Iterative Design of an Immunization Information System in Pakistan

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ABSTRACT
Routine early age child immunization is one of the most cost-effective public health interventions. The use of Information and Communication Technology (ICT) tools such as Immunization Information Systems (IIS) to improve efficiency of vaccination programs has shown mixed but encouraging results in terms of success. The objective of this paper is to present evidence of Evaccs – a successfully deployed smartphone based vaccinator monitoring app, discuss the need to create a smartphone enabled IIS (called *Har Zindagi* – every life matters) that can store digital records of every child, discuss various design and implementation features of *Har Zindagi's android application*, and present findings of the usability testing performed on the *Har Zindagi* android app. Given that the vaccinators are non tech-savvy, and the real estate on a smartphone is limited, this application was particularly designed to allow easy record entry process, and smoothen the workflow. This paper builds upon previous work on user interface design for low-literate users, and identifies techniques to iteratively design interfaces with government employees, who may be uncomfortable with giving usability feedback due to fear of repercussions or might have different field reality when compared to their supervisors and policy makers.

CCS Concepts
• Human-centered computing → Human Computer Interaction (HCI) • Human-centered computing→Interaction design. • Applied computing→Life and medical sciences

Keywords
ICT4D; child-health; Immunization; Information systems; participatory development; m-health; NFC;

1. INTRODUCTION
Diseases against which lifelong immunity can be developed by provision of early age vaccinations are referred to as Vaccine preventable diseases (VPDs). Early age vaccination against Vaccine Preventable Diseases (VPDs) plays a key role in reducing child mortality and occurrence of lifelong diseases amongst the vaccinated populations [1]. VPDs include most of potentially deadly or lifelong paralyzing diseases such as polio myelitis, measles, Diphtheria-Tetanus-Pertussis (DTP), tuberculosis, yellow fever, hepatitis B, and Haemophilus Influenzae type B [1]. Early age vaccinnations and resulting prevention of VPDs thus reduce the disease burden on public health infrastructure and improve the living standards of the community in general [2] [1]. Routine early age child immunization is one of the most cost-effective public health interventions [1].

Given the significant role of these early age child immunizations, World Health Organization (WHO) introduced the Expanded Program on Immunization (EPI) in 1974, with an objective to vaccinate children globally against VPDs [3]. The Expanded Program on Immunization (EPI) has a few broad functions, including but not limited to, supply chain of vaccines, cold chain maintenance of vaccines, inoculation of infants, data management of records, and monitoring and evaluation of the entire immunization process. The EPI was a much needed initiative, as globally, only 5% children were immunized against such diseases at the time [4]. The program has seen immense success, where today the global percentage of fully immunized children has reached 83%, with some low income countries reporting immunization coverage as high as 99% [4]. The overall success of the EPI can be attributed towards lower cost burden of early age vaccines and the overall global support generated by the idea of saving child deaths [4].

However, many countries have not only missed the Millenium Development Goals (MDGs) of 2015, but also face an even strenuous challenge with the post-2015 Sustainable Development Goals (SDGs). One of the goals among the SDG includes reducing under 5 child mortality to as low as 25 per 1000 live births [5]. To achieve these ambitious yet feasible goals, a few challenges are inevitable which primarily include (i) reaching the most vulnerable and inaccessible communities (ii) defining mechanisms for introduction and prioritization of effective new vaccines, though not at the expense of sustaining current progress, (iii) upscaling to include adult, older population, (iv) scaling up immunization surveillance and (v) improving the quality of coverage monitoring mechanisms [6].

The advancements in Information and Communication Technologies (ICTs) can help overcome some of the above mentioned challenges. Immunization information systems (IIS) are confidential, computerized, population-based systems that collect and consolidate vaccination data from vaccination providers and provide important tools for designing and sustaining effective

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immunization strategies [7]. Evidence from 240 studies in a systemic review [7] suggests these IIS have the capabilities to create and support immunization drives and campaigns via features such as SMS and robo call based reminders, monitoring and evaluation of vaccination programs, informing policy makers to devise plans to counter VPD outbreaks, providing necessary data on vaccination coverage and recognizing data discrepancies. All of these features embedded within IIS serve as a medium to increase overall vaccination coverage [7]. However, evidence from a systemic study [8] based on 14 different studies on the cost-benefit analaysis of IIS, concluded that though sufficient evidence does not exist to prove that benefits outweigh the cost of IIS, but it is likely that larger body of evidence will prove the case, both financial and non-financial.

In this paper, section 2 gives a background of the immunization scenario in Punjab, highlights the successful deployment of an ICT based vaccinator monitoring app called Evaccs, and justifies the need for a smartphone powered Immunization Information System. Section 3 highlights the methodology for data collection. Section 4 details user feedback of the deployed Evaccs app and a potential redesign for Evaccs. Section 5 outlines the system architecture and features of the iteratively designed android application for *Har Zindagi*. Section 6 presents the usability data collected on *Har Zindagi's* android application, followed by an discussion and recommendation for future work.

2. BACKGROUND

Pakistan was among the six countries with the highest number of children who did not receive the DPT-3 vaccine within their first year of life [9], and thus missing the MDG2015 goal, of 90% national immunization coverage and 80% district immunization coverage, by a margin. Pakistan is also one of the only two countries, where polio myelitis still remains an endemic [10]. Overall, a study [11] indicated that Pakistan had the third highest global burden of child mortality combined with maternal mortality. The country also suffers from major sociopolitical instability, security challenges and deep rooted economic issues [11]. The status of fully immunized children at 56% in 2014 and the ongoing state of sociopolitical and economic affairs, called for drastic measures [11] .

2.1 Immunization Infrastructure in the Punjab Province

After the 18th amendment in the constitution of Pakistan in 2010, the federal health ministry of Pakistan was dissolved, and its powers including immunization administration, were devolved to the provincial level [3]. As a result, dedicated funds for EPI were not earmarked in the provincial budgets, contrary to the fedral practice of earmarking dedicated funds for EPI in the federal budget [10]. Thus, the EPI in Punjab is now managed directly under the Government of Punjab's provincial budget.

To ensure coverage in remote or underserved areas, the EPI department in Punjab employs outreach staff at grass root level called *vaccinators,* who transport vaccines and immunize infants in the field. This is due to the sparsity of population in rural areas, the cultural context of infrequent female visits outside of home, and to compensate for limited health facilities in rural areas. These 3750 vaccinators, all permanent male government employees, are issued with an official motorcycle and monthly fuel allowance [12] [13].

As per the child vaccination schedule currently practiced under EPI on the provincial as well as national level [14], each child is immunized six times, from birth to the age of 15 months as shown in Table 1. Vaccinators then manually enter these records against each individual immunization into two sets of registers depending upon the permanent address of the baby. [15]. A separate register is maintained for Adverse Effects Following Immunization (AEFI).

Visit #	Child Age	Antigens
1	At Birth	BCG, OPV-0, Hep-B
2	At 6 Weeks	OPV-1, Penta-1, Pneumo-1
3	At 10 Weeks	OPV-2, Penta-2, Pneumo-2
4	At 14 Weeks	OPV-3, Penta-3, Pneumo-3
5	At 9 Months	Measles-1
6	At 15 Months	Measles-2

Table 1: EPI child Immunization Schedule

Monitoring of vaccinator performance is carried out by their immediate supervisors, Deputy Superintendent Vaccination (DSV) and sometimes Assistant Superintendent Vaccination (ASV) who are based at the district headquarters. Aggregated records are passed up the chain to DSVs, ASVs, then to the Executive District Officer Health (EDOH) on district level, and finally to the EPI directorate on the provincial level. Given that all data compilation happens manually on paper, it is prone to data compilation errors, forging of records, or data fabrication at all levels of compilation. Furthermore, as there is considerable lag in the generation and transmission of data, the data cannot be used to improve service delivery by highlighting poor performing areas or earmarking children that have fallen out of the vaccination net.

Given that vaccinators collect vaccines from the Basic Health Unit (BHU), and perform their duties in the field, it is difficult for DSVs to monitor vaccinator performance. Work in [16] explored the use of ICTs to solve the 'last-mile problem' - the inability of higher-level bureaucrats to govern a vast expanse of the area in their jurisdiction due to the limited number of civil servants employed and a deep-rooted unwillingness to cede power to the locals. He found that while the higher-level bureaucracy has deployed various forms of surveillance mechanisms to control the practice of the lower-level bureaucrats, lower bureaucrats found imperfect ways to circumvent surveillance as well as control. The extent of population's access to immunization services is largely dependent on the outreach of vaccinators in the field. With ubiquitous cellular coverage in Punjab and decreasing costs of smartphones, the next section explores the successful deployment of a smartphone based app that allows increased monitoring of field staff.

2.2 Successful deployment of Evacss – a Smartphone Based Vaccinator Tracking App

The two dominant ways that the "state" gets dealt with are through the metaphor of seeing, we are either "seeing like a state" or "seeing the state" [16] [17] [18]. On one hand, state actors are using technology to monitor or increase the "legibility" of its citizens. On the other, open government looks into how technology can be used to open up the workings of the government to citizens. Technology is rarely being used by the government to monitor itself. [16] explored how higher level bureaucrats in the state of Andhra Pradesh used technology to survey lower-level bureaucrats, and found it to be a desirable measure.

In 2014, to increase the vaccinator attendance and geographical coverage, the Punjab IT Board (PITB) began to digitize the vaccinator's attendance and track their visits in the field through Global Positioning System (GPS) data. Under this program (Evaccs), all vaccinators in Punjab were given an android based smartphone, with a customized, preloaded android application called eVaccs for vaccinators' tracking.

2.3 Making a case for a smartphone powered Immunization Information System (IIS)

Literature review of possible benefits of an Immunization Information Systems reveals wholesome improvements in service delivery, reduced manual administrative costs, ability to generate aggregated as well as granular historical data on vaccination, improvement in service efficiency, assessment and feedbacks and as mentioned earlier, ability to send reminder messages and robo-calls [8]. The study further found that the use of ICT also has significant opportunity costs [8], both financial and non-financial. These costs include monetary support for operations as well as upgrade of infrastructure, HR training, data exchange, vendor payments, labor and software costs etc. Other intangible costs such as diversion of HR to ensure smooth IIS functioning, and a plausible loss of focus from the primary function i.e. providing vaccination services, are also involved [8].

In our particular scenario, efforts to use technology to improve immunization coverage have been underway since 2014, when the initial versions of a smart phone based app[1] for vaccinators was deployed to all 3750 vaccinators in the province [19]. Given that the capital cost has already been incurred, processes have been placed to incorporate technology into vaccinator workflow, HR training to ensure smooth functioning of the app has taken place, and behavior change around adoption of technology by vaccinators has taken place, it is reasonable to investigate the possibility of an Immunization Information System (IIS) centered around the use of smartphones to gather data and create digital records.

A WHO working guide [20] refers to lack of immunization knowledge among parents, poor perceptions regarding immunizations, and lack of awareness about potential risks carried by the diseases as major barriers to achieving universal immunization. Evaccs essentially increased accountability of vaccinators by collecting digital attendance through GPS coordinate based check-ins, using pictures as proof of vaccine administration.[2] However, there is a need to use ICT tools to increase understanding and demand (pull) of immunization services. Our previous work of [21] redesigned immunization card for low-literate users, and the mobile app discussed in this paper, target not only bringing about a difference in attitudes and behaviors of mothers and families, but also also create digital records for every child.

Digital child records are essential in a country like Pakistan, where the last census took place in 1998 [22]. Child data can be used for the provision of other social services such as family planning, child enrollment in schools, direct cash transfers for safety net.

3. SYSTEM ARCHITECTURE

Our proposed immunization information system consists of three core components. Their details and how they integrate is explained below:

Digitally read-and-write enabled immunization card: for the consumption of parents as well as the use of vaccinators. The 'Card' contains information about immunizations administered, due data for upcoming vcacinations, etc.

Android (based mobile) application: to be used by vaccinators in combination with the Card, to create digital immunization records in the field..

Web dashboard: for viewing of real time data collected from the field by immediate supervisors and policy makers.

All the three components of the system combine together to form the Immunization Information System called *Har Zindagi* – Every Life Matters. The workflow of the system is described below.

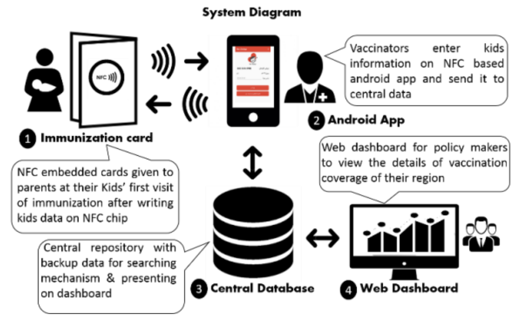


Figure 2: System diagaram showing the interaction of card, application and web-dashboard

The immunization card is issued for each new born child upon registration with the system. Building upon our previous work [21], our card contains a Near Field Communication (an NFC) chip that can be read and written to multiple times by the android based application. The NFC chip will contain the system-level unique identifier of the child, child recordbook ID and the due date for the next due immunization of the child.

Once the smartphone with the pre-installed application is given to each vaccinator, the unique number of the phone called IMEI number, is used to bind the vaccinator with the phone in the central database. This is done to capture three things:

i. The data uploaded by each IMEI number (or the phone) is counted towards tasks performed by the vaccinator who is allocated this phone.

ii. The data initialization for the android application is done based upon the designated location of the vaccinator. One example of initialization is the preloaded list of villages within the union council (smallest official geographical boundary by the government) of the particular vaccinator.

iii. All infants within the vaccinator's jurisdiction whose immunizations are due are are added to the due immunization list of the app.

All the information from the android based application which includes vaccinator attendance and geographical coverage, alongside child records, is uploaded into a central database. Once the vaccinator data such as attendance and geographical coverage is available in the central database, it is also made visible on the web dashboard for supervisors and policy makers to review performance, workload etc. In case the vaccination card is lost, we use the same central database to search for the child's record, and assign/burn the previously assigned unique id to the new card's NFC chip. Routine reminders and informational text messages to

[1] Refers to versions of eVaccsE-vacs 1 and eVaccsE-vacs 2, an android based app which requires vaccinators to mark their attendance, captures their GPS coordinates whenever they perform an administration of a vaccine and makes it mandatory for them to take picture of a child after administering each vaccine.

[2] The GPS points lead to geographical coverage mapping of vaccination in the province. This along with some other relevant issues such as the facial recognition paradox have been discussed later in this paper.

parents are also sent directly from the centralized dashboard to the cell phone numbers stored for the parents of innoculized children.

4. METHODOLOGY

We used a variety of approaches for data collection. Our methods include participant observation, unstructured and semi-structured interviews with vaccinators, surveys administered with fifty vaccinators, and content analysis of government documents. The authors have attended over thirty meetings with senior-level bureaucrats in the health sector. At least ten focus groups, trainings, usability testing sessions were conducted with four or more vaccinators with vaccinators from districts of Sahiwal, Sheikhupura, Lahore, Murree, Jhang, Sargodha, and Kasur districts of Punjab. Together the authors have conducted over a hundred semi-structured interviews with mothers, lady health workers and vaccinators. The data for this paper comes primarily from interviews and field notes of the authors.

5. E-VACCS– a smartphone driven vaccinator monitoring app

Before starting work on the Android App for Har Zindagi – the Immunization Information System, we sought to understand the features and user feedback for Evaccs, the vaccinator monitoring app. The following sections discuss the salient features of eVaccs, vaccinator feedback and our initial redesign.

5.1 Salient features of eVaccs

In order to monitor the vaccinators' performance and attendance, the first version of eVaccs was developed that only reported vaccinators' attendance and the number of children vaccinated per day by each vaccinator in an aggregated form. A revised version of this app recorded the kinds of vaccines administered to each child, and monitored vaccination coverage area through satellite imagery. The eVaccs app being used in the province has the following salient features:

Check-in and Check-out: To mark the attendance of vaccinators on daily basis, a check-in, check-out feature was included. Vaccinators have to click on check in once they arrive at their duty station in the field to mark the start of their duty, whereas check-out marks the completion. Every time vaccinators successfully perform the paired operations of check in and checkout, their attendance is marked in the database.

Kit station picture: A picture of the remote vaccination station called 'Kit Satation' is required as pictorial evidence of the vaccinator's presence at the designated location of immunization. Each picture is uploaded with GPS coordinates and time stamp as metadata, to validate their physical presence in the field for vaccinations.

Children's Registration: A new record is created for each child, and the type of vaccines administered are recorded, alongside a picture of each child. Since a unique id isn't created, each child gets re-entered in the system. However, the application is divided into two parts: a) *EPI Child* – a child that has been vaccinated before; this is determined either through mothers recall or visible vaccination mark and b) *Non-EPI child* – a newborn child that hasn't ever been vaccinated before. This allows policy makers to keep an aggregated count of new children entering the system every month.

All the data is then displayed on a web dashboard to policy makers including Deputy Commissioner Officer (DCO) and Executive District Officer Health (EDOH). Policy makers can view the attendance of vaccinators, alongside the geographical coverage of the entire province. In case of a shortfall, the geographical area gets red flagged on the dashboard for urgent corrective action.

Since the eVaccs app was designed for monitoring vaccinators' performance, it had a minimalist design so as not to interfere with the vaccinators routine tasks including creating paper based register entries for each child and filing up registers. Evaccs did not aim to create digital child records, and so the user interface of the app was not of primary importance during the creation of the app.

5.2 Insight about eVaacs from vaccinators

Some concerns that came up in our interactions with vaccinators were:

Internet connectivity issue: Many rural and farflung areas of the province have poor and slower mobile internet connectivity [23]. It is hard for vaccinators to upload all the data, particularly pictures of infants and the kit station. In some cases, vaccinators were unaware about the data not being uploaded till they were notified of their absences.

Standalone online data submission for each record: The app currently does not retain data, and each individual record has to be uploaded before the next record can be created. Due to the requirement of uploading every child's picture, it can take up to 10 minutes to upload a record in poor coverage areas.

Attendance: Vaccinators cannot checkout of app unless they upload all the data. Given their attendance depends on both check-in and check-out from the app, vaccinators suffer due to the app's limitation to not allow delayed submission of data.

App increases workload: Besides entering data in app, vaccinators have to manually fill the vaccination card alongside creating paper based child records on registers. This duplication of effort between digital and paper based systems causes frustration.

6. THE ITERATIVE PROCESS OF MOBILE APPLICATION REDESIGNING

Since the end users or vaccinators already had access to ICTs in the form of android phones, it was decided to develop an Android application for data entry and card integration. The mobile application is designed to complement the existing paper based system and enable data gathering and monitoring along with the card. As majority of the population in low-resource settings is semi or low literate, they have a fear of technology that prohibits them from interacting with gadgets and their functionality [24]. Given such a demographic, developers should design interaction on mobile applications in a way that better adapts to users' needs and expertise so as to achieve greater usability [25]. International Organization for Standardization (ISO) defines usability as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" [26].

A majority of apps created currently are designed keeping in view a predefined level of education of end users. Applications are designed such that they can be used across borders with minimal changes. It is important to understand that standard design, usability and HCI practice is not always applicable in all contexts [12]. Hence the gap between the need for mobile applications that cater to users with limited technical knowledge and the lack of interaction techniques is increasing. To address this gap Chua et al propose a term 'acclimatization' [27] for a technique that provides personalization of content, structural navigation and representation on mobile applications adapting to the users' needs and expertise levels. The sections below describe how the mobile application described in this paper was acclimatized for vaccinator needs and uses. Particular empashis was given to the small screen size of an android phone and data entry in field conditions.

6.1 First iteration – Building on top of Evaccs

After our initial observation of the eVaccs application, we designed an android application with four basic functions while addressing the shortcomings explained by our field visits through special features. The four functionalities were Register Child, Scan Card, Search (lost) Card and Plan my day. This section explains Plan My Day and special features. The other three functionales are explained in subsequent sections, as Plan My Day had to be removed from the future versions after vaccinator feedback.

Plan My Day: To optimize vaccinator movement within the designated area during field visits, a *plan my day* function was introduced in the redesigned app. The idea was to provide each vaccinator with an optimal path of travel using shortest path algorithms and GPS locations of all possible places of visit. This was to enable them to spend less time in travel and more time in performing their activities.

The special features included to cater feedback received on Evaccs are explained below:

Delay Tolerance: To enable the vaccinators to perform their duties in cellular data blackspots, we added the feature of offline work in our android application. All the data entered in the application is stored locally. Once cellular Internet is available on the phone, the vaccination data is uploaded to the central server.

Single click Upload: The app accumulates all records locally and vaccinators can initiate the upload of all new records with a single click. If uploading of data is interrupted due to Internet unavailability, the application pauses the uploading process and automatically resumes from that point on when Internet becomes available. However, the vaccinators are prompted at each such instance where uploading is paused.

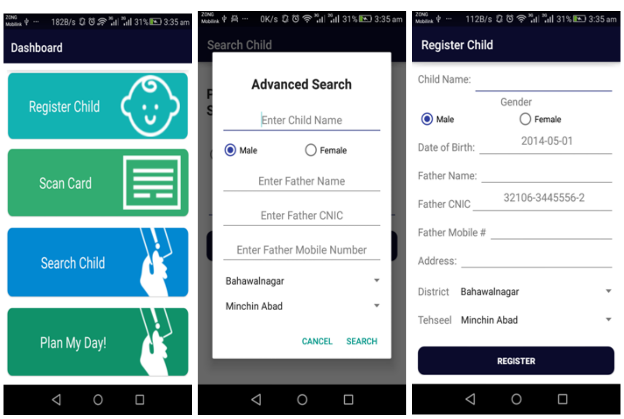


Figure 1: Version 1 with main screen the four options(left); Advanced search (middle); Child registration screen (right)

6.2 Feedback on Version 1:

Through field visits, initial feedback on the redesign included:

Translation of Application in Local Language: In our field surveys, vaccinators informed us that they would prefer if the application was in Urdu, the national language of Pakistan. Although they preferred using the qwerty keyboard to enter data in English alphabets, they requested that the application text and prompts be changed to Urdu. Thus, the entire application was translated to Urdu.

Defaulters list: Vaccinators daily prepare a defaulters list for the babies who have been due for immunization for one month, but have not reported to the kit station. At the end of the month, they create a second list that aggregates all the defaulters for a given month. Vaccinators requested that the app automatically create these defaulter lists for them.

Removing Plan my Day: The vaccinators informed us that they have preassigned field plans for each day that are made in conformance with their supervisors, therefore a *plan my day* feature would not be useful. Given vaccinator feedback, this feature was scrapped in subsequent iterations of the app.

Given usability feedback on Evaccs and our first iteration, it became very clear that in order to create a digital records of every child, a redesign of the app wasn't enough. The need of the hour was to create an entire Immunization Information System (IIS) that educates mothers about the schedule and importance of vaccinations, tracks the progress of every child, sends reminders to parents when their child is due, etc. The next section highlights the system architecture of Har Zindagi and focuses on the design of the Android Application to create digital child records in the field.

6.3 THE IMMUNIZATION CARD

During our field work with the parents and the vaccinators, it became evident that the existing design of the immunization card was neither user friendly nor functional. [21] describes the detailed design of the redesigned immunization card, which uses NFC stickers to store immunization information on the paper based immunization card. NFC cards are easily readable using NFC-enabled smartphones, and allow for fast data retrieval and writing from the Android app.

6.4 Iteration 2 –Four Core Functions

The second version of the mobile application was built upon the feedback from the vaccinators' survey, our observations of their usage of the application, as well as recommendations from government officials linked to the vaccination program. The application included four functions listed below.

6.4.1 Register a new child:

When a new born child is vaccinated, the vaccinator uses the child registration process in the Android app to register him/her.

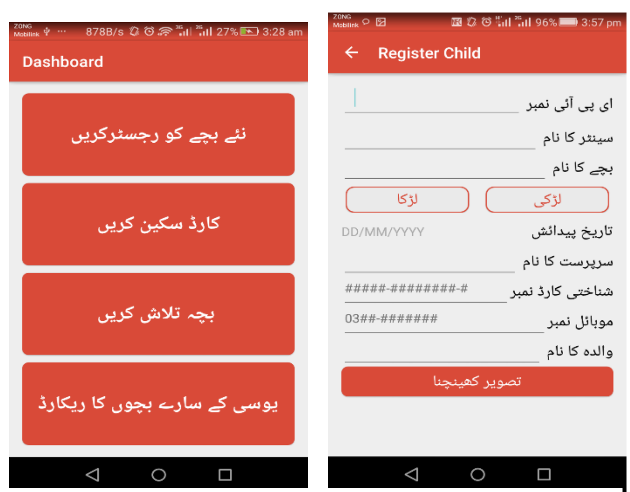


Figure 3: Application home screen with four features (left); Child registration screen with fields (right)

The registration process consists of taking basic information about the child (name, date of birth, gender) and the guardian (address, phone number and Computerized National ID Card (CNIC) number). The process also requires to take a picture of the baby for record purposes. Once all of this information is entered, the data is written to the NFC chip embedded in the card by tapping the phone onto the card. This binds the Card to that particular child's unique id.

Immunization Schedule Display: The register child screen takes to the first visit immunization screen. To display the immunizations administered as well as due immunizations, a tab based navigation was designed. All the colors of the tabs correspond with the color coding for each visit on the immunization card. This was to provide a visual cue to the vaccinators that they were on the right page when filling the paper based card as well as entering data into the immunization application. On each visit, the number of vaccines to be administered is preloaded exactly as per the national EPI immunization schedule (Table 1). The vaccinator can select one or more of the immunizations depending upon the immunizations administered to the child. This was changed from a binary (all administered or none) choice after vaccinators informed that sometimes there is a shortage of a certain ampule or they would wait for a certain number of children to open an expensive vile that could potentially immunize 15-20 children but might go waste if opened only for one child. Keeping this in mind, we added check boxes for each immunization administered. Vaccinators select the ones administered, take a picture of the child and save the entire visit details to the system.

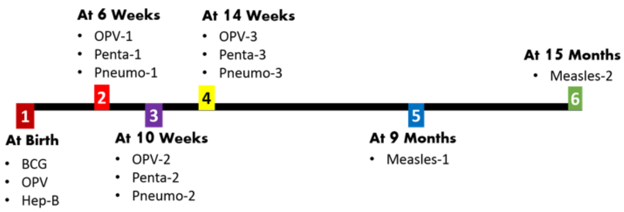


Figure 4: Immunization schedule currently in use, showing the vaccine names and their administration timeline

6.4.2 *Scan a Card:*

The NFC based card that works with the Android based mobile application can be scanned upon subsequent visits of already registered children. Scanning of the card is meant to reveal the identity of the child (the immunization ID of the system and the current due immunization). Upon scanning a card, the application opens the exact visit which the child is due for. For example, if a child had two immunization visits and is now visiting for the 3rd immunization shot, upon tapping his card to the smartphone, the application would display 3rd visit screen, listing the vaccinations administered on the third visit. This was designed to save the vaccinators' from scrolling through different tabs to reach the desired vaccination.

6.4.3 *Search a child:*

There are multiple instances reported by the vaccinators' in the field where upon subsequent visit of an already registered child, mothers or guardians forget to bring the immunization card along with them. This ability to lose card has already been reported in existing works [28]. Thus to retrieve vaccination record for a registered child, the child record is first searched within the local Android app database. If the app does not return any results, either because the child is a resident of another location or because the search query data provided by the guardian is inaccurate, the data is then searched from the central database. Two mechanisms were defined to search in the central server database:

Online Search: If internet connection is available in the area where the vaccinators are performing the duty, then online search is used to search for the child. This enables a real time search from the central database using the information filters in the application.

Offline Search using SMS: If the app is being operated in offline mode due to unavailability of Internet, then an SMS is sent to request data from the central database.

Filters used by our application to search a child include Child EPI number, Booklet Number, Phone Number or CNIC Number.

6.4.4 *View all children of my Union Council:*

The view all children of my UC feature was also designed as a separate tab in the navigation menu. This was done to keep consistency throughout the application design as well as to enable vaccinators to view large lists of data in one place. There are three tabs in view all children, namely:

Defaulter children: Children who do not get immunized for a month after their due date of immunization become part of the defaulter children list.

On-time Children: Children who have not yet completed their immunization schedule but have received all vaccinations on time thus far; and

Completed children – denoting children belonging to the vaccinator's designated area who have completed their six visit immunization schedule.

The vaccinators also described the need to view the defaulter children of their designated area. They are special focus of the EPI system because an increase in defaulter children means a decrease in retention.

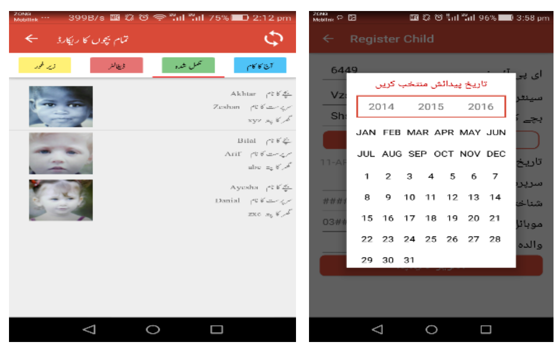


Figure 5: Viewing all children of a UC, with tabs of defaulter, completed immunization and immunized on time (left); Calendar for fast date of birth entry (right)

The following additional features were added to this iteration of the application:

- ***Image compression to reduce image size for uploading***: To enable the fast uploading to the central server, all images are compressed to reduce image size.
- ***Addition of Calendar for Date Entry:*** Previous versions had drop down menus for entering dates such as the date of birth. In version 3, a pop-up calendar was added to save time and reduce chances for error.

- ***Authentication for using the application:*** The existing eVaccs application did not use any authentication mechanism. Since child records are sensitive, usernames and passwords were used for authentication. Since phones are pre-assigned to each vaccinator, username field is prefilled and the vaccinator only has to enter the password.
- ***Password recovery Options:*** To enable password recovery two options of recovery via either SMS or Call were introduced. However, difficulty of verification over phone (using both voice or text) and conversations with the vaccinators showed SMS and Call to be less secure. An email from the EDO of the district (supervisor of the vaccinator) will generate a new password for the vaccinators and email it to the EDO. This was done because all EDOs have availability of internet at all times and can verify all the vaccinators in the system at all times.

Pilot testing of this application requires the withdrawal of existing system EVACS from the pilot districts, which would result in temporarily missing data. The next section discusses how this and other issues were addressed in the third iteration.

6.5 Iteration 3 – APPLICATION WITH ADDITIONAL FEATURES:

After another round of user feedback, it was decided to improve certain features of the app:

- ***Backward Compatibility:*** During discussions with health officials, it was decided that the Har Zindagi app should replicate certain components of the eVaccs application for monitoring purposes. It was decided that upon the start of the pilot, NFC enabled cards will be given to new-born children. Infants who've previously been vaccinated will continue to be recorded via the Evaccs app (without unique id's). Thus to enable functioning of two parralel systems simultaneously, an extra screen was added at the launch of the application. This enabled the vaccinators to choose between newly born child or previously vaccinated child via the old regimen.
- ***Facial detection for photographs***: Health officials revealed that vaccinators sometimes do not take pictures of the children in the picture taking step. They instead take pictures of objects in order to move on to the next step. Thus Google Face Recognition [29] was added to the application that does not allow users to move forward unless a face is detected in the picture taken. Processing of the face detection is done locally in the application.
- ***Update Application Remotely:*** Remote over the air updates and request-based update features were added to the application for the ease of vaccinators so that they don't have to go to their supervisors or visit us for reinstalling the app on every update.
- ***Data Recovery (from central server) on fresh install:*** As we have given vaccinators the facility to lookup all kids of their union council and their immunization status, we have given them the leverage to automatically reload the children record and immunization status from the locations assigned to the vaccinator everytime our app is reinstalled or loaded on a new phone.
- ***Calculation of next due date:*** Vaccinators have to enter the next due date once the baby is immunized and enter it in the card and their registers. While vaccinators calculate this very quickly, since the immunization schedule has gaps of different durations between immunizations, the app calculates next due date depending upon the visit, and displays it for the vaccinator to copy on the immunization card. It also adds a threshold of 28 days in next due date, as policy makers and vaccinators told us that they can inject vaccines to kids within 28 days after their due date. After 28 days they put them in defaulter list if kids don't show up for vaccinations.
- ***GPS location tracking with each vaccination***: Policy makers want to track the movement of vaccinators, especially when they immunize a baby. This enabled them to monitor vaccinators' location – if they are in the field or at a different location when they post their tasks. For this purpose, the location of the vaccinator is recorded with every immunization record entry.
- ***Improved Font for Better readability:*** During field research we found out that some vaccinators read text from app by tilting their phones and adjusting their glasses. Upon asking them the reason, they said that the font is not readable. Lab testing revealed that the Noori Nastaleeq font for Urdu improves readability, as it is closer to how Urdu is printed in literature. Figures 6 shows the earlier (left) and changed fonts (right).

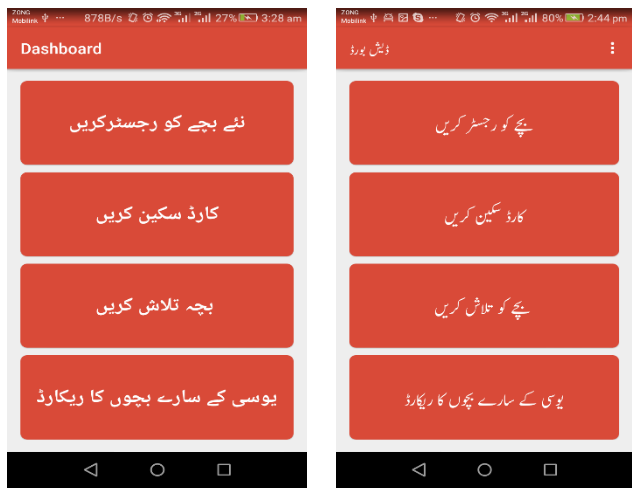


Figure 6: Native font used in Ver 2.0 (left); Urdu custom font used in Ver 3.0 (right)

6.6 Small Scale App Testing with real time Users

Up till iteration 3, the app was tested via exploratory, smoke, sanity, regression and functionality testing with EPI members and our research and technical team. The focus of in house lab testing was to ensure acceptable performance, efficiency and stability. Besides a dedicated quality assurance expert, we followed various phases of STLC (Software Testing Life Cycle) to ensure the working of our app before taking it to real time users i.e. vaccinators. Software Testing Life Cycle refers to a testing process which has specific steps to be executed in a definite sequence to ensure that the quality goals have been met. Hence with our first stable app version i.e. version 3 we adopted field study methodology [30] to evaluate our app usability with vaccinators.

6.6.1 Methodology

We conducted a training and testing session of the 3rd version of our app with 50 vaccinators from two districts of Punjab i.e. Sahiwal and Shehikhupura i.e. 25 vaccinators from each district. The main reason of conducting this training and testing was to find out the effectiveness, efficiency and satisfaction of vaccinators by allowing them to run and test the mobile app.

Our field study for app testing comprised of two parts:

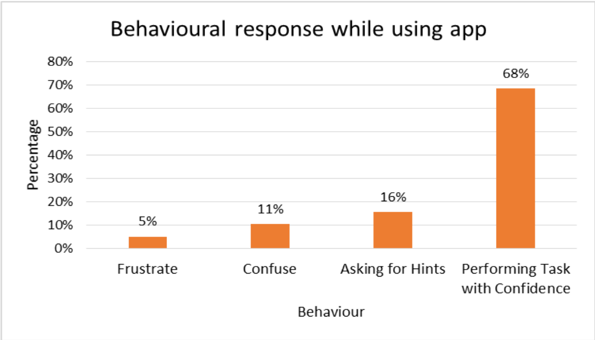
i) Training for using the new app: We conducted a comprehensive hands on training session with the aim to make vaccinators comfortable with the new app following repeated use of eVaccs. We explained how the redesigned immunization card worked in integration with the app, explained all the individual features of app in detail via power point presentation and videos in local languages i.e. Urdu and Punjabi. Each training session was around 2 hours long and was followed by a question and answers session.

ii) Task based assessment: After training sessions, we assigned 'Child Registration' task to vaccinators groups with 3 to 4 vaccinators in each group. Each group was observed by a technical staff member and a researcher. Each vaccinator group was given a redesigned card with NFC chip embedded and a mobile phone with the app. The maximum time taken to perform a given task (such as register a child) was 5 minutes. The technical staff member would help vaccinators understand certain features while the research staff observed understanding following the Gorman et al methodolgy which encourages facilitation during training and testing [31].

A usability testing observation sheet was created before hand, and was filled while vaccinators were performing tasks. Given field challenges, the research staff were unable to fill observation sheets with all vaccinator groups.

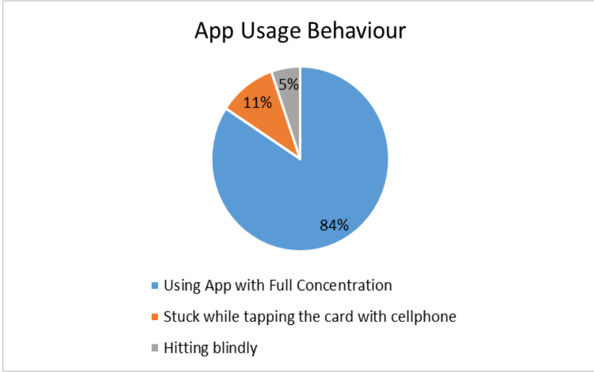
6.6.2 Quantitaive Findings

Vaccinator Demographic: 62% of the vaccinators involved in training and testing had completed 10th grade education (matriculation level) and the rest had 12 or more years of formal education. They all were able to read and write English and Urdu. They all were also able to type English and Numeric text on android app given to them (eVaccs). 48% of the vaccinators had more than 20 year's job experience in vaccination field. Vaccinators with experience of 20 years and above have an average income of approximately US $300 per month.



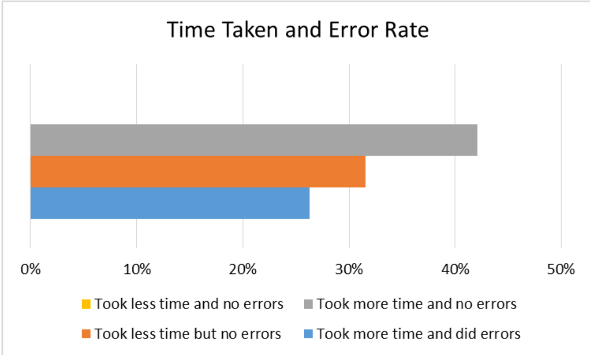
Graph 1: Behavioural Reponse of Vaccinators

Vaccinators' Behavioural response while using app: Graph 1 and 2 demonstrate accumulative behavioural response from 50 vaccinators. These graphs show that majority of the vaccinators performed assigned tasks confidently, with full concentration and understanding, following a detailed training. Familiarity with using smartphones because of Evaccs may be a potential reason for confidence in using the app.

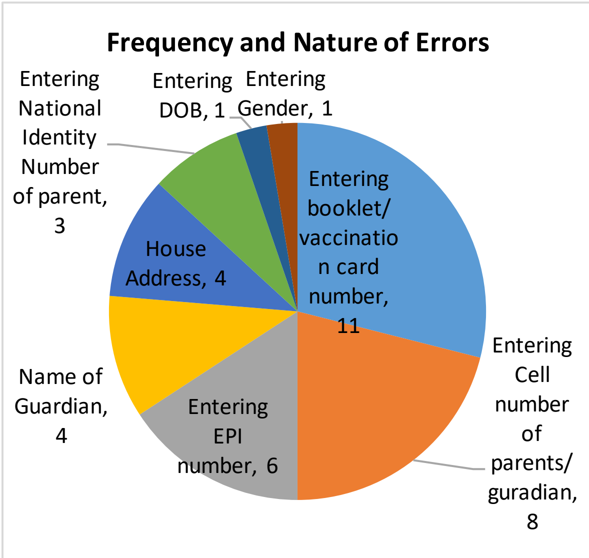


Graph 2: App usage Behaviour

Time Taken and Error Rate: One of the measures to test the efficiency of our app was to perform a comparison between time taken to perform a preassigned task and the number of errors made. This data is shown in Graph 3. This graph shows that majority of the vaccinators, whether they took less or more time with our application usage did not make many errors while using the app.



Graph 3: Time Taken and Error Rate



Graph 4: Frequency and Nature of Errors

Graph 4 is an expansion of the information presented in Graph 3. The errors that were recorded in the application usage were then categorized to see which areas had more errors. Graph 4 shows the components of the app which had errors and the frequency of each error type pointing to room for further improvement within the app.

6.7 Qualitative Findings

We collected qualitative feedback at the end of training and testing sessions, and asked about likes and dislikes around different features of the app. Features liked by most vaccinators include: data retrieval through NFC, face recognition, defaulters list, searching records for lost cards and one click upload. The features disliked by majority of the vaccinators includes: twice image capturing in case of registration and first immunization on same day, which is usually the case and duplicate entries on paper based card as well as via NFC write.

As a suggestion, vaccinators wanted us to show them a list of daily immunized kids on app screen that they can copy to their daily and permanent registers easily. They also wanted us to make checkout offline so unavailability of internet connection wont effect their attendance. Vaccinators supervisors played a major role in the comfort of vaccinators to give open feedback, as one vaccinator remarked:

"These vaccinators are not educated enough to learn everything in one go. You should give them more training sessions but make sure that for all next training session, supervisors are not around, especially if you want them to speakout and to give you their honest opinion."

7. DISCUSSION:

We have used user centered iterative design process to extract user requirements from vaccinators and administrators. It was observed that seeking opinion from public sector employees, with previous experience of top-down deployments, was difficult. Many participants were reluctant to share criticism or negative feedback fearing on-the-job reprecussion. Vaccinators assumed interface failure as their inability to understand a new system and perform their job well. Thus, they felt reluctant to share their struggles, as they did not want to appear less informed or comfortable with the system. Presence of vaccinator supervisors made the requirements gathering even more difficult.

The difference, and sometimes contradictory requirements of vaccinators and policy makers, reflected a difference in viewpoints from different positions. This observation highlights the need to include the end users and ensuring they have a real voice in the design process.

While most of the requirements were gathered explicitly from users, some were implicitly extracted by observing users, their activities and responsibilities, or by talking to supervisors, and consumers of data – the policy makers. Recommendation of features that can reduce their tasks of filling registers, or creating defaulter lists, daily lists and searching from registers was suggested after observation of their activities.

Another insight from our field research shows that after collection of usability and feature requirements, there is a need to validate these requirements using field knowledge. Secondary analysis of our discussions with vaccinators revealed that not all the requirements shared with us were genuine, some were to create room for them to skip duties and forge data. One such request is ability to move between immunization visits without tapping a card. Similarly, the recommendation and removal of plan my day, a feature that was endorsed by authorities and donors, also confirmed the need to validate the implementation with the users. Upon implementation it was revealed that our understanding of their problem of daily task scheduling and suggestion of optimal travel routes for every day, although technologically appealing, were not required by them. Thus a careful evaluation of requirements after gathering, along with cross-validation of information mentioned above, needs to exist.

Our work lists various software requirements to support simpler technology solutions for usability, administrative and security concerns. Our work also shares the various technological solutions like data binding to IMEI, pictorial evidence, GPS location to verify presence to survey lower level bureaucrats by higher level bureaucrats. Lastly, internet and connectivity issues are also sought to be solved using data caching, initialization of application data to avoid field based downlaod, and remote updation of application.

The iterative application development shows the need for frequent and user centered approach in building solutions for real-life deployments.

8. FUTURE WORK AND RECOMMENDATIONS

This paper only shares the lessons learned from the development of the android application portion of the Immunization Information System. The app not only helps creates digital health records in the field, it also helps check and validate the vaccinators' performance using realtime data. However, the performance of the vaccination program is not only dependent upon vaccinator performance, but awareness, availability and compliance of parents. In our future work, we will present the design and utility of an ICT enabled intervention that informs and motivates the parents as well as seeks confirmation of vaccination administration. Digital child records created with this app, and the cell phone numbers of parents stored during registration, will be key for the reminder system.

The data for the immunization system was being produced by the vaccinators. But without consumers of this data or supervisors being aware of the performance and coverage of the vaccinator's the system would have no effective use. Thus, a web dashboard is being developed using user-centered design principles to enable the supervisors and provincial policy makers to view the data. The existing system of Evaccs has a web based dashboard that is heavily used. However, it only provides information regarding vaccinator attendance and coverage maps etc. We want to complement that data with digital child records. A six-month pilot is planned with 50 vaccinators in two treatment groups, and 25 vaccinatiors in a control group.

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10. REFERENCES

[1] M. A. Miller, Sentz and J. T., "Vaccine-Preventable Diseases,," in *Disease and Mortality in Sub-Saharan Africa. 2nd Edition*, The World Bank, 2006, p. Chapter 12.

[2] The World Bank, "World Development Report 1993: Investing in Health," Oxford University Press, Oxford, 1993.

[3] T. Masud and K. V. Navaratne, "The Expanded Program on Immunization in Pakistan, Recommendations for improving performance," The World Bank, 2012.

[4] M. Chan, "Beyond expectations: 40 years of EPI," *The Lancet,* vol. 383, no. 9930, pp. 1697-1698, 2014.

[5] UN, "Sustainable Development Knowldge Platform," 2015. [Online]. Available: https://sustainabledevelopment.un.org/?menu=1300. [Accessed 28 6 2016].

[6] P. Duclos*, J.-M. Okwo-Bele and Marta Gacic-Dobo, "Global immunization: status, progress, challenges and future," *BMC International Health and Human Rights*, vol. 9, no. I, 2009.

[7] M. Holly Groom, D. P. Hopkins, L. J. Pabst, J. M. Morgan, M. Patel, N. Calonge, R. Coyle, K. Dombkowski, A. V. Groom, M. B. Kurilo, B. Rasulnia, A. Shefer, C. Town, P. M. Wortley and J. Zucker, "Immunization Information Systems to Increase Vaccination Rates: A Community Guide," *J Public Health Management Practice,*, vol. 21, no. 3, pp. 227-248, 2015.

[8] P. Mona, P. Laura, C. Sajal, H. David, G. Holly, M. Stuart, J. M. Morgan and T. C. P. S. Taskforce, "Economic Review of Immunization Information Systems to Increase Vaccination Rates: A Community Guide Systematic Review," *J Public Health Management Practice*, vol. 21, no. 3, p. 253–262, 2015.

[9] S. Subaiya, L. Dumolard, P. Lydon, M. Gacic-Dobo, R. Eggers and L. Conklin, "Global routine vaccination coverage, 2014," *Weekly epidemiological record,* pp. 617-632, 13 November 2015.

[10] polioeradication.org, "Global Polio Eradication Inititave," [Online]. Available: http://www.polioeradication.org/Keycountries.aspx. [Accessed 29 6 2016].

[11] Z. A. Bhutta, A. Hafeez, A. Rizvi, N. Ali, A. Khan, F. Ahmad, S. Bhuttal, T. Hazir, A. Zaidi and S. N. Jafarey, "Reproductive, maternal, newborn, and child health in Pakistan: challenges and opportunities," *The Lancet,* vol. 381, no. 9884, p. 2207–2218, 22-28 June 2013.

[12] "Punjab Key Findings Report," Multiple Indicator Cluster Survey, 2014.

[13] "Vaccinators given bikes," The Nations, 2015. [Online]. Available: http://nation.com.pk/lahore/07-May-2015/vaccinators-given-bikes.

[14] The Expanded Program on Immunization (EPI), Pakistan, "Immunization Schedule," [Online]. Available: http://epi.gov.pk/?page_id=139. [Accessed 29 6 2016].

[15] "Environmental and Social Management Plan," Federal Expanded Program on Immunization, 2015.

[16] R. Veeraraghavan, "Dealing with the digital panopticon: the use and subversion of ICT in an Indian bureaucracy," in *Proceedings of the Sixth International Conference on Information and Communication Technologies and Development: Full Papers-Volume 1*, 2013.

[17] J. C. Scott, Seeing like a state: How certain schemes to improve the human condition have failed, Yale university Publishers, 1998.

[18] S. Corbridge, Seeing the state: Governance and governmentality in India, Cambridge University Publishers, 2005.

[19] M. Ahmad, "Punjab takes stride towards e-governance," The News-International, [Online]. Available: http://www.thenews.com.pk/print/95578-Punjab-takes-stride-towards-e-governance.

[20] WHO, "Behavioral Factors in Immunization- Behavioral Sciences Learning Module," World Health Organization, Geneva.

[21] A. Batool, U. Ali, S. Razaq and M. Naseem, "Child Immunization Health Card Redesign: an Iterative, User-Centered Approach," in *Proceedings of the Eighth International Conference on Information and Communication Technologies and Development*, 2016.

[22] The Daily Dawn, "17 years and no census in Pakistan — A country running on guesswork," Dawn, 07 09 2015. [Online]. Available: http://www.dawn.com/news/1204917. [Accessed 30 06 2016].

[23] J. Haque, "PAKISTAN'S INTERNET LANDSCAPE," Bytes for All, Pakistan, 2013.

[24] I. Medhi, S. Gautama and K. Toyama, "A comparison of mobile money-transfer UIs for non-literate and semi-literate users," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2009.

[25] A. Sears and B. Shneiderman, "Split menus: effectively using selection frequency to organize menus," in *ACM Transactions on Computer-Human Interaction (TOCHI)*, 1994.

[26] A. Abran, A. Khelifi, W. Suryn and A. Seffah, "Usability meanings and interpretations in ISO standards," *Software Quality Journal,* vol. 11, pp. 325--338, 2003.

[27] W. Y. Chua, M. P.-H. Wan, K. Chang and W. Yi, "Improving mobile applications usage experience of novice users through user-acclimatized interaction: a case study," in *Twentieth Americas Conference on Information Systems, Savannah, 2014*, 2014.

[28] S. S. Sadiq and S. A. Ali, "Predictors of Vaccination Card Retention in Children 12-59 months old in Karachi, Pakistan," *Oman Medical Journal,* vol. 29, no. 3, pp. 190-193, 2014.

[29] Google Developers, "Google Mobile Vision," Google, [Online]. Available: https://developers.google.com/vision/.

[30] F. Nayebi, J.-. M. Desharnais and A. Abran, "The State of the Art of Mobile Application Usability Evaluation," in *Canadian Conference on Electrical and Computer Engineering*, 2012.

[31] T. Gorman, E. Rose, J. Yaaqoubi, A. Bayor and B. Kolko, "Adapting usability testing for oral, rural users," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2011.