A Biometric Attendance Terminal and its Application to Health Programs in India

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Abstract

Tracking attendance is a necessity in a variety of contexts in the developing world, encompassing health programs, schools, government offices, and a litany of other milieux. While electronic attendance tracking systems exist and perform their core function well, they are expensive, monolithic and offer little customizability.

In this paper we describe a fingerprint-based biometric attendance system implemented using off-the-shelf components: a netbook computer, a commodity fingerprint reader, and a low-cost mobile phone. The system identifies visitors based only on their fingerprint, and uploads attendance logs to a central location via SMS. Its functionality goes beyond that of existing market offerings while improving modularity, extensibility, and cost of ownership.

We deployed this system in two health programs – supporting tuberculosis patients in New Delhi and sex workers in Bangalore – and logged over 550 users and 4,500 visits over the course of several months. Our experience suggests that the system is usable in real-world contexts, though incentives are needed to sustain usage over time. We reflect on the sociocultural factors surrounding adoption and describe the potential to impact health outcomes in the future.

1 Introduction

While robust personal identification is a prerequisite for providing many health, financial, and government services, the process of identifying individuals remains a major challenge in many developing regions. Due to low literacy rates, it can be difficult for individuals to spell their names consistently. Other details that could disambiguate identities are often unavailable; for example, a canonical format for addresses might not exist, and dates of birth and surnames are not always known. In addition, there is rarely a national identity number that citizens in low-income areas possess.

In response to this situation, there has been increasing interest in utilizing biometric technologies as a tool for personal identification in developing regions. One of the most ambitious projects in this space is the Unique Identifier (UID) project in India, which aims to establish a unique biometric identity for all 1.2 billion citizens of the country. Other recent proposals include biometric attendance tracking for students in all 40,000 schools in the Indian state of Gujarat [2] and biometric monitoring of judges in Delhi courts [17]. Organizations such as FINO in India have also used handheld biometrics to extend the reach of financial services to 12 million new customers [8].

Despite this surge of applications, the systems available for biometric identification remain highly specialized and are often inaccessible or unusable by small organizations. While commercial devices for biometric authentication are available [6, 7, 14], they are generally designed and manufactured for a single purpose (such as banking) and cannot be customized to suit the needs of a new domain (such as healthcare) without explicit support from the vendor. In accordance with their specialized functionality, existing biometric terminals typically come with small screens that are unsuited to displaying the graphical content needed to engage novice and low-literacy users. Finally, as a specialized device, they are a sunk cost that cannot be used for other general-purpose computing tasks within an organization.

In this paper, we describe a simple terminal for biometric attendance tracking that is comprised of off-the-shelf components and can be easily extended to meet the needs of small organizations. The terminal consists of a netbook computer, a fingerprint reader, and a low-cost cell phone (attached via USB cable). In its simplest form, the terminal has the capacity to register visitors, log their attendance, and upload those logs via SMS to a server that is hosted in the cloud (again a commodity provided by a third-party provider). The logs can be downloaded via the Internet and imported into a database for analysis and visualization. An important feature of our system is that it does not rely on any physical token (such as a smart card) to log the attendance of visitors; identification is performed using the fingerprint alone, making it accessible to many low-literate populations.

As the technology underlying the biometric terminal is relatively straightforward, our focus in this paper is on understanding its appropriateness for real-world applications in India. We describe two deployments in the healthcare space: one for monitoring and improving the delivery of tuberculosis medications, and one for maintaining accurate records

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NSDR'10 June 15, 2010, San Francisco, CA, USA.

at women's health centers. The application to tuberculosis clinics requires several careful design decisions, including lightweight synchronization between different terminals in the organization, hybrid paper and electronic tracking of patients, and usable security to prevent tampering with data on the machine. In total, we have deployed 8 terminals in the field, registering approximately 550 visitors and over 4,500 visits during the last 5 months. Our experience suggests that the terminal is usable by local organizations, and can potentially impact the delivery of health services in resource-poor environments. We summarize our specific contributions in the conclusions (Section 7).

2 Related Work

The use of biometrics for patient identification in the developing world has been explored in other contexts, including health clinics in South Africa [18], anti-retroviral therapy in Malawi [19], clinical trials in Vietnam [11], and tracking of nomadic pastoralists in Chad [10]. The largest of these studies considered over 19,000 patients [18], successfully enrolling 94-97% (depending on the clinic) into the biometric system. Problems with enrollment were due to scars and cuts on fingers, refusal (more common amongst men), and technical challenges. None of these systems incorporated a mobile phone for relaying visitation logs to a central location.

Other programs have utilized biometrics for verification of identity, rather than as the sole identification mechanism. This is often done in concert with a smart card that carries a template of the patient's fingerprints. Biometric smart cards have been deployed to over 1,300 patients on anti-retroviral therapy in South Africa [1]. They have also been widely used for financial service delivery in India, where an organization called FINO has enrolled over 12 million customers, many of them using biometrics [8]. Such organizations rely on commercially-available mobile fingerprinting terminals [6, 7, 14], which also have support for wireless network connectivity. However, we are unaware of any other terminal that communicates over SMS, which contributes to the cost savings of our solution (see Section 3.2 for details). While fingerprint readers have also been integrated on mobile phones [9], it has yet to be seen whether they offer the image quality and computational power to uniquely identify each person in a large group.

Fingerprinting is but one of many biometric technologies [16] that might find application in developing regions. The use of ordinary photography has been shown to be effective in monitoring and improving teacher attendance in rural India [4]. Unfortunately, taking pictures is often out of the question for tracking patients in health clinics, where there can be stigma associated with attendance (this holds true for both of the applications in this paper). Voice recognition is also an attractive technology in low-income areas, as it can be done over an ordinary phone. Authenticating the identity of a speaker based on his or her voice is becoming feasible from a technical standpoint, with error rates of 5% over mobile phones [13] and recent systems that target emerging markets [3]. While we initially expected to use voice recognition in tuberculosis clinics, we found three unexpected barriers: 1) loud background noises, including traffic and bells, 2) the perceived possibility (whether or not it is real) of spreading disease by sharing a phone or microphone amongst patients, and 3) the ability of health workers to initiate conference calls, making it impossible for a server to distinguish whether a health worker is visiting with the patient, or whether they are simply calling them on the phone.

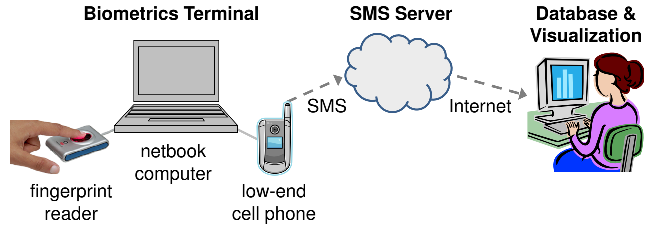

Figure 1. Overview of our system.

3 Biometric Terminal

As depicted in Figure 1, our biometric terminal consists of three main components: a low-cost netbook computer, a commodity fingerprint reader, and a low-end mobile phone (connected via USB). Messages sent from the terminal are received by an SMS server and made available over the Internet to administrative users, who can download the messages from any location and automatically import them into a database for further analysis and visualization.

3.1 Usage Scenario

We focus on the scenario in which the terminal is operated by a health worker, in either a fixed or mobile location. A user who wishes to log her attendance with the terminal first needs to register, which is accomplished by providing a name and four scans of a given finger to create a template. As the finger used for registration may become dirty, decorated, or damaged subsequent to registration, we also require registration of a second, 'backup' finger from the opposite hand. Additional fingerprints can optionally be registered as appropriate on a per-application basis. However, to increase fingerprint recognition speed, we recommend that only one finger from each visitor be actively recognized by the system at any point in time. The active finger for a given visitor can be toggled by the health worker.

Once registered, a visitor can log her attendance by scanning her chosen finger once. No keypresses are necessary on the part of the health worker or the visitor during login, making the system accessible to novice computer users.

The health worker periodically uploads the visit logs by clicking a button on the user interface. Activities at the terminal (registrations, visits, and other events) are encoded in compressed SMS messages and uploaded to a server via the attached mobile phone. Uploads are incremental: only new events are relayed to the server. Approximately 4 new registrations or 40 visits can be encoded in a single SMS message. To account for the possibility of lost SMS messages, each SMS contains a sequence number; if an administrator detects a missing message, he can request that the health worker resend old messages by using a button on the user interface.

3.2 Implementation

The current implementation of the biometric terminal relies on the following components:

Component	**Implementation Choice**	**Cost**
Fingerprint Reader	Digital Persona U.are.U4500	$100
Netbook	Asus Eee PC 1005HA	$360
Mobile Phone	Nokia 1650	$30
SMS Plan	Reliance 1p Pack (10 SMS/Day)	$<$$4/Year

Thus, the total cost of the terminal is $494, using components commonly available in India. This is approximately $250 / year when amortized over a two year expected lifespan: significantly less expensive than commercially available alternatives while offering superior functionality and customizability. Mobile fingerprinting terminals such as the Ingenico BIO930 [6], the Innoviti Vx610-trueID-GPRS [7] and the M.POS2002 Fingerprint GPRS Terminal [14] cost over $600 for the terminal, plus at least $120 / year for GPRS connectivity, amounting to an annual cost of $360 (assuming a two-year lifespan). It is also important to note that while the modular nature of our solution allows piecemeal replacement if one component should break, commercial solutions must either be repaired or replaced as a unit.

The client software is written in .NET / Windows Presentation Foundation and uses the Gnokii [5] framework for sending SMS via Nokia phones. An open-source release of our software is planned for summer 2010.

We are currently using smscountry.com to receive and archive SMS messages at a cost of $140 / year. We utilize a .NET application to download and process messages and Microsoft Access to manage and visualize the data on administrative machines. As data management is performed offline by the administrator, Internet connectivity is only required to connect to the SMS server and download new messages.

4 Application in Tuberculosis Clinics

Our first application of the biometrics terminal is to monitor and improve the delivery of tuberculosis (TB) medications. The terminal is used to track delivery of medications to TB patients. To the best of our knowledge, this represents the first use of biometrics in a tuberculosis treatment program.

4.1 Context

Tuberculosis remains the largest infectious killer of adults worldwide, with 1.8 million deaths annually [12], of which nearly one fifth occur in India [12]. These deaths are especially tragic given that there are free and effective antibiotics available from the Indian government. However, in order to be cured, an infected patient needs to take the drugs (initially 7 pills at a time) on a strict schedule: three days per week continuously over a 6- to 8-month period. This task is difficult for many patients because the medications themselves have the potential for serious side effects. Adherence to this regimen is further complicated by myriad socio-cultural factors including education, stigma, travel, and forgetfulness.

In order to improve adherence to tuberculosis treatment regimens, India and other countries have adopted a program known as Directly Observed Therapy, Short Course (DOTS). In this scheme, patients ingest each dose of medication under direct observation. The observers, known as medication *providers*, keep the medications with them in order to closely control their distribution and administration. Patients are therefore required to travel to a clinic or other outlet to receive each dose. Providers are expected to seek out any patients who fail to appear for scheduled doses, finding them in their homes or elsewhere in order to administer the drugs and to encourage them to continue treatment. While the DOTS program has had a significant impact on tuberculosis treatment in India, it remains difficult to manage the program at scale. In practice, many doses remain unsupervised or missed, leading to unsuccessful treatment outcomes and fostering the emergence of drug-resistant forms of the disease.

Our approach in this work is to utilize biometrics to provide a transparent and tamperproof record of which doses of TB medication are administered to a patient under supervision of a health worker. While similar records are recorded on paper today, they are widely regarded as being unreliable and unrepresentative of daily operations; also, they are difficult to promptly aggregate and analyze. Using a biometric terminal with daily uploads to a central location, it becomes possible for program managers to identify missed doses as soon as they occur, and to respond with improved counseling or supervision as needed. In addition, DOTS programs can provide better incentives for providers, whose pay typically depends on the final treatment outcome of a patient and may take 12 or 18 months to process. By logging each visit, the terminal enables compensation to be tied to each dose, incentivizing providers to be diligent on a daily basis.

To evaluate the potential of biometrics in tuberculosis treatment, we partnered with Operation ASHA, one of the premier treatment programs in India. Operation ASHA serves almost 3,000 patients across six Indian states, including a longtime focus on slum communities in New Delhi. They utilize a highly innovative model that includes all the elements of government DOTS programs, as well as some additions. In an ASHA clinic, there are two actors: a *provider* and a *counselor*. The provider is a member of the local community who offers physical space for use as a clinic throughout the day. The counselor is a full-time ASHA employee who administers medication for several hours per day from the provider's location, and also delivers doses to patients' homes when they fail to come to the clinic. The salary of the counselors is dependent on their performance; counselors receive a monthly bonus for tightly controlling the number of patients who default (fail to collect medication for two consecutive months). While ASHA's model has been highly successful, they are seeking to improve the transparency of clinic operations to enable them to scale across other areas of India. This prompted our collaborative development of the biometric terminal.

4.2 Adapting the Technology

Several technical extensions are needed in order to apply the biometric terminal in the context of ASHA's treatment program. The most interesting design decisions are as follows.

Loosely coupled terminals for counselor and provider. In ASHA's model, both the counselor and provider may be distributing medication simultaneously at different locations due to the counselor's responsibility to track down missing patients. Thus it is necessary to support two terminal types: stationary provider terminals and mobile counselor terminals. This creates additional requirements: the ability to recognize the same patient on both machines and to maintain consistent visit data across the machines, to name two.

We addressed these constraints by creating a synchronization mechanism between the counselor and provider terminals. After arriving at, and prior to departing from, the provider's clinic the counselor connects her terminal to the provider's terminal via an Ethernet cable. She then clicks a "synchronize" button on both terminals, which causes all registration and visitation logs to be merged between the two machines. The end result is that both machines have a consistent view of all the patients who have interacted with either terminal, without the tedium of manually logging visits or registrations on both machines. As counselors may work at multiple clinics and synchronize their terminals with multiple providers, a patient's records are only merged onto a provider's machine if the patient attends the provider's clinic.

Hybrid paper/electronic patient tracking. Another challenge in TB treatment is that, due to the length of the regimen, patients may migrate from one location to another during the course of treatment. While it is possible to track patients across different locations by distributing their fingerprint templates to every terminal, this would require more communication bandwidth than is provided by low-cost SMS messaging. Maintaining a universal set of patient fingerprints on every terminal would also considerably degrade performance, as it would increase the number of templates a given scan would have to be compared with.

To overcome this limitation, we rely on a hybrid paper-electronic system. The terminal assigns each patient a unique alphanumeric ID upon their first registration with the system, which is written on the patient's nationally standardized TB treatment card. As the patient keeps a copy of this card, it would remain accessible in the event of relocation or enrollment in a different program. When the patient registers at the new location, he provides the ID written on the treatment card for entry into the system, rather than generating a new ID. The patient's medical history can then be preserved across the migration event, as the server can uniquely identify the patient using this ID.

After-hours security. As the provider's premises are often community spaces, and may potentially house a family at night, terminals left at these locations are susceptible to tampering during off-hours. Even without malicious intent, children may be drawn to the novelty of the machine and could corrupt records while playing with the system.

In order to prevent such tampering without impeding the usability of the terminal, we impose two security measures. First, new registrations and edits to patient data are locked unless a counselor has scanned her fingerprint within the preceding hour. This gives reasonable assurance that the counselor (who is trusted to modify all data on the machine) is either present or has recently left, in which case the clinic is likely to remain in active operation and tampering is less likely than at night. Second, to guard against unknown parties registering on the system and gaining the permissions needed to modify data, any attempt to register a new counselor on the device triggers an SMS alert to existing counselors on the system. If the new registration is unexpected, the existing counselor(s) are expected to follow up with the provider to ascertain the condition of the device.

Figure 2. Patient (left) logging into the biometric terminal at a tuberculosis clinic. Each box in the background holds the drugs for one patient. The counselor is at right.

4.3 Preliminary Deployment Experience

The biometric terminal has been deployed in four clinics in South Delhi for approximately two months (see Figure 2). So far, they have registered approximately 275 patients. This represents only the initial stages of our deployment, which we plan to scale to 13 centers in coming months. Here we offer only our initial observations.

Patients are not hesitant to give their fingerprint, and usually do so without difficulty. Most patients are not hesitant to use the technology, although there has been occasional concern about supplying the thumb print, as the thumb is also used for financial transactions in this context. After observing patients in the clinic, our current recommendation is to register the middle finger with the terminal, as the thumb and index fingers are frequently used for handling medication and may be more likely to spread germs from the fingerprint reader to the patient's mouth. About 20% of patients had difficulty in triggering the fingerprint reader to take any scan, but this was typically easy to remedy by pressing harder, with coaching from the counselor. With the exception of two children (who have known to present challenges for biometric enrollment [18]), all patients were eventually able to register successfully with the terminal.

The biometric terminal helps the counselors to strictly enforce the DOTS protocol. In one case, we observed a father request a dose for his child, but the counselor refused, indicating that the terminal made the patient's presence necessary. Eventually the father was persuaded and returned with the child within 30 minutes. We believe that the counselor's ability to appeal to an abstract, impersonal device over which she has only limited control will assist in persuading patients to come to the clinic for regular doses.

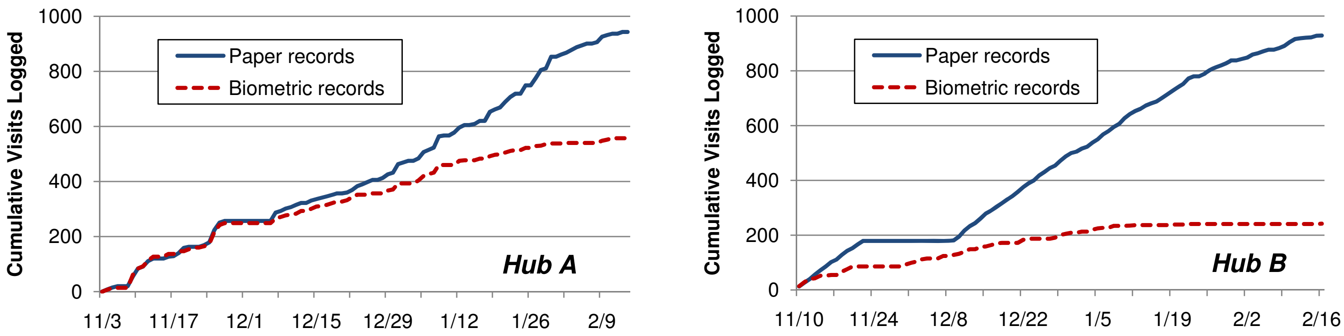

Figure 3. Cumulative number of visits recorded at two Pragati hubs via paper ledgers and biometric terminals.

5 Application in Women's Support Centers

The second application of our biometrics terminal is for attendance monitoring at support centers serving sex workers in urban Bangalore. The terminal was tested as a replacement for a paper-based "hub register" used to record visits to these centers, which provide daytime services, such as bathing facilities and medical consultation, to visitors.

5.1 Context

India has an estimated 2-3 million sex workers [15]. (While it is illegal to operate brothels or publicly solicit sex in India, it is not illegal to exchange sex for money.) Because female sex workers are at high risk of contracting HIV/AIDS and other sexually transmitted infections, there are organizations in India that seek to support the health and well-being of these women. One project with this mission is called Pragati (meaning "Progress") and is a joint initiative between Swasti, an Indian NGO, and Swathi Mahila Sangha, a community-based organization comprised of women who work as sex workers in Bangalore. The project aims to empower women to take control of their personal health and well-being, motivating the increased use of condoms and decreasing the spread of sexually transmitted infections. The project has set up four drop-in centers around Bangalore that serve as daytime shelters, providing, a places to rest, bathe, watch television, and see medical specialists.

Our partnership with project Pragati grew out of mutual conversations in which they expressed a desire to improve their attendance records. The motivation for using biometrics as a replacement for their existing paper records is twofold: (1) Enabling accurate tracking of women who visit multiple centers, particularly for (anecdotal) cases in which they use different pseudonyms at different places, and (2) Provision of high-quality digital records and reports to funders and obviation of data entry specialists currently retained for the sole purpose of transcribing paper records. Both have the potential to increase the cost-effectiveness of the project.

5.2 Preliminary Deployment Experience

The terminal was deployed in two of four centers over a period of four months. In total, 284 people were registered to use the system: 239 at Hub A and 45 at Hub B. These registrants generated a total of 799 logged visits.

5.2.1 Quantitative Observations

Figure 3 depicts cumulative attendance data in each of the two centers. Initially, and especially in Hub A, the system was logging nearly the same number of daily visits as the paper-based system. During that period, a researcher was both monitoring attendance (and prompting visitors to log into the biometrics system) and training the hub manager to use and monitor the terminal herself. The researchers discontinued their daily visits to the hubs in early December, which is when the number of visitors logged diverges.

There are a number of factors that may have influenced the divergence between the electronic and paper-based logs. One likely cause is the increased demand on the hub manager's time, especially when the hub is busy or there is a sudden influx of visitors. We also noticed that once a significant number of people had been registered, the system's performance lagged in both registration and recognition. This frustrated not only the visitors but also the hub manager, especially in Hub A where over 280 people had registered, causing recognition times to slow from near-instantaneous to approximately 15 seconds. However, of six regular visitors to Hub A (some visiting daily) we spoke with, only two reported being bothered by the amount of time required to report a visit. Divergence between the paper and biometric records was greater at Hub B, where women arrived early in the morning after working all night and were eager to sleep as soon as they entered the building.

5.2.2 Qualitative Observations

The deployment in women's centers sparked very different insights about the use of biometrics in the context of monitoring hub traffic than our observations in the TB case. People were much more hesitant to provide fingerprints, and difficulties in fingerprint recognition did arise. Due to the nature of their work and the associated stigma, as well as the fact that, according to the project head, only twenty percent of the women involved in the project actually inform their families about the work they do, these women are often protective of information that may tie them to their work. The association between fingerprinting and financial records also caused reluctance among the women we intended to register. Furthermore, because another biometric system had been deployed in their medical clinics, women showed concern for the privacy of their health records. Finally, four women were unable to register due to irregularities in their fingerprints.

6 Performance Optimizations

As mentioned in Section 5.2.1, one unanticipated problem we observed was that as large numbers of people register with the terminal, response times to scan activity rise significantly. This is due to the fact that each time a scan is taken, it is compared against each template on the system until it matches one. The time required to find the match depends on the order in which the templates are considered. In a naive and static ordering in which templates are ordered by registration time, when the *n*th registrant visits the terminal, $n-1$ negative comparisons would be required before matching the template. In this section we describe how to improve this performance by reordering the templates to consider the most-likely visitors first.

TB Patients: Rigid Visit Schedules. In cases (such as our ASHA deployment) in which the expected arrival date and time of a given user is highly predictable or externally imposed, the set of fingerprints to be matched against can be optimized by placing the subset which is expected on any given day at the front of the queue of templates. It is also possible to perform statistical analysis on known arrival times to estimate when during the day the person is likely to arrive, further optimizing the queue.

Sex Workers: Arbitrary Visit Schedules. In other, less structured, cases, no simple mechanism for predicting visit order is possible. In the case of the Pragati hubs, visitors arrived sporadically, some arriving no more than once or twice. In order to optimize for this case, we retrieved three years' worth of paper logs from one hub and applied several different optimizations in an attempt to reduce the number of template comparisons performed.

Given these data, a naive scheme which maintains the queue in order of registration requires 1,943,560 comparisons for a population of 757 users across the three-year span of visits. We tried various models to attempt a general improvement on this number, and the best general-purpose model appears to be using move-to-front, placing the fingerprint template of the most recent visitor at the front of the queue. This results in a total of 1,063,006 comparisons for the case above, translating to an average speedup of 45.3%.

We foresee rich opportunities for future work in predicting the arrival times of visitors to health clinics so as to improve the speed of biometric identification.

7 Conclusions

Reliable identification and authentication of patients is an important issue facing health programs in developing regions. This paper offers new tools and field experience to advance the use of biometric fingerprinting technologies as an appropriate solution to this problem.

Our specific contributions are four-fold. First, we describe an extensible fingerprinting terminal that uses off-the-shelf components, includes a large graphical display, and (to the best of our knowledge) is the first to utilize a low-end cell phone for uploading visitation logs via SMS. Second, we adapt this terminal to the context of tuberculosis treatment programs, where biometric monitoring of supervised medication delivery represents a novel and potentially high-impact intervention. Third, we deploy our terminal for over four months in women's support centers, elucidating several socio-cultural factors impacting acceptance of the technology. Finally, we identify a new technical problem – the prediction of patient visitation order to improve the speed of biometric identification – and demonstrate a 45% performance improvement using a simple move-to-front heuristic.

Our overall experience demonstrates that while the biometric terminal is usable by organizations in India, incentives are needed to sustain that usage over time. In the women's support centers, usage decreased as researchers lessened their involvement with the project, suggesting that the terminal was either lacking a clear value proposition to the daily staff at the center, or was lacking an internal champion to ensure that it was used as intended. We believe that the terminal has more traction in the context of tuberculosis treatment, where initial observations suggest that it might improve the transparency and reliability of medication delivery. We look forward to evaluating this premise and its potential effect on health outcomes in the coming months.

8 Acknowledgments

We are deeply indebted to all of the staff at Swasti and Operation ASHA, particularly Sandeep Ahuja, Bhagwati, Rekha, Rakesh, Shiv, Shekhar, Diana, Pushpa, Prabhakar, Renuka and Mynavathi, for their unwavering help and support.

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