Supporting Immunization Programs with Improved Vaccine Cold Chain Information Systems

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Abstract—**Immunization is recognized as one of the most successful public health interventions ever devised. A critical component of immunization programs is the vaccine cold chain – the cold storage to keep vaccines safe from manufacture to eventual delivery to the child. Countries need to manage their vaccine cold chains and logistics systems to ensure sufficient storage capacity, distribution of adequate supplies of vaccines, and functional cold storage equipment. There are particular challenges for remote facilities where transportation costs are high, power infrastructure is lacking, and communication is limited. Accurate information about the cold chain is essential to address these challenges and to evaluate the impact of different interventions.**

A Cold Chain Information System (CCIS), which tracks health facility information and the country's cold chain equipment can help address these challenges at both the strategic (planning) and tactical (management) levels. This paper describes our efforts to develop a CCIS for Laos, in collaboration with UNICEF and the Lao Ministry of Health. The work builds on experience with deploying CCIS's in multiple countries along with developing analysis tools and data standards. The CCIS in Laos uses DHIS2, a widely used web based health indicator system as the back end, which is integrated with SMS reporting from the district and health center level where internet is not guaranteed to be available. A central goal of the system is to allow regular reporting of vaccine stock levels and vaccine refrigerator status (measured by logging devices recording high and low temperature alarms). The system is designed with notifications to promote action by technicians or managers. The technical contributions of this work include the development of a new data model for DHIS2 and a text message system using an Android gateway to RapidSMS with a custom notification engine interfacing to DHIS2.

Keywords—Immunization, Logistics, Vaccine Cold Chain, SMS, Health Information Systems, DHIS2

I. Introduction

A. National Immunization Programs

Immunization is recognized as one of the most successful public health interventions in history. Vaccines save millions of lives every year from preventable diseases. An example of the success of immunization is the near eradication of polio. The number of cases per year has declined from an estimated 400,000 in 1980 to under 300 in 2012 [17]. Robust global organizations support immunization, both in terms of donor funding, as well as in global governance and coordination. In almost all developing countries, routine immunization is part of the public health system and is administered centrally by a department inside the Ministry of Health, which we refer to as the National Immunization Program (NIP). Vaccines are distributed nationally and are available for free or at low cost in public health facilities. Vaccines are imported into the country to the national vaccine store, and then distributed through a hierarchy of vaccine stores until they reach health facilities. At health facilities, vaccines are stored until they are used for immunization or are sent on to secondary facilities. Different schemes are used for immunization, such as outreach delivery, where vaccines are carried to a remote site for use, or static delivery, where people come to the facility for immunization. To ensure that the vaccines remain viable, it is critical that they are kept at appropriate temperatures during transit and storage. This is done with refrigerators and freezers at storage locations, and refrigerated trucks and cold boxes for transit. These are collectively referred to as the *vaccine cold chain.*

B. Logistics challenges

There are two basic logistical problems for vaccines. The first is the distribution of vaccines; ensuring that every health facility has an adequate supply of all vaccines in the routine and supplementary immunization schedules. A 'stock out' is said to occur when a facility has insufficient vaccines on hand to perform scheduled services. Stock outs mean that immunization sessions must be cancelled or children who arrive do not receive vaccinations. Since missed vaccinations are often not made up, overall coverage is reduced. There are multiple causes of stock outs including overall shortages of vaccines in the system (for example, if insufficient stock comes in to the national level), delays or mistakes in ordering at different levels, over allocation of stock to some facilities (which means there is not enough to get to other facilities), travel delays or lack of transport, and incorrect forecasts of demand.

The other major challenge is maintaining the cold chain to keep vaccines in a safe temperature range. The safe range is generally considered to be 2C to 8C with the freezing of vaccines the biggest concern. Some exposure to temperature above 8C is acceptable, although this varies across vaccines. The WHO guidelines are that vaccines should not be exposed to temperatures of less than -0.5C for more than one hour, or temperatures of more than 8C for more than 10 hours. These conditions are referred to as alarm conditions. A countries' NIP generally requires that facilities store vaccines in dedicated vaccine refrigerators. WHO maintains a list of refrigerators that have been certified as suitable for vaccine storage, the PQS list[21]. This list currently consists of about 45 models. The reason for this number of models is that there are a range of sizes, as well as different energy sources (electricity, solar, gas, kerosene) for the refrigerators. Many of these refrigerators are specially designed for areas with poor power infrastructure and extreme temperatures. For example, an Ice Lined Refrigerator (ILR) is an electric refrigerator that maintains a layer of ice, so that vaccines remain cold during power interruptions. There are many practical difficulties that countries face in keeping their cold chain equipment functioning. One common problem is extended power cuts or lack of fuel. Equipment maintenance is often poor, so that refrigerators can get either too hot or too cold, for example, a refrigerator might have improper thermostat settings, causing the temperature to plunge below freezing during cooling cycles. When refrigerators fail, it can often take a very long time to have the refrigerator repaired or replaced. This can be caused by the non-availability of spare parts or delays in finding service personnel. In this case a facility may be left without vaccine storage for extended periods of time.

C. *Information Systems*

One of the big challenges in strengthening immunization logistics systems is lack of information, especially detailed information from the health facility level that can be used for mid-level management decisions. There is generally very little information available from individual health facilities on the level of vaccine stocks or the quality of the cold chain equipment. In many countries there is a lack of basic information such as whether health facilities have adequate equipment to store their vaccines, or if they have stock on hand. When this information is available, it often comes from aggregate reports which are collected at the top level of the health system, or from cold chain assessments which are conducted at infrequent intervals. What is generally lacking is detailed information that can directly support management to improve the stock and cold chain equipment at the facility level. This brings us to the focus of our work - we are interested in developing Cold Chain Information Systems (CCIS) that make information available to health system managers, so that they can take action based on data to improve the functioning of their health systems. We define a CCIS to consist of the following components:

- A national level database of health facilities and associated cold chain equipment that allows updates to be performed in a distributed fashion.
- A mechanism for bi-directional information flows that allows facility information to be communicated up the health system hierarchy from facilities, and also allows communication of summary information back down to facilities.

The database for a CCIS is a Cold Chain Equipment Inventory (CCEI). This includes a registry of all of the health facilities and vaccine storage facilities in the country, along with information on the facilities, such as the size of the population they serve, and the power sources available at the facility. The database also tracks all of the vaccine refrigerators and other cold chain equipment, with information on the models, the power sources used, and storage capacity of the equipment. It is necessary to track this information to determine if the equipment is sufficient for storing the required vaccines. The information that is most important for immunization logistics is information on stock as well as status of the storage equipment. The system would allow reporting of low stocks or equipment problems, which could trigger either immediate remedial actions, or institute changes that would improve performance later on.

Currently, information for most CCIS is manually collated from paper forms. Paper based solutions cannot provide real time information and recently there have been efforts to collect data via SMS[9] in other supply chain domains. SMS is attractive because of its low cost and wide accessibility in the field[10]. One such study, SMS for Life, used text messages to track stock levels for anti-malarial drugs in Kenya [2,11]. Multiple projects, including Tanzania's Integrated Logistic System (ILS), Kenya's Mission for Essential Drugs and supplies (MEDS) and Benin's Cola Life uses SMS to track orders, vaccines, tablets and other clinical supplies [18].

There have been studies and efforts in making successful vaccine end to end distributions [6,8,13]. Having an immunization information system enables better decision making for quality and impact [13]. Cold Chain Equipment Manager (CCEM) [1] is being used in several countries to maintain country wide inventories of vaccine refrigerators and cold rooms. CCEM is used to track and resolve shortages in vaccine storage capacity which is a common bottleneck in the vaccine supply [13]. Nextleaf developed Cold Chain Monitor [15] to automate SMS temperature reporting. OpenLMIS[19], VaxTrac [120] and Jeev [7] are among other vaccine coverage tracking system being used in different parts of the world.

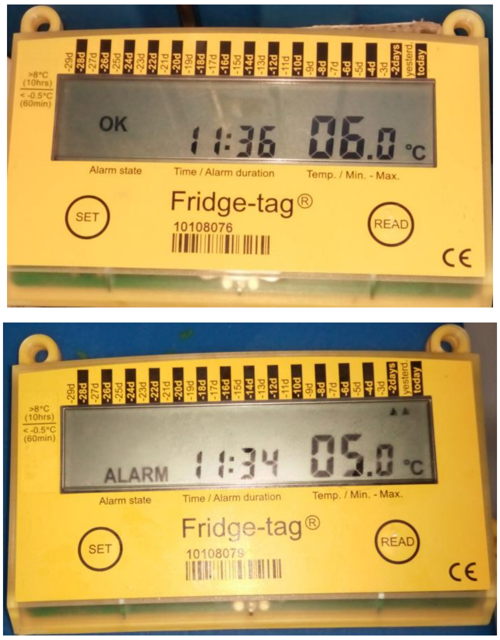

Figure 1. (top) FridgeTag 30DTR with no alarms in last thirty days, (bottom) FridgeTag 30DTR with two high temperature alarms, yesterday and two days ago.

D. Data Reporting

Our goal is to enable information to be collected from health facilities to allow improvement in vaccine stock distribution and the vaccine cold chain. This means that we need to have information from health facilities communicated to managers in a timely manner. For vaccines, this simply means reporting the quantity of vaccines on hand. These numbers can be compared with the vaccine requirements to determine if the facility is under or over stocked. Action taken on this information can include adjusting the supply of vaccines that are delivered, or sending emergency stock to make up for a short fall. For reporting information on refrigerator status, we base our reporting on the FridgeTag 30 Day Temperature Recorder (30DTR). This electronic temperature logging device is placed in a refrigerator and record temperatures over the month. The device tracks daily high and low temperatures, and also shows an alarm if temperatures are out of range for an extended period of time. A high alarm is registered if the temperature is above 8C for more than 8 hours, and a low alarm is registered if temperature is less than -0.5 C for more than an hour (see Figure 1.) The number of high temperature and low temperature alarms over the last 30 days can be read from the device. The reporting that we are interested in is the number of high alarms, and the number of low alarms over the month. A functioning refrigerator should have zero alarms, so the presence of any alarms indicates a problem, and if there are multiple alarms, especially freeze alarms, then action needs to be taken to repair the refrigerator. The value of the 30DTR is that it gives a very good measure of whether or not the equipment is working well.

The FridgeTag devices have been widely distributed by UNICEF and individual countries. However, the experience in the field is that when these devices are deployed, information is not reported back to management, the devices just sit in the refrigerators, and the information is not acted on. One of the main contributions of our work is to develop a system that allows the 30DTR information to be reported back to the district level to support actions. We note that there are multiple systems for automatic reporting of temperatures, where regular reports of the temperature are sent to a server via the GSM network. This includes devices developed by BeyondWireless[16], Nexleaf[15] and University of Washington [5]. Automatic reporting can be viewed as complementary to the work we are doing, and a backend system could be developed to receive both automatic and manual SMS reporting. We focus on the manual reporting of FridgeTag results because costs are much lower for a FridgeTag than real time devices, and there are hundreds of thousands of FridgeTags deployed worldwide with no adequate reporting system.

II. DEVELOPING A CCIS FOR LAOS

A. Laos

This project was initiated in Laos following a series of discussions between UNICEF and the Lao Ministry of Health. UNICEF chose to implement this project in Laos as part of a much larger effort in strengthening the vaccine cold chain. Laos was selected as a representative country that would easy to work in for an initial project, being a small country with a stable political environment.

Laos is a landlocked Southeast Asian country located between Thailand and Vietnam. The population of Laos (2014 est.) is slightly under seven million. Laos is categorized as a lower middle income country, with a per capita income roughly the same as Pakistan's. The economy is expanding with annual growth of about 8% in recent years.

The public health system for Laos is a standard, hierarchical system, with three levels: national, province. The country has 17 provinces and 145 districts. We note that since Laos is a small country, province and district populations are

Figure 2. Lao PDR, the NIP office is located in the capital of Vientiane.

Figure 1 Typical rural health center staffed by approximately four health workers

low, and the provinces behave much like districts in larger countries. Immunization services follow this hierarchy, with vaccines stored at the national store, provincial stores, and district stores. A substantial amount of the system management takes place at the provincial level. For example equipment repair is an activity managed by a provincial staff. In rural areas, the primary health facility is a health center which provides basic services (including immunization) and has a staff of about four.

Laos has a fairly good electrical system due to substantial hydroelectric resources, and almost all health facilities are on the grid. On our facility visits, health workers did report that there will be occasional day long outages. Since electrical power is generally available, almost all health facilities use electric refrigerators, although there are a few facilities in remote regions using solar powered refrigerators.

B. Requirments and Specifications

The requirements and specifications for this project were defined in collaboration between UNICEF, Lao NIP, PATH (a Seattle based global health NGO), and University of Washington. The project was initiated with stakeholder meetings in Laos in March and October 2013. The initial concept for the project was reporting and monitoring of fridge tag alarm data from all health facilities each month. In the initial meetings, Lao NIP emphasized the value of including stock level data in addition to the temperature monitoring data. The idea of monthly electronic reports was very exciting to local stakeholders and many different schemes were discussed for expressing complicated reports via SMS. However, stakeholders also realized that any implementation of the project would need to be deployable and therefore accessible to people unfamiliar with SMS.

From the collaborative design process three overarching requirements emerged for the project:

- *Scale:* The system must be able to scale to the national level. This meant that the all health facilities must have the capability to make reports, the system backend must be able to handle a large influx of messages during reporting time, and managers must be able to view aggregated vaccine and refrigerator reports.
- *Low burden:* There must be a balance between collecting as much information as possible and decreasing the monthly reporting burden on individual clinics. Requiring an excessive amount of information creates an arduous task and increases the likelihood that the reports will not be submitted. Additionally, complicated monthly reporting requires longer training and delay system deployment.
- *Use of data:* the motivation for the project was to strengthen the immunization program by making better data available to managers. There needs to be consideration of how data can be acted on, as well as who needs to receive original data or summary reports.

The first, major design decision for the system was to select SMS reporting as the mechanism for monthly data submission from all health facilities. The desire was to have a system that could be deployed using technology accessible at health centers, and it was assumed that almost all health workers would have access to mobile phones for sending SMS messages. UNICEF and NIP conducted field studies evaluating the feasibility of SMS based reporting. An important finding from these visits was that the SMS cost of 100 - 150 Kip (USD 0.02) per SMS was not a problem if a handful of SMS reports were sent per month. However, these findings also revealed that few health workers had much experience with SMS. One of the reasons related to the Lao script. Mobile phones in Laos generally do not support the Lao script. For text messaging, the common solution is to transliterate Lao into the Latin script using a style of messaging referred to as "Karaoke". The feasibility study determined that it would be practical to use SMS with the following conditions and caveats:

- Since all health workers have access to basic phones, the project could rely on personal phones and is not required to distribute phones; however, access to data connections or smartphones could not be assumed.
- The price of SMS messages would not be an issue as long as messages could be sent to a Lao number.
- The reading of Latin scripts would be difficult for some health workers. However, there is no practical alternative. The system would need to be robust to accommodate common errors in text entry.
- Acknowledgments must be sent back to health facilities upon the receipt of message reports notifying the sender of any errors or actions taken.

The final reporting specification extended beyond the fridge tag alarms to support monthly vaccine stock levels, the reporting of refrigerator failures, vaccine stock outs and other events that can occur in the middle of the month. These events, that need immediate attention, can quickly be forwarded to the appropriate individuals to facilitate repair and attention. During the design discussion multiple mechanisms for registering users with the system and associating them with a health facility were proposed. SMS could not be the sole method to register or unregister a user because that would over complicate the message syntax. The SMS management system

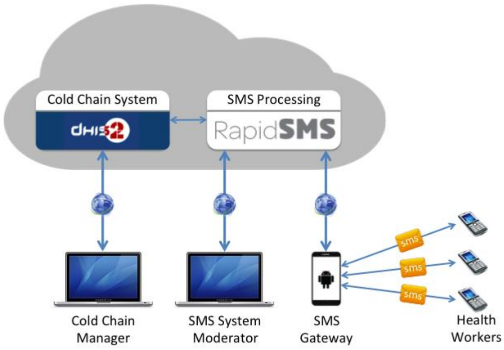

Figure 2 System Architecture: Health workers send data via SMS to an android phone that syncs with cloud system. Cold Chain Manager and SMS Moderator manage these systems using their respective web interfaces.

would need to have a web accessible management console for UNICEF and NIP staff to moderate users and messages.

C. *System Components*

The final system design consisted of three components: a backend database responsible for maintaining the cold chain inventory; a SMS processing system responsible for translating incoming messages into actions on the backend database, and SMS to HTTP gateway to upload incoming SMS messages to the system and send out responses generated by the system. See Figure 4.

1) *Cold chain information system backend.*

a) *Cold Chain Inventory Data Model*

It is critical that health information systems are built on top of common standards. This is necessary so that common solutions can be applied across multiple countries, and so that different systems can exchange data. With this in mind, we built the system on top of the Cold Chain Equipment Inventory (CCEI) data model. The data model was developed by some of the paper's authors in collaboration with the UNICEF Cold Chain Logistics Working Group. The model gives standard definitions for a national cold chain equipment inventory, identifying specific information that is needed both from the health facilities and from the cold chain equipment. The model was designed in a collaborative fashion, beginning with an initial set of inventory definitions that was put together based on several existing software tools for cold chain logistics. The document was then collaboratively edited by the UNICEF Cold Chain Logistics group. Based on that effort, a more formal set of definitions was developed that was circulated individually to about 15 immunization cold chain experts, from UNICEF, WHO, and NGOs including PATH and CHAI, who provided very detailed feedback. The data standard was built upon existing standards where possible, such as using the WHO Performance, Quality and Safety (PQS)/Product Information Sheets (PIS) catalogs [21] and defining several of the fields with respect to ISO standards.

The core of CCEI is the model of facilities and their associated equipment. The full standard contains several other components such as a representation of the administrative hierarchy, the association between facilities and assets, and some localization information. Although we do not have space in this paper to present the full model, we encourage the reader to explore it online [14].

b) *Backend system*

The back end of the CCIS is built on top of the District Health Information System (DHIS2), a widely used health indicator and reporting system. DHIS2 was initially developed by HISP (Health Information Systems Programme), as an open source tool for ministries of health to use to collect and analyze health indicators. It is currently deployed in 46 countries as an integral part of health system reporting systems. The software is a Java web server which may be deployed at the country, province, or district level and easily integrate into existing workflows. It includes a data layer, service layer, and web presentation layer which facilities to support user report generation, integration with mobile devices, and a GIS module. The core data model for DHIS2 is designed around an organizational hierarchy, which associates data elements with organizational units at every level of the hierarchy. Once data has been entered, the system allows aggregation of the data elements over the hierarchy in to regional reports of health indicators. The DHIS2 system has been designed to allow full country level customization of data elements making it a very flexible tool.

The CCIS module is an extension of DHIS2 to support cold chain equipment and stock inventory. The extension of DHIS2 to support a cold chain equipment inventory required significant software development. Development of the cold chain module took roughly one year to complete. The technical extension of DHIS2 was to allow organizational units to maintain a collection of "assets", with properties associated with each asset. The introduction of a new data model required low level additions to the source code. A new user interface was also developed to support the management of equipment, including the viewing of assets across different administrative levels. The cold chain module was built on top of version 2.14 of DHIS2, and is available as a download on the DHIS2 download site[1]. There were two very important reasons for building the CCIS on top of DHIS2. The first was that the DHIS2 platform provided a vast amount of functionality, so it was a practical choice that reduced system development effort. The second and more important reason is that by building on top of a system that is already extensively deployed, it is easier to sustain the system, as well as integrate it into a countries' existing health information system.

D. *SMS Processing System*

The SMS processing engine receives messages, processes them, communicates with the CCIS backend, sends responses and notifications and allows for administrative moderation. We built the the SMS processing engine on top of RapidSMS which is an open source Django server application designed for customized scalable mobile web services. RapidSMS provides the basic features of a

[1] http://www.dhis2.org/downloads

messaging system: integration of an SMS to HTTP gateway, management of contacts, and message logging. The most important feature of RapidSMS is a message routing system with hooks for custom applications to process incoming and outgoing messages. The SMS processing system consists of three modules built on top of RapidSMS.

The first module is the message parser which is programmed to interpret message reports and system commands. A more detailed overview of the message syntax supported by the system is given below. The parser and message syntax have been designed to be as robust as possible in order to accept slight variations of correct messages. For example all whitespace, capitalization and punctuation is ignored. The second module is the administration and user management console. This is a web front end for local NIP officials to manage the SMS system from. Besides the basic user and facility operations the administrator module also allows for moderation. Even though the system is designed to be automated, we expect a small number of users might have difficulty with the message syntax. From the administrator console messages that cannot automatically be parsed can be handled individually. The last module in the SMS processing system is a connection to the CCIS backend. This connection imports an organizational hierarchy and basic inventory so that users phone numbers can be associated with health facilities and basic errors such as incorrectly labeled refrigerators can be detected as soon as possible. The CCIS connection is also responsible for updating the CCIS module in DHIS with the monthly vaccine reports and fridge alarms. This is a fundamental piece of the entire system and the link between two of the major components.

E. SMS Gateway

The final component of the system is an SMS to HTTP gateway that connects the RapidSMS server to the Lao telecommunication system. We are currently in discussions with several Lao telecommunication operators to get a short code that is accessible from Lao mobile phones and has support for an HTTP gateway. While waiting for the short code we are using an Android SMS to HTTP gateway so that health facilities can SMS monthly reports immediately via a Laos based number. The gateway is an application running on an Android phone that forwards all incoming SMS messages to a URL over an available mobile data or wifi connection. The server processes the HTTP request and responds with a JSON document containing an SMS response. The Android application parses the HTTP response and forwards the outgoing message to the original phone number. This method allows people with basic phones in Laos to seamlessly interact with the RapidSMS and CCIS servers through a local Lao phone number via SMS.

There are several existing Android HTTP to SMS gateway applications already in existence. For this project we examined SMSSync by Ushahidi and EnvayaSMS. Both applications have a well-documented REST API to receive and send SMS messages on a local number in any country. They have the ability to forward messages based on prefix keyword, blacklist spam numbers and basic HTTP authentication. Both applications also allow a polling interval for the phone to check the server URL for any pending messages that need to be sent. This allows for messages to originate from the server. A major limitation of Android based HTTP to SMS gateway is that each Android application is limited to 100 SMS messages per hour by the Android OS. EnvayaSMS provides a simple method around this limit by providing expansion packs that increase the limit to 500 messages per hour. This plus additional logging features and more robust recovery from network errors lead us to choose EnvayaSMS as the HTTP to SMS gateway for this project.

Besides the message limit there are other inherent limitations for an Android based HTTP to SMS gateway. The Android phone represents a single source of failure for the whole system. Currently the phone stays at the NIP offices in Vientiane and it is NIP's responsibility to make sure the phone is charged, has a data connection, and is recharged with sufficient airtime to send outgoing messages. This is a large amount of work to add to already busy workloads of NIP officials. The Android phone isa source of constant attention and possible errors and we are currently looking at methods to eliminate it. The ideal solution is to get a Laos based mobile short code that works across networks and have begun the discussion necessary with telecommunication operators to establish one.

F. Message Syntax

A unique feature of our system's design is the robust message syntax. We carefully designed a syntax that would not be dependent on whitespace, punctuation or special characters. Even so, we knew that with limited SMS experience, health-workers might still have difficulties so we also strove to make the syntax as flexible as possible. We made several assumptions about message content that allowed us to simplify the syntax. A message is a concatenation of keyword plus argument pairs. The crucial aspect of the message syntax is that all keywords are two letters while all other labels are single letters or digits. This means that we can ignore whitespace for separation, as long as every keyword has at least one argument when multiple keywords are chained. Additionally, for this deployment all of the numeric data being collected is integers, so we also assume that there will be no floating point numbers and therefore it is safe to ignore commas and periods. We were also able fit the number of high and low alarms into a single digit each because UNICEF determined that reporting a maximum of nine alarms per month was sufficient, as more alarms in a month would indicate a serious problem and no additional information is gained from the exact number of alarms.

There are three classes of keywords the system uses, these are for monthly reports, spontaneous reports, and administration tasks. The monthly reports use two keywords: *ft* (Fridge Tag) which takes as an argument the 30DTR information for each refrigerator at the facility and *sl* (Stock Level) which records the stock of up to five vaccines. When entering refrigerators into the CCIS database a single letter is associated with each refrigerator at a health facility. The refrigerator is labeled with this letter (Figure 5) so that when composing messages the correct refrigerator can be referenced. Similarly each vaccine is assigned a unique letter

Figure 3 Vaccine refrigerator labeled with 'A' for reporting.

to be used in the message syntax. Currently, health workers are reporting Pneumococcal vaccine (with a P), and Pentavalent vaccine (with a D). Other codes have been set aside to allow reporting of all routine vaccines. Figure 6 shows several variations of similar monthly report messages that are all valid. Spontaneous reports are for events that need immediate action such as a refrigerator needing repair or a vaccine stock out. The administration tasks are more advanced features but are provided for completeness and include keywords for help pages, changing response language, and registering a new phone number.

III. Field Experience

A. Deployment Status

The project is active in three districts in three separate provinces in Laos. The plan is to start in these districts, and as the system is established, expand to the remaining districts in each of these provinces, and eventually expand to the remaining provinces. The project began in October 2013 by having health centers report by SMS, with the results being manual interpreted. An initial version of the SMS gateway and SMS processing system was deployed in January 2014. The SMS reporting is being done from all of the health facilities in the districts, along with the district and provincial vaccine stores. Reports are being received from 27 facilities all together.

The initial results are favorable, there is a high rate of reporting, and acceptance of the system from the health workers. The process of reporting on stock levels and fridge tag alarms is making information visible that was not previously available. In particular, there is some information on faults with refrigerators being reported which is actionable. This work is at the feasibility stage, so results are being fed back into operational improvements, and it is too early to assess impact. In April, all participating sites were visited

1. ft a 0 b 0 sl d 30 p 20
2. a00b00sld30p20
3. A 0 0 B0 SL D30 P20
4. ft a0,b0;sl d30; p20
5. Ft0 SL d   30, p 20

Figure 6: Five valid messages that all have the same semantic meaning. Each message tells the system that refrigerators A and B had zero alarms and that the current stock levels for Pentavalent and Pneumococcal are 20 and 30.

with interviews of health workers, so there is substantial on-going assessment. When the full system is established, there is a plan to do an impact study based on key performance indicators such as number of stock outs and rates of equipment repair.

B. Challenges

Field visits have identified various challenges for the project. We had anticipated that there would be some adjustments necessary, and are investing significant effort in field monitoring and ensuring we get feedback from participants. Here are a set of issues relating directly to the SMS deployment:

- Almost all phones in Laos support the Thai script, but few phones support the Lao script. When we conducted a survey of 23 health workers, we found 100% could read Lao written in Thai script, 65% could read Lao written in Latin script, and 22% could read English script. Unfortunately, for political reasons, it is not possible to use the Thai script, so we sending text messages where Lao is transliterated into the Latin script.
- Our SMS commands are a mix of Latin characters and digits. Since many health workers were not familiar with English characters, there were difficulties with visually similar characters. We have seen confusion in sending `O' instead of '0' and '$' instead of 'S'.
- There are four cellular carriers in Laos. There appear to be some issues in sending SMS messages between carriers.
- The SMS format evolved over the period of deployment as new sites were added. This introduced a challenge for our system to provide backward compatibility of SMS format.
- There are difficulties in tracking the phones used to submit messages. We do not require a health center code in the message, but associate the message with the facility that the phone is registered with.

IV. Discussion

As the project is in the initial feasibility phase, we are currently focusing on various operational issues. However, there two other very important components of this project that we need to mention. The first is training, health workers need to receive training in the process of reporting the monthly data through structured SMS messages. It turns out that about 33% of the health workers also need training in how to send SMS messages. The project is currently investing in various training aids and technologies to support training. The training of health workers is considered to be biggest component of scaling the system to a national scale project. The other big issue is use of data. District and provincial managers have expressed great interest in the system, and standard operating procedures are being developed on how the data that is reported will be acted up. It is recognized that the system will only be of value if leads to people using the data to address problems with stock, or to repair or allocate cold chain equipment.

This project was launched in Laos to develop a system that will help strengthen the Lao immunization system. However, the goal of the project is to develop a system that can be deployed across multiple countries, since there are common problems to immunization systems. In terms of system design, we are considering issues such as localization early in the project. There are country specific issues such as developing an SMS gateway solution that will have to be repeated in each deployment. Deployments of SMS solutions in other countries have had to focus more on payment issues that we have. The specific challenges we faced around choosing a script for SMS may not come up in many countries, since Laos is a small country with its own script, which is not a large enough market for handset manufactures to implement the script.

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VI. REFERENCES

[1] R. Anderson, J. Lloyd, and S. Newland, “Software for National Level Vaccine Cold Chain Management,” in Proceedings of the Fifth International Conference on Information and Communication Technologies and Development, New York, NY, USA, 2012, pp. 190–199.

[2] J. Barrington, O. Wereko-Brobby, P. Ward, W. Mwafongo, and S. Kungulwe, “SMS for Life: a pilot project to improve anti-malarial drug supply management in rural Tanzania using standard technology,” Malar J, vol. 9, no. 1, pp. 1–9, Dec. 2010.

[3] J. Braa, O. Hanseth, A. Heywood, W. Mohammed, and V. Shaw, “Developing Health Information Systems in Developing Countries: The Flexible Standards Strategy,” MIS Quarterly, vol. 31, no. 2, pp. 381–402, Jun. 2007.

[4] J. Braa and C. Hedberg, “The Struggle for District-Based Health Information Systems in South Africa,” The Information Society, vol. 18, no. 2, pp. 113–127, 2002.

[5] R. Chaudhri, G. Borriello, and R. Anderson, “Monitoring Vaccine Cold Chains in Developing Countries,” IEEE Pervasive Computing, Special Issue on Informations and Communication Technologies for Development, 2012.

[6] J. J. Henriques, B. T. Foster, W. G. Schnorr, and R. Barton, “Implementation of a Mobile Vaccine Refrigerator with Parallel Photovoltaic Power Systems,” in 2012 IEEE Global Humanitarian Technology Conference (GHTC), 2012, pp. 128–131.

[7] A. Katib, D. Rao, P. Rao, and K. Williams, “Jeev: A Low-Cost Cell Phone Application for Tracking the Vaccination Coverage of Children in Rural Communities,” in 2013 IEEE International Conference on Healthcare Informatics (ICHI), 2013, pp. 115–120.

[8] C. Nelson, P. Froes, A. M. V. Dyck, J. Chavarría, E. Boda, A. Coca, G. Crespo, and H. Lima, “Monitoring temperatures in the vaccine cold chain in Bolivia,” Vaccine, vol. 25, no. 3, pp. 433–437, Jan. 2007.

[9] A. Shovlin, M. Ghen, P. Simpson, and K. Mehta, “Challenges facing medical data digitization in low-resource contexts,” in 2013 IEEE Global Humanitarian Technology Conference (GHTC), 2013, pp. 365–371.

[10] P. Singh, S. Kulkarni, E. Keech, R. McDermott-Levy, and J. Klingler, “Making Health Care More Accessible to Rural Communities in Waslala, Nicaragua Using Low-Cost Telecommunications,” in 2011 IEEE Global Humanitarian Technology Conference (GHTC), 2011, pp. 194–200.

[11] R. W. Snow, D. Zurovac, G. Jagoe, J. Barrington, S. Githinji, S. Kigen, A. M. Mbiti, D. Memusi, A. N. Muturi, A. Nyandigisi, and A. Wamari, “Reducing Stock-Outs of Life Saving Malaria Commodities Using Mobile Phone Text-Messaging: SMS for Life Study in Kenya,” Jan. 2013.

[12] T. Wirkas, S. Toikilik, N. Miller, C. Morgan, and C. J. Clements, “A vaccine cold chain freezing study in PNG highlights technology needs for hot climate countries,” Vaccine, vol. 25, no. 4, pp. 691–697, Jan. 2007.

[13] M. Zaffran, J. Vandelaer, D. Kristensen, B. Melgaard, P. Yadav, K. O. Antwi-Agyei, and H. Lasher, “The imperative for stronger vaccine supply and logistics systems,” Vaccine, vol. 31, Supplement 2, pp. B73–B80, Apr. 2013.

[14] “CCEI,” Scribd. [Online]. Available: http://www.scribd.com/doc/152853455/CCEI. [Accessed: 02-Jun-2014].

[15] “Cold Chain Monitor | Nexleaf.” [Online]. Available: http://nexleaf.org/technology/cold-chain-monitor. [Accessed: 02-Jun-2014].

[16] “Cold chain temperature monitoring.” [Online]. Available: http://www.beyondwireless.net.au/index.php/products/bc-340/77-applications/76-cold-store-temperature-monitoring. [Accessed: 02-Jun-2014].

[17] “Global Polio Eradication Initiative > Data and monitoring > Polio this week.” [Online]. Available: http://www.polioeradication.org/Dataandmonitoring/Poliothisweek.aspx [Accessed: 02-Jun-2014].

[18] “Pharmalink Newsletter, Vol 11, Issue 1, November 2011. Effective Pharmaceutical Supply Chains - On the Road in Low Income Countries.” [Online]. Available: http://apps.who.int/medicinedocs/en/d/Js19965en/. [Accessed: 02-Jun-2014].

[19] “Supply Chain Management Newsletter, Quarter 2, 2013, June 30, 2013 - SCM_Newsletter_Q2_2013.pdf.” .

[20] “VaxTrac | What is the VaxTrac ‘system’?”[Online]. Available: http://vaxtrac.com/blog/2012/03/what-is-the-vaxtrac-system/. [Accessed: 02-Jun-2014].

[21] “WHO | World Health Organization.” [Online]. Available: http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/. [Accessed: 01-Jun-2014].