Design and Deployment of a Blood Safety Monitoring Tool

S. Thomas, A. Osuntogun, J. Pitman, B. Mulenga, and S. Vempala

Abstract—**Blood is a scarce resource critical to the management of a variety of life-threatening medical conditions. It can also be a medium for the transmission of infections, including HIV. Monitoring the quality and quantity of available blood, essential to utilizing it as effectively as possible, has been a challenge in many developing countries. This paper describes the design and implementation of a web-based tool to monitor the collection, screening and distribution of blood in developing countries. This project was conducted under the auspices of the US President's Emergency Plan for AIDS Relief (PEPFAR), which funds blood safety projects in 14 countries in Africa and the Caribbean. We report results from a usability study, formulate relevant design principles and discuss prospects for long-term sustainability.**

Index Terms—**developing nations, health, ICT and development, Internet, medical services**

I. Introduction

Blood is a scarce resource worldwide. But the scarcity is particularly acute in the developing world. In 2008, the World Health Organization estimated that although 80% of the world's population lives in developing countries, these countries only collect 45% of the global blood supply [1]. Effectively managing this scarcity—deciding who gets blood and when—is a challenge for health care systems throughout the developing world. Blood is also a highly effective medium for the transmission of blood borne illnesses, including HIV, hepatitis and syphilis. The WHO estimates that between 95-10% of all HIV infections worldwide may be linked to unsafe blood transfusions. In 2004, the US President's Emergency Plan for AIDS Relief (PEPFAR), identified blood safety as a key element in its comprehensive HIV prevention strategy. Since then, PEPFAR has committed $192 million in funding to National Blood Transfusion Services (NBTS) in 14 countries (Botswana, Cote d'Ivoire, Ethiopia, Guyana, Haiti, Kenya, Mozambique, Namibia, Nigeria, Rwanda, South Africa, Tanzania, Uganda, and Zambia). To track, monitor and evaluate the impact of this funding, the Centers for Disease Control and Prevention (CDC) worked with global blood safety experts to develop a set of program indicators and a Microsoft Excel-based data collection tool. In this paper, we describe a web-based data collection and management tool developed as a collaboration between CDC, the Georgia Institute of Technology and the participating countries. The tool expands on the Excel-based system to facilitate the efficient and accurate collection and analysis of more than 80 indicators from 14 countries.

S. Thomas, A. Osuntogun, and S. Vempala are with the Georgia Institute of Technology, Atlanta, GA 30332, supported in part by a Raytheon Fellowship and the NSF.

J. Pitman is with the Centers for Disease Control and Prevention, Global AIDS Program, Atlanta, GA 30333

B. Mulenga is with the Zambian National Blood Transfusion Service, Lusaka, Zambia

II. Related Work

Several ICT projects have focused on improving the health care system in developing countries. These projects have had several different themes including development of web-based tools for information tracking, implementations of electronic medical record systems and telemedicine systems to support education of clinicians and referral of difficult cases for further review.

In [2] a web based information system supported medical record keeping and tracking of HIV treatment in Haiti. While this work is similar to our work in that there is a centralized database and an online interface for certified users to enter and track data, the population and scale of users is quite different. In our work we focus on users in 14 different countries worldwide with varying levels of internet access and technical support. We also present evaluation of the system by prospective users which indicated that the system was easy to adapt to and use.

Blaya *et al* in [3] created a web based tool, e-Chasqui, to improve the timeliness and quality of reporting tuberculosis laboratory data in Peru. This national system is able to provide access to a hierarchy of users in health centers, regional laboratories and the national laboratory to test results. These results are then used to prescribe treatment regimens for patients at the local level.

In analyzing the use of web-based tools, Marquez found that such tools provide notable enhancements in quality improvements in health care [4]. The web-based tool described in this paper is an example of such tools.

III. Problem and background

Monitoring the development of a national blood service requires data from a diverse set of sources. The WHO, in its Aide Memoire for National Blood Programmes [5], advises developing countries to build national blood strategies around four "key areas", including: The establishment of a nationally-coordinated blood transfusion service; the collection of blood only from voluntary non-remunerated blood donors; universal testing of all donated blood, including screening for transfusion-transmissible infections, blood grouping and compatibility testing; and the reduction of unnecessary transfusions. These broad recommendations can be further categorized by technical area:

1) Policy information is needed to track progress in standardizing procedures (e.g., laboratory testing) and establishing a blood service's legal authority over the national blood supply,

2) Social and demographic information is needed to identify, recruit and retain blood donors with low behavioral risk profiles for infection with HIV and other transfusion-transmissible infections (TTI),

3) Scientific data are necessary to track the prevalence of infectious markers in donated blood and to monitor laboratory performance,

4) Administrative data are needed to measure human resource and logistical capacity, and, in many cases, to manage large grants from bilateral or multilateral donors, and

5) Medical information is critical to ensure that blood is used appropriately and to monitor patient outcomes.

A blood service could potentially collect data on hundreds of variables.

With PEPFAR support, CDC and its international partners developed a limited, but comprehensive, set of programmatic indicators. These indicators are broken down into a subset of variables which cover the five technical categories described above.

Collecting these data from 14 developing countries with different data systems was the principal challenge associated with this project. To begin to address this problem, CDC developed a standardized data collection tool using Microsoft Excel. This format was selected for its ease of use (data managers in all of the PEPFAR countries were familiar with Excel) and its ability to be transferred via e-mail over low bandwidth internet connections. A version of this tool, with pre-programmed formulae and skip patterns, was field tested in 2007. While countries reported the tool was easy to use and met the programs' PEPFAR-related reporting needs, the pilot phase also revealed several weaknesses in the use of a spreadsheet-based tool, including:

1) Difficulty in tracking versions of multiple files in circulation as new data were entered and re-saved by different users,

2) Countries' inability to quickly modify, clean or correct a data set after a file was submitted to CDC,

3) The potential for transcription and other errors as multiple versions of the spreadsheet were merged (e.g., from multiple regional centers) prior to submission to CDC.

4) PEPFAR requires quarterly reports from each country, but blood is collected, tested and utilized continuously. This meant the Excel-based tool could sit idle for weeks or months at a time.

These challenges increased the possibility of inaccurate, or out-of-date, reporting. To illustrate, in several countries, regional or provincial blood service offices would would fill out and email the Excel-based tool to the national manager, or save the report on a disk or flash drive and send the disk back to the national manager by road. The national office would then compile all the results from the different provinces and send a final report to the CDC. Each update from a regional center required re-entry and re-aggregation of the data, leading to multiple versions and increasing the chance of error.

To address the weaknesses of the Excel-based tool, the team developed an Internet-hosted database accessible with a standard Web browser. Storing the data in a Web-based relational database provides several key benefits compared to ad hoc circulation of a spreadsheet file:

1) There is a reliable, authoritative source of reported data. (No more wondering which file among several is most accurate.)

2) Data is continuously available throughout the reporting period allowing immediate modifications and corrections. (No files "in transit" or lost via email.)

3) The system can support automated, real-time aggregation of reported data from multiple sources with less risk of transcription errors.

4) Full change tracking with audit logs is available.

Additional benefits derive from the system's use of a standard web browser interface:

5) Access is ubiquitous and available on all modern computing platforms.

6) End users are familiar with web browsers (e.g., Internet Explorer, Firefox, Safari).

7) Updates and enhancements can be easily managed and deployed.

The specific design principles for the system follow directly from its requirements:

1) [Network compatibility] The system must support access through low bandwidth, dial-up connections, as high bandwidth connections cannot be assumed for all users.

2) [Intuitive interface] The system must provide a user experience appropriate for blood safety staff who may be familiar with the use of standard office software (e.g., web browsers, spreadsheets, word processing), but who lack high-level IT training.

3) [Security] The system must provide appropriate security and access control for aggregated health information.

4) [Flexible and adaptable] the system must be easy to manage, adapt, and expand. For example, it must be easy for administrators (many of whom will not be trained IT managers) to add new countries, regions or users, and ensure that data entered by these new sources are properly aggregated. (Based on previous experience, the CDC did not feel the need to support languages other than English

in the initial deployment. The site was designed, however, to accommodate localization to alternate languages should that be desirable in the future.)

The tool was designed via collaboration between CDC, Georgia Tech, and NBTS data managers in the 14 PEPFAR countries. The Zambian National Blood Transfusion Service (ZNBTS) agreed to host the pilot phase described in this paper. This partnership was made possible through a program at Georgia Tech which seeks to leverage student and faculty expertise to address social and development problems in low-income settings. Funding for logistics during the pilot project was provided, in part, by PEPFAR and the ZNBTS. The Georgia Tech team's time and expertise were donated gratis as part of a course.

After multiple rounds of testing, user feedback and usability studies (described later), it was evident that the web tool was highly welcomed by NBTS data managers in Zambia and elsewhere. Their feedback led to changes both in the user interface and in the architecture of the system. Further, data managers expressed a strong desire to use the system not just for reporting but also as a decision informing tool. We redesigned the system to allow individual countries and individual centers within countries to choose the frequency of data entry (to match the frequency at which data was actually being aggregated physically), and to choose the type of reports and views of historic data that they desired. This was all done while maintaining a uniform quarterly PEPFAR report for all participating countries.

IV. Initial Design

Initial prototypes for the system used common web application techniques and technologies. MySQL database tables were defined to collect and store reported information. Scripts written in PHP provided a web-based front end to the database, allowing users to enter data and view collected information. The web-based user interface also provided a means for system administration, including defining regions and countries, managing users, and supporting data backups.

A key aspect of the user interface design was its reliance on unobtrusive enhancement[6]. This strategy creates a layered user interface, where successive layers provide more functionality, but are only invoked if the user (in particular, the user's web browser) supports the required technologies. For example, many of the input pages consist of a number of individual data elements. To make it easy for the user to focus on the information in manageable pieces, the interface provides selective disclosure--information not relevant to the immediate task is hidden or de-emphasized so that it does not distract the user. This approach has significant benefits to the user compared to alternative strategies (such as making each section a separate page or screen), as users are able to decide for themselves what information is relevant to the task. For example, a user may wish to refer to other inputs when supplying a particular value. If the other inputs exist on separate pages, then the user would be forced to jump back and forth between multiple pages. With selective disclosure, users are able to view as much or as little of the information as they wish, all on one page, as Figure 1 highlights.

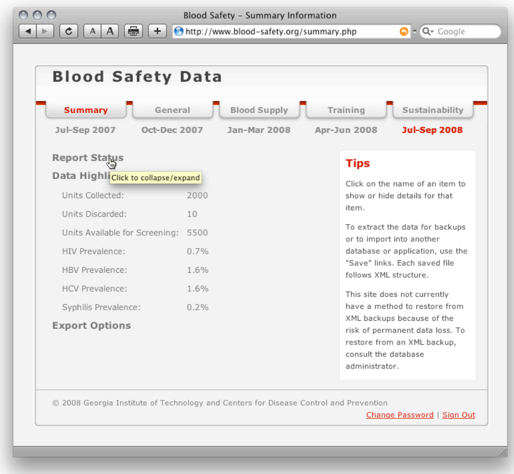

Fig. 1. Selective disclosure allows the user to show only those sections of the page that are relevant for the task at hand.

Although it is theoretically possible to implement selective disclosure strictly through PHP scripts executing on the web server, most users would find the resulting lag between their action and the interface's response to be intolerable. For a suitably responsive interface, selective disclosure is implemented solely on the web browser client, using javascript to show or hide the appropriate interface elements. However, not all web browsers can fully support javascript, and some users may choose to disable javascript even when their browser supports it. To accommodate these users, unobtrusive enhancement in the initial design adds selective disclosure as an optional, additional layer in the interface. The prototype accomplishes this by first creating a page with all interface elements available and disclosed. Figure 2 shows a screen capture for such a page.

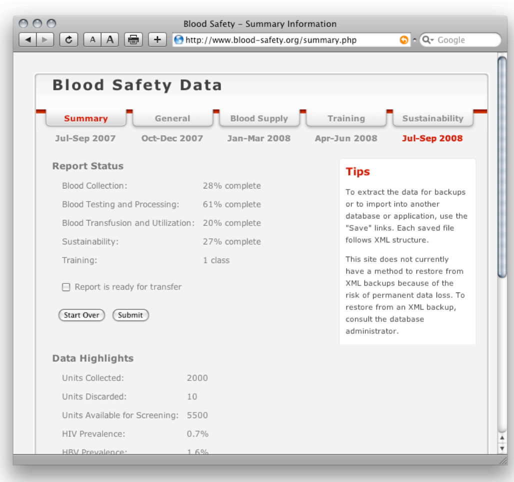

Fig. 2. When the page loads initially, all sections are fully shown. If the browser does not support javascript, the page remains displayed in this form.

The interface then attempts to execute javascript to add selective disclosure. If the web browser does not support javascript (or if the user has disabled that option), then the page remains as in Figure 2. Although there is no selective disclosure, the interface remains fully functional. When javascript is available, however, selective disclosure immediately activates and the new functionality is available to the user. Figure 3 shows a screen capture for the same page after the javascript executes. Note that in most cases the javascript execution is fast enough that the user will never even notice the initial interface of Figure 2. For most users, the only interface of which they will be aware is the interface of Figure 3.

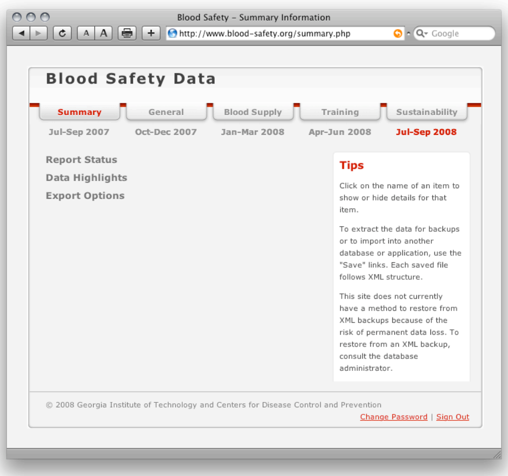

Fig. 3. If javascript is able to execute in the user's browser, it activates selective disclosure and enables the user to hide or reveal sections independently.

This design illustrates the benefits of unobtrusive enhancement. Users without the more advanced technology (in this case, browser support for javascript) still have access to a serviceable interface. The majority of users who do have the necessary technology, however, receive a more advanced user interface.

V. Evaluation

A. Methodology

Prior to the implementation of the web-based system, there were several meetings between the CDC and the team from Georgia Tech. These meetings helped determine the specifications of the system including the design of the user-interface, the preferred programming language and hosting and management of the website.

To evaluate the effectiveness of the tool, we conducted a series of studies involving the end-users. We selected a subset of the PEPFAR countries to use for evaluation. All the data managers in the National Blood Transfusion System in the PEPFAR countries are currently expected to use the Excel based reporting system and therefore already had some understanding of what kinds of data would be requested.

Zambia was chosen as the lead country for deployment and evaluation due to the progress in using the Excel based tool and their overall blood safety effort. The team from Georgia Tech spent approximately two weeks, July 27 to August 8, 2008, in Zambia studying the local setting, usability of the system, network characteristics and gathering qualitative feedback. The usability study component was conducted in the national blood center in Lusaka, Zambia as well as in Kitwe, the center for the Copperbelt region. While in Zambia, the team also conducted the study with data managers in Dar-es-Salaam, Tanzania, over the telephone. We next describe each of the three test sites in more detail.

Zambia National Center, Lusaka. The evaluation conducted at the ZNBTS consisted of 6 participants in total, some were assigned tasks as country managers while others were assigned tasks for provincial managers. The participants consisted of a physician, biomedical scientists, financial manager, information technology manager and data managers. The participants were given the web address to the web tool and were asked to complete the tasks. Two observers from Georgia Tech were available to administer the evaluation and provide help only if absolutely necessary. None of the participants had prior experience with the website so they were allowed to navigate around the website to determine how to use the features. Internet connectivity available was via satellite and evaluators used laptops with wireless connections.

Zambia Copperbelt Center, Kitwe. In Kitwe, there was dial-up internet connectivity, although it had not been functioning for some months. After several attempts during the first hour of our visit, the problem was discovered and fixed, making it possible for the evaluation to happen. There were 3 participants consisting of a physician and two data managers who were all familiar with the Excel-based tool. The dial-up connection had to be reset twice during the entire evaluation.

Tanzania National Center, Dar-es-Salaam. The usability study for the Tanzania data managers was conducted over the phone. The observers called in from Lusaka, Zambia and went through the tasks on the task list with each participant individually; two participants had a copy of the task list by email and were asked to indicate by speaking aloud how they were navigating the system. Fiber-based internet connectivity was available in Tanzania which made for significantly faster navigation.

B. Study Design and Analysis

The usability study consisted of 3 components: a pre-trial survey, an observed trial where data managers were asked to perform a set of tasks and a post-trial survey.

Pre-trial survey. A survey in form of a questionnaire was conducted prior to the trial of the web-based tool to assess the expectations of the levels of ease or difficulty of using the web-based tool. The survey was conducted via the web by using a commercial web-survey tool that provided information about the date the survey was taken, the IP Address and aggregate results from all participants etc. By conducting a web-survey, we were also able to assess the response time and the availability of internet access. There were 9 participants in the pre-trial survey, all from the Zambia NBTS; 7 from the Lusaka and 2 from Kitwe. The pre-trial survey link was sent out by July 21, 2008 and all surveys except one were taken between July 22 and July 27. 2008, prior to observers' arrival in Zambia. All the participants had some prior knowledge of the Excel-based tool. The questions in the survey are shown in

Table I. Each participant was asked to rate the ease of each task on a Likert scale of 1-5 when appropriate, with 1=very easy, 2=easy, 3=neither easy nor difficult, 4=difficult and 5=very difficult. Questions 4 and 5 were given out to aid in qualitative analysis.

Table I. Pre-trial Questions

1	You have forgotten your password and need to log into the web-based system. How hard or easy do you expect to find this task?
2a	You are only responsible for reporting some of the data, while other users report the remaining data. You need to enter the data for which you are responsible without disturbing the other data. How hard or easy do you expect to find this task?
2b	At the close of a deadline, you have only partial information to report. How hard or easy do you expect to find this task?
3	Previously entered data is wrong, and you must provide the correct information. How hard or easy do you expect to find this task?
4	What are some of the advantages you expect from a web-based system compared to the old spreadsheet tool?
5	What are some of the disadvantages you expect from a web-based system compared to the old spreadsheet tool?

Trial and post-trial survey. Discount usability techniques were used to evaluate the usability of the system and the interfaces. This evaluation provided a means of obtaining insights about usability problems and possible solutions. A task list was used to obtain quantitative and qualitative measurements of the ease of use of the tool. When participants completed all tasks, they were asked to rate the ease of use of the system on the same rating scale as in the pre-survey. This evaluation occurred immediately after each participant completed all tasks, during the observers visit to Zambia. The list of tasks to be completed by each evaluator is shown below in Table II.

Table II: Evaluation Task List

1	Your username is country/province@blood-safety.org and the password is the word "password". Use the system to change the password to "country/province".
2a	Enter the regional information for the current quarter.
2b	You are entering data for the current quarter for your country/province. You only have data for all the non-numeric fields. Enter and save this part of the data.
3	There is an error in the HIV prevalence field. Please correct it.
4	Export the country/province data to an XML file and view the data using Excel.

C. Results

Analysis of the results obtained from this evaluation, shown below in table I and figure 4, revealed that most evaluators rated most of the tasks between scale level 1 and 2. These results indicate that user expectations of the difficulty of using the web based tool were above the actual difficulty encountered while using the tool. There was a reasonable level of ease while working with the web-based tool. Participants were also able to find some typographical errors and provide concrete suggestions for changes.

The overall survey results indicate that the system was not very difficult to adapt to and use. Figure 4 shows the average difficulty levels pre- and post-trial for each site. From Figure 4, it is apparent that the difficulty experienced by users in Zambia was significantly lower than what they anticipated.

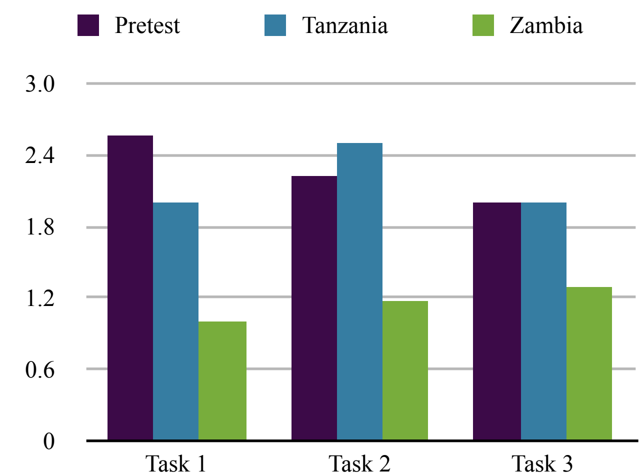

Fig 4. Pre- and post-evaluation comparisons show tasks were as or easier than expected.

The results from Tanzania, show less ease in using the system; this effect may be attributed to the additional difficulty of having to evaluate the system while on the phone with the observers. Also, the evaluators may have felt some pressure to accomplish the tasks quickly because the observers were waiting for them to complete each task while holding on the phone line.

In table III, the average difficulty for each task is given. Overall, the pre-trial results are higher than the post-evaluation results, this supports the notion that the interface was well-designed, to the extent that such a self-evaluation can assert. The "Export" task, not mentioned in the pre-trial survey was perceived to be more difficult than the other tasks; it involved transferring data from the system to the local computer in a standard format (XML) which may have been unfamiliar to many evaluators.

Table III. Mean Scores for Selected Tasks

Task	Pre	TZ	ZM	ZM-NTL	ZM-CB
1	2.56	2	1	1	1
2	2.22	2.5	1.17	1.33	1
3	2	2	1.29	1.67	1
Export	-	3	2.5	3	2

D. Qualitative findings

Utility and maintenance. Respondents to the pre-trial survey felt that the web-tool would:

- Result in more timely reporting.
- Be quicker and less tedious.
- Be more cost-effective.
- Reduce the number of errors.
- Be more user-friendly than a spreadsheet.
- Permit easier correction of data entry errors.
- Make it easy to share data between users.

All respondents were strongly of the opinion that a web-based tool would be considerably superior to a spreadsheet-based report.

Security. On one hand, some users felt data security is a concern since the data is no longer locally stored and vulnerable to malicious attacks; on the other hand, keeping data on a server insures against data loss in the case of problems with local computers. In any case, it was clear that users were concerned about how secure the data would be.

Functionality. While the original purpose of the tool was to allow for data aggregation for the purpose of generating PEPFAR-mandated reports, data managers were quick to see that having a real-time aggregate picture would greatly enhance their ability to manage blood collection and utilization. They asked for data analysis, such as historical trends and comparisons of data from different regions to be included in the functionality of the system.

Network constraints. Given the state of network infrastructure in Zambia and other participating countries, the potential pitfall of relying heavily on the internet was noted by several data managers. Would pages load too slowly? Would the system be able to handle connectivity going up and down? While Dar-es-Salaam has a fiber-based internet connection, there is no fiber connecting Zambia to the rest of the world. Thus, all internet traffic goes via satellite, imposing a strong constraint on bandwidth, and perhaps even more significantly, on latency. Indeed we did not notice much difference in response times between Kitwe, with a dial-up connection, and Lusaka, with wireless connectivity and a dedicated satellite connection.

IV. Revised Design

Usability testing of the initial prototype indicated that, in general, the application and its interface were suitably easy to use. None of the tasks were rated as difficult or very difficult by any user. Comments made by participants during the study, however, indicated that one of the most unsatisfying aspects of the system was the time required for the initial loading of each web page. The main cause of the lengthy delay was the quality of the network infrastructure[1]. Because the same infrastructure was used for all Internet access and, thus, lengthy page load times were common for nearly all web sites, participants were somewhat conditioned to expect this delay. Nonetheless, their dissatisfaction levels suggested that it would be worthwhile to investigate opportunities to reduce the page delay.

The revised design significantly reduces the perceived initial loading time through the use of Asynchronous Javascript and XML (AJAX) technology[7]. With AJAX, a web page can continue to interact with the server after it is initially loaded without requiring explicit action on the part of the user. By using AJAX, the initial contents for each page can be substantially reduced so that the page loads more quickly. While the user views or interacts with the page, it continues to retrieve additional information from the server. By combining AJAX functionality with selective disclosure, the revised design provides quicker initial page loading in a manner that is seamless for users.

Figures 5 and 6 illustrate the steps involved in loading a page using the approach of the revised design. The server first supplies an initial web page that is almost completely empty. However, the individual sections on the page are marked as hidden. Even though they contain no content, users do not perceive a problem because the sections are hidden.

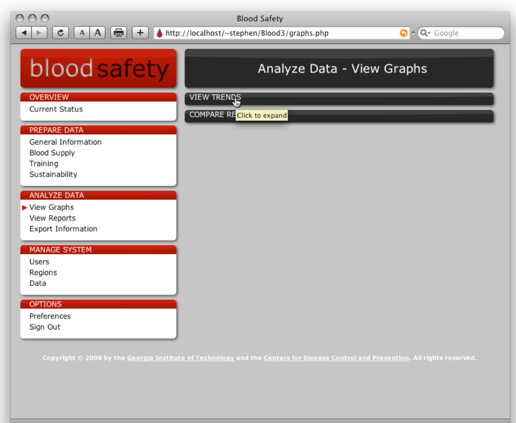

Fig. 5. The web server initially supplies only the skeletal framework for the full page; however, since the framework contains minimal content the network can transfer it very rapidly and present the user with the appearance of a full interface.

As soon as the initial page has loaded, it begins using AJAX requests to retrieve the actual content for each section. During this time, however, the user is still viewing the initial page and deciding how to proceed. In many cases, by the time users take their first action by selecting to show one of the sections on the page, the content will have been retrieved from the server and can be displayed immediately. When that is not the case, a progress bar tells the users that the interface is acting on their requests.

---

[1] While on site in Zambia, the developers were able to make measurements of network bandwidth and latency from several locations over 24-hour periods. The tests measured performance from a local computer in Zambia to the prototype web site operating by a commercial web hosting company in New York. The tests showed available bandwidth ranging from 12 to 57 kb/s to New York and 88 to 116 kb/s from New York. Mean latency ranged from 5.1 s to 6.8 s.

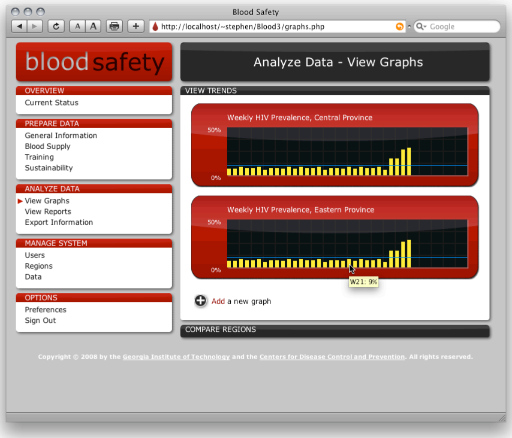

Fig. 6. While the user decides which section to view, the network is able to complete the transfer of the hidden content. When the user choses to reveal that content, it can be immediately displayed.

The timeline in figure 7 compares the perceived and actual page loading times for the initial and revised designs. Even though it actually takes longer for the entire page and all its content to load in the revised design, the perceived load time is less.

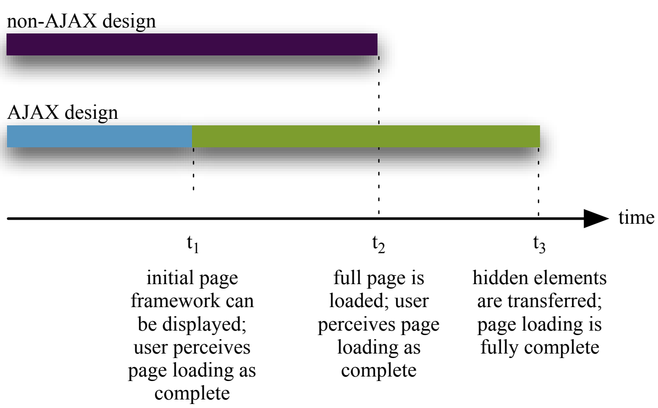

Fig. 7. Although the AJAX design requires longer to load because of extra content, it allows the web browser to present a functioning page sooner than the non-AJAX design; to the user, this difference gives the perception of faster loading to the AJAX design.

One consequence of the revised design is that it requires javascript. There is no way to make the page fully functional when the user's browser does not have javascript support, so unobtrusive enhancement is not possible. Based on interactions with prospective users, however, it was determined that improving page loading times was more desirable than supporting non-javascript capable browsers. In the future, should support for non-javascript browsers be necessary, a separate user interface could be developed.

Another key element of the revised design directly incorporated requests from the blood safety staff in the remote locations. In many cases, local staff wished to collect and track information in addition to that required by the CDC. Also, reporting periods were sometimes more frequent than the quarterly reporting required by the CDC. By supporting collection of local information at locally-defined reporting periods, the system provides a much greater incentive for its use. Because the database captures all inputs to the system as new data insertions (rather than updates to existing data), there is no need to lock database access to avoid concurrent updates. Such updates are problematic for any Internet-based application, and would be especially challenging in an environment with sporadic connectivity. The system's approach resolves conflicts during report generation rather than database modification. These features ensure that the system meets the needs of both the sponsoring agency and the local health officials.

V. Deployment Timeline

An initial prototype for the blood safety system was created during the spring of 2008. Field trials and evaluations took place during the summer, and the revised design was created in the fall.

Beginning in the first quarter of 2009, the system will transition into production in 14 countries which are part of the PEPFAR program. Discussions are currently underway with the World Health Organization to deploy a version of the system worldwide.

VI. Discussion

Overall survey results indicate that a web-based system was highly desirable and the system developed here was easy to adapt to and use. This finding is in line with other experiences with web-based tools for health projects in the developing world[8]. A very significant observation from our survey is the need to incorporate local users in the preliminary design phases of a project. The original goal of the system was to serve as a data collection tool for CDC data managers in Atlanta; while conducting surveys, we discovered a gap in the stakeholder perspectives as the local users perspective had not previously been incorporated in the design. This highlights the necessity for human-driven design and research practices as noted by Brand & Schwittay [9]. Local data managers stressed their preference for a tool that would also help in blood management by analyzing and tracking recorded data. The final design incorporates perspectives of both stakeholders; the CDC data mangers and local users. This reflects several dimensions of Information and Communications Technology for Development (ICT4D) as outlined in work by Tongia et al. [10] by addressing the original goals of the CDC's Excel-based data entry system while also meeting the needs of the local users in the developing countries.

We highlight two aspects of our design that give us confidence in its long-term sustainability and might serve as a model for similar projects in the future.

Data flow constraint. The data entry requirements of the system should match the data collection, i.e., if the system expects too much data, it will be hard to maintain and impose an overhead on data collection. In technologically advanced countries, there is often an abundance of easily available data and thus it is possible to deploy systems that use vast amounts of data collected rapidly. For a system to be sustainable, however, its data requirements should match the local data flow, even if this necessitates a less complex system.

Flexible design. The second most important aspect of our system design, closely related to the first, is its flexibility, both in data entry and analysis. Web-based systems are, in general, designed to minimize the constraints inherent with variable rates of data entry. As we observed with the spreadsheet based data collection system, the potential for errors seemed to rise as the numbers of users, and the numbers of copies in circulation, increased. The web-based tool is less vulnerable to these errors: delays between entries will not have as great an impact on the overall quality of submissions. Because of this, users will be more confident in the database, and more likely to use it as a decision-informing tool. Our design goes further in that data managers can choose the frequency of entering data to match the frequency at which they receive data. For example, in Lusaka we observed that blood collection data arrived weekly (by fax) from each of the other centers. On the other hand, blood utilization data was not obtained so regularly and a month-long window was more realistic. The system allows users to choose views of the data for analysis and management. The views of interest depend on the local context; e.g. in Zambia blood types have roughly the same distribution across the country, but the incidence of malaria (and thus the need for blood) varies by both time of the year and region. Therefore, reports that show geographic and seasonal trends in demand for blood would be more relevant than reports that indicate blood type distributions.

Blood safety monitoring is an important special case of the more general problem of monitoring and tracking large data sets which are updated frequently. The latter has many possible applications in health, emergency relief, water and other basic resources, etc. In all these cases a web-based distributed monitoring and aggregation solution seems worthy of exploration, in spite of network constraints. We believe that the insights gained from our development of a blood safety monitoring tool could be applied more generally.

ACKNOWLEDGMENT

We are grateful to the Zambian National Blood Transfusion Service, Tanzania National Blood Transfusion Service, the Centers for Disease Control and Prevention in Zambia and Atlanta, and the US President's Emergency Plan for AIDS Relief. We thank Sridhar Basavaraju, Michael Best and Gregory Abowd for helpful comments on earlier drafts of this paper.

REFERENCES

[1] World Health Organization, "Fact Sheet No. 279: Blood Safety and Donation." 2008. http://www.who.int/mediacentre/factsheets/fs279/en/.

[2] H.S.F. Fraser, D. Jazayeri, P. Nevil, Y. Karacaoglu, P.E. Farmer, E. Lyon, M.K.C.S. Fawzi, F. Leandre, S.S. Choi, and J.S. Mukherjee, "An information system and medical record to support HIV treatment in rural Haiti," *BMJ (Clinical Research Ed.)*, vol. 329, Nov. 2004, pp. 1142-6.

[3] J. A. Blaya, S. S. Shin, M. J. Yagui, G. Yale, C. Z. Suarez, L. L. Asencios, J. P. Cegielski, and H. S. Fraser. "A web-based laboratory information system to improve quality of care of tuberculosis patients in Peru: functional requirements, implementation and usage statistics." *BMC Med Inform Decis Mak*. 2007;7:33.

[4] Lani Marquez. Are Web-Based Platforms to Support Quality Improvement Feasible in Developing Countries? Experiences from Ecuador, Honduras, Nicaragua, and Rwanda, 2007. http://www.qaproject.org/news/ISQUA07/ISQua2007%20Marquez%20handout.pdf.

[5] World Health Organization, "Blood Transfusion Safety", 2004. http://www.who.int/bloodsafety.

[6] Jeremy Keith, *Bulletproof AJAX*. New Riders Press. February 2007.

[7] Jesse James Garrett. "Ajax: A New Approach to Web Applications". 2005. http://www.adaptivepath.com/ideas/essays/archives/000385.php.

[8] Jennifer Manne and Walter Curioso (2007). "Technology and health care in the developing world." *Student BMJ*, December 2007. http://student.bmj.com/issues/07/12/life/436.php

[9] P Brand, A Schwittay. The Missing Piece: Human-Driven Design and Research in ICT and Development. In *Proceedings of the International Conference on Information and Communications Technologies and Development*, May 2006.

[10] R Tongia, E Subrahmanian. Information and Communications Technology for Development (ICT4D) – A Design Challenge? In P*roceedings of the International Conference on Information and Communications Technologies and Development*, 2006.