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Optimum hardware, software and personnel requirements for a paperless health and demographic surveillance system: a case study of Cross River HDSS, Nigeria

Iwara Arikpo[1*], Ideba Mboto[1], Anthony Okoro[1], Unyimeabasi James[1], Ememobong Aquaisua[1],Kalu Osonwa[1], Michael Ushie[1], Ekaette Enang[1], Ekpereonne Esu[1], Ime Asangasi[2], Martin Meremikwu[1]
[1]Cross River Health and Demographic Surveillance System
Directorate of Research, University of Calabar, Calabar- Nigeria
PMB 1115, Calabar, Cross River State, Nigeria
Tel: 234-7081430681*E-mail: iiarikpo@gmail.com
[2] Department of Informatics
University of Oslo, Norway

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Abstract
Health and Demographic Surveillance Systems (HDSS) are a robust and rigorous data collection, validation, storage, analysis and reporting platforms for community-based data on vital events. These processes make high demands on paper and man-hours with attendant implications on running costs and environmental impact. However, with the rapid development of ICT and increasing affordability of computing devices, some of the manual processes can be replaced with ICT tools. This paper presents a case study of the Cross River HDSS in Akpabuyo Southern Nigeria with a view to highlighting the essential personnel, hardware and software requirements for running an IT-based paperless HDSS in low income settings. The DSA comprised of 22 contiguous EAs of 1370 households. The case study entailed four update rounds, each of which involved field workers visiting households and obtaining information on vital events. The first update round was purely paper-based involving the use of large collections of paper forms for interviews. The last three rounds were IT-based, devoid of paper questionnaires and ran on web-based open source software. Hardware was a set of high-end servers, desktops, tablet PCs and android phones for data collection.

The case study demonstrated the feasibility of running a paperless IT-based HDSS in a resource-poor setting using free and open source software, such as the web-based OpenHDS, MySQL, ODK, MirthConnect, etc. This overcomes the limitations of the popular HRS2 in terms of costs, complexities, and lack of compatibility with changing hardware and system software configurations. However, running IT-based paperless HDSS threw up some challenges, such as cases of poor internet connectivity, absence of GSM network connectivity using mobile devices, and having the right mix of staff with sufficient IT skills. This paper recommended solution strategies for overcoming these challenges. The need for the development of new set of protocols for data quality in a paperless HDSS is also discussed.

Keywords: Health, demographic surveillance system, information technology, paper, environment, enumeration area

1. Background

Nigeria's health indices rank among the poorest in low and middle income countries. The recent national surveys give estimates of maternal mortality rates that range from 165 to 549 across the six geo-political zones of the country. Infant mortality also remains high at between 59 and 109 per 1000 live births in the six zones (NDHS, 2008). Although the national estimate of maternal mortality ratio declined from 1000 in 1990 to 545 in 2008, this rate remains high when compared with MDG targets and the figures from other African countries. Among other socio-economic factors, these poor health indices have been attributed to the weakness of the health system (Ibekwe, 2010). The nation's government is embarking on far-reaching reforms of the health system with a major focus on strengthening the primary health system which is widely acclaimed to be the bedrock of the Nigerian health system. The poor state of the national health management information system has made it extremely difficult to obtain relevant data for planning and resource allocation in a timely and comprehensive manner. The inefficiency of the health information system also makes it difficult to track the outcome and impact of recent investment in the health system including the ones specifically targeted at achieving the MDGs. Health and demographic surveillance systems (HDSS) could provide some interim solutions to these national health information system deficiencies where they exist.

A health and demographic surveillance system is a community-based information system that collects longitudinal data on core demographic indices (births, deaths, marriages and migration) as well as key health indicators at regular intervals within a defined geographical location. There are currently 38 research centers running 44 HDSS sites from 20 countries in Africa, Asia and Oceania, with 32 of the sites in sub-Saharan Africa. The activities of HDSSs are co-ordinated by the International Network for the Demographic Evaluation of Populations and Their Health – INDEPTH (Ye et al., 2012). The HDSS process entails meticulous series of data collection and collation routines beginning with a baseline census leading to the establishment of a database containing key socio-demographic information of all residents. Each household and resident receives a unique identification number which enables longitudinal follow up at 4-6 monthly intervals. This enables the tracking of changes (events) related to the health and social status of each individual. The operation of the HDSS includes robust mechanism implemented in the field and the data room to assure the quality of data obtained through the system. The population under surveillance (which should include contiguous units of communities) could range from 30,000 to 200,000 depending on the objectives of the site and resources available.

One of the key challenges of the HDSS is the heavy demand the manual paper-based processes make on human resources and materials especially paper. This high demands on paper and man-hour has implications for the running costs and the environment given the detrimental effects of excessive paper use on the environment. The long time taken to enter data collected on paper into desktop computers often delays the availability of the reports and tends to compromise on timeliness which is a vital characteristic of an efficient health information system.

The advent of affordable information technology including hardware and software has opened new opportunities to eliminate some of the problems posed by paper-based HDSS. Getting the right mix of human resources, hardware and software applications to run paper-free HDSS could be a challenge even for HDSS sites that have run paper-based HDSS for several years. This paper presents a case study of a newly established HDSS in Akpabuyo Cross River State Nigeria with a view to highlighting the essential personnel, hardware and software requirements for running an IT-based paperless HDSS in low income settings.

2. METHODS

2.1 Study Area

Akpabuyo is a predominantly rural Local Government Area (LGA) in Cross River State which is one of the six States that make up the South-south zone. The area is located in the Niger Delta within the tropical rainforest with annual rainfall of 2500mm to 3000mm. The main occupation is farming, with coastal communities engaging also in fishing. The main language is Efik. Malaria is highly endemic in the area with intense year-round transmission. The Cross River Health and Demographic Surveillance System (CRHDSS) was established in the last quarter of 2010 with the goal to generate timely and reliable data on health, demographic and socio-economic indicators to inform policy and planning. The CRHDSS established a database of a population 5668 drawn from 1370 households in 22 enumeration areas (EAs).

Ethical Considerations: The CRHDSS obtained ethical approval from the Cross River Health Research Ethics Committee.

2.2 HDSS Procedure

A comprehensive description of how to establish and run a demographic surveillance system (HDSS) is given in a manual (Starter kit) developed by the INDEPTH Network (INDEPTH Network, 2004). The key steps on how to run the HDSS is here described in brief to highlight the essential personnel, hardware and software requirements for an IT-based paperless HDSS. The HDSS comprises two closely-knit systems namely; the field system and the data system. The field system refers to the processes, equipment and personnel responsible for obtaining quality-assured longitudinal data from households and individuals within the demographic surveillance area (DSA). While the data system includes the hardware, software, data protocols as well as the data personnel responsible for ensuring that data brought in by the field team are entered into the HDSS database, quality-assured, analyzed, reported or archived.

2.2.1 Field system

In a paper-based HDSS the key tools are series of questionnaire and forms as interview guides for obtaining information during baseline census, update surveillance cycles or studies within the HDSS. Bicycles or motorbikes, handheld GPS and personal gear were other major items required by the field worker within a paper-based HDSS. The paper questionnaires include Pregnancy Registration, Birth Registration, Death Registration, Migration-in, Migration-out, Neonatal verbal postmortem (VPM), Post-neonatal VPM, and Adult VPM. The equipment requirement for the field system in a paperless HDSS differs from the paper-based by replacing paper forms with electronic forms contained in mobile devices running an appropriate software application.

The personnel required for field system in a paper-based HDSS and paperless HDSS differ in their level of knowledge and proficiency in the use of mobile data device. At inception, the CRHDSS ran paper-based field procedures (baseline census and first update cycle). The transition to IT-based procedure commenced in the second 4-monthly cycle with the same field enumerators who had been originally trained to collect data with paper questionnaire. The highest level of education for these enumerators was the senior high school. They were all successfully trained to use the mobile devices (with android technology), and had conducted three 4-monthly update cycle with these devices prior to this paper.

The initial version of the mobile application required the enumerators to type in the unique ID numbers of each household member assessed during the second update cycle run on mobile technology. Typing in these long unique IDs resulted in a high proportion of erroneous unique IDs identified by electronic quality check by the data personnel. Subsequent versions of the mobile application running on tablet PC provided for automated selection of unique IDs and complete elimination of these errors.

The field supervisor in paper-based HDSS performed standard survey supervision routines and manual quality check on 5% of the households. The field supervisor in paper-less HDSS should have as much knowledge of survey methodology as the paper-based supervisor but should have sufficient knowledge of IT procedures to access the main database from remote locations and draw random samples for quality check. To provide these IT solutions in the field system, the CRHDSS trained computer science graduate assistants on field procedures and supervision. They were thereafter deployed to supervise the enumerator supervisors. The lower level of supervisors performed the supervision routines common to all HDSS paper-based and paperless alike. The top level of field supervisors further did spot checks on the data corrected by the lower level of supervisors using a version of the software tools called Mobile Helper, thus ensuring the quality of the CRHDSS data.

The field team maintains a busy field office with huge storage for the several questionnaires and forms issued to or received from the field personnel. The filing clerks in the field office are charged with the task of documenting the movement of forms, questionnaire, queries and household registration books (HRBs) between the field office and the data office or field personnel. In the paperless HDSS, the filing clerk logs only HRBs and mobile devices. Since the filing clerk has fewer tasks to perform in the paperless HDSS, he/she could take on additional administrative task such as tracking logistics, motorcycle maintenance, fuel and mileage logs.

2.2.2 Data system

The data system in a paper–based HDSS includes a variable number of data entry clerks (which could range from three to ten depending on the size of population under surveillance). The other data personnel are data entry supervisors, data manager and an assistant. The focus of activity in the data room of a paper-based HDSS is data entry, generation of queries on paper and resolution of queries. In the paper-less HDSS the focus of activity is quality check of all data received from direct transfer from the mobile devices at remote (field) locations. The mobile device obtains data from field and transfers same directly to the HDSS database via GSM-enabled internet. The role of the data entry clerks is eliminated in a paperless HDSS. This is replaced in the data office by two levels of data quality supervisors. One set of data supervisors work in the field performing quality checks on the spot by viewing data transferred from mobile devices and providing feedback to enumerators and enumerator supervisors. The second layer of data quality check occurs in the data office in an ongoing basis to identify and resolve additional data queries missed by the first level quality check.

A description of hardware and software used in the CRHDSS to successfully implement a paper-free HDSS with limited budget is given in the next section to illustrate the essential options.

2.3 Hardware

Servers: PowerEdge DELL servers running 64-bit Windows Server 2008 R2 Operating System. The Server runs RAID technology (having four hard disks of 250GB each connected to each other) to facilitate seamless automatic data backups. The backend database and core applications are hosted on the server.

Personal Computers: Desktop computers connected to the main server via LAN. All computers run Windows 7 operating system and were used to input the baseline data, first update round and for correcting data entry errors.

Smartphones: Smart phones with full wireless network capabilities running the Android v2.3.4 (Gingerbread) operating system, and GPRS Class 12 (4+1/3+2/2+3/1+4 slots), 32 - 48 kbps. GPRS enabled the geo-tagging of locations in the DSA. Phones were used by field workers for data collection. Backups were provided to ensure quick replacement in case of breakdown.

2.4 Software

OpenHDS: A web-based application for managing and reporting longitudinal data developed for Health and Demographic Surveillance Systems and piloted by Cross River HDSS. It is a web variant of the HRS2 currently in use at most HDSS sites, but of which update and scalability has been exceeded due to software compatibility and configuration issues. As a web application, OpenHDS needs only to be installed on the server, and clients can load it with any web browser preferably Mozilla Firefox. It is developed in Java and can run on any Java-enabled computer. OpenHDS is an open source application developed at the University of Southern Maine USA (INDEPTH Network, 2013).

MySQL: This is the relational database management system (RDMBS) that runs the backend database server and houses the entire data for the HDSS. It is resident on the PowerEdge DELL server. MySQL is free software and robust with full capacity for complete transaction processing and adequate backup and restore capabilities. MySQL Community version 5.5 was used for this study.

Apache Tomcat: A web server container that sits between the client and the server, sending client requests to the server and receiving server responses for the client. Apache Tomcat is free and open source software. Apache Tomcat version 6.0.35 was used in the deployment of the OpenHDS. Higher versions of Tomcat such as 7.0.35 can also be used, although not tested with this beta version of the OpenHDS.

ODK: The mobile components of the data collection tools were built on ODK which is free and open source software. The client software that runs on the Android phones is ODKCollect, and is used to download the forms for the update cycles onto the phones. ODKAggregate is an intermediate level software residing on the server. It is used to assemble data sent from the phones. ODKCollect v1.1.7 and ODKAggregate v1.0.4 windows-installer were used. MobileHelper, a client android application developed with eclipse IDE and running on the Tablets is used by field supervisors to check the data, identify and resolve errors before it is transferred to the ODKAggregate with derived IDs for onward processing by MirthConnect before dropping in to the CRHDSS database.

MirthConnect: This is intermediate level software that was used to interface ODKAggregate with the OpenHDS database running on MySQL. It checks the records sent in Aggregate against those in the database for consistency. Mirthconnect-2.2.0.5828.b1215-windows was used. This is also a free and open source software.

2.5 Electronic-based Update Cycles

The second, third and fourth update cycles were conducted with electronic mobile devices. Each cycle started with field workers signing out their Android phones and HRBs (*without any paper forms of vital events*), directly from the data office, a section of which was now merged with the supervisory arm of the field systems. All the forms/questionnaires were then downloaded onto the phones once. Each of these phones ran ODK Collect which provided the environments for the forms to run. Field workers would then visit households, where there was an event such as new birth, death, etc. and the relevant form would be opened on the phone and the interview conducted directly with the mobile. Prior to visitation to an EA, the field workers download a section of the database containing relevant information on the EA, so they could use dropdown menus to select names and details of their respondents without having to type their names and personal identity numbers (PIDs).

At the end of each interview, the field worker updates the HRB with the new information and could send the data straight to the Cross River HDSS server or later at the completion of the day's work. The software component that combined with ODKCollect was developed to run on the Android phone as the OpenHDS Mobile. The phone's communication with the server was via GSM technology, and is not restricted to any GSM provider. There were cases were the location of interviews for a day were too remote for any GSM network to reach; in such cases, the field workers collected all their data for the day and then got to an area where there was connectivity to send the whole day's data to the server.

As the data was being collected and sent to the server (ODKAggregate), supervisors, using the Android tablets commenced the data quality checks on the data using another component of the OpenHDS Mobile called Mobile Helper, also developed on ODK. The two supervisors were assigned three field workers each. This application helped supervisors to view the data sent in by each field worker under them to start cleaning and raising queries against outliers. This was the first round of checks as the data was dropping. The second level was after the completion of an EA, the HRB for that EA would be returned, against which the supervisor would check the consistency between HRB entries and the mobile entries. Queried mobile entries were sent back to the relevant field worker, who then re-downloaded the entries, corrected and sent them back to the server for re-checking. If everything is okay at the aggregate level, the data is enabled to get to the CRHDSS database server through another middle-level validator, MirthConnect. This software automatically validates each sent entry against the original individual data in the database. Fields to compare include PID, round number, location ID, etc. Any entry that is not validated is not allowed to drop on the database. At this level, the Database Manager, extracts the invalid entries and sends to the field workers for correction. The valid entries update the relevant tables of the database, and the data is almost ready for analysis and reporting.

Technical Support: The OpenHDS was undergoing further development while the CRHDSS surveillance programme was ongoing. This necessitated frequent technical support and interaction with the software developers. The CRHDSS team held fortnightly Skype conferences with the software developers for several months during which solutions were discussed and agreed on between the implementing team (CRHDSS) and developers. Similar support was also received for the development of the ODK application running on the mobile devices. These frequent needs for software solutions could have been a serious hindrance to the use of this new software had the support not been available. The OpenHDS now has a stable beta version that requires less software engineering interventions.

Data analysis: Data were exported from the HDSS database for analysis using EPI-Info, STATA and R data analysis software. Developing proficiency in the use of robust but free software as EPI-Info and R could further reduce the overall cost of procuring licenses for software.

3. Discussion of findings

This case study has shown that it is feasible to successfully set up and run a paperless, information-technology based health and demographic surveillance system in a resource-poor setting. Scientific leadership for the various core roles and components of the Cross River HDSS is provided by a multi-disciplinary team of tenured academic and research staff of the University drawn from computer science, demography, sociology, public health, statistics, community medicine, epidemiology and child health. The role played by the multi-disciplinary team of tenured academics who do not require additional salary costs illustrates one of the benefits of running HDSS from academic institutions. The engagement of graduate computer science staff to provide a second level of supervision for the field and data systems was responsible for high data quality. The availability of opportunities for graduate studies within the participating departments could enhance the capacity of the HDSS to retain these graduate personnel for a longer period than would be the case if there was no such motivating factor. High school leavers who worked as field enumerators were able to use the mobile devices to obtain data following a week-long training on the use of the electronic forms.

The hardware used in the HDSS under study were widely available, reliable and affordable. Using trusted rugged hardware brands would ensure durability and reduce cost of maintenance. The cell phones cost less to procure but had issues with short battery life and limited data space, hence could only hold limited size of software and data. Tablet PCs cost more money than the android phones but had the advantage of holding more data and offering a better user interface.

The whole range of software used in the Cross River paperless HDSS were free and open source with a wide range of inter-operability. The ability of the OpenHDS software to interface with mobile devices particularly offers huge promise for wider use of the software in HDSS sites across Africa and Asia. The OpenHDS is a big improvement on HRS2 which is widely criticized for lack of inter-operability and data transfer.

Many HDSS site have continued to use HRS2 despite the limitation largely because affordable alternative software for running demographic surveillance systems did not exist until now. The apparent enthusiasm across the countries of the world regarding the potential usefulness of information technology in health has not been matched by the level of uptake of these advancements. In the US for instance, delay in reaping the expected benefits of information technological advancement has been blamed on sluggish adoption of health IT tools and the choice of systems that are either difficult to use or not interoperable.

This case study has shown that a stable open source version of the OpenHDS is now available. Since this version available could still be classified as beta version, it would be advisable for HDSS sites that intend to deploy the software to have knowledgeable computer scientists in their employ or as long-term consultants. This would enable user sites to promptly resolve minor software issues which may continue to occur occasionally until the software becomes fully stable.
Limited access to internet significantly affected the quick and smooth implementation of the CRHDSS case as described in this study. However, one way we overcame absence of GSM connectivity was for the field workers to collect the data on the mobile phones and then take the phones to areas of connectivity and send to the server at the end of the day's data collection. One of the key outputs of a paperless HDSS should be ability to deliver health information to community members. This could be sent through email or cell phones. Accessibility of internet connectivity and ICT at national level may contribute to improvement of such public health indices as adolescent fertility rate, child immunization coverage, tuberculosis case detected, life expectancy, and adult mortality rate (Wu and Raghupathi 2012).
Mechanisms for ensuring adequate quality control of information obtained by IT-based paperless methods continue to attract attention. New or poorly developed applications may generate errors which will compromise the quality of data delivered through such systems. Both the developers and implementers of new open software ought to develop protocols and checks capable of detecting these errors. These issues are particularly crucial for IT systems used in health and human services where potential for harm could be substantial. There have been recent efforts in Canada, UK and America to address errors generated by health IT systems. Improved design methods, regulation and educational initiatives have been recommended as approaches to minimize error and improve the safety of health information technology (Kushniruk, 2013).

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