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ABSTRACT  Capture of surveillance data on mobile devices and rapid transfer of such data from these devices into an electronic database or data management and decision support systems promote timely data analyses and public health response during disease outbreaks. Mobile data capture is used increasingly for malaria surveillance and holds great promise for surveillance of other neglected tropical diseases. We focused on mosquito-borne dengue, with the primary aims of: 1) developing and field-testing a cell phone-based system (called Chaak) for capture of data relating to the surveillance of the mosquito immature stages, and 2) assessing, in the dengue endemic setting of Mérida, México, the cost-effectiveness of this new technology versus paper-based data collection. Chaak includes a desktop component, where a manager selects premises to be surveyed for mosquito immatures, and a cell phone component, where the surveyor receives the assigned tasks and captures the data. Data collected on the cell phone can be transferred to a central database through different modes of transmission, including near-real time where data are transferred immediately (e.g., over the Internet) or by first storing data on the cell phone for future transmission. Spatial data are handled in a novel, semantically driven, geographic information system. Compared with a pen-and-paper-based method, use of Chaak improved the accuracy and increased the speed of data transcription into an electronic database. The cost-effectiveness of using the Chaak system will depend largely on the up-front cost of purchasing cell phones and the recurring cost of data transfer over a cellular network.

RESUMEN  La captura de datos en dispositivos móviles y su rápido envío a sistemas de manejo o de toma de decisiones promueve el rápido análisis y la pronta respuesta de los sistemas de salud durante brotes de enfermedades. En la vigilancia de la malaria el uso de dispositivos móviles se ha incrementado y su posible uso en otras enfermedades tropicales desatendidas es alentador. Nos enfocamos en la enfermedad del dengue, con los objetivos de: 1) desarrollar y probar en el campo un sistema basado en celulares (llamado Chaak) para la captura de datos de vigilancia del mosquito transmisor del dengue y 2) evaluar, en la ciudad de Mérida, México (enérmica a dengue) la relación costo-beneficio de esta nueva tecnología en contraste con la captura con papel y lápiz. Chaak incluye un componente para computadora de escritorio, donde el coordinador selecciona los predios a revisar y un componente para celular donde el encuestador recibe las tareas asignadas y captura la información. La información capturada puede ser enviada a la base de datos central usando varios métodos, incluyendo tiempo casi real donde los datos son enviados inmediatamente (p.ej. usando el Internet) o almacenando los datos en el celular para su envío posterior. Los datos espaciales son manejados por un sistema de información geográfica que es parte del programa. Comparado con el uso de lápiz y papel, el uso de Chaak aumenta la precisión y la velocidad de transcripción a una base de datos electrónica. El costo-beneficio del uso del sistema Chaak depende del costo inicial de la compra de celulares y el costo recurrente de la transferencia de datos en la red celular.

KEY WORDS  Aedes aegypti, dengue, surveillance, informatics, cell phone

Effective control of neglected tropical diseases with explosive outbreak dynamics, such as dengue (Kan et al. 2008, Vazquez–Prokopec et al. 2010, Jeefoo et al. 2011), is dependent upon timely analysis of collected surveillance data and rapid response. Dengue virus is transmitted by Aedes mosquitoes, principally Aedes
The primary aims of this study were to 1) develop and field-test a novel system, Chaak, for cell phone-based capture of data relating to the surveillance of the immature stages of dengue virus mosquito vectors, and 2) assess, in the dengue endemic setting of Mérida, México, the cost of using this new technology versus paper-based data collection followed by manual entry into an electronic database. We reported previously on the evaluation of the system performance, with regards to time needed to complete data entry per premises and the rate of data entry error (Lozano-Fuentes et al. 2012). In this article, we provide an extended description of the system and present additional information for the cost of using the system, based on the time needed per premises to complete a survey, the projected salaries for surveyors, and the local cost for data transfer over the cellular network.

Materials and Methods

System Development Strategy. Projected users of the Chaak system include a system administrator, management personnel for vector surveillance and control, and surveyors (field workers). System administrators and management personnel use a desktop thin client and surveyors use cell phones to enter data. The system was developed in an iterative process over

Mobile capture of electronic data is a rapidly evolving information technology with great potential for incorporation into a data management system and decision support system to achieve timely transfer of field-collected data into the system. With the aid of mobile computers (e.g., laptops or netbooks), remote sensors, or even cell phones, electronic data capture can now be achieved during the initial data-capturing session in the field or the laboratory. Mobile computing has been improved with the advent of faster, cheaper low-power processors and more robust wireless data transmission technologies. The technical capabilities of mobile devices are constantly improving and mobile Internet access is now achieved in most large urban areas of the world.

There is strong interest in using mobile devices for data capture, data transfer, or both, in public health, including the surveillance and control of neglected tropical diseases (Kaplan 2006, Safaie et al. 2006, Tem et al. 2009, Tomlinson et al. 2009, Blaya et al. 2010, Kahn et al. 2010, Adedeji et al. 2011, Lang 2011, The malERA Consultative Group on Diagnosis and Diagnostics 2011, Matthews et al. 2012). Recent studies have evaluated the use of personal data assistants (PDAs) for data collection during household surveys for malaria or bed net use (Vanden Eng et al. 2007, Ahmed and Zerihun 2010), and collection of data for suspected dengue patients in clinical studies (Aviles et al. 2008). The potential for use of cell phones as mobile data-capturing devices was evaluated for infectious disease surveillance in Africa and South America (Johnson and Blazes 2007, Randrianasolo et al. 2010), and for malaria surveillance and monitoring in Africa and Southeast Asia (Mueller et al. 2009, Meankaew et al. 2010). Moreover, a recent study (Matthews et al. 2012) suggests that cell phones potentially can be used for rapid diagnosis of dengue in conjunction with a medical test patch for which the presence of dengue virus biomarkers result in color changes. An image of the test patch captured by the cell phone’s optical sensor is analyzed via a colorimetric-based algorithm that can be run on the cell phone, and the result can then be transmitted over a wireless network.

The primary aims of this study were to 1) develop and field-test a novel system, Chaak, for cell phone-based capture of data relating to the surveillance of the immature stages of dengue virus mosquito vectors, and 2) assess, in the dengue endemic setting of Mérida, México, the cost of using this new technology versus paper-based data collection followed by manual entry into an electronic database. We reported previously on the evaluation of the system performance, with regards to time needed to complete data entry per premises and the rate of data entry error (Lozano-Fuentes et al. 2012). In this article, we provide an extended description of the system and present additional information for the cost of using the system, based on the time needed per premises to complete a survey, the projected salaries for surveyors, and the local cost for data transfer over the cellular network.

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a 2-yr period, with close contact between the software developers, at Colorado State University, Fort Collins, CO, and Universidad Autónoma de Yucatán, Yucatán, México, and subject matter experts from Servicios de Salud de Yucatán, Yucatán, México. Furthermore, the system was developed based on the workflow and requirements of Servicios de Salud de Yucatán, and it complies with national Mexican guidelines for conducting entomological surveys (Hernandez Avila 2011).

System Architecture and Software Components. The software has a four tier architecture (Fig. 1). The top tier is the application tier consisting of thin clients on desktops running Microsoft Windows .NET (Windows.Net 2012) and cell phones running Android (Android 2012). We used a variety of Android phones running unmodified Android versions 2.1 and higher: Google Nexus 1, S, and Galaxy Nexus (Galaxy Nexus 2012); HTC Desire and HTC Legend (HTC 2012); and Motorola Backflip (Motorola 2012). The Android and thin client applications communicate with the business tier using web services in the business access tier. The Web services are hosted on an Apache Webserver (Apache–Tomcat 2012) with module mono installed (Mono 2012). The business tier supports data validation, decisions, evaluations, calculations, and data CRUD (create, read, update, and delete) operations.

In the bottom tier (the data tier) storage is achieved with a PostgreSQL server (PostgreSQL 2012), and a PostGIS plugin (PostGIS 2012) to manage spatial data, such as city blocks or individual premises. A basic geographic information system, based on Lozano–Fuentes et al. (2008), was extended to allow the system to manage spatial data and create maps, and to capture spatial data in the field using an Android device. Reports are generated in HTML and optionally con-

![Diagram of system architecture](image-url)
Field-Testing of the System

The performance and use cost of the cell phone-based Chaak system was compared, in the dengue endemic setting of Mérida, México, with pen-and-paper-based field data capture followed by manual data entry into an electronic database. The evaluation of system performance, with regards to time needed for data entry and error rate on data entry, was reported previously (Lozano–Fuentes et al. 2012) but is summarized briefly in this article for completeness of the description of the system. In this article, we also present new information for the cost of using the system, based on the time needed to complete a survey, the projected salaries for surveyors, and the local cost for data transfer over the mobile network.

The time needed for data entry was assessed under field conditions in 13 randomly selected Mérida neighborhoods. We randomly selected two blocks from each neighborhood, one of which was assigned for Chaak system surveys (three surveyors) and the other one for pen-and-paper-based surveys (three surveyors). Entomological surveys were only conducted on premises for which the residents granted permission for the surveyors to examine containers for presence of mosquito immatures. In summary, the pen-and-paper-based method had a performance time, including subsequent entry of data into an electronic database, of 9.6 min per survey, while the Chaak system survey had a performance time of 7.8 min per survey (representing a 19% time reduction with the cell phone-based system) (Lozano–Fuentes et al. 2012).

The error rate on data entry was assessed in a controlled environment with mock entomological surveys, where premises were represented by sections of a large room and containers by paper printouts. The printouts were divided into four panels that depicted, respectively, container type, absence or presence of water, whether immatures were present in the container, and whether it contained pupae. The mock entomological surveys were conducted in 10 rounds of 5 min each with the data-gathering method assigned randomly to six surveyors. The number of containers in the premises was also randomly selected at the beginning of each round. In total, 30 surveys were completed for each method. The surveyors using pen-and-paper also reentered the collected data into an electronic database. Errors were scored as deviations from the known exact value (perfect score = 0, all entries incorrect = 1). Each breeding site type has four records in the survey as previously described. Because there were 11 different container types in the survey that the surveyors had to record 44 values, that is, they had 44 chances of success. Thus, the error rate is the total number of errors divided by the total number of entries. The averaged error rate was 0.23 for the pen-and-paper-based method versus 0.17 for cell phone-based data collection (Lozano–Fuentes et al. 2012).

Results

**Key Features of the Chaak System.** The Chaak system was developed as a proof-of-concept project for cell phone-based field data capture and rapid transfer of collected data into a central database, including over a wireless network. The system deals specifically with the collection of surveillance data for mosquito immatures (larvae and pupae) in artificial containers located on individual premises, which is a common surveillance methodology for mosquito vectors of dengue virus.

There are three different roles defined in the Chaak system: system administrator, manager, and surveyor (field worker). A system administrator can create an individual user and assign the role of that user, and also can register individual authorized cell phones for use to collect data. Managers have access to domain-specific functionalities, such as: 1) defining options in selectable lists, 2) defining geographic entities to be surveyed, or 3) managing task assignment to surveyors. The surveyor role is limited to data entry through
the cell phone interface and transfer of collected data to a central database. The system allows a manager to assign specific tasks to a surveyor through the thin client desktop/laptop interface (Fig. 2), which results in the surveyor receiving the assigned tasks when activating the application on the cell phone (Fig. 3) and then being able to capture complex data on the cell phone interface to complete the tasks (Fig. 4).

Another important feature is the capability to transfer data collected on the cell phone to a central da-
database through different modes of transmission, including: 1) continuous Internet access where the surveyor enters data into the cell phone and sends the data immediately to the central database over the Internet; 2) periodic Internet access where the surveyor enters data into the cell phone, saves the data in the local system database, and then sends the data to the central database over the Internet or locally setup wireless network when a connection is available; and 3) desktop or laptop data transfer where the surveyor enters data into the cell phone, saves the data in the local system database on the cell phone, and then transfers the data to a desktop or laptop computer containing or connected to the central database via a file (no Internet access needed).

Managing the Surveillance Effort Through the Chaak System Desktop Interface. One of the most important features of the Chaak system is that it allows managers to create surveillance tasks, that is, assign specific premises to surveyors for completion in a given time period. These tasks then are relayed to the surveyors when they activate the Chaak system cell phone application (Figs. 2 and 3). To be broadly useful, systems such as Chaak must be adaptable to local settings. In the specific case of surveillance of mosquito immatures in artificial containers, this entails being able to: 1) define locally appropriate container type classifications (e.g., tire, flower pot, 20-liter bucket, etc.) and 2) handle different geographic hierarchies. Using the Chaak system desktop application, a person with the role of manager can customize options for container type classifications to match the local standard.

To ensure a locally acceptable geographic depiction, the desktop application allows the manager to define a customized geographic hierarchy. This is achieved by allowing the manager to: 1) recreate the local hierarchy of geographic classes (e.g., country, state, municipality, city, neighborhood, premises) without providing a fixed one; and 2) creating cases, which we call geographic entities, for the geographic classes (e.g., México, Yucatán, Municipality of Mérida, City of Mérida, Santa Rosa, Calle 35 norte Numero 2). The geographic entities are related by the space they occupy. Using a verbal description and the City of Mérida example, we can say that the City of Mérida is located in the State of Yucatán, and, because the neighborhood of Santa Rosa is located in the City of Mérida, we can further say that Santa Rosa is located in the State of Yucatán. As a result of using this approach, the system can generate tree structures to present and aggregate data. The development of a robust geographic backbone for the system is critical because surveillance activities commonly are carried out and recorded at the spatial level of premises and data are expected to be aggregated at other levels. For example, premises are identified by their postal address and are assigned to surveyors to visit. The resulting data are later aggregated and displayed in reports at a higher level to decision makers. Finally, the system does not enforce a particular format of postal addresses.

Data Capture on the Chaak System Cell Phone Interface. When activating the Chaak system on the cell phone, the surveyor is presented with a log-in screen. After a successful log-in, the system displays a
series of tasks organized in three groups: premises to visit, premises to revisit, and premises completed (Fig. 3). The premises to visit can be viewed as a list or organized in a tree. Figure 3 illustrates a scenario where premises assigned to a particular surveyor are grouped by block (073-7003 and 073-7006), and as both blocks are located in the Santa Rosa neighborhood, they are shown to belong to that neighborhood in the tree view. This system feature was created to help surveyors in resource-constrained environments to locate premises without the aid of global position system-enabled mobile devices.

The surveyor proceeds to select premises and enter the data for that specific premises through the cell phone interface. An initial selection refers to the basic outcome of the premises visit: 1) entry granted, 2) no one home, 3) entry denied, or 4) to revisit (Fig. 4). If entry is granted, the surveyor proceeds to complete the survey for mosquito immatures, which includes capturing data by container class (e.g., small trash containers, tires, barrels or drums, and water tanks) and location (indoors or outdoors) for total number of containers present, number of containers with water, number of containers positive for immatures (i.e., with at least one larva or pupa) (Fig. 4). Upon completion of data entry, the surveyor can choose to immediately transmit the data to the server database or to save the data in the local system database on the cell phone (1 MB of storage capacity is sufficient to store data for thousands of premises). After saving the data locally, the surveyor can transmit the data from the surveyed premises at a later time. Figure 4 shows the status of premises and the option for selecting premises for data transmission.

To minimize data entry error for the cell phone interface, data entry fields make use of terms from predefined select lists, radio buttons, and buttons (Fig. 4) as opposed to free text input. Entries of numbers are typically achieved through buttons used to increase (+) or decrease (−) a number from a starting number of 0. Use of text fields to record the number of containers is optional.

We also made some design changes based on our field testing experience. We favor a white background and black lettering because it is easier to read under sunlight. Furthermore, the (+) and (−) buttons were moved below the text boxes where the number of containers are recorded because otherwise the finger used to operate the buttons obstructs the view of the text box. Finally, we note that one-handed operation becomes difficult when the screen size, measured diagonally, is larger than 10 cm.

**Reporting.** The thin client application also has built-in reporting capabilities, including the presentation of data for commonly used larval surveillance indices (i.e., house index, container index, and Breteau index) in a table format or as a Google Earth map (Fig. 5). In addition, the thin client can automatically "recreate" survey paper forms with the data entered by each surveyor, and it allows for entering immature surveillance data by providing a data capture screen.

**Comparison of the Chaak System with Pen-and-Paper-Based Method.** As reported previously (Lozano-Fuentes et al. 2012), use of the Chaak system, compared with pen-and-paper data capture followed
by manual entry of data into an electronic database, resulted in reduced time of data entry (averages of 7.8 vs. 9.6 min per premises, or 0.13 vs. 0.16 person-hours per premises, respectively). In the Table 1, we present new data for cost estimates for use of the Chaak system (surveyor salary and cost of data transfer over the wireless network) versus the pen-and-paper-based data capture method (salary for surveyors, data entry personnel, or both). The U.S.$5.0 daily minimum wage estimate represents the high end of the minimum wage range for Mexico (based on data from Mexico’s “Comisión Nacional de los Salaríos Mínimos” for minimum wage by geographical area from 1992 to 2012; www.conasami.gob.mx/pdf/salario_minimo/sal_min_gral_area_geo.pdf and a U.S.$0.08 for one Mexican peso exchange rate). The amount (KB) of data used per survey of a single premises and transmitted over the wireless network was estimated from our field records (102.4 KB), and the cost of data transmission was calculated based on two different rates representing the worst and best case scenarios for Mérida (U.S.$0.02/KB vs. U.S.$0.0002/KB). The resulting estimates for total cost per premises survey are U.S.$0.10 for the traditional method of pen-and-paper data capture followed by manual entry of data into an electronic database (0.13 man-hour per premise × U.S.$0.63 hourly wage), compared with a range from U.S.$0.10 to U.S.$2.13 for the Chaak system depending on the data transfer cost rate used (Table 1).

### Discussion

We describe an example of a novel public health computer system with capacity not only for field data capture through a cell phone interface but also for using cell phones to receive specific surveillance tasks defined on the desktop component of the system. This system deals with the collection of surveillance data for mosquito immatures, but the underlying conceptual and technical solutions can be applied to a wide range of surveillance data for neglected tropical diseases. The freely available system, which was successfully field-tested in the dengue endemic setting of Mérida, México, addresses several problems inherent in dengue virus mosquito vector surveillance by: 1) providing capacity for data aggregation at different granularities by storing data at the finest spatial scale, 2) facilitating division of labor by helping program coordinators to manage and assign personnel to specific areas, and 3) enabling personnel oversight by tracking. The system can be adapted for local conditions through a configurable geographic information system and a configurable list of container types. Modifications to include additional functionalities (such as pupal demographic surveys) will require more development work with the participation of software developers. We went to great lengths to design and engineer the software to allow for further development, and we also made the full code available through an established code repository.

We previously reported that use of the system, compared with pen-and-paper data capture followed by manual entry of data into an electronic database, resulted in reduced time of data entry per premises as well as a reduced rate of data entry error (Lozano–Fuentes et al. 2012), and here we additionally show that using the system does not substantially increase cost, compared with pen-and-paper data capture followed by manual entry of data into an electronic database, as long as a control program can secure a low data transfer cost rate from a local provider. We did not yet perform a cost estimate for a large scale implementation of the system but this should be addressed in future work.

There has been an explosive development in mobile phone technology, including the emergence of cell phones that can store substantial amounts of data, over the last decade. Mobile phones are now commonplace throughout most of the world, and it has been estimated that there were over a billion mobile phones in developing countries by 2008 (Donner 2008). The proliferation of mobile phones in resource-constrained environments removes some previously noted obstacles for their use as surveillance tools: the risk of robberies and potential for arousing suspicions of residents through the use of mobile phones during field surveys (Curioso 2006). However, intermittent connectivity for mobile phones, especially with regards to Internet access, remains a problem in developing countries (Brewer et al. 2005). This can be counteracted, as done in our project, by the use of cell phones with capacity for local data storage, thus allowing for data to be continuously collected and then transferred when the Internet or locally setup network becomes accessible.

Table 1. Cost estimate (U.S. dollars) for daily use of the Chaak system vs the traditional method of pen-and-paper data capture followed by manual entry of data into an electronic database in Mérida, México

<table>
<thead>
<tr>
<th>Estimates</th>
<th>Traditional method</th>
<th>Chaak system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Man-hour used per premises</td>
<td>0.16</td>
<td>0.13</td>
</tr>
<tr>
<td>Minimum wage per hour*</td>
<td>$0.63</td>
<td>$0.02</td>
</tr>
<tr>
<td>Data use per premises</td>
<td>0 kb</td>
<td>102.4 kb</td>
</tr>
<tr>
<td>Data transfer cost rate</td>
<td>$0</td>
<td>$0.02/KB</td>
</tr>
<tr>
<td>Data cost per premises</td>
<td>$0</td>
<td>$2.05</td>
</tr>
<tr>
<td>Total cost per premises</td>
<td>$0.10</td>
<td>$2.13</td>
</tr>
</tbody>
</table>

* Based on an 8-hr labor day.
data, rapid data transfer to a central database, and cost savings through reduced time to complete a survey. Our previous finding that the use of the Chaak system, compared with pen-and-paper data capture followed by manual entry of data into an electronic database, resulted in \( \approx 25\% \) reduction in data entry error (Lozano–Fuentes et al. 2012) is not surprising considering the tedious and error-prone nature of the task of manually transcribing data from paper records into an electronic database. A similar result was reported from a study where handheld computers (PDAs) were compared with paper-based collection of survey data in South Africa (Seebregts et al. 2009). Our testers reported that errors most commonly resulted from not being able to see the screen in direct sunlight. Common errors included selecting an incorrect container type, entering data for the container type located next to the intended one on the screen, and removing containers instead of adding them or vice versa. The Chaak system does not have built-in algorithms to pull out unusual or inconsistent data entries; however, it records basic data for auditing including the date and time of data entry, the user name making the entry, and data updates and deletes. Another study from South Africa where community health workers used mobile phones to conduct household surveys showed that data capture on mobile phones also can facilitate data transfer to a central database in real-time or near real-time in operational settings in developing countries (Tomlinson et al. 2009).

Our field trial revealed a 19% reduction in the overall time spent per survey while using the Chaak system, compared with pen-and-paper data capture, along with less errors in the data (Lozano–Fuentes et al. 2012). Because this essentially represents a salary cost saving, it has direct implications for the feasibility of implementing this type of data capture system in resource-constrained environments. Previous studies indicate that initial set-up costs for mobile data capture (primarily hardware including desktops and mobile devices) are offset in the longer term through increased data collection efficiency (Mueller et al. 2009, Seebregts et al. 2009). In our study, the best case scenario for the Chaak system provides no cost savings compared with paper-based collection of survey data when considering both salary and data transfer costs, but the time saved translate to 19 more surveys per 100 completed surveys. The practicality of implementing a system like Chaak is facilitated by the rapidly falling prices of cell phones with capacity to support the current state of the Chaak system (e.g., U.S.$90 for Huawei 8100, Motorola XT316, Dell AERO).

One potential factor to consider is the salary for field surveyors and IT personnel. We used a high-end minimum wage estimate for México in our cost calculations. Lower salaries will reduce the cost of the pen-and-paper-based method (salary cost only) to a greater extent than for the Chaak system (salary and data transmission cost), unless agreements can be reached with local network providers to heavily subsidize this type of societally beneficial public health use of cell phones for data transfer.

Potential logistical problems for the use of mobile devices as data capture tools include battery life, difficulties reading the phone screen in direct sunlight, and cell phone durability. The cell phone can be protected by use of a hard case but this will add to the cost of the device. Data security is another potential problem, as the cell phones can be stolen or misplaced. The Android operating system provides tools to manage user access and prevent data theft from a cell phone, but there is no mechanism to render the cell phone unserviceable without the help of the cell phone service providers. Data theft prevention functionality does not currently exist in the Chaak system. Owing to limited readability of cell phone screens in direct sunlight, entry forms for field data collection cannot be very elaborate. An easier-to-read screen could allow more (or smaller) data entry elements in the screen. Commercially available potential solutions include devices with an e-ink screen, devices such as tablets with a larger screen, or devices that use voice commands for data entry. Another important logistical issue is that the Chaak system is highly dependent on address data. We designed the system around “premises” as used, for example, by a taxing authority. Urban environments are very dynamic and in poorly planned cities, there might not even be proper addresses. To address this problem, the system can use local administrative geographic hierarchies and does not restrict the format of the address.

Another issue that can only be resolved in larger scale field trials of the Chaak system is that we tested the system with a small workforce (<10 individuals), whereas a real-life scenario may involve a much greater number of field surveyors. Although the system performed robustly in our limited field trial, and the selected operating system (Linux) and the relational data base management system (PostgreSQL) are well suited for large scale implementation, unexpected problems may occur with larger scale use. A final possible problem area is the server and IT infrastructure. For the testing, we used a low power netbook (Dell Latitude 2100; 1 GB of RAM) with a price of approximately U.S.$250, but in an operational setting, we expect that a server class computer would be required (approximately U.S.$1,000). Managing the server and database also requires a control program to include a person with IT skills, adding to the cost of the computer system.

We focus herein on description of the Chaak system and preliminary small-scale testing for system performance and use cost relative to a pen-and-paper method. The system allows for the connection of multiple surveyors and supervisors at the same time, but more work is needed before we can adequately address how the system will perform on a large scale, for example, when used by hundreds of surveyors and multiple supervisors, and requiring the use of a large number of cell phones. One particular challenge is how to distribute and pair the surveyors to the cell phones because the system is dependent on this information for work distribution and auditing. This can be solved in different ways, such as by using radio-
frequency identification tags or other more mundane means to identify individual cell phones. A possible path to a large-scale implementation of the system is to start with data entry in the field using paper and later recapture the data into the system. As local workflows and issues are resolved a gradually growing number of mobile devices can then be incorporated into the surveillance activities until the system is fully implemented.

Operational use of the Chaak system could provide several logistical advantages. For example, a surveyor with a network connected device could bypass traveling to the central office and instead travel directly from his place of residence to the areas that need to be surveyed. If surveyors need to travel to central locations to “clock in” and “clock out” or to pick up supplies every day, data transfers could be completed twice a day. We speculate that use of the system may lead to more rapid entry and analysis of surveillance data and reduced reaction time for vector control response measures. Another notable advantage is the recording of data at the premises level that can later be retrieved and summarized for use at other spatial scales.

Our study underscores the great potential for use of cell phones in the surveillance of neglected tropical diseases. The presented system is adaptable in that the geo-political hierarchy is customizable and that options for data entry can be readily changed to suit local data collection practices. In addition, the system makes use of a mass-produced consumer product—the cell phone—and allows for use of various cell phone models to ensure that there are available options in local markets. One important future direction is to extend the functionalities offered in the system so that it can be used more broadly as a surveillance tool to support efforts to reduce the burden of neglected tropical diseases.

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References Cited


Galaxy Nexus. 2012. (http://www.google.com/nexus/#).


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