The CHARMS Application Suite: A Community-based Mobile Data Collection and Alerting Environment for HIV/AIDS Orphan and Vulnerable Children in Zambia

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Abstract:

World Vision (WV) uses the Core HIV and AIDS Response Monitoring System (CHARMS) to track and measure core indicators related to individuals with HIV and AIDS within the communities WV serves. WV uses community care coalitions of volunteer caregivers to care for orphans and vulnerable children (OVC). Current CHARMS data collection involves the registration of caregivers, households and OVC. Data is manually collected by caregivers about OVC during monthly home visits and manually aggregated semi-annually. This research project developed a software application that runs on a low-cost cell phone to automate the CHARMS data collection, alerting and reporting process. The mobile application allows for caregivers to record CHARMS data using the mobile application and transmit the data in real-time using an SMS-based wireless communication service. The application also includes real-time web and email based reporting and mobile phone alerting based on key events (food shortage, OVC not visited). During the summer of 2009, a field pilot project was conducted in Zambia involving 10 caregivers. The system allowed for the registration of 300 OVC and 200 households. A total of 145 home visits were recorded via the mobile application. Extensive assessment data was collected during the field experience. 100% of the caregivers would recommend the continued use of cell phone to record CHARMS data for reasons ranging from time savings (90%), ease of use (70%) and more interesting to use (40%). The caregivers said the cell phone application either had a very positive (80%) or positive (20%) impact on the quality of their home visit.

Keywords: mobile field data collection, SMS, OVC, HIV/AIDS

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1. INTRODUCTION

In 2006, World Vision (WV) [2010] introduced CHARMS (**C**ore **H**IV and **A**IDS **R**esponse **M**onitoring **S**ystem) to track and measure core indicators related to HIV/AIDS within the communities they serve. WV uses community care coalitions of volunteer caregivers (herein referred to as caregivers) to care for orphans and vulnerable children (OVC). Current CHARMS data collection involves the manual registration of caregivers, households and OVC. Data is manually collected by caregivers during monthly home visits and manually aggregated semi-annually.

A high-level business process model for the existing CHARMS process follows. It depicts the role of Community Care Coalitions (CCCs) as community-based partners for World Vision and other NGOs to coordinate the HIV/AIDS response effort. World Vision field operations are managed via a hierarchical structure. The world is divided into regions spanning multiple countries. Each country where World Vision is involved is managed via a National Office. The programs within a country National Office are broken down into Area Development Programmes (ADP). ADPs contain community care coalitions (CCC). Caregivers are volunteers that work in conjunction with a CCC. OVC are managed are part of an ADP.

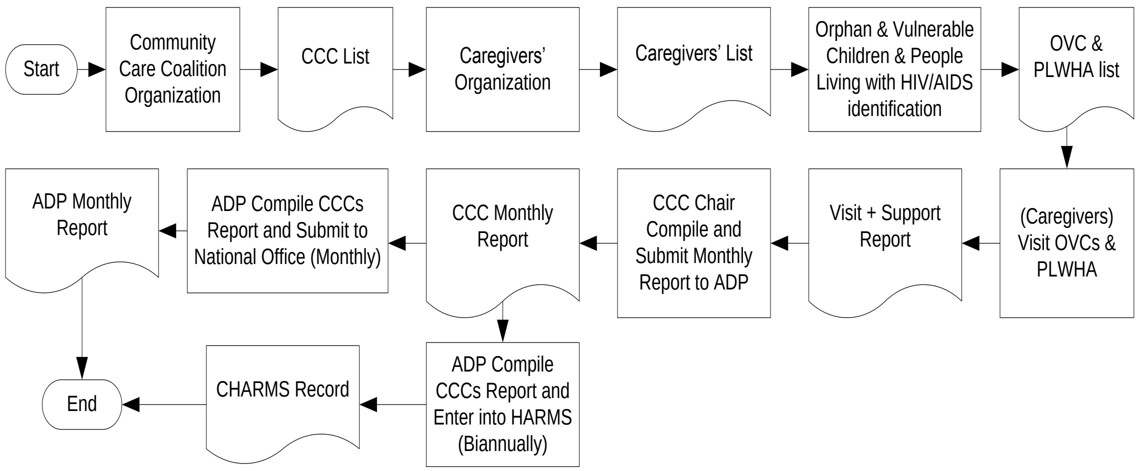

Figure 1. CHARMS current process model

The overall purpose of the pilot project was to transform the current manual CHARMS data collection and reporting process into one that was mobile-based and real-time. The project had the following goals:

- To train WV field staff and volunteer caregivers (CGs) on the use of mobile and web applications and to see them successfully use the applications;
- To test the usability of the mobile and web applications by WV field staff and caregivers;
- To explore and understand the connectivity options (cost, reliability, security, etc.) for transmitting the data from the mobile device to the database;
- To develop a cost/benefit analysis to validate the mobile concept;
- To validate that the data has been correctly entered and correctly stored in the database;
- To explore reports that would be helpful to WV staff related to CHARMS forms;
- To define new features to explore for making the applications more valuable to WV;
- To record lessons learned about the project.

The initial prototype for this project was developed as part of two service-learning courses taught at Messiah College over a twelve-week semester during the spring of 2009. The two courses were a database applications course and a systems analysis and design course. Service-learning is a pedagogical model in which student learning is greatly enhanced through practical, experiential projects. For a course at Messiah College to be considered as service-learning course, it must contain the components of:

- Service: students must engage in meaningful service that is mutually beneficial. In this case, the development of the mobile and web applications for World Vision to be used in Zambia was the service component of the courses. As part of our understanding of service, the professor and students saw the project as inspired, guided and directed by James 1:27 "Religion that God our Father accepts as pure and faultless is this: to look after orphans and widows in their distress and to keep oneself from being polluted by the world."
- Content: students must be exposed to the non-profit organization and people group which they are serving so that they may better understand the motivations or the organization and needs of the people they are serving. In this case, World Vision staff lectured in classes at Messiah College and the students were able to interact with field personnel about the nature of their work and those they serve. In addition, World Vision staff showed various videos of their staff interacting with the OVCs.
- Reflection: students must reflect on their experience in terms of how it informs their notions of vocation and calling in life. In this case, students maintained journals and were prompted throughout the semester by the professor with probing questions that acted as a catalyst for journal entries. At the conclusion of the semester, students submitted a paper that chronicled the nature of their reflections over the semester and summarized the main ways in which this experience informed their notions of vocation.

In addition, several of the students from these classes and the professor worked over the summer of 2009 to complete the project and ready it for field usage. Field trials of the prototype occurred during the latter part of the summer of 2009.

2. CHARMS APPLICATION SUITE

2.1 Introduction

World Vision has a keen interest in the use of mobile technology to facilitate field data collection and rapid response systems. The convergence and ubiquitous nature of mobile devices and communications technology has created an unprecedented opportunity to reliably, securely and economically connect remote end points to central repositories of data. World Vision desired to pursue a *"proof of concept"* prototype project to explore the efficacy and appropriateness of deploying mobile applications in the developing world.

This research project developed a software application, using the JavaRosa [2010] open source platform that runs on a low-cost cell phone to automate the CHARMS data collection, alerting and reporting process. The mobile application allows for caregivers to record CHARMS data using the mobile application and transmit the data in real-time using an SMS-based wireless communication service on a low-cost Nokia phone. The application also includes real-time web and email based reporting and mobile phone alerting based on key events (food shortage, OVC not visited).

There are two different categories of system users. The first category of user is the mobile user. This is likely to be a caregiver or World Vision field staff. The second category of user is the web user. This is a user who actively uses the web application to enter agency, household, caregiver or OVC-related data. This might include a World Vision field manager, a CHARMS manager, World Vision National Office staff or a World Vision IT manager.

2.2 Future State CHARMS Process Model

The major improvement of the CHARMS business process focuses not in eliminating the main business processes, but on the way data is collected, transmitted, stored, analyzed and reported on. Instead of the caregivers submitting their activity reports to the CCC chairman, they will directly send the data to a central database via the mobile application.

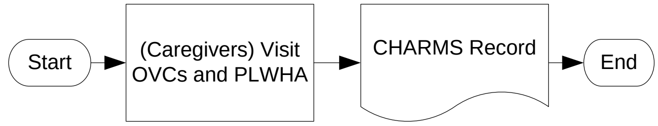

Figure 2. CHARMS future state process model

Once the data is stored in the CHARMS database, it can be accessed on-demand through a web application containing pre-defined reports. Unlike the existing CHARMS process where data is complied twice (at the CCC level and at the area development programme [ADP] level), data is only captured once in the new CHARMS process. Secondly, the compilation and aggregation of the data is automatically done in the new CHARMS process versus the current CHARMS process where data is manually aggregated. Finally, in the new CHARMS process, detailed individual home visit data can be easily obtained as there is full traceability from the aggregate reports to the individual records versus the old CHARMS process where data is not automatically traceable once it is aggregated. Though this information is not relevant for high level data consumers (e.g. for experts at the National, Regional or Global level), the existence of data in that traceable detailed form helps to perform root cause analysis which is difficult to do in the existing CHARMS process.

2.3 CHARMS Application Suite Architecture

Figure 3 shows the high-level architecture of the CHARMS application suite.

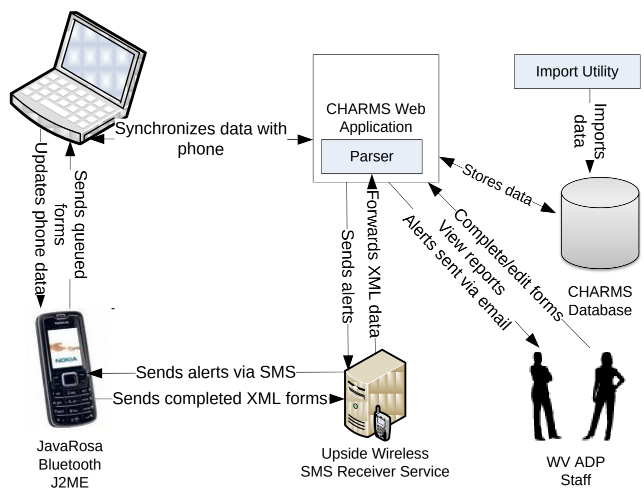

Figure 3. CHARMS high-level architecture

The CHARMS mobile application runs on the Nokia 3110c low-cost cell phone. The phone provides the J2ME platform [2005], which runs the CHARMS application. This mobile application is a customized version of JavaRosa [2010], an open source data collection tool that runs on J2ME. The JavaRosa framework includes a form engine as the primary means for data collection. After one of these forms is completed on our custom JavaRosa application, the CHARMS data is encoded in XML and transmitted as a series of SMS messages from the mobile phone over the GSM network. This data is sent to the Upside Wireless SMS receiver service [2010]. In turn, the SMS receiver service forwards the SMS messages over HTTP to a custom web application. The web application contains a parsing engine that decodes the XML-encoded form data and inserts the data into the MySQL CHARMS database. The CHARMS database allows for various CHARMS-related reports to be produced on-demand. The CHARMS database also monitors the data for various critical events identified (i.e., a child in need of food, etc.) and immediately transmits a message over SMS via the SMS receiver service to a mobile phone or email address to alert on a potential emergency. Finally, the desktop/laptop application is a Java program that is used to communicate with the mobile CHARMS application software and database over the Internet. It allows for software and client list updates to be made to each of the mobile phones and for data on the mobile phone that could not be transmitted over SMS to be transmitted to the database over the Internet.

2.4 Mobile Application

The process of designing a mobile application that would collect information for the CHARMS dataset originated by identifying an open source project that was extensible and easily customizable. JavaRosa [2010] was chosen for our mobile component as it is an open source project designed for data collection, analysis, and reporting using a low cost cell phone. Although JavaRosa proved to be a great fit, our objectives required much modification and customization of this application to support the World Vision CHARMS business process.

After choosing the JavaRosa platform, a cell phone was required to run the mobile application. For our purposes, we required a low-cost cell phone as the primary users would be volunteer caregivers. One of our constraints of the project required keeping the price of cell phone hardware down to reduce the cost of procurement of tens of thousands of phones and potential replacements for theft or damage. In addition, we spoke with the JavaRosa support community for recommendations on compatible cell phones that were known to be quality builds to withstand the conditions of rural areas of Africa. This research pointed to the Nokia 3110c which was determined to be the phone that would run our customized JavaRosa application.

The CHARMS dataset required a custom menu structure to provide easy interaction to the caregivers. The main menu (Figure 4) of the application allows a caregiver to complete a form for a monthly visit, household registration, or OVC registration. Our menu design was driven by the relational aspects of the objects in the CHARMS framework. For example, in CHARMS, a household contains one or more children. Therefore, on the main menu, if the caregiver attempts to perform a standard home visit with an OVC, the caregiver must first select the household they are visiting. Once the household is selected, a list of OVCs that reside within the selected household is shown (Figure 5). Note that in Figure 5, the names of blackened out to not disclose the names of actual OVC. This menu structure not only increases the efficiency of the caregiver, but also eliminates the chance of misspelling a name and helps us better track each OVC in the CHARMS database.

Figure 4. Mobile application main menu

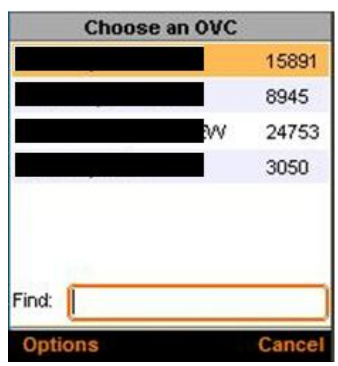

Figure 5. Mobile application selection of OVC

The JavaRosa project includes a module that allows for quick creation and deployment of question and answer forms by utilizing the industry standard XForms [2010]. Our team built forms to model the CHARMS dataset by creating simple questions using the various question types supported by XForms. Through these options, XForms allowed our team to focus our design to minimize the amount of typing required by the user to enter data into the system. Thus, we created more of an objective approach to CHARMS data collection. For example, the mobile forms were designed to utilize check boxes to allow for easy recording of key indicators by simply selecting items needed by the OVC or support that was provided from a checklist (food security, social/psychological assistance, abuse/neglect, etc.). Another use of XForms was using conditional questions. For example, CHARMS data collects information about the OVC's parents. Information about if the child's mother and/or father are alive or ill. Using conditional questions, if the mother or father is dead, we will not ask if that parent is ill. XForms transparently takes the answer to a previous question and displays an appropriate next question. A key benefit of this design includes reduced costs for data transmission since only selection numbers from a list were transmitted instead of long input text strings. This design also minimized the amount of typing and time required to enter data, thereby reducing the opportunity for erroneous data entry by the caregivers.

2.5 Wireless communications

Once the form has been completed, the JavaRosa application transparently creates an XML structure (from XForms) and sends the data via SMS. Depending on the number of characters in the XML encoded string, JavaRosa splits the XML string into a number of SMS messages in an organized way to deal with the issue of long form data (SMS messages are limited to be no more than 160 characters). Before the message is sent, the caregiver is presented two options based on the perceived emergency gained from the home visit.

The first option is "Send Now" which immediately sends the completed form via SMS. In order to keep data transmission costs low and anticipating that the phones may not have great cellular coverage in our target location, our team built the mobile application to save by default a completed form that was unable to be sent. As we indicate later in the paper, cellular coverage in our target location did not prove to be a problem. However, in the chance of limited or no connectivity, unsent forms would be placed in a queue and could be sent the next time the caregiver entered into a coverage area.

For the second option, if the results of the home visit did not appear to be an emergency, the caregiver could choose "Send Later", which would allow the completed form to be saved on the phone and sent to the CHARMS database at a later time.

A final piece to the mobile application was the need for an SMS receiver service. This service acted as an intermediary between the text messages and the database. Our team negotiated with Upside Wireless [2010], a large player in the SMS receiver service market, to handle receiving the text messages. The basic role of this service was to provide a phone number for the mobile application to send the SMS message. Upon receipt, the message would be forwarded over HTTP to our website, which parses out the data from the XML and stores it in the CHARMS database.

The SMS receiver service also provided the ability to send a message back to a specific cell phone. This feature was used to send various alert messages back to the caregivers based on specific events generated by the database.

2.6 Desktop/laptop application

The mobile application's SMS feature is an integral piece to successfully perform mobile data collection. However, while designing the application suite, our team realized in order for our solution to be scalable, a direct communication channel would need to be set up to the CHARMS database. We envisioned the need for OVC client lists to be pushed onto a cell phone issued to a caregiver if the phone was lost or stolen or if OVC data was updated via the web application. Further, we needed a solution that could drive cost down from solely relying on the GSM wireless network.

Using these requirements, our team determined that an application on an internet-connected computer would solve these issues. However, a connection between the computer application and the phone would need to be established. Bluetooth became the technology of choice to synchronize the phones with the computer application.

Bluetooth was chosen for a variety of reasons. First, programming libraries and large support communities exist for the standard (compared to proprietary cell phone USB connection cables). Second, Bluetooth was not limited to a specific phone manufacturer and USB connection cable. Rather, the standard can be utilized by any phone that offers Bluetooth capabilities. This was an important consideration as future versions of the mobile application might need to be run on a variety of cell phone makes and models.

Therefore, the choice of Bluetooth for data transfer between mobile phone and desktop computer proved to be favorable.

With this design decision, we created the mobile application to perform an initial configuration step that mapped the cell phone number to a caregiver. This operation allows the computer application to download the caregiver's entire client list of OVCs and households from the CHARMS database and sends this information to the phone via Bluetooth. Upon completion of this step, the caregiver could begin using the phone for data collection.

The second purpose of the computer Bluetooth application allows any unsent messages or unsynchronized data to be sent to the database from the phone via the computer application. The queued messages could be a completed form for OVC registration, household registration, or a home visit that was not thought to be an emergency and the caregiver chose "Send Later".

One issue we ran into was the case where a caregiver might register a child and would want to complete a home visit form during that visit. However, when the child is added on the phone, it does not have a unique key generated by the database. Thus, our team created a method to temporarily assign keys for that child, so the caregiver could perform their home visit. Upon synchronization to the database, these temporary keys would be converted to the database generated keys resulting in the synchronization of the CHARMS database and the phone data. In addition, during a synchronization using the computer application, any new or updated households or OVCs created from the web application would be added to the mobile application.

By incorporating the Bluetooth application on a computer connected to the internet, we are able to have much more flexibility in future designs. Additionally, through the benefits of cost savings and updated client lists, we could better manage the data between the cell phone application and the central CHARMS database.

2.7 Web application and database

A complimentary web application was designed for quality assurance and viewing data by ADP staff. The web application is not a vital piece for field data collection; however, it serves as a management window to view the status of an ADP.

The web application utilizes user management with various rights depending on the needs of the user. For example, an ADP manager might have the ability to create users within their specific ADP, but not in others. Thus, the web application serves as an interface for the ADP staff to help monitor the programme they are managing and review recent updates sent by the mobile phones and perform corrections and updates as needed. While not all data would be reviewed, an intuitive interface is available in the case of any needed changes.

The web application also provides the ability to enter in new data. Each of the forms available on the mobile application is available for the web application user. The web application does have additional forms for management of the ADP. For example, a form to add a CCC was created and an "OVC – caregiver assignment" form is available. The latter form allows an ADP staff web user to change an OVC to a different caregiver if such a circumstance were to come up.

Additionally, the web application provides the programmatic interface between the SMS receiver service and the database. The web application includes a robust parsing engine that takes the raw XML messages sent by the mobile phones, reconstructs, decodes, and stores the data in the CHARMS database. The database backend is created in such a way as to keep data organized and allows for easy reporting. This concept provides great flexibility in not only reporting but also in alerting (discussed later).

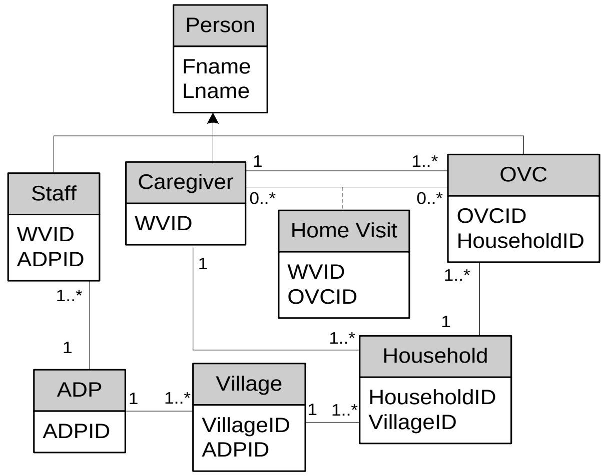

Figure 6. High-level database model

The CHARMS dataset, collected manually, includes redundancy within the data that was collected to keep the information organized. However, by storing the information in a database, our team was able to use an entity relationship model to abstract out super-types and sub-types to avoid redundancy and keep the information storage more structured and organized. For example, a super-type in our database model was the person class. This class contained three sub-types of WV staff, caregivers, and OVCs (shown in Figure 6). Similar to the structure used on the mobile application, the database allows one or more OVC to be contained in a household unit and a caregiver to care for one or more OVC. Additionally, the CHARMS dataset hierarchy included groupings by location and by caregiver allowing relationships to exist, which could be leveraged by reports.

2.8 Reports

The web application not only provides the ability for an ADP manager to monitor, edit, and enter new data, but one of the more powerful features is the reporting engine. Our team found reports to be easily designed and implemented due to the granularity of the data captured at the database level. These reports provide many new options to World Vision staff compared to the old aggregated data reports created from the manual method.

The old process of generating reports for stakeholders of World Vision includes a tedious process of manual data entry and aggregated data to produce a high level report. ADP managers and other ADP staff would spend several days aggregating data provided by caregivers from handwritten notebooks. Human error has become an issue in aggregating numbers and misreading entries written by the caregivers. Therefore, the accuracy of data from this manual collection method presents an issue to World Vision, as the reports help decide the amount to invest into the communities.

Additionally, this manual system burdens the larger national directors as they are required to take time to sign off on the data and declare the data valid. Following this action by national directors, a final head of CHARMS would need to prepare final reports to the World Vision stakeholders. By implementing the reporting aspect to the web application, this time consuming process is essentially removed.

Utilizing the structured relationships and near real-time data, the reporting engine leverages the database to provide highly accurate and extremely detailed reports. The central storage provides a streamlined approach to reducing the excess hours to complete and aggregate reports. In fact, the reporting section of the web application provides reports similar to the old reports produced as well as other varieties.

A few reports we created include a CCC report, annual report, ADP report, indicator report as well as others. The CCC report displays each caregiver, the households and the OVC for which they tend. The annual report is similar to the aggregated report used by World Vision with additional options. The ADP report lists all the CCCs in that ADP and the number of caregivers, households, and OVC in a specific

CCC. The indicator report can show percentages for each indicator (food, health, etc.) for a CCC, ADP, or nationally.

These new reports allow managers to drill down into more details if desired. For example, whereas previously reports were rather high level in nature, reports can now look at communities, ADPs, regions, or other levels as well. Due to the structured database, the types of reports can be rather dynamic and easily created to suit future needs for better allocation of funds and staff and other trending. For example, one report displays a caregiver and the number of households, OVCs, and visits that individual made during a specific time period. This report would allow an ADP manager to better identify areas of high volume to help reduce the burden on each volunteer caregiver.

2.9 Alerts

While database driven reporting helps greatly reduce World Vision staff's effort required to produce reports, alerts provide a means to benefit individual communities. Alerting was implemented in several areas. Each application allows for a better quality of service to communities aided by World Vision.

For example, our team set up a trigger that would alert an ADP if an OVC were under an extreme circumstance and needed immediate attention. One of the CHARMS indicators is the amount of food a child available to a child. In the pilot, if a child had not eaten for more than a day, we instructed the caregiver to mark the "Food" indicator and select the "Send Now" option to send the completed form. Once this form reached the database, a trigger was called and an email was sent to an ADP office where they could take immediate action and instruct staff where to deliver the available aid.

Alerting was also used for accountability reasons. For example, a caregiver is supposed to visit a child at least once a month. However, sometimes caregivers might lose track or neglect to visit a specific child. In such a case, a child might be ill and in dire need of attention. Therefore, the database periodically scans through each child's record and checks to see when the last visit was performed. If the child was not visited for a given length of time, such as 25 days, the database would use the SMS receiver service to forward an SMS message back to the caregiver's phone to remind them of which child needed to be visited and how much time elapsed since the last visit.

2.10 Data import/export

The features and solutions our application suite provides perform well as data is added to the database. However, initially, our team needed to add preexisting data into the database. For example, for the main menu to work as intended, we needed a list of the households and OVC each caregiver looked after.

We were able to obtain Excel spreadsheets of the current data for each caregiver in the pilot along with each OVC they cared for and the households they resided in. Our team wrote a custom script to import the data from the spreadsheets into the database.

While the data import tool proved to be successful, to be scalable, future consideration would be given for a more robust "Extract-Transformation-Load" (ETL) tool, such as the one Songini describes [2010]. Such a tool could import large amounts of data into the database from a variety of import formats. As a future consideration, it would be useful to allow data to be exported from the database in the form of well-formed Excel files as well.

3. PILOT PROJECT

A pilot project of the CHARMS application suit was conducted in Zambia during the summer of 2009. The pilot project involved the participation of various World Vision field staff and ten volunteer caregivers. A faculty member and senior student were involved in the Zambia fieldwork for approximately three weeks. The total pilot project was five weeks in duration. The ten caregivers who participated in the field experience were half male and female. Their education ranged greatly from: 30% primary school, 50% secondary school and 20% college. 80% of the caregivers indicated they used a cell phone to make a call prior to beginning this project. 60% of caregivers indicated they used a cell phone to send a text message prior to beginning this project.

3.1 Training

The pilot project began with a three day training session. The training materials (PowerPoint slides) were written and presented in English. The spoken words of the training were translated (in real-time) by one of the caregivers in the local language dialect. The training covered the following topics and audiences:

1. Phone training (primary audience: caregivers)
   a. How to use the phone
   b. Typing on the phone
   c. Creating, editing and submitting CHARMS forms on the phone
   d. Guidance on how to best use the mobile application

2. CHARMS application training (primary audience: World Vision ADP staff)
   a. Navigating the web application
   b. Creating, editing and submitting CHARMS forms via the web
   c. Guidance on how to best use the web application
   d. Web administration and IT manager training (primary audient: World Vision ADP staff and IT staff)
   e. Navigating the CHARMS application suite web site
   f. Logging into web application
   g. Administering users
   h. Forms
   i. Reports
   j. Alerts
   k. Problem Reports
   l. Installing the mobile application
   m. Desktop synchronization and updating the mobile application

The primary challenge of the training proved to be linking the manual approach to the mobile phone solution. Walking through each of the forms along with role-play activities proved to be effective. Additionally, pairing caregivers based on comfort level of the application allowed sharing of knowledge and understanding. A field ready reference guide developed in the native language would have been very beneficial.

3.2 Field Activity

Over the five-week pilot project period 247 OVC were registered via the import utility and 54 OVC were registered via the mobile application. 167 households were registered via the import utility. 32 households were registered via the mobile application. 142 home visits and 3 end home visits were recorded via the mobile application. All ten caregivers were actively involved in using the mobile application throughout the pilot project.

3.3 Field Assessment

Surveys given throughout the pilot revealed a positive attitude and experience with the mobile application. 100% of the caregivers believe the cell phone keeps information safer and more confidential than the paper method. 100% of the caregivers believe CHARMS forms can be completed quicker using the mobile application than writing down data in a notebook. 100% of the caregivers would recommend the continued use of cell phone to record CHARMS data for reasons ranging from time savings (90%), ease of use (70%) and more interesting to use (40%). The caregivers said the cell phone application either had a very positive (80%) or positive (20%) impact on the quality of their home visit.

For every home visit we observed, there were 1-2 communication bars on the phone (average of 2.07 bars per visit). However, when caregivers were surveyed, 3 (30%) of them indicated that they had difficulties sending data because they could not get a communications signal. It is not clear if the caregivers correctly understood the question, as our field work indicated that every one of the 15 household locations we visited had a communications signal.

We devised a data accuracy protocol, but the field staff was unable to complete it for personal reasons. However, the mobile application was designed to minimize typing by displaying more objective style questions. Therefore, we have a high degree of confidence that the information received by the cell phone application was complete and accurate. We have done some high-level spot checking of the data in the database for data accuracy based on our limited knowledge of the OVC and community caregivers. It appears as if data was accurately transmitted from the mobile phone into the database, although some number of typographical errors appears in the data.

In terms of process execution, there are two key metrics to focus on. Process duration (the amount of elapsed time required to complete a process) and process effort (the amount of work effort required to complete a process). During our field experience, we observed a negligible difference between the effort required between the manual approach and the mobile phone process for completing registration and home visits. From observation, the comparative effort required to produce reports using the manual process vs the automated process is dramatically different. With the automated system, producing reports is instantaneous vs significant effort and duration required to produce the reports with the manual process. In addition, the report generation process using the automated system drastically increased both precision and detail and cut the time to compile the reports significantly from the manual approach. Further, the reporting feature of the automated system allows for new reports of greater analysis and provides flexibility of reporting with the specific nature of the stored data. Process effort and duration have both been greatly reduced for producing reports using the automated system. All of the registration processes have duration of 2-4 weeks using the manual system; the registration processes have duration of 15-30 minutes using the mobile phone (given that registrations are instantly available). In short, process duration has been substantially reduced for reporting and getting data into the automated system.

One key aspect to the mobile system is the ability to send data in real time. During the pilot, an alert email was sent to WV staff if a caregiver selected a food shortage during a home visit. Properly implemented, this system could track other emergency issues to provide immediate response by WV staff. Similarly, an administrative email was sent to WV staff and an SMS message was sent to the caregiver if a child had not been visited within a given number of days to help develop accountability to the caregiver position.

We held focus groups with the caregivers to get their feedback on the system. Below is a summary of their positive comments:

- The automated system has reduced the paperwork and bureaucracy of the manual process.
- Caregivers felt greatly valued by receiving the mobile phone and were encouraged and motivated by it to complete their work.
- Households were intrigued and very positive about the mobile phone application.
- One caregiver reported being able to visit 15 children per day with the mobile application compared to visit 5 children per day versus the manual system.
- Members of the community are pleased to see their needs being sent directly to authorities.

Negative comments from the focus groups follow:

- One caregiver indicated that the desktop synchronization for the phone failed one time.
- One caregiver reported that the phone battery would run out of power and needed to be charged twice a week.

In terms of the battery charging issue, many of the caregivers paid to have their phones charged at a phone charging station. In a number of cases, the phone charging stations were not conveniently located. In the future, solar charges could be used to charge the phones. This is further discussed in the lessons learned section of the paper.

The GSM wireless communications network proved to be widely available and reliable for the regions of Zambia where the field experience was conducted. The average wireless communications cost to complete a mobile transaction was about $0.15. Industry experts, such as Louden [2009], suggest that GPRS/EDGE is more reliable and cost effective than GSM. However, from our field experience, the availability of SMS appeared to be much greater than GRPS/EDGE. This is based on the fact that our 3G wireless access for the Internet was very spotty in many parts of Zambia compared to the relatively common availability of a GSM signal from the mobile phone. It should be noted that JavaRosa supports GPRS and the development of GPRS appears more straight-forward given that you can assume the mobile application runs in an IP-addressable space. Thus, there is no need to deal with multiple SMS messages for a single form instance since the data would be sent over the IP network and not as a series of SMS messages. In addition, this means that a GPRS-based system would not require the use of an SMS Receiver Service.

We completed a high-level estimated costing model to deploy the system across a typical World Vision program region. The model includes estimates for the following costs: communication, equipment, software and support. The model assumes that a typical World Vision program in Zambia will register 4,000 OVC in year 1 and 600 OVC per year thereafter. It assumes that the number of end home visits is 5% of the OVC population per year. It also assumes that 50% of OVC registrations will happen on the mobile application and 25% of household registrations will happen on the mobile application. Based on these assumptions, we estimated that the average annual cost to support the CHARMS system would be about $35,000. There would be one-time fixed costs of approximately $60,000 for acquiring the mobile phones, solar charges, servers and related system software.

4. RELATED WORK

There are a variety of platforms available for creating mobile phone-based applications for rural patient monitoring in the context of community health. By platform, we mean a set of factored out common services that can be used to construct specific mobile applications to support a particular form of field collection of patient data. These common services include the definition and rendering of data forms, the validation of data during entry and the transmission of the data over one or more wireless transport protocols. Some of these platforms focus on the development of the client-side mobile application. They require the development of a structured system for persistent storage, reporting and analysis of the data. Other platforms include a server-side component for managing the data collected via the mobile client applications. In this survey of related work, we focus on open-source platforms as we believe such platforms offer cost-effective options for mobile field data collection among not-for-profit organizations. For each platform, we also reference an example of a community health mobile application written using the platform.

Open Data Kit (ODK), discussed by Anokwa et al. [2009], is an open-source client and server platform for developing mobile applications based on the Google Android operating system. Thus, any Android-enabled device can be supported by the ODK Platform. The ODK is being developed at the University of Washington with support from Google. The platform suite includes three components: ODK Collect, ODK Aggregate and ODK Manage. ODK Collect allows for form design, rendering and navigation, repeating sub-structures and data entry validation. Forms are based on the XForms [2010] standard. ODK Collect supports the standard data types such as checkboxes and plain text entry plus a myriad of rich media data types, including photos, audio, video and barcodes. ODK Collect supports the GPRS wireless transport protocol and Wi-Fi for data transmission. Data can also be transmitted via a USB cable. ODK Aggregate is a Google App Engine cloud-based server that hosts forms and aggregates submitted data results. ODK Manage supports managing the deployment of the forms-based applications to mobile phones. A good number of projects use the ODK platform, including a Kenya-based project focused on mobile data collection for home-based counseling and testing related to the prevention and treatment of HIV.

JavaRosa [2010] is an open-source client platform for developing mobile applications based on the Java Mobile Edition (J2ME) operating system. JavaRosa supports a variety of J2ME-based phones, ranging from the Nokia 3110c to high-end smart phones. It includes support for user authentication, forms definition, rendering and navigation, as well as data validation. JavaRosa forms are based on the XForms standard. JavaRosa supports the GSM (SMS) and GPRS wireless transport protocols for data transmission. Data can also be transmitted via Bluetooth or a USB Cable. No significant server or deployment support is offered by JavaRosa. A number of mobile field data collection applications have been written using JavaRosa, including CommCare, discussed by Svoronos et al. [2010], and GATHERdata [2010]. CommCare is a community health data collection application. GATHERdata uses JavaRosa to deliver a broader platform of support for mobile data collection applications, including server support for persisting and reporting on transmitted data. Our CHARMS mobile application was also written using JavaRosa.

RapidSMS [2010] is an open-source platform for developing SMS-based mobile applications. RapidSMS uses the notion of specifically defined and formatted text messages as the basis for its data collection. These text messages contain keywords that represent actions interpreted by a back-end web application to insert data into a database. The platform also includes workflow support that may trigger responses back to the user based on data received by the application. RapidSMS includes a web interface that allows users to view the data in the system. RapidAndroid [2010] is an implementation of RapidSMS that runs on the Google Android operating system. Several projects have used RapidSMS, including a project in Malawi to collect child nutrition data by Blaschke in 2009 documented by RapidSMS [2010].

FrontLineSMS [2010] is an open-source platform for creating SMS-based mobile applications. It also includes a Java-based simple forms management capability. FrontLineSMS does not require an Internet connection and allows field data to be stored on a laptop equipped with a SIM card. FrontLineSMS supports a wide variety of phones. It only supports the use of SMS for data transfer. It has been used in a wide variety of projects, including a project discussed by Banks and Nesbit [2008] at St. George's Hospital in Malawi where it has been used to support a rural healthcare network.

EpiSurveyor [2010] is a cloud computing based mobile data collection and reporting platform. It includes support for the design and deployment of survey forms on mobile phones to collect field data. EpiSurveyor supports a wide array of phones. EpiSurveyor also includes a cloud-based server environment for managing submitted form data and allowing this data to be viewed and analyzed via a web application. The data can also be exported in various formats. A number of EpiSurveyor community health mobile applications have been developed, including a project focused on containing a polio outbreak in Kenya described by the BBC News [2008].

OpenXdata [2010] is an open-source client and server platform for the development of mobile applications. It includes support for field survey form design and data collection. It also includes support for data validation. It includes server support for managing data collected via mobile form surveys. OpenXdata supports the GPRS wireless transport protocol. Data can also be transmitted via SMS and Bluetooth. OpenXdata supports a wide variety of phones. Cell-Life [2010] is a significant organization focused on the use of mobile technology to improve the lives of people affected by HIV in South Africa. Cell-Life is leveraging the OpenXdata platform in the development of its mobile community health applications.

The Nokia [2010] Data Gathering platform is open-source and includes client and server components. The platform allows for field survey questionnaires to be created via a web application and then downloaded to mobile phones for use. The mobile applications can run on any J2ME-enabled phone. Nokia recommends using smart phones such as the Nokia E71 and E72. Data collected via the mobile applications are then transmitted over GPRS or SMS to a MySQL database. A web application allows for reporting and analysis of the submitted data. A number of community health mobile applications have been written using Nokia's [2010] platform.

In the context of the related work, the CHARMS application suite is the first known fielded project that used JavaRosa to transmit mobile form data over SMS. In addition, it is one of the first known community health mobile application projects to be developed as a faculty-student service-learning project at an American undergraduate institution. The CHARMS application suite also contained some novel elements, such as reminder alerts to visit a specific child, that have not been widely reported on in the literature to date. Finally, the lessons learned from the CHARMS application field experience offer other researchers and practitioners insights about mobile field data collection and application development in a rural African setting.

In summary, there are a variety of mobile development platforms available for creating community health applications. These platforms are rapidly evolving and new platforms are likely to emerge in the near-future. Care should be taken to select the platform that best suites future mobile application development needs.

5. LESSONS LEARNED AND THE FUTURE

5.1 Benefits of the CHARMS Application Suite

The benefits of the prototype CHARMS system proved to be numerous.

- World Vision staff and caregivers were genuinely excited about the project and use of mobile phones.
- There were significant improvements in process efficiency and effectiveness (previously discussed) as the system simplified the overall process of data collection and reporting while improving analysis of data
- It demonstrates World Vision as an appropriate user of technology to donors, government and community members.
- It provides anytime, anywhere (Web) access to critical CHARMS data for World Vision staff on a global basis. Fully automated, on-demand reporting was also seen as a strong positive. Traceability reports to the individual level were seen as a huge value-add by staff. New Reports and analysis are now possible, including trend analysis, comparisons, etc. based on database-centered report/analysis capability.
- In theory, a donor facing application can be built to provide donors insight into ADP activity and results.
- By improving the quality, timeliness and completeness of CHARMS data process, beneficiaries (OVC) should be better served via active interventions, follow-up and analysis.
- It facilitates rapid field response to critical situations based on alerts and making critical information visible to the right people in a timely manner.

5.2 CHARMS Application Suite

The pilot in Zambia provided key insights into the benefits and areas of improvement for the CHARMS application suite. The lessons learned from the pilot project demonstrate the feasibility of such a technology to be used to help benefit rural communities and improve the quality of life.

5.2.1 Mobile Phone

The mobile device chosen proved to be a good fit; however, additional lessons learned became prevalent. The low-cost phone was a smart choice for both cultural and economic reasons. The rural villages where the caregivers volunteered were in poor standing. Thus, a high-end smart phone might have been insulting to the culture. Additionally, as World Vision is looking into mass deployment of a similar system, cost of tens of thousands of phones might be too drastic and unachievable. Overall, the low-cost Nokia handset proved to work well for the pilot.

A few observations demonstrated areas that would need consideration before a full deployment of the technology. The battery life and additionally cell phone features were quickly determined to be potential issues. For example, some of the caregivers used the phone for personal use, including features such as games, the camera, and even music. When the caregivers would use the phone outside of the mobile CHARMS application, the battery appeared to drain quicker. Therefore, one of the lessons learned for the cell phone is to consider locking down the phone and disabling functions to save battery life.

A few solutions to the battery life issue include solar chargers and weekly or biweekly charging at the ADP offices. Solar chargers can greatly benefit the caregivers as they would not be required to send the phones to be charged. The other option could incorporate current ADP staff trips to the villages each week to pick up the cell phones to be charged back at the ADP office.

5.2.2 Mobile Application

The mobile application proved to be quite successful in performing the function of a data collection device. Many design decisions appeared to work well, however improvements could have been made.

Despite initial worries, the learning curve for the multitap input system proved to be low. Even after the first day of training, most caregivers were inputting data into the fields without much difficultly.

The current XML parsing approach to data transmission and storage proved to be a tedious process. A small change in the forms translated to large overhead on reconfiguring the XML parsing engine. Other avenues exist including using binary representations of the form data and to serialize and deserialize the objects at the mobile device and the receiving database. Many foreseeable benefits to such an approach exist, including added security, reduction in messages sent, and ease of extracting data from the message.

The actual mobile application's user interface could have been improved for an even shorter learning curve. For example, some of the forms from the CHARMS dataset appeared to be rather subjective rather than objective. By working with experts in the field, creating objective questions could save caregivers time from manually inputting letters into the phone by creating drop down lists to select from. This type of data would also greatly aid in a more granular and consistent analysis by World Vision managers and staff as trends could be more apparent with structured data.

The language barrier became an issue as most caregivers struggled to understand English. Therefore, native language support could greatly improve the data collected and ease of understanding for the caregivers. Additionally options could include the use of pictorial icons to represent questions as well to help the caregivers who struggle reading better understand the questions as well.

Finally, while the mobile device worked great to transfer data and review it from a web application, no reporting features existed to do longitudinal analysis in real-time during visits. For example, in the manual approach currently used, the caregivers use a paper notebook that tracks their visits. During a visit, a caregiver can easily browse over the past few entries to identify the child's status as better or worse. Thus, a feature to allow a caregiver to look at the past few entries could improve the visit quality with the mobile device.

5.2.3 Communications

The communications proved to be better than expected with satisfactory GSM coverage even in rural villages in Zambia. At every location we visited during our observation of home visits there was at least one bar of service and in many cases two or more bars of service. In fact, the average signal strength was 2.07 bars out of four.

The internet access proved to be more of a challenge and may potentially have a negative impact on communications above GSM. In our experience, GPRS coverage was spotty and often unavailable to use in most locations.

The use of an SMS communications service proved to work well for the application suite. Future considerations could include creating an in-country SMS receiver service to reduce the cost of long distance text message fees. Overall, the communications aspect of the project proved to be a positive experience.

5.2.4 Computer Application

The desktop application provided a reliable and scalable method for installing the mobile application, distributing client lists, and synchronizing data to the central database.

The phones appeared to provide enough local storage as to not be an issue with saved, unsent forms. Thus, data storage between synchronizations with the computer Bluetooth application did not prove to be a problem.

The desktop application worked rather well for most of the phones. However, one phone out of the ten had an issue with connecting to the computer application via Bluetooth. Additionally, some of the ADP offices do not have internet availability at all times. This fact demonstrated the need for a queuing functionality for the computer Bluetooth application to hold data before attempting to transmit over the internet.

5.2.5 Reports

The reporting engine worked well and demonstrated the advantage to the collection and storage of granular data. In fact, the creation of new reports was added to showcase the ease and power of the database and the reporting utility.

The reporting feature also proved to allow better knowledge and information for a variety of individuals. After the pilot project, it became apparent that multiple new reports could greatly aid in decision making for programme managers and the community chairperson.

The primary lesson learned with the reporting function was the benefit of structuring the CHARMS dataset into entity relationships. This structured format allowed for a multitude of report possibilities to allow for global core metrics, national office metrics, ADP specific metrics, and even community metrics.

5.2.6 Alerts

Alerting seemed to be the function that can potentially have the most impact on communities themselves. By creating intelligent algorithms, automated alerts could be sent to ADP staff based on trends identified by the tracked indicators.

While the current implementation of the CHARMS forms was rather rudimentary, rules and smart algorithms could replace the human decisions of whether or not to send an alert. By deciding on a standard as to determine when to send an alert, the database can trigger meaningful email alerts to ADP managers who can quickly provide aid to an in-need child.

5.3 Service-learning Impact on Students

All students were required to produce a 3-5 page paper that chronicles their learning and discovery of community service throughout the semester. The instructor provided prompts throughout the semester for the types of information that should be included in the service learning and community engagement reflections document. These student reflection papers clearly demonstrated the profound impact that this service-learning project had on the students. The below excerpts from some of the student papers illustrate the impact of the project on the students.

- "While this has turned one of the greatest learning experiences of my life – it started out one of the rockiest! I can speak for the team when I say I felt in over my head in a sea of code and technological knowledge that I did not have any awareness of before this past semester. Mobile development was completely foreign to me. Words like open source, GPRS, JavaRosa, Parser, and SMS Receiver Service were being thrown around, and the learning curve seemed steeper and steeper."
- "This project has changed me as a student. I've learned so much in 8 months – I know anything is possible with determination and hard work. It has changed my outlook on the potential of technology to better humanity with the tools necessary to help people in need. This project has also changed me as a person. It has taken my Computer Science education at Messiah College and completely altered the meaning of it. I now fully understand the importance of using your major to glorify God. In my four years at Messiah, I worked to achieve high grades for my own personal standards – while I worked on this project, all I could think about were children who needed help. The project to me was no longer a letter grade, because you can't attach a letter to a child's life."

5.4 The Future

There are many future directions for this project. The current CHARMS prototype system was conceived as a field facing application with limited regard to the implications of the application and support required by regional offices and national offices in terms of reports, analytics, etc. In the future, consideration should be given to longitudinal analysis, comparative analysis across individual programs, countries, regions, etc.

Using the mobile platform opens a wide range of potential uses in the future. Health clinics could integrate with the system allowing for OVC referrals, appointments, and rapid response in emergencies. Similar to clinical algorithms is the notion we termed *support algorithms*. Such algorithms would allow caregivers to more objectively answer questions. For example, CHARMS asks the question: "Is the household poor?" Presently, the caregivers do not consistently answer this question using the same criteria. We are exploring the possibility to define criteria that would allow caregivers to consistently and objectively answer questions. Finally, the integration of GPS could allow WV to analyze trends and geographic coverage of programmes and OVC.

This work has been very well received by World Vision. World Vision is currently working with other large NGOs to obtain funding to support the development, deployment and support for a series of mobile application projects in the future.

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