Development and Implementation of a Loosely Coupled, Multi-Site, Networked and Replicated Electronic Medical Record in Haiti

William B. Lober
Clinical Informatics Research Group (CIRG)
Biobehavioral Nursing and Health Systems, School of Nursing,
University of Washington, Seattle, WA
1-206-616-6685
lober@uw.edu

Stephen Wagner
Clinical Informatics Research Group (CIRG)
Biobehavioral Nursing and Health Systems, School of Nursing,
University of Washington, Seattle, WA
1-206-685-8596
shw2@uw.edu

Christina Quiles
Clinical Informatics Research Group (CIRG)
Biobehavioral Nursing and Health Systems, School of Nursing,
University of Washington, Seattle, WA
1-206-685-7789

ABSTRACT
Since 2005, we have been developing and implementing an electronic medical record (EMR) that supports both individual and population health care for HIV-infected patients in Haiti. The need to support countrywide monitoring and evaluation drove early architectural decisions to support linking systems under conditions of network uncertainty. Despite numerous challenges including frequent power outages and inadequate Internet access and support, the system (iSanté) is currently implemented in 55 clinic sites nationwide, tracks over 41,000 patients, and synchronizes patient data between in-country sites and the central site databases on a daily basis.

Categories and Subject Descriptors
C.2.1 [Computer Communication Networks]: Network Architectures and Design – satellite communication, network communications, network topology

General Terms
Management, Documentation, Performance, Design

Keywords
Database Replication, EMR, VSAT, HIV

1. INTRODUCTION
Haiti is the poorest country (per capita GDP) in the Western Hemisphere, with 80% of the population living in poverty. The agricultural sector is mainly small-scale subsistence farming, and is vulnerable to frequent natural disasters, the effects of which are exacerbated by the country’s widespread deforestation. Following both political and economic instability the communications infrastructure is among the weakest in the western hemisphere, but approximately 7.5% of the population have used the Internet, a level of usage which is similar to that in Kenya, which has a similar GDP, and high compared to other similar African and Asian economies.[1]

Haiti accounts for the largest HIV burden in the Caribbean, despite a recent stabilization of prevalence rates.[2] Between 2.2% and 3.8% of Haiti’s population is living with HIV—one of the highest percentages outside of Africa—and AIDS remains the leading cause of death among adults age 15-44.[3] In addition, malnutrition, deficient water supplies and sanitation services, and high rates of TB infection exacerbate the effects of this disease. Antiretroviral therapy (ART) throughout the Caribbean reaches just one in four (23%) of those who need it. Haiti and the Dominican Republic together account for nearly 75% of the 230,000 people living with HIV in the region.[2] Lack of access to ART by infected persons, has led to a high rate of vertical transmission of HIV (27-37%), and therefore to a large population of pediatric HIV patients.[4]

As Haiti scales up efforts to treat this personally and economically devastating disease, it needs a system both to support the care and treatment of these patients, and to conduct population-based monitoring and evaluation (M&E) of publicly funded and nationally driven interventions. These M&E needs are shaped both by the formal reporting requirements of donor nation programs such as the US-sponsored President’s Emergency Plan for AIDS Relief (PEPFAR), as well as those of international organizations such as the World Health Organization (WHO) and UNAIDS. In addition, the system must provide data on quality of care measures to inform improved service delivery and strengthened national program
implementation and support population-level research to better understand and mitigate the epidemic.

For the past four years, we have endeavored to address both clinical and M&E needs through the development and implementation of a networked and replicated electronic medical record (EMR) to support the care of both individuals and populations.

In early 2005, at the request of the Centers for Disease Control and Prevention (CDC) and the Haitian Ministère de la Santé Publique et de la Population (MSPP), the Clinical Informatics Research Group (CIRG) at the University of Washington began working with the International Training and Education Center on HIV (I-TECH) to develop an electronic medical records (EMR) system for Haiti. I-TECH was established in 2002 by the Health Resources and Services Administration (HRSA) in collaboration with the CDC, with the mission of supporting the ongoing development of health care worker training systems that are locally determined, optimally resourced, highly responsive and self-sustaining in countries and regions hardest hit by the AIDS epidemic.

2. OBJECTIVES AND CHALLENGES

2.1 Considerations

The design, development, and implementation of the project have, from its inception, been driven by a number of considerations, including:

- Uneven infrastructure in Haiti, requiring both a computerized system for efficiency and an integral paper-based system for fault tolerance;
- Language localization in French and English;
- Reliance on highly structured information to support population-level aggregation;
- Existing clinical workflow including the specific culture of record-keeping;
- Local clinical site IT capacity including limits to electrical power, paper, toner, and Internet access;
- Need to provide information directly to users in support of clinical care, quality improvement, and reporting capability;
- A phased implementation encompassing paper-based data capture as well as interactive computerized forms entry supporting incremental changes in workflow and processes;
- Incremental validation against, and replacement of, existing population reporting processes;
- Local site, national, multi-agency, and international support for further development and implementation of the system;
- Implementation in pure web architecture.

2.2 Unique Challenges in System Design

While we subscribe to the widely held opinion that participatory design is almost essential to the successful adoption of an IT intervention, the initial requirements for the project were driven by PEPFAR (President’s Emergency Plan for Aids Relief—the funding source for the project) programmatic needs. The structured nature of the data collection and the data model, as well as support for site-level data quality and for quality of care metrics, were driven by prior experience with a university-based HIV research and reporting system. The MSPP and the strategic information office of the CDC in Haiti drove both initial interaction design and national reporting requirements. Information used in iterative design improvements to the system typically did not come directly from end users or usability testing, but through the site data quality staff, the CDC site support staff, and the field staff and management of the I-TECH Haiti office. These design criteria, and our limited ability to directly engage our end users, led us to make a series of both functional and technical choices in implementing the system. Cultural differences, especially with regard to language (English, French, Creole, and even Spanish are in the mix) as well as the geographical separation between Seattle and Haiti personnel also made rapid consensus on system requirements and design decisions extremely challenging.

Beyond the above considerations, it was well understood that inadequate power and Internet access would be significant barriers to success. Most facilities, even in the main city of Port-au-Prince, lack dependable power to support computer equipment due to reliance upon public power and inadequate backup generators.

Issues of hardware failure, climate, difficult ground transportation, and political instability gave rise to concern for data integrity. Our Haiti-based colleagues often asked us to confirm that we would maintain complete backup of the data in Seattle. This suggested that redundant storage via off-site network transmission was imperative.

Haiti does not have any buried cable for Internet—all sites at present depend solely upon VSAT (Very Small Aperture Terminal) for Internet communications, at various tiered support levels. We expected that network communication would be quicker between a site in Haiti and Seattle than between two sites in Haiti because of the satellite network topology, and this has proven to be true.

I-TECH network technicians maintaining a site’s satellite dish

Responding to the need for data redundancy and coping with the characteristics of the VSAT networking were both critically important to the success of the system.

3. METHODS AND ARCHITECTURE

3.1 System Use Cases and Workflow

We developed a hybrid paper-electronic workflow with the intent to move to a fully interactive computerized system once the system was operational in-country. The forms are organized around the clinical process, with separate components for
registration, intake and follow-up clinical visits, laboratory, pharmacy, counseling, and discontinuation, and with separate forms for adult and pediatric care. We had to reject preprinting forms with identification or historical information due to unreliable printing capacity at the clinic sites, though that would have afforded considerable workflow benefit.

3.2 Web Server Architecture
We chose to use open source tools as much as possible, tempered by our awareness that local Haitian expertise was more aligned with commercial products. All initial in-country deployments were on Windows servers with WISP (Windows, Microsoft Internet Information Server, Microsoft SQL Server, and the PHP scripting language). We currently have in-country deployments in both WISP and LAMP (Linux, Apache Web Server, MySQL, and PHP).

Lightweight Directory Access Protocol (LDAP) is used for system authentication and authorization. We have not chosen to replicate our LDAP directories except in very limited ad hoc fashion; each site maintains its own unique LDAP directory.

3.3 User Interface and Reporting Infrastructure
We initially avoided using JavaScript in the user interface because of our concerns with its stability, portability, and suitability in the VSAT environment. However, our newer releases use the Ext JavaScript library extensively—this has allowed us to move field validations to the browser and given us a much richer set of form widgets and interactive user interface capabilities. The improved interactivity possible with client-side libraries has opened up more options for point-of-care systems. It is also more feasible to have a thick rather than thin client now that our larger sites are running web servers locally.

The reporting subsystem uses PHP for simple graphs and tables as well as Jasper Reports, which allows us to write a single report that can then be output in a variety of document formats (PDF, HTML, Excel, etc.).

3.4 Network Architecture
Because we use standard web server architecture, we were able to develop and provide the system to our pilot site in Haiti very rapidly in application service provider (ASP) mode—within about three months of project inception. This deployment involved a network consisting of VSAT Internet access on the Haiti side and utilization of one of our CIRG group servers at the University of Washington. Performance was relatively poor, as expected, but we had the advantage that our initial implementation was very lightweight. As the application functionality increased and the web application became weightier, there was an increasing desire, especially at the larger sites, to go local—which we referred to as “in-country.” These were stand-alone sites running their own web server and local area network. Stand-alone sites are freed from the VSAT network and can work independently, only requiring it for the short burst of data sent daily during replication transmissions.

3.5 Database and Data Model
The system uses a hybrid relational model, employing a combination of fully normalized tables to gain maximum flexibility for the capture of laboratory, diagnosis, and treatment observations while also employing de-normalized tables for ease of reporting, simplicity in the development and implementation of interactive forms, and optimal performance during data entry and retrieval. The data model also supports the computation of summary data via data warehouse tables that are kept up to date throughout the working day via an asynchronous process. These tables provide for improved interactive performance as well as for more sophisticated data analysis. As the system software has evolved, the database schema has evolved as well, with small and large changes to the schema coming with each new release of the software. Each release checks the current database schema version and upgrades it automatically. The standardized nature of SQL and relational databases permits migration of the database schema from MySqL to MS SQL Server and back to MySqL with relatively little extra effort.

3.6 Database Replication
Our replication architecture is generic and independent of the LAMP/WISP implementation; each source site generates daily transaction files that can be transmitted over the Internet or via “sneaker-net” as desired. The replication algorithm is able to determine changed database records since the last replication read. Changed records are written to a JSON-like transaction file (all data not transferred since the last replication). Globally unique site and database identifiers (GUIDs) are contained within each transaction record. Each site polls the central site(s), and uses CURL to send these transaction files to our central database site. This is attempted until successful. Reads, transmission successes, and transmission failures are logged to the source database. Transmitted files are retained as redundant backup at the site.

A corresponding load program at the central site(s) reads all files and applies their data to the central databases. The loading algorithm depends upon uniqueness of the records to properly insert or update records as appropriate. Both a unique GUID and its logical key (the site identifier, patient identifier, visit date and specific object key of the record inserted) are specified. Loads are logged in the target database(s) and transmitted transaction files are retained at the central sites for redundant backup. In Figure 1 below, dotted lines represent file transfer paths, while solid lines represent web server communications paths.

![Figure 1. Replication Architecture](image-url)
is essential to this approach, and is responsible for the multiple uses it affords.

4. DISCUSSION

4.1 Trajectory of Adoption

The paper forms were first used by pilot clinical facilities in January 2005. The first use of the computerized system (now called iSanté) to enter clinical data was in April 2005 by Grace Children’s Hospital in Port-au-Prince. Grace used iSanté in ASP mode, connecting to a server located in a secure facility at the University of Washington.

A handful of clinics began using the system in ASP mode at the beginning of 2006. By the end of 2006 iSanté had gone through three significant enhancement releases and was used by 16 different clinics, all in ASP mode.

The first in-country server was installed in April of 2007; by June, six additional sites were hosting their own servers. Now in mid-2009, iSanté has gone through four additional enhancement releases in the areas of reporting, pediatric patient support, replication, and a module for prevention of mother-to-child transmission of HIV (PMTCT). iSanté is used by 55 clinics, of which 24 are hosting their own servers.

Our network continues to grow. New sites may start by using our ASP server and then migrate to their own server, while others start immediately with a local server. Our newest installations are exclusively on LAMP for a number of reasons. Our Haiti partners have found the LAMP version easier to install, they feel it is more reliable, and, because only open source software is used, they estimate that it saves more than US$3,000/site in software costs (J. S. Vallès, email communication).

4.2 Installation, Implementation and Deployment

Systems must be easy to install, configure, and use. We have adapted iSanté in various ways to make these steps easier with each new release. This is particularly important considering the scarcity of clinical resources in Haiti and the limited availability of health care workers. There remains a steep adoption curve to overcome in implementing the EMR and integrating it into site workflow. As in most cases with the adoption of an EMR into a clinic, a large amount of preliminary effort is required of the clinicians and health care staff before any foreseeable benefits of the system can be realized. An ongoing major issue is the backlog of patient records that need to be entered into iSanté. Procedural solutions to this problem include creating task forces of data entry persons to aid in resolving backlogs, and designing a workflow around entering a subset of critical information for active patients first, then following up with inactive patient data. A technical solution has been the implementation of an electronic registry interface where a minimal dataset can be entered to facilitate quick entry of patients into iSanté.

Automated reporting has been adapted throughout the life of iSanté to better meet the needs of the sites, the Ministry, and sponsoring entities and stakeholders. Insufficiencies in the completeness and accuracy of data continue to prevent the full benefit of this reporting from being realized. A data quality effort is underway to resolve this.

4.3 Standard and Open Source Software

Low licensing cost is important for sustainability, as is local technical expertise. We tried both open source and mixed platforms to accommodate these criteria. However, we feel that simplified installation and configuration are perhaps the most critical pieces for sustainability, and best supported by open source software. While we have not yet created a development community around this system, open source approaches may better support local development and sustainability.

4.4 Data Model

The data model has evolved as iSanté has been enhanced. The addition of linkage between intake/follow-up visits and labs/prescriptions, tracking of next visit information, and addition of pediatric patients are just three feature areas that required database schema changes. Changes to the data model have in turn required us to develop more sophisticated tools for manipulating the schema, for generating reports, and for facilitating data entry. The result is greater system complexity and the potential for poor performance. Most performance issues have been dealt with straightforwardly via judicious use of indexes; compared to large-scale banking or finance applications, these databases are relatively small—often full-table scans yield acceptable performance. Our use of asynchronously generated summary warehouse tables has also facilitated generally good performance for interactive use and for reporting. Sites still using our ASP server in Seattle must oftentimes suffer with quite poor Internet performance; the rapid adoption of in-country local clinic servers is undoubtedly due in part to unhappiness with ASP mode.

4.5 Replication Metrics

Replication has been remarkably successful, given the constraints under which we operate. The relatively small amount of data transmitted and the loosely coupled nature of the overall data model are part of the reason why. Figure 2 below plots a typical site’s file transmissions in kilobytes between March 2008 and early June 2009. This site has 1,131 registered patients. Horizontal length of segments gives an indication of lapses in transmission. For instance, the long segment between September and October 2008 likely represents severe weather conditions in Haiti during that period. The peaks early on in the plot represent additional activity to reduce the backlog of patient records not yet entered to iSanté. The plot shows the steady-state nature of transmissions once iSanté is established at a site.

![Figure 2. Replication KBs Transmitted](image)

Another interesting metric is to compare the number of individual replication file transmissions from a site to the number of failed transmissions from that site. Figure 3 shows this for a number of sites in Haiti. Fortunately, and perhaps unexpectedly, the failure rate is relatively small in most cases. Sites with a relatively small number of successful transmissions and a relatively high failure rate (i.e., sites 65 and 135) should be looked at more carefully.
Replication has proven to be useful above and beyond its initial function of merging data into our central databases for system-wide backup, consolidated reporting, and analysis. It has been useful for recovery, because the central database can be unloaded for a specific site and then applied to that site as a recovery process. In many specific cases, this has proven to be a simple way to recover a site. It has been used to convert sites from WISP to LAMP. It is used for upgrading and enhancing the database’s concept model as it becomes more robust; other lookup tables in the database are maintained and enhanced in the same way. Replication is also used for transfer of patient records between sites within the country.

4.6 Unexpected Usage Patterns

In the last year, there has been significant progress in the implementation and use of iSanté. Overstepping our initial development timeline, sites that have resolved their backlog and have sufficient technical resources have begun to interactively enter forms into the EMR during patient visits, instead of transcribing from paper forms. In addition, some sites use the prescription forms as a primitive computerized physician order entry (CPOE), filling out a prescription form for patients, flagging the form for the pharmacist, and sending the patient to the dispensary to pick up their medication.

Maintaining a fault tolerant system in the midst of interactive data entry has required the definition of a workflow appropriate for backup of patient records. In addition to replicating the data to a central server, sites that are doing interactive data entry have been asked to periodically print the patient clinical summary (a consolidated report of all the data entered for the patient) for use in the case of an extended power/system failure.

5. Conclusion

Perhaps the most important conclusions of our work thus far are that success with M&E on a national scale is best driven by creating value at the local level, and that we must closely examine our preconceptions of what health care providers want and need in resource-limited settings. There is a strong desire in Haiti to have efficient, comprehensive clinical information systems, and a strong desire to deploy them to support general health care delivery.

Through our development and deployment of a national, networked EMR in this challenging setting, we hope we will continue to make contributions to both the care and treatment of people living with HIV in Haiti, and to a general understanding of how to implement complex, linked information systems in resource-limited settings that support both individual and population health.

6. Project Contacts

Bill Lober, MD, MS, I-TECH EMR Project Informatics Lead, Associate Professor, University of Washington Center for Public Health Informatics, lober@uw.edu

Christina Quiles, Technical Program Manager, Clinical Informatics Research Group (CIRG), University of Washington, nodinX23@uw.edu

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8. References


