desire to better understand data quality at AMPATH, this analysis explored what medications were being corrected by doctors in this deployment.

The data shows that while medications were corrected at varying rates, there were problems with the data quality team approving and applying those changes to the patient's records.

7.7.1 Methods

When a doctor sees a patient during a return visit, the doctor confirms the medications the patient is taking by comparing the medication bottles the patient has brought to the clinic

with what is noted on the summary. If there is a difference, a correction must be made on the summary. Medications in the summary are based on the previous encounter form and so any mistakes found were likely made during the previous encounter (or previous data entry of the form). Once corrections are made, any other changes to the patient's regimen must be made on the encounter form.

When a summary is opened in ODK Clinic, the doctor is asked if a return visit form is being completed for that patient. If the answer is yes, ODK Clinic notes the number of medications the patient's record has, and the number of medications the doctor corrects in that record. ODK Clinic also differentiates between ARV and OI medications. If no medications are changed, the correction rate is 0%. If all medications are changed, the correction rate is 100%.

7.7.2 Results

Figure 7.7 explores the frequency of medication correction rates for ARV and OI medications. On the Y-axis is the frequency of correction in log scale. The X-axis has medication types and 1% bins of correction rates. The analysis shows that 4.83% (464 of 9,614) of ARV medication groupings had some corrections. For OI medications, .994% (80 of 8,045) had some corrections. Across all ARV and OI groupings, 1.34% (236 of 17,659) had all (100%) medications corrected.

The analysis also compares medication correction rates for each doctor. For each doctor and medication type, the total number of medications added or removed is divided by the total number of medications. In Figure 7.8, the medication addition and removal rate is placed on the Y-axis, while medication type and doctors are placed on the X-axis.

The analysis shows that Doctor G has the highest overall correction rates (10.81% for 1,249 ARV medications, 4.37% for 663 OI medications). The lowest correction rate for ARVs is Doctor C (1.26% for 2,069 medications). The lowest non-zero correction rate for OIs is .59% for 848 medications by Doctor A. Across all doctors, ARV medications have an total correction rate of 4.5% with many of those corrections categorized as additions (3.48%). OI medications have a lesser correction rate of 1.04%, and again, many of those

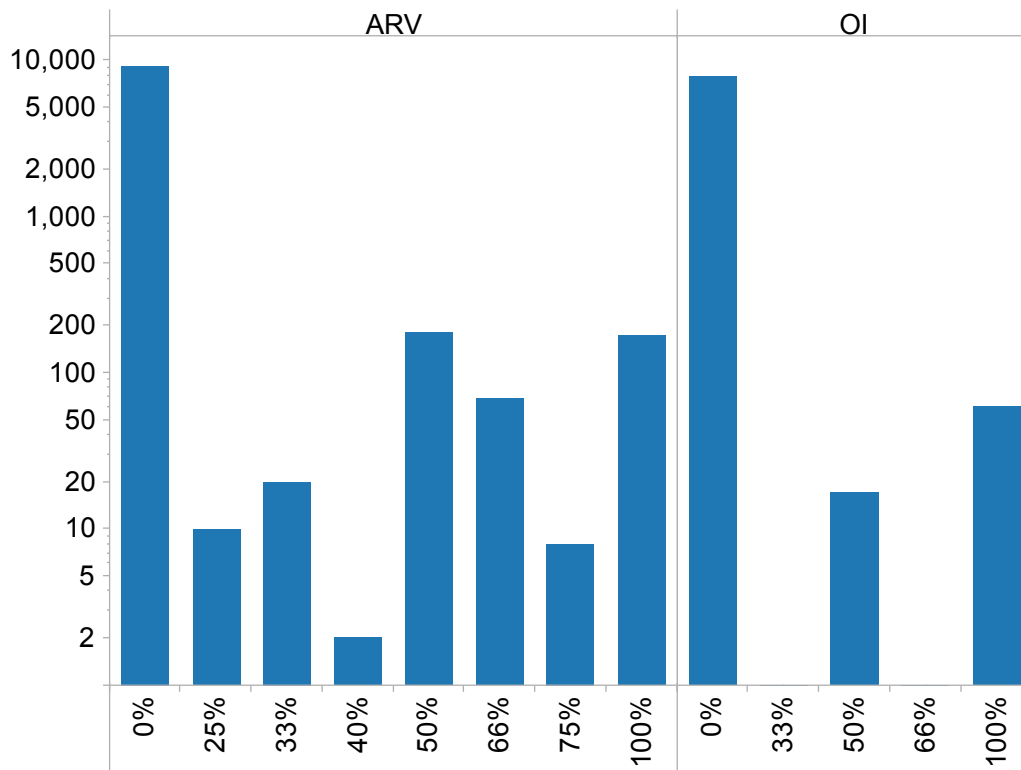


Figure 7.7: Frequency of medication correction rates for ARV and OI medications in 1% bins. On the Y-axis is the frequency in log scale. The X-axis has medication types and 1% bins of correction rates with empty bins hidden. While most medication groupings for patients have no corrections, 4.83% of ARV medications and .994% of OI medications required some correction.

corrections are additions (.93%).

7.7.3 Discussion

The correction rates described above are not a perfect measure for actual medication errors. This is evident in Figure 7.8 where correction rates vary widely by doctor. While the individual patients seen by doctors are likely randomized, the analysis does not control for patients and that may explain the difference in rates. What is more likely, however, is that due to training or interest, doctors correct at different rates.

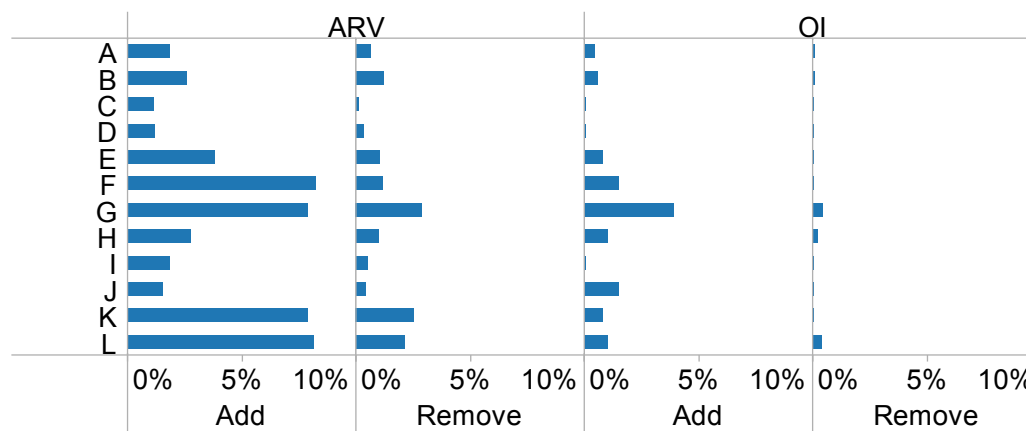


Figure 7.8: Medication addition and removal rates across medication types and doctors. The medication addition and removal rate is placed on the Y-axis, while medication type and doctors are placed on the X-axis. ARV medications have a much higher correction rate; with most corrections are adding to, and not removing from the existing set of medications.

Additionally, just because all doctors add more medications than they remove does not mean AMRS has more missing medications than unnecessary medications. Despite the trainings and AMPATH policy, a doctor may be using ODK Clinic to start and stop regimens instead of correcting medications. Combination medications could also misrepresent changes. A doctor may remove a combination medication like ‘Lamivudine and Tenofovir’ and add a single medication ‘Lamivudine’. This analysis considers those changes as an addition and removal, when it is a single medication change.

The contribution here is the ability to gather rates of corrections automatically — important functionality that AMPATH needs. What this analysis are variations in correction rates across doctor and medications that need exploration.

A review of patient records in the study shows that none of the 842 medication corrections sent to AMRS were acted on by the data quality staffers tasked to approve or reject

medication changes. This again highlights the difficulties of implementing such systems. Data is only the first step in exposing gaps. Once those gaps are identified, processes are needed to track and address each gap.

Without these processes, there is a clear danger to patients who have medication errors. There is also danger to clinical decision support, because as doctors see patients with the same medication errors they have corrected in the past, the doctors begin to doubt the efficacy of the mobile solution, and thus may eventually abandon the application and return to seeing patients without the assistance of decision support. AMPATH has begun the process of addressing the gaps this data has identified.

7.8 Phone perturbs paper processes

Doctors write orders for lab tests on the encounter form, but they also order those tests on a separate lab order form. The lab order form goes to the lab technician who does the test while the encounter form is entered into AMRS. It is the encounter form's entry into AMRS that properly ties the lab order to the patient's record (and thus to the summary). The test result is eventually sent from the lab information system to AMRS.

While writing lab tests on the encounter forms is redundant, it is important because it is the only reliable method for associating lab orders to the patient record. Moreover, at AMPATH the encounter form is often considered 'ground truth.'

The data from this deployment shows that doctors who start using ODK Clinic to view reminders about lab tests drastically reduce test ordering on the encounter form. Doctors do continue to order lab tests on the lab order form.

7.8.1 Methods

ODK Clinic was deployed at two randomly chosen clinics in the same hospital building. These intervention clinics had versions of ODK Clinic with minor differences. A third clinic (control), also in the same building, did not have ODK Clinic.

The Before period is August 15th, 2011 to September 19th, 2011. The After period is September 20th, 2011 to December 16th, 2011. Clinics 1, 2, and 3 used paper-based

summaries in the Before period. Clinics 1, and 2 switched to ODK Clinic in the After period while Clinic 3 continued with paper-based summaries.

The analysis of the Before period confirms that the doctor marked the summary (or responded to reminders on the summary). The analysis of the After period uses data from ODK Clinic to confirm that the doctor opened the summary for a patient and looked at the reminder.

Across both periods, data from AMRS is used to confirm that the doctor completed an encounter form for that same patient. The analysis only considers reminders where a doctor could order a lab test, and does not take into account the doctor's response to that reminder. That is, the analysis only considers the doctor's actions (e.g., ordering a lab test), and not their response (e.g., Ordered Today, I Disagree with Reminder) on the phone or paper summary.

The unit of analysis was the individual clinic visit (doctor-patient-week tuple). The analysis controls for confounding of measured characteristics and clustering effects in the model. A before-after comparison was also conducted to control for confounding due to unmeasured differences between the clinics.

Comparisons of categories (summarized by percentages) were performed with Fisher exact tests. A generalized linear mixed-effects model was used to control confounding due to potentially non-randomized assignment to intervention and control groups. For all analyses, a two-sided p value of < 0.05 is considered statistically significant.

7.8.2 Results

On the Y-axis of Figure 7.9 is the percentage of reminders seen by doctors that had ordered tests on the encounter form. On the X-axis are the individual clinics and the Before and After periods. In Clinics 1 and 2 where ODK Clinic was deployed, lab order rates on the encounter form fell from 47.57% to 27.97% and from 52.10% to 27.94%, respectively. These changes are significant ($p < 0.0001$). Over that same period, Clinic 3 only shows an insignificant drop from 35.28% to 34.34% ($p = 0.6292$). The significance of these results are further detailed in Table 7.2. The significant differences in the Before and After period

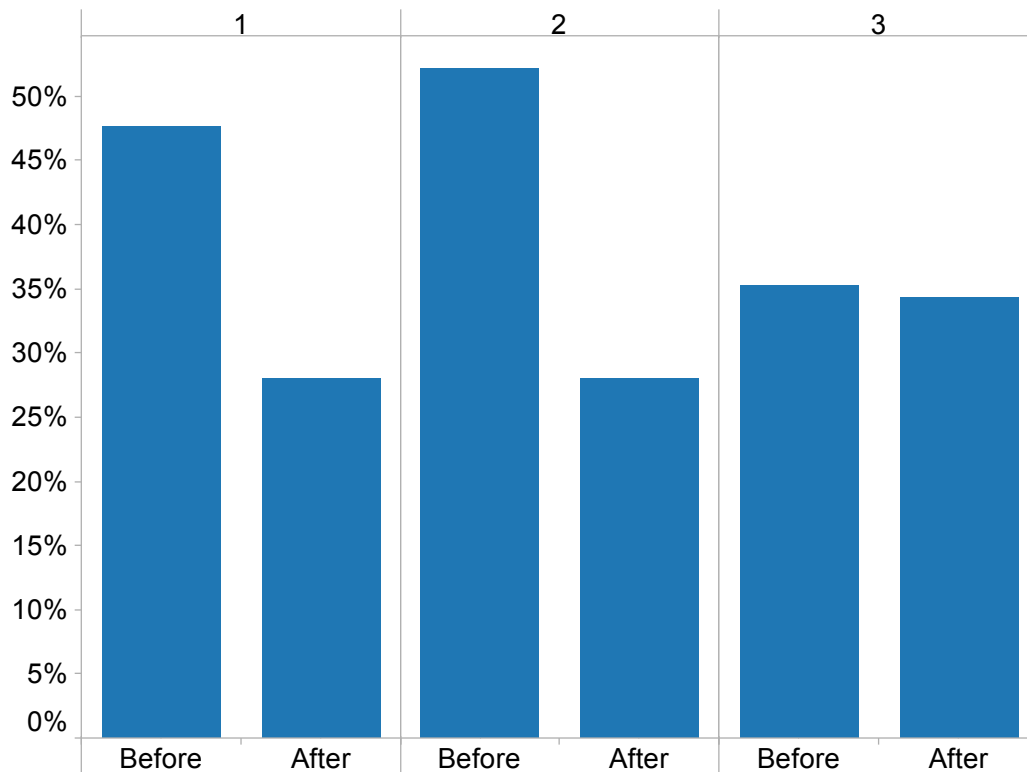


Figure 7.9: On the Y-axis is the percentage of reminders seen by doctors that had tests ordered on the encounter form. On the X-axis are the individual clinics and the Before and After periods. In Clinics 1 and 2 where ODK Clinic was deployed, lab order rates on the encounter form fell drastically. These changes are significant ($p < 0.0001$). Over that same period, Clinic 3 only shows an insignificant change. The significance of these results are further detailed in Table 7.2.

across all clinics show that no direct comparisons can be made across individual clinics (detailed in Table 7.3).

7.8.3 Discussion

There is likely no impact of this behavior on patient care because doctors still order tests using the drug order form. A closer look at the data shows that across all three clinics,

Clinic 1	Before (47.57%) is more likely to have tests ordered than After (27.97%). Odds Ratio (95% CI) = 4.53 (3.75, 5.48); $p < 0.0001$
Clinic 2	Before (52.10%) is more likely to have tests ordered than After (27.94%). Odds Ratio (95% CI) = 7.14 (5.56, 9.18); $p < 0.0001$
Clinic 3	No significant difference between Before (35.28%) and After (34.34%). Odds Ratio (95% CI) = 1.05 (0.86, 1.29); $p = 0.6292$

Table 7.2: Differences in test ordering rates in Clinics 1, 2 and 3 grouped by clinic. The data shows significant differences between Before and After periods of Clinic 1 and 2 (intervention). Clinic 3 (control) does not show any significant differences.

Before	Clinic 1 (47.57%) is more likely to have tests ordered than Clinic 3 (35.28%). Odds Ratio (95% CI) = 1.62 (1.31, 2.02); $p < 0.0001$ Clinic 2 (52.10%) is more likely to have tests ordered than Clinic 3 (35.28%). Odds Ratio (95% CI) = 2.06 (1.61, 2.63); $p < 0.0001$
After	Clinic 1 (27.97%) is less likely to have tests ordered than Clinic 3 (34.34%). Odds Ratio (95% CI) = 0.38 (0.32, 0.45); $p < 0.0001$ Clinic 2 (27.94%) is less likely to have tests ordered than Clinic 3 (34.34%). Odds Ratio (95% CI) = 0.30 (0.25, 0.37); $p < 0.0001$

Table 7.3: Differences in test ordering rates in Clinics 1 and 2 (intervention) and Clinic 3 (control) grouped by period. The data shows significant differences between Clinics 1, 2, and 3 in both the Before and After period.

results for tests are available in AMRS and there are no large differences between the clinics that would suggest that doctors have stopped ordering tests altogether.

It is unlikely that doctors think the act of responding to reminders somehow orders the lab test — the data shows a similar decrease in tests ordered on the encounter forms even when the reminder has no response. A more likely explanation is that as doctors are introduced to technologies that make their workflow more efficient, they become less likely to continue tasks they find redundant. Further investigation is needed to understand the reasons for this drastic change in behavior.

This analysis shows that supervisors must carefully consider the impact of any change on other parts of clinical workflow. While ODK Clinic may offer improvements of availability, supervision and correction of summaries, it can also change workflow in unexpected and potentially unwanted ways. Fortunately, because of the very nature of the change, supervisors can now at least measure where and how those unexpected changes occur.

Chapter 8

USER FEEDBACK

In this chapter, I describe the feedback doctors provided about ODK Clinic. The doctors who used the application were surveyed every few months in this deployment to see how their responses changed over time. As a group, the doctors started out slightly preferring the phone (based on what they saw in the initial training), and over time showed a growing preference for ODK Clinic over paper summaries. Doctors consistently reported that the application was easy to use, fast, and reliable. Early negatives in the deployment started with doctors' concerns with mastering the system, but eventually point to inherent weaknesses — few unscheduled patients on device, phone battery life, fragility of screen, etc. Six months after the deployment began, the doctors wanted to continue using the system despite these problems.

This chapter is organized as follows. Section 8.1 describes the methods used to gather the feedback. Section 8.2 outlines the results and Section 8.3 discusses limitations of the findings.

8.1 Methods

An average time of 40.73 minutes (standard deviation = 9.90) was spent with each doctor. Much of that time (27.23 minutes, standard deviation = 8.06) was spent training doctors on the phone and ODK Clinic. Immediately after training on usage, doctors were asked about expectations of usability, speed, reliability and patient interaction. Doctors were also asked about what functionality they liked or disliked.

All fifteen doctors who completed the training were interviewed. The trainings and interviews were conducted from September 6th, 2011 to September 24th, 2011 and were audio recorded. Seven doctors used computers daily, six used them weekly, and two used them monthly. Four doctors used touchscreen phones daily, three had used them infrequently

(once or twice over a year), and eight had never used them. Six of the doctors are women, and the rest are men. Twelve were aged between 30-40 years of age, two were 40-50, and one was 20-30 years of age.

In early November 2011, about a month after the training, eight doctors who were available in the clinic were interviewed again. All interviews were audio recorded. The same questions from the September interviews were asked. The analysis excludes one doctor who had recently started using the phone. Of the seven doctors in this analysis, four are women.

Two months later, in mid-January 2012, all available doctors who had used ODK Clinic were given anonymous surveys. The survey asked the same questions from the previous interviews, and included a question about whether or not to continue the phone-based summaries. Twelve doctors responded. The analysis excludes one doctor who had only used the phone for two weeks. As the surveys were anonymous, no age or gender information was collected.

Not all doctors trained in September were available in November, and so these results only consider doctors who were available at both times. For this reason, these results are not statistically significant. The results are instead used to gain a sense of the trends in doctor preferences. Finally, it is important to note that the results from January are anonymous and so no rigorous comparisons can be made against the September and November results.

8.2 Results

In audio interviews, doctors were asked about ease of use, speed, reliability and patient interaction of phone-based summaries as compared to paper-based summaries. The questions were phrased as follows.

“On a scale of 1 to 5, with 1 being much harder to use and 5 being much easier to use, and 3 being about the same, how would you compare the phone summary to the paper summary?”

Figure 8.1 and Figure 8.2 show the results. The indicators are shown on the X-axis. On the Y-axis is the average result from the doctors. A zero value means the phone was the same

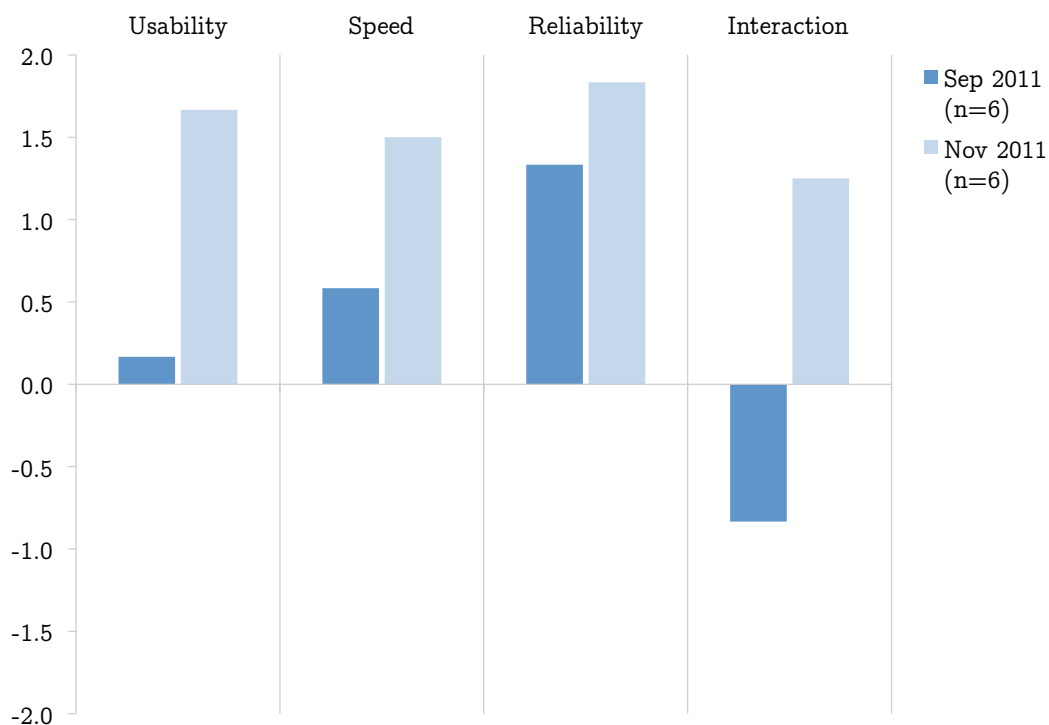


Figure 8.1: Doctor comparisons of ODK Clinic to paper-based summaries over time. Doctors were asked to compare the usability, speed, reliability and patient interaction of ODK Clinic to paper-based summary. These indicators are shown on the X-axis. On the Y-axis is the average result from the doctors. A zero value means the phone was the same as paper. Positive two (the maximum) means the phone was much better. Negative two (the minimum) means the phone was much worse. Doctors were asked about these indicators over time (shown by color). Results from the same group of doctors in September and November show increased average preference for ODK Clinic across all indicators over time.

as paper. Positive two (the maximum) means the phone was much better. Negative two (the minimum) means the phone was much worse. Doctors were asked about these indicators over time (shown by color). Results from the same group of doctors in September and

November show increased average preference for ODK Clinic across all indicators over time.

8.2.1 September 2011

In September, the six doctors shown in Figure 8.1 considered ODK Clinic easier to use (+0.2), faster (+0.6), and more reliable (+1.2) than paper-based summaries. They also thought the phone would worsen patient interaction (-0.8).

Fifteen doctors who completed the training were also asked what they considered advantages and disadvantages of ODK Clinic. In describing advantages, doctors mentioned ease of use (eight times), speed (seven times), and freshness of data (six times). Doctors noted reliability (five times), independence (three times) and time saving (three times) as positives as well. Other positives included convenience, saving on paper costs, and increased efficiency.

Negatives mentioned were the time required to learn the system (eight times), small size of device (three times), and the touchscreen (two times). Doctors also mentioned deployment issues four times (e.g., charging, secure storage, loss and breakdown). Finally, a few doctors were also concerned that the process looked slower than paper, especially if AMRS was down.

8.2.2 November 2011

In November, doctors were interviewed again. The same six from September now considered phone-based summaries easier to use (+1.7), faster (+1.5), and more reliable (+1.8) than paper. They now thought the phone made patient interaction better (+1.3). Across all doctors, ease of use, speed, reliability and doctor interaction increased.

In describing what they considered positive aspects, doctors mentioned ease of use (three times), speed (three times), convenience (three times), and reliability (three times). Independence in retrieving summaries and a reduction in paper work were both mentioned twice. A direct connection to AMRS to correct summaries, looking up historical data, ordering lab tests, and forced responses to reminders were also noted. One doctor stated that any use of technology was a positive step forward.

As far as negatives, doctors noted network problems (four times) and power or charging (two times). One doctor noted that the system was not as fast if you had a reminder and did not have the patient's chart with all historical data. That is, to address a reminder, the doctor might need information (e.g., a list of all the patient's medications) that is in the chart, but is not in the summary (e.g., the most recent medications). Two doctors noted that there were many reminders, but mentioned that this would change with time, and that the problems occurred with paper reminders as well. One doctor wanted to print lab requisitions to the printer inside their office because they found that nurses would not always bring the lab forms for them to sign. Finally, one doctor noted a dislike of carrying multiple phones (ODK Clinic phone, personal phone, and a shared clinic phone).

8.2.3 January 2012

In January 2012, all doctors who had used ODK Clinic and were available, completed a survey that asked the same questions as the interviews from September and November. The eleven doctors who responded self-reported that they had used the phone for an average of 18.54 weeks. The doctors considered phone-based summaries easier to use (+1.2), faster (+0.5), more reliable (+1.3), and enabled a better patient interaction (+1.1). Doctors also wanted AMPATH to continue using the phone-based summaries (+1.5). Because the population in the January result was different from the September and November result, the results cannot be compared directly.

Doctors were also asked to describe what they liked or considered positive aspects of ODK Clinic. They noted that the system was fast (six times), accurate (five times) and reliable (five times). Doctors also noted that ODK Clinic was more economical (two times) and saved time (two times) for the clinic. Doctors liked that so many of the patient records were always available on the phone, that changes were reflected immediately, that there was no writing, and that the reminders were relevant.

When asked about dislikes or negative aspects of the system, doctors mentioned that the connection to AMRS was unreliable (five times), that phones were fragile (five times), that battery life was not great (five times), and that the power chargers were of poor

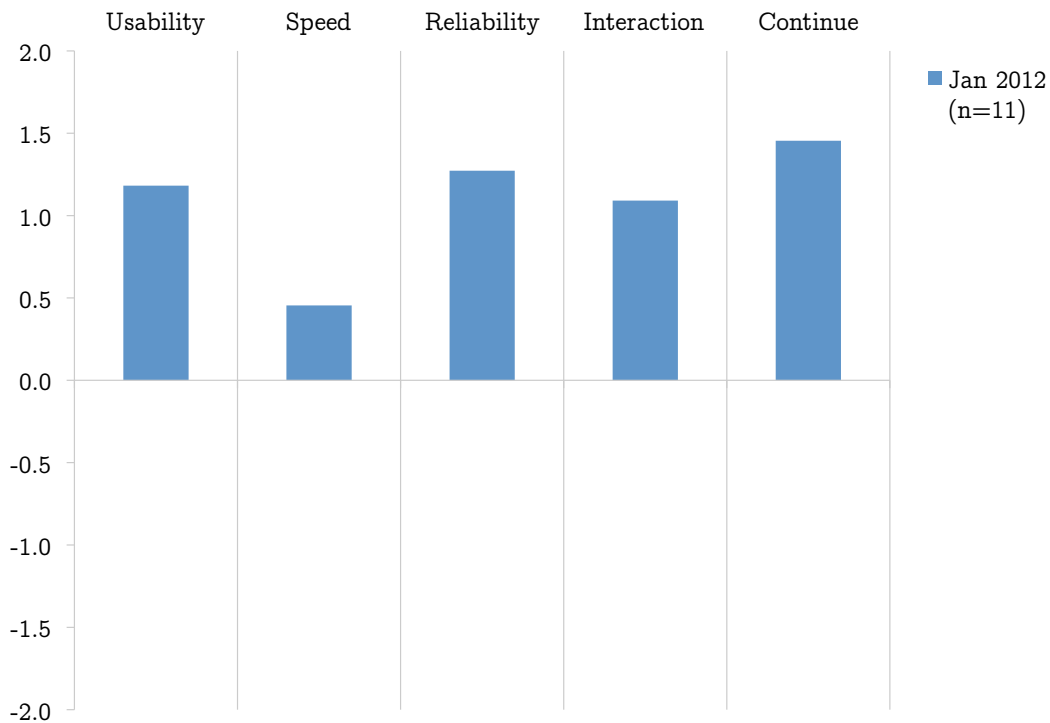


Figure 8.2: Doctor comparisons of ODK Clinic to paper-based summaries in January 2012. Across all indicators, these doctors preferred ODK Clinic to paper summaries. In this survey, doctors were also asked if they wished to continue using the system. They did.

quality (two times). Two doctors also noted that other technical glitches (likely bugs) were negative aspects. One doctor noted the small phone was problematic when typing patient identification numbers or names, and another requested a larger device. Security of patient data was mentioned twice. One doctor said the phone introduced added responsibility for patient data. Another noted that the phone was discreet and thus ensured patient confidentiality.

8.3 Discussion

8.3.1 September 2011

Overall, doctors were cautiously optimistic about ease of use, speed and reliability of the phone. A number of doctors suggested deploying in more remote clinics and for entering data from the entire encounter form. In regards to speed, the time taken during a patient visit was not as important as the convenience of always having access to all patient summaries, and not relying on others to print the summaries and make them available. Also important was the notion that data doctors entered at the point of care would be directly sent to AMRS. Doctors believed that this up to date data would be in the summary and would reduce many of the reminders. One doctor spoke passionately about this.

“It will be faster for me to get the information ... the summaries are being processed somewhere else [as opposed to being available on demand] ... We are the ones responding to it [the reminders] and we correct it. The other time we respond to [reminders on] the [paper] summary sheet itself. The next time, it comes back again with the same reminder. Maybe somebody was not responding to it on the other side [data entry]. I think that’s going to be an advantage. The reminders will be reduced.”

Doctors were not so concerned about the phone itself being damaged, but were focused instead of the implications on their workflow when the device broke, ran out of batteries, or was lost. There were similar concerns about impact on workflow if AMRS was down and there was a need to find a summary for an unscheduled patient. Finally, doctors noted some concern about the time required to master the phone itself and the workload implications during that learning period.

“[One concern is] the slowness in learning since I have not used ... the touch screen, and the kind of phone.”

“[The phone is] a new gadget to me ... My fingers occasionally don’t hit it well.”

As a group, doctors thought patient interaction would likely suffer with the phone — especially if patients were not informed or educated during the visit. One doctor was concerned because the summary sheet is shown to patients who can read so they can track their own progress. The doctor was concerned that the patient might disturb the phone in some way.

“I will be concentrating on the phone. I will not be able to pick the non-verbal. When you are seeing a client, you need to be to pick the non-verbals on the face of the client . . . Even in the phone, still I have to show them [their results] . . . [But] in the moment . . . the client . . . he touch, and then everything goes off!”

8.3.2 November 2011

Doctors most often cited ease of use, speed and convenience as positive aspects of the phone-based summary. One doctor re-stated a problem he had with the paper-based summary and how ODK Clinic enabled doctors to get summaries regardless of nurse workload. This sentiment was repeated by other doctors who all liked the independence the phone enabled. This independence is again reflected in the ability to easily see a patient’s historical data without asking a nurse to generate a summary.

“Initially if the workload in the nurse station becomes high, they at times they used to skip. I thought they were skipping printing it intentionally. That was my interpretation. Now we are able to see patients faster.”

“Many doctors from other sites told me they would like to have the smartphone more than the paper work. Because they are saying that occasionally there is breakdown in their printers or the computers . . . they are not reliable.”

Connectivity to AMRS was mentioned multiple times as a negative when looking for summaries for unscheduled patients, but doctors noted how the offline functionality solved problems with the unreliable AMRS. A doctor who visits remote sites noted that it would be useful to have there.

“Sometimes the AMRS is down and you can’t get a summary even for scheduled patients. I can’t even remember the last time I had that problem [finding patients on the phone].”

“It’s a part of me now . . . I really can’t see a patient without this phone. It’s like something is amiss. We went to our satellite [remote clinic] on Friday and we felt like how come we [can’t] be using the phone there.”

Despite the unsolved problem of AMRS connectivity for unscheduled patient summaries, doctors did not want to stop using the phones. This desire to continue was true for doctors who were comfortable with the phone and for those who were not.

“If the problem was happening every day, the solution is not to go back to the paper work. The solution is to look where the problem is and we sort it out.”

Doctors at these clinics expressed some desire to try to use technology to improve their process. One doctor wanted the phone to pull lab results immediately from the lab information system (instead of AMRS). The same doctor wanted more decision support to catch data entry mistakes at the point of care. Another doctor mentioned that it was difficult to leave the summary without responding, and then noted this was a good thing because with paper summaries, one could easily miss making corrections.

The most drastic change across time for all doctors was in their expectations of how the phone would change patient interaction. A few months prior, doctors were concerned that the phone may worsen patient interaction. A doctor who had just been trained on the system noted this change. Others noted that once the system was explained, patients appreciated the use of technology.

“When we were rolling down this thing, someone thought I was doing Facebook. So when I realized that, I started educating our patients. If a patient comes in, I tell them, look, this gadget is your file. I’m going to use it to have a look at your case. And now they understand. So the interaction is good.”

8.3.3 January 2012

Doctors did not rate ODK Clinic as much faster (+0.5) than paper summaries. Paradoxically, two of the three doctors that rated it the worst, noted in the qualitative data that the positive aspects of the application were its speed and ability to view pre-loaded summaries.

“Much faster using phone than paper.”

The inconsistencies here have to do with what part of the system was being considered when doctors answered the survey. The data shows that the application itself is considered fast and easy to use (+1.2). For all but two doctors, a patient visit is as fast, or faster than using paper-based summaries. All but two doctors also believe that the quality of patient interaction is better (+1.1) with the phone when compared with paper.

“I do not depend on other staff to print for me summary ... [or] to put the summaries in charts. I can assess AMRS with the phone while in the room thus enabling me to make corrections.”

Doctors believe that the application is also faster (and more economical) at the clinic level due to the independence of summary retrieval it affords, the ability to send corrections directly to AMRS, and reduction in printing costs. That is, for individual patient visits, it may be slower for two doctors, but those doctors still considered it a time saver for the clinic.

“Depends on AMRS to search for patients not downloaded [unscheduled patients] and AMRS is down mostly.”

When the phone cannot connect to AMRS, it displays a “AMRS is down. Kindly try again.” message. ODK Clinic did not distinguish between connectivity between the phone and Wi-Fi routers, the router and AMRS, and technical bugs with AMRS itself. It is likely the majority of connectivity problems were due to the AMRS server itself going down. It is unlikely that AMRS reliability issues will be solved in the near future, and thus caching

more patient records on the device would be a good first step to addressing doctor concerns. As it stands, ODK Clinic was still considered more reliable than paper-based summaries (+1.3).

“We were given adapters that are inadequate and of poor quality.”

Doctor complaints about battery life and quality of power adapters underscore the importance of considering how these systems are deployed. Doctors did not have enough opportunities to charge phones. The locked file cabinet that was used to store phones did not have power, and so doctors had to charge the device at their desks while seeing patients. If a doctor forgot to power off the phone before storing it, they may find it out of power in the morning. The power adapters used at doctor desks were purchased locally and were unreliable, compounding the problems with keeping the phones fully charged. A simple solution to this issue is a storage bin with slots for power, or even extra batteries.

Fragility was noted many times as a negative. The phones themselves were not put in cases for this deployment. Despite this oversight, only one of the eighteen deployed has had a major problem — a broken screen. In future deployments, the devices will have cases to help address this issue.

“The team which looks at the results (historical results) input from the doctors should update them promptly to avoid delays.”

A final concern that one doctor noted was what happened to corrected data. In particular, corrected medications and lab results are currently not entered into the patient record. This mirrors problems with the paper-based system. Here, ODK Clinic has improved the process of getting the data into AMRS, but actually applying it to the patient record still requires a data quality team to approve the changes.

“This innovation has made work easier and would be of great benefit if it was extended to other modules/sites. It would be beneficial to AMPATH if other documents e.g. prescriptions and visit forms would be incorporated into the system.”

Despite these problems, doctors wanted to continue to use ODK Clinic (+1.5) and wanted the system extended to support encounter forms, drug orders, error detection on input, and even an obstetric wheel to calculate due dates for pregnant women. The doctors considered the system efficient, but noted that better support for viewing summaries of unscheduled patients was important. Also important was ensuring that corrected patient data would actually be added to AMRS.

The findings from the case study in Chapter 3 remain true. Doctors want to be responsible for summary retrieval and patient data entry, the impact of phone on time with patients is minimal, there is a desire to use the phone throughout clinical practice, the user interface is considered easy to use, and the increasing experiences with smartphones have likely improved interaction speed.

What has changed over time are the concerns doctors expressed. Before the phones were deployed, securing the devices was a primary concern. After the training, mastering the phones was the most important issue. After a month of use, doctors became more comfortable and the problem of unscheduled patients became the most pressing need. After a few months, doctors added charging concerns, phone breakage, and gaps in data actually being applied to the patient's record.

Despite these negatives, doctors find the system easy to use, reliable, fast, and find that it improves patient interaction. Moreover, doctors want to continue using and improving the system.

Chapter 9

CONCLUSION

The combination of lightly trained doctors, under-resourced hospitals, and complex treatment protocols can sometimes result in sub-standard care for HIV patients in low-income regions.

While previous work has shown that printed patient summaries with reminders improve the quality of care, reliable access to such decision support is limited. Moreover, even when summaries are available, there are no efficient mechanisms for doctors to correct serious errors found in the summaries. Supervisors of these systems also face challenges, such as depending on unreliable manual processes to monitor summary usage across geographically dispersed clinics.

The thesis behind this work is that a mobile phone application can make patient summaries more available at the point of care, can enable doctors to correct mistakes in a patient's record, and can empower supervisors with detailed usage data. As evidence to support this thesis, I have contributed the following.

1. Identification of problems with paper-based decision support

In Chapter 3, I documented an approach that builds on previous research, observations of clinical workflow, surveys of stakeholders, and tens of thousands of patient visits to determine causes of failure in a large-scale paper-based decision support system. The approach produced findings that guided the implementation of a mobile application that addresses problems with availability, supervision and correction of summaries.

2. Design and implementation of phone-based decision support

In Chapter 5, I described the design and implementation of ODK Clinic, a phone-based decision support application that enabled greater availability of clinical summaries and reminders at the point of care. For doctors, the system enabled direct entry of

responses to reminders, corrections of patient medications and lab test results, and automated lab test ordering. Supervisors gained near real-time monitoring of various measures of system usage.

3. Deployment and evaluation at large hospital network

I have presented a deployment of ODK Clinic at one of the largest HIV treatment programs in Sub-Saharan Africa. Informed by the results of a 90-day deployment with over 13,000 patient encounters, I provide evidence of ODK Clinic's positive impact on the availability, correction and supervision of clinical decision support. I also provided evidence that suggests that while doctors prefer ODK Clinic to previous practice, supervisors must carefully consider the impact of this intervention on other parts of their clinical workflow. These results are described in Chapters 6, 7 and 8.

9.1 Future Work

There are a number of future directions that would be interesting to pursue.

9.1.1 *More unscheduled patients on phone*

One limitation of this work is how ODK Clinic provides summaries for unscheduled patients. There are far too many unscheduled patients at AMPATH to rely on AMRS to be available when a doctor needs a summary. Understanding this problem requires studying how unscheduled these patients are. For example, do patients present for a visit within a few days, a few weeks or a few months of their scheduled date? Understanding this would enable ODK Clinic to use a more intelligent algorithm about what summaries need to be on the phone. An alternative approach is to put all summaries of all patients on the phone at all times, but ensuring the data is cost-effectively kept up-to-date and synchronized with the server adds further challenges. With resource-constrained settings gaining more connectivity, and with smartphones gaining more storage space and processing power, the problem of summaries for unscheduled is important to explore.

9.1.2 More logic encoded in downloadable files

ODK Clinic currently places much of the business logic for AMPATH's operating procedures on the phone. This choice was made because of the limited time for development. Much of this on-phone logic could be encoded in a more flexible summary definition that would be downloaded from a server. This flexibility is important because as systems like mobile clinical decision support scale, it becomes logistically difficult to update all phones when a process changes.

9.1.3 Tablet form filling to replace all forms

Doctors expressed a desire for replacing paper forms and using larger devices such as tablets. Tablets are an ideal device because they enable a larger surface to display more information. This large surface could be used to support richer functionality (e.g., to replace an encounter form) than is currently available. Additionally, with the success of ODK Clinic, AMPATH is interested in exploring moving more of clinical workflow to mobile devices.

9.1.4 Tools to visualize breakdowns in workflow

The deployment findings show that corrections are not approved by data quality staff. For that reason, the corrections are not added to the patient's record in a timely fashion. Every intervention reveals new gaps in processes. Tools that empower staff to see where there are breakdowns in a workflow would be very useful. It is important that these tools are easy to use by typical supervisory staff and not require technical expertise.

9.1.5 Does ODK Clinic improve care?

Does enabling availability, supervision, and correction show a measurable difference in the patient's health outcomes? While the data I present suggests that ODK Clinic could improve the quality of care, the conclusions that can be drawn from this work are indirect. They improve the existing system and the consistency of care, but a more controlled and rigorous evaluation is needed to answer this question definitively.

9.2 Final Remarks

I believe that technology interventions are at their best when they improve an existing system. This work has been an evolution of a paper-based system that AMPATH created, and working with them, I have been able to create phone-based summaries that give them more capabilities than they had before. AMPATH continues to evolve with this work, and I suppose as a researcher, that might be the best I can hope for my efforts.

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BIBLIOGRAPHY

- [1] AMPATH-Kenya. <http://ampathkenya.com>.
- [2] Android. <http://www.android.com>.
- [3] Bob Collymore. <https://twitter.com/bobcollymore/status/172736353132494848>.
- [4] CommonsWare Android Components. <http://commonsware.com/cwac>.
- [5] iText. <http://itextpdf.com>.
- [6] ODK Clinic. <http://code.google.com/p/opedatakit/wiki/ODKClinic>.
- [7] PrinterShare. <http://www.printershare.com>.
- [8] ZXing. <http://code.google.com/p/zxing>.
- [9] John G Adair. The Hawthorne Effect: A Reconsideration of the Methodological Artifact. *Journal of Applied Psychology*, 69(2):334–345, 1984.
- [10] Herbert Altricher, Allan Feldman, Peter Posch, and Bridget Somekh. *Teachers Investigate Their Work: An Introduction to Action Research Across the Professions*. Routledge, 2 edition, December 2007.
- [11] Yaw Anokwa, Christian Allen, and Hamish S F Fraser. Building a Better Clinician Experience in OpenMRS. *Global Partners in Public Health Informatics*, 2008.
- [12] Yaw Anokwa, Christian Allen, and Tapan Parikh. Deploying a Medical Record System in Rural Rwanda. *HCI for Community and International Development at CHI 2008*, 2008.
- [13] Yaw Anokwa, Thomas N Smyth, Divya Ramachandran, Jahanzeb Sherwani, Yael Schwartzman, Rowena Luk, Melissa R Ho, Neema Moraveji, and Brian DeRenzi. Stories from the Field: Reflections on HCI4D Experiences. *Information Technologies and International Development*, 5(4):101–116, December 2009.
- [14] William Avilés, Oscar Ortega, Guillermina Kuan, Josefina Coloma, and Eva Harris. Quantitative Assessment of the Benefits of Specific Information Technologies Applied to Clinical Studies in Developing Countries. *The American Journal of Tropical Medicine and Hygiene*, 78(2):311–315, February 2008.

- [15] Eta S Berner. Clinical Decision Support Systems: Theory and Practice. *Health Informatics*, 2007.
- [16] Benjamin Birnbaum, Brian DeRenzi, Abraham D Flaxman, and Neal Lesh. Automated Quality Control for Mobile Data Collection. In *ACM DEV*, page 1, New York, New York, USA, 2012. ACM Press.
- [17] Jørn Braa and Calle Hedberg. The Struggle for District-Based Health Information Systems in South Africa. *The Information Society*, pages 113–127, 2002.
- [18] Eric Brewer, Michael Demmer, Melissa R Ho, RJ Honicky, Joyojeet Pal, Madelaine Plauché, and Sonesh Surana. The Challenges of Technology Research for Developing Regions. *IEEE Pervasive Computing*, 5:15–23, 2006.
- [19] Cathy Bryan and Suzanne Austin Boren. The Use and Effectiveness of Electronic Clinical Decision Support Tools in the Ambulatory/Primary Care Setting: A Systematic Review of the Literature. *Informatics in Primary Care*, 16(2):79–91, 2008.
- [20] B Castelnuovo, J Babigumira, M Lamorde, A Muwanga, A Kambugu, and R Colebunders. Improvement of the Patient Flow in a Large Urban Clinic With High HIV Seroprevalence in Kampala, Uganda. *International Journal of STD & AIDS*, 20(2):123–124, February 2009.
- [21] D W Chadwick, P J Crook, A J Young, D M McDowell, T L Dornan, and J P New. Using the Internet to Access Confidential Patient Records: A Case Study. *BMJ (Clinical research ed)*, 321(7261):612–614, September 2000.
- [22] K Chen, Joseph M Hellerstein, and Tapan Parikh. Designing Adaptive Feedback for Improving Data Entry Accuracy. *Proceedings of the ACM Symposium on User Interface Software and Technology*, 2010.
- [23] Kuang Chen, Joe M Hellerstein, and Tapan S Parikh. Data in the First Mile. In *Proceedings of the Conference on Innovative Data Systems Research (CIDR)*, 2011.
- [24] Lincoln Chen, Timothy Evans, Sudhir Anand, Jo Ivey Boufford, Hilary Brown, Mush-taque Chowdhury, Marcos Cueto, Lola Dare, Gilles Dussault, Gijs Elzinga, Elizabeth Fee, Demissie Habte, Piya Hanvoravongchai, Marian Jacobs, Christoph Kurowski, Sarah Michael, Ariel Pablos-Mendez, Nelson Sewankambo, Giorgio Solimano, Barbara Stilwell, Alex de Waal, and Suwit Wibulpolprasert. Human Resources for Health: Overcoming the Crisis. *The Lancet*, 364(9449):1984–1990, November 2004.
- [25] Vital Wave Consulting. *mHealth for Development: The Opportunity of Mobile Technology for Healthcare in the Developing World*. February 2009.

- [26] David A Davis, Mary Ann Thomson, and Andrew D Oxman. Changing Physician Performance: A Systematic Review of the Effect of Continuing Medical Education Strategies. *Journal of the American Medical Association*, 1995.
- [27] Nicola Dell, Vidya Vaidyanathan, Indrani Medhi, Edward Cutrell, and William Thies. "Yours is Better!" Participant Response Bias in HCI. *ACM SIGCHI Conference on Human Factors in Computing Systems (CHI 2012)*, 2012.
- [28] Brian DeRenzi, Benjamin Birnbaum, Leah Findlater, Joachim Mangilima, Jonathan Payne, Tapan Parikh, Gaetano Borriello, and Neal Lesh. Improving Community Health Worker Performance Through Automated SMS. In *Proceedings of the Fifth International Conference on Information and Communication Technologies and Development*, pages 25–34, New York, New York, USA, 2012. ACM Press.
- [29] Paul R Dexter, Susan Perkins, J Marc Overhage, Kati Maharry, Richard B Kohler, and Clement J McDonald. A Computerized Reminder System to Increase the Use of Preventive Care for Hospitalized Patients. *The New England Journal of Medicine*, 2001.
- [30] Gerald Douglas, R A Deula, and S E Connor. The Lilongwe Central Hospital Patient Management Information System: A Success in Computer-Based Order Entry Where One Might Least Expect It. *Proceedings of the AMIA Annual Symposium*, page 833, 2003.
- [31] Gerald P Douglas, Oliver J Gadabu, Sabine Joukes, Soyapi Mumba, Michael V McKay, Anne Ben-Smith, Andreas Jahn, Erik J Schouten, Zach Landis Lewis, Joep J van Oosterhout, Theresa J Allain, Rony Zachariah, Selma D Berger, Anthony D Harries, and Frank Chimbandira. Using Touchscreen Electronic Medical Record Systems to Support and Monitor National Scale-Up of Antiretroviral Therapy in Malawi. *PLoS Medicine*, 7, 2010.
- [32] Theodore C Eickhoff. Human Immunodeficiency Virus (HIV) Infection. *Annals of Internal Medicine*, 120(4):310–319, February 1994.
- [33] Mathieu Forster, Christopher Bailey, Martin W G Brinkhof, Claire Graber, Andrew Boulle, Mark Spohr, Eric Balestre, Margaret May, Olivia Keiser, Andreas Jahn, Matthias Egger, and ART-LINC collaboration of International Epidemiological Databases to Evaluate AIDS. Electronic Medical Record Systems, Data Quality and Loss to Follow-Up: Survey of Antiretroviral Therapy Programmes in Resource-Limited Settings. *Bulletin of the World Health Organization*, 86(12):939–947, December 2008.
- [34] Hamish S F Fraser, Christian Allen, Christopher Bailey, Gerald Douglas, Sonya S Shin, and Joaquin A Blaya. Information Systems for Patient Follow-Up and Chronic Management of HIV and Tuberculosis: A Life-Saving Technology in Resource-Poor Areas. *Journal of Medical Internet Research*, 9(4), 2007.

- [35] Hamish S F Fraser, Darius Jazayeri, Carole D Mitnick, Joia S Mukherjee, and Jaime Bayona. Informatics Tools to Monitor Progress and Outcomes of Patients With Drug Resistant Tuberculosis In Peru. *Proceedings of the AMIA Annual Symposium*, pages 270–274, 2002.
- [36] Constance H Fung, Juliet N Woods, Steven M Asch, Peter Glassman, and Bradley N Doebbeling. Variation in Implementation and Use of Computerized Clinical Reminders in an Integrated Healthcare System. *The American Journal of Managed Care*, 10(11 Pt 2):878–885, November 2004.
- [37] Jeffrey Gettleman. Kenya’s Middle Class Feeling Sting of Violence. *The New York Times*, February 2008.
- [38] Carl Hartung, Yaw Anokwa, Waylon Brunette, Adam Lerer, Clint Tseng, and Gaetano Borriello. Open Data Kit: Tools to Build Information Services for Developing Regions. *Proceedings of the International Conference on Information and Communication Technologies and Development*, pages 1–11, December 2010.
- [39] Dereck L Hunt, R Brian Haynes, Steven E Hanna, and Kristina Smith. Effects of Computer-Based Clinical Decision Support Systems on Physician Performance and Patient Outcomes. *Journal of the American Medical Association*, 1998.
- [40] Partners in Health. *The PIH Guide to the Community-Based Treatment of HIV in Resource-Poor Settings*. 2008. <http://pih.org>.
- [41] Inveneo. *Inveneo ICT Sustainability Primer*. September 2010. <http://www.inveneo.org>.
- [42] Darius Jazayeri, Paul E Farmer, Patrice Nevil, Joia S Mukherjee, Fernet Leandre, and Hamish S F Fraser. An Electronic Medical Record System to Support HIV Treatment in Rural Haiti. *Proceedings of the AMIA Annual Symposium*, 2003:878, 2003.
- [43] J G Kahn, J S Yang, and J S Kahn. ‘Mobile’ Health Needs and Opportunities in Developing Countries. *Health Affairs*, 29(2):252–258, February 2010.
- [44] Mari M Kitahata, Peter W Dillingham, Nathorn Chaiyakunapruk, Susan E Buskin, Jeffrey L Jones, Robert D Harrington, Thomas M Hooton, and King K Holmes. Electronic Human Immunodeficiency Virus (HIV) Clinical Reminder System Improves Adherence to Practice Guidelines Among the University of Washington HIV Study Cohort. *Clinical Infectious Diseases*, 36(6):803–811, March 2003.
- [45] Katharina Kober and Wim Van Damme. Scaling up Access to Antiretroviral Treatment in Southern Africa: Who Will Do the Job? *The Lancet*, 364(9428):103–107, 2004.
- [46] Pooja Kumar. Providing the Providers — Remedying Africa’s Shortage of Health Care Workers. *New England Journal of Medicine*, 356:2564–2567, 2007.

- [47] Henry Lucas. Information and Communications Technology for Future Health Systems in Developing Countries. *Social Science & Medicine*, 66(10):2122–2132, May 2008.
- [48] Rowena Luk, Melissa R Ho, and Paul M Aoki. Asynchronous Remote Medical Consultation for Ghana. *arXiv*, cs.HC, 2008.
- [49] Robert A Malkin. Design of Health Care Technologies for the Developing World. *Annual Review of Biomedical Engineering*, 9:567–587, 2007.
- [50] Burke W Mamlin, Paul G Biondich, Ben A Wolfe, Hamish S F Fraser, Darius Jazayeri, Christian Allen, Justin Miranda, and William M Tierney. Cooking up an Open Source EMR for Developing Countries: OpenMRS — A Recipe for Successful Collaboration. *Proceedings of the AMIA Annual Symposium*, pages 529–533, 2006.
- [51] Clement J McDonald. Protocol-Based Computer Reminders, the Quality of Care and the Non-Perfectability of Man. *The New England Journal of Medicine*, 295(24):1351–1355, December 1976.
- [52] Gayo Mhila, Brian DeRenzi, Caroline Mushi, Timothy Wakabi, Matt Steele, Prabhjot Dhaldialla, Drew Roos, Clayton Sims, Jonathan Jackson, and Neal Lesh. Using Mobile Applications for Community-based Social Support for Chronic Patients. *HELINA*, 2009.
- [53] Marc Mitchell, Bethany L Hedt, Ingrid Wilson, Hamish S F Fraser, Melanie-Anne John, Colin Menezes, Martin P Grobusch, Jonathan Jackson, Jantjie Taljaard, and Neal Lesh. Electronic Decision Protocols for ART Patient Triaging to Expand Access to HIV Treatment in South Africa: A Cross Sectional Study for Development and Validation. *International Journal of Medical Informatics*, 81(3):166–172, March 2012.
- [54] Jonathan Monda, Jeremy Keiper, and Martin C Were. Data Integrity Module for Data Quality Assurance Within an e-Health System in Sub-Saharan Africa. *Telemedicine and e-Health*, December 2011.
- [55] R W Morrow, A D Gooding, and C Clark. Improving Physicians’ Preventive Health Care Behavior Through Peer Review and Financial Incentives. *Archives of Family Medicine*, 4(2):165–169, February 1995.
- [56] Vasant Narasimhan, Hilary Brown, Ariel Pablos-Mendez, Orvill Adams, Gilles Dus-sault, Gijs Elzinga, Anders Nordstrom, Demissie Habte, Marian Jacobs, Giorgio Soli-mano, Nelson Sewankambo, Suwit Wibulpolprasert, Timothy Evans, and Lincoln Chen. Responding to the Global Human Resources Crisis. *The Lancet*, 363(9419):1469–1472, May 2004.
- [57] NASCOP. *Guidelines for Antiretroviral Drug Therapy in Kenya*. National AIDS and STI Control Programme, Ministry of Health. <http://nascop.or.ke/art>.

- [58] D D Nicholas, J R Heiby, and T A Hatzell. The Quality Assurance Project: Introducing Quality Improvement to Primary Health Care in Less Developed Countries. *Quality Assurance in Health Care*, 3(3):147–165, 1991.
- [59] Sheraz F Noormohammad, Burke W Mamlin, Paul G Biondich, Brian McKown, Sylvester N Kimaiyo, and Martin C Were. Changing Course to Make Clinical Decision Support Work in an HIV Clinic in Kenya. *International Journal of Medical Informatics*, 79(3):204–210, March 2010.
- [60] Thomas A Oniki, Terry P Clemmer, and T Allan Pryor. The Effect of Computer-Generated Reminders on Charting Deficiencies in the ICU. *Journal of the American Medical Informatics Association*, 10(2):177–187, 2003.
- [61] Jerome A Osheroff, EA Pifer, Jonathan M Teich, Dean F Sittig, and RA Jenders. Improving Outcomes With Clinical Decision Support: An Implementer’s Guide. *Health Information Management and Systems Society*, 2005.
- [62] Jerome A Osheroff, Jonathan M Teich, Blackford Middleton, Elaine B Steen, Adam Wright, and Don E Detmer. A Roadmap for National Action on Clinical Decision Support. *Journal of the American Medical Informatics Association*, 14(2):141–145, 2007.
- [63] Andrew D Oxman, Mary Ann Thomson, David A Davis, and R Brian Haynes. No Magic Bullets: A Systematic Review of 102 Trials of Interventions to Improve Professional Practice. *Canadian Medical Association Journal*, 153(10):1423–1431, November 1995.
- [64] Tapan Parikh, Paul Javid, Sasikumar K, and Kaushik Ghos. Mobile Phones and Paper Documents: Evaluating a New Approach for Capturing Microfinance Data in Rural India. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2006.
- [65] Emily S Patterson, Bradley N Doebbeling, Constance H Fung, Laura Militello, Shilo Anders, and Steven M Asch. Identifying Barriers to the Effective Use of Clinical Reminders: Bootstrapping Multiple Methods. *Journal of Biomedical Informatics*, 38(3):189–199, June 2005.
- [66] Emily S Patterson, Anh D Nguyen, James P Halloran, and Steven M Asch. Human Factors Barriers to the Effective Use of Ten HIV Clinical Reminders. *Journal of the American Medical Informatics Association*, 11(1):50–59, 2004.
- [67] Zeshan A Rajput, Sam Mbugua, Jason J Saleem, Yaw Anokwa, Carl Hartung, Burke W Mamlin, Samson K Ndege, and Martin C Were. Development and Implementation of an Open Source, Android-based System for Population Surveillance in Developing Countries. *Proceedings of the AMIA Annual Symposium*, pages 1–23, April 2011.

- [68] Divya Ramachandran, John Canny, Prabhu Dutta Das, and Edward Cutrell. Mobile-izing Health Workers in Rural India. In *CHI '10: Proceedings of the 28th International Conference on Human Factors in Computing Systems*. ACM Request Permissions, April 2010.
- [69] Divya Ramachandran, Vivek Goswami, and John Canny. Research and Reality: Using Mobile Messages to Promote Maternal Health in Rural India. *Proceedings of the International Conference on Information and Communication Technologies and Development*, pages 1–10, July 2010.
- [70] Joseph K Rotich, Terry J Hannan, Faye E Smith, John Bii, Wilson W Odero, Nguyen Vu, Burke W Mamlin, Joseph J Mamlin, Robert M Einterz, and William M Tierney. Installing and Implementing a Computer-Based Patient Record System in Sub-Saharan Africa: The Mosoriot Medical Record System. *Journal of the American Medical Informatics Association*, 10(4):295–303, 2003.
- [71] Charles Safran, David M Rind, Roger B Davis, David Ives, Daniel Z Sands, Judith Currier, Warner V Slack, Harvey J Makadon, and Deborah J Cotton. Guidelines for Management of HIV Infection With Computer-Based Patient’s Record. *The Lancet*, 346(8971):341–346, August 1995.
- [72] Jason J Saleem, Emily S Patterson, Laura Militello, Marta L Render, Greg Orshansky, and Steven M Asch. Exploring Barriers and Facilitators to the Use of Computerized Clinical Reminders. *Journal of the American Medical Informatics Association*, 12(4):438–447, 2005.
- [73] Badara Samb, Francesca Celletti, Joan Holloway, Wim Van Damme, Kevin M De Cock, and Mark Dybul. Rapid Expansion of the Health Workforce in Response to the HIV Epidemic. *The New England Journal of Medicine*, 357(24):2510–2514, December 2007.
- [74] Christopher J Seebregts, Burke W Mamlin, Paul G Biondich, Hamish S F Fraser, Benjamin A Wolfe, Darius Jazayeri, Christian Allen, Justin Miranda, Elaine Baker, Nicholas Musinguzi, Daniel Kayiwa, Carl Fourie, Neal Lesh, Andrew Kanter, Constantin T Yiannoutsos, Christopher Bailey, and OpenMRS Implementers Network. The OpenMRS Implementers Network. *International Journal of Medical Informatics*, 78(11):711–720, November 2009.
- [75] Steven Shea, William DuMouchel, and Lisa Bahamonde. A Meta-analysis of 16 Randomized Controlled Trials to Evaluate Computer-Based Clinical Reminder Systems for Preventive Care in the Ambulatory Setting. *Journal of the American Medical Informatics Association*, 3(6):399–409, 1996.
- [76] J Sherwani, N Ali, S Mirza, A Fatma, Y Memon, M Karim, R Tongia, and R Rosenfeld. HealthLine: Speech-based Access to Health Information by Low-literate Users.

In *International Conference on Information and Communication Technologies and Development*, pages 1–9. IEEE, 2007.

- [77] Kamran Siddiqi, James Newell, and Mike Robinson. Getting Evidence Into Practice: What Works in Developing Countries? *International Journal for Quality in Health Care*, 17(5):447–454, October 2005.
- [78] William M Tierney, Joseph K Rotich, Terry J Hannan, Abraham M Siika, Paul G Biondich, Burke W Mamlin, Winstone M Nyandiko, Sylvester N Kimaiyo, Kara Wools-Kaloustian, John E Sidle, Chrispinus J Simiyu, Erica M Kigotho, Beverly Musick, Joseph J Mamlin, and Robert M Einterz. The AMPATH Medical Record System: Creating, Implementing, and Sustaining an Electronic Medical Record System to Support HIV/AIDS Care in Western Kenya. *Studies in Health Technology and Informatics*, 129(Pt 1):372–376, 2007.
- [79] Elaine Tomasi, Luiz Augusto Facchini, and Maria de Fatima Santos Maia. Health Information Technology in Primary Health Care in Developing Countries: A Literature Review. *Bulletin of the World Health Organization*, 82(11):867–874, November 2004.
- [80] Eva Toth-Pal, Gunnar H Nilsson, and Anna-Karin Furhoff. Clinical Effect of Computer Generated Physician Reminders in Health Screening in Primary Health Care – A Controlled Clinical Trial of Preventive Services Among the Elderly. *International Journal of Medical Informatics*, 73(9-10):695–703, September 2004.
- [81] Kentaro Toyama. Can Technology End Poverty? *Boston Review*, November 2012. <http://bostonreview.net/BR35.6/toyama.php>.
- [82] UNAIDS. *AIDS Epidemic Update: November 2009*. <http://www.unaids.org>.
- [83] UNAIDS. *2008 Report on the Global HIV/AIDS Epidemic: Executive Summary*. 2008. <http://www.unaids.org>.
- [84] International Telecommunication Union. Information Society Statistical Profiles 2009: Africa. *World Telecommunication Development Conference*, 2010.
- [85] D J Vassallo, P Swinfen, R Swinfen, and R Wootton. Experience With a Low-Cost Telemedicine System in Three Developing Countries. *Journal of Telemedicine and Telecare*, 7 Suppl 1:56–58, 2001.
- [86] Rajesh Veeraraghavan, Naga Yasodhar, and Kentaro Toyama. Warana Unwired: Replacing PCs With Mobile Phones in a Rural Sugarcane Cooperative. *Information Technologies and International Development*, 5(1):81–95, 2009.

- [87] R Vranken, D Coulombier, T Kenyon, B Koosimile, T Mavunga, W Coggin, and N Binkin. Use of a Computerized Tuberculosis Register for Automated Generation of Case Finding, Sputum Conversion, and Treatment Outcome Reports. *The International Journal of Tuberculosis and Lung Disease*, 6(2):111–120, February 2002.
- [88] M C Were, C Shen, W M Tierney, J J Mamlin, P G Biondich, X Li, S Kimaiyo, and B W Mamlin. Evaluation of Computer-Generated Reminders to Improve CD4 Laboratory Monitoring in Sub-Saharan Africa: A Prospective Comparative Study. *Journal of the American Medical Informatics Association*, pages 1–7, January 2011.
- [89] Martin C Were, Nneka Emenyonu, Marion Achieng, Changyu Shen, John Ssali, John P M Masaba, and William M Tierney. Evaluating a Scalable Model for Implementing Electronic Health Records in Resource-Limited Settings. *Journal of the American Medical Informatics Association*, 17(3):237–244, May 2010.
- [90] Martin C Were, Burke W Mamlin, William M Tierney, Ben A Wolfe, and Paul G Biondich. Concept Dictionary Creation and Maintenance Under Resource Constraints: Lessons from the AMPATH Medical Record System. *Proceedings of the AMIA Annual Symposium*, pages 791–795, 2007.
- [91] Martin C Were, Changyu Shen, Mwebesa Bwana, Nneka Emenyonu, Nicholas Musinguzi, Frank Nkuyahaga, Annet Kembabazi, and William M Tierney. Creation and Evaluation of EMR-Based Paper Clinical Summaries to Support HIV-care in Uganda, Africa. *International Journal of Medical Informatics*, 79(2):90–96, February 2010.
- [92] WHO. *Antiretroviral Therapy for HIV Infection in Adults and Adolescents*. 2010. <http://www.who.int>.
- [93] WHO. *The Global Shortage of Health Workers and Its Impact*. May 2010. <http://www.who.int>.
- [94] Adam B Wilcox, Spencer S Jones, David A Dorr, Wayne Cannon, Laurie Burns, Kelli Radican, Kent Christensen, Cherie Bruncker, Ann Larsen, Scott P Narus, Sidney N Thornton, and Paul D Clayton. Use and Impact of a Computer-Generated Patient Summary Worksheet for Primary Care. *Proceedings of the AMIA Annual Symposium*, pages 824–828, 2005.
- [95] Faustine Williams and Suzanne Austin Boren. The Role of the Electronic Medical Record (EMR) in Care Delivery Development in Developing Countries: A Systematic Review. *Informatics in Primary Care*, 16(2):139–145, 2008.
- [96] World Bank. *World Development Indicators*. April 2011. <http://data.worldbank.org>.