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Prototype Demonstration

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Abstract

Maternal and perinatal mortality is a persistent problem in low-income settings, including sub-Saharan Africa. Reducing mortality requires high quality data gathered in as near real time as possible. Existing paper-based systems such as Tanzania's MTUHA Health Management Information System are not amenable to data analysis. Such data, therefore, are not available to drive decision making at the individual, clinic, district, regional and national policy levels. The ULTRA mobile application provides a means of capturing all mother and child data from the first antenatal visit, through delivery, to the final postnatal visit. As well as being a research platform, ULTRA also provides workflow support so that existing paper systems may be fully replaced. ULTRA is being deployed on a pilot basis in October and November. It will be monitored and evaluated in line with WHO guidelines. ULTRA's widespread deployment has the potential to transform Tanzanian maternal health policy and patient outcomes.

Keywords

Maternal, perinatal, mortality, mobile, electronic, birth, registry.

Introduction

Maternal and perinatal mortality rates greatly burden sub-Saharan Africa, with statistics indicating that mortality rates account for roughly two-thirds of all maternal deaths per year worldwide. This is equivalent to 533 maternal deaths per 100,000 live births or 200,000 maternal deaths per year (Seale, 2020; UNICEF,

2019; WHO, 2019). The most problematic areas are in east, west, and central Africa (Mangu, C.D. et al 2021). In Tanzania, the most recent infant and neonatal mortality rates stand at 43 and 25 deaths per 1,000 live births respectively from 2019, a minor decrease from 45 infant deaths and 26 neonatal deaths per 1,000 live births, in 2015 (Health sector strategic plan).

Reducing maternal and perinatal mortality requires quality, evidence-based data collection to identify local priorities and target evidence-based solutions. The purpose of perinatal data collection is to monitor delivery outcome patterns and trends within obstetric services (Craswell, A. *et al*, 2013). However, obtaining accurate statistics can be challenging in places where only paper-based registries are used for data collection. Traditionally, these are large cumbersome books filled in by birth attendants soon after the birth of the newborn. The quality of the content can be variable, with the potential for underreporting of deliveries and poor outcomes, and births outside facilities (i.e. home births) often not recorded at all. Paper-based registers are also difficult to store making the information difficult to access for future pregnancies or institutional audits. These factors make monitoring and comparing trends between institutions challenging.

Low- and middle-income countries carry the greatest global burden of maternal and perinatal mortality and morbidity rates. It is likely that these issues will lead to an imprecise analysis of maternal risk factors through underreporting and therefore, will disproportionately affect those most at risk and in need of care facilities. However, the scale of the problem is unmeasured and unknown (ACOG, 2018; Mboya et al., 2020). Hospital and clinic Electronic Health Record systems are expensive to install, customize and maintain and are therefore ill-suited to low-income environments (Katarura, 2018). A solution that is cheap and easy to configure and maintain is needed.

E-health systems in healthcare have been associated with reductions in recording error rates and improved completeness, accuracy, and timeliness of data transfer and collection. (Craswell, A. et al, 2013) Electronic data collection is a means to accurately measure and maximise the potential impact of interventions to help address underlying structural gaps between high and low-income countries at a health system level.

To address these problems in capturing pregnancy and birth data, we developed the ULTRA app in partnership with clinicians and information communications technology specialists in Tanzania. ULTRA is a development of prior birth registry research by CoLAB, INFANT and Kilimanjaro Clinical Research Institute. ULTRA is also derived from previous research work by Bergsjø *et al* (2007) and Myatt and Redman (2015). Thus the registry builds on prior work by Kilimanjaro Christian Medical Centre (https://www.kcmc.ac.tz/) and the Global Pregnancy Collaboration (https://pregnancycolab.tghn.org/).

The objective of the ULTRA project is to prove that we can replace ubiquitous but inefficient paper-based delivery registers with an easy-to-use, low-cost, sustainable electronic delivery register. ULTRA will be monitored and evaluated in line with published standards per WHO (2016). Additionally, ULTRA will demonstrate that data harmonisation is possible to enable comparisons across institutions, populations and globally. The ULTRA application is therefore designed to fulfil four specific objectives: To provide access via smartphone or tablet, thus removing the need for desktop or laptop computers; to give healthcare professionals access to data, either online or offline; to host all data on a locally owned server; to furnish all this using only open source and free software. The rest of this paper describes the ULTRA application and its Tanzanian context in more detail.

The ULTRA application

ULTRA is a mobile electronic registry covering all stages of pregnancy and childbirth from first antenatal visit, through delivery, to final postnatal visit. It is designed with the specific purpose of reducing maternal and perinatal mortality rates in the Kilimanjaro region. It is implemented through a specific configuration of the DHIS2 software and is based directly on Tanzania's paper-based MTUHA Health Management Information System (HMIS). Tanzania's '*Mfumo wa Taarifa za Uendeshaji Huduma za Afya (MTUHA)*' HMIS was introduced in 1992 and consists of a manual, a set of paper registers for primary data collection and secondary data books where aggregate data from the MTUHA books is counted or used for calculations and reported to the regional medical offices (Wilms, 2014).

ULTRA also reflects the organisational structure of the Tanzanian health system. Tanzania is subdivided administratively into zones, regions, districts and wards. ULTRA is focused on districts within the

Kilimanjaro region in the Northern zone. Within each district, the health system is organized into district hospitals, health centres and dispensaries. All provide maternity services, with the breadth and depth of service dictated by facility size and capacity. The most basic services are offered at dispensary level.

Figure 1 illustrates part of the Moshi Urban and Rural districts within Kilimanjaro region. Dispensaries in Msaranga (upper left) Himo (upper right) and Chekereni (lower centre) have been designated as initial rollout sites for ULTRA.

ULTRA relies on the open-source District Health Information Software (DHIS2) application. This software is designed specifically for resource-poor communities, where deliveries may occur in places lacking internet connectivity. The system is developed using the DHIS2 web- and mobile-based platform, making all recorded events easily exportable and user-friendly. DHIS2 facilitates decision-making for local administrative and policy levels based on time and volume aggregated data. Further, decision support will be enhanced also at the individual level by summarising all data pertaining to a case and at the clinic, district or regional level by providing aggregate and count data across multiple cases.

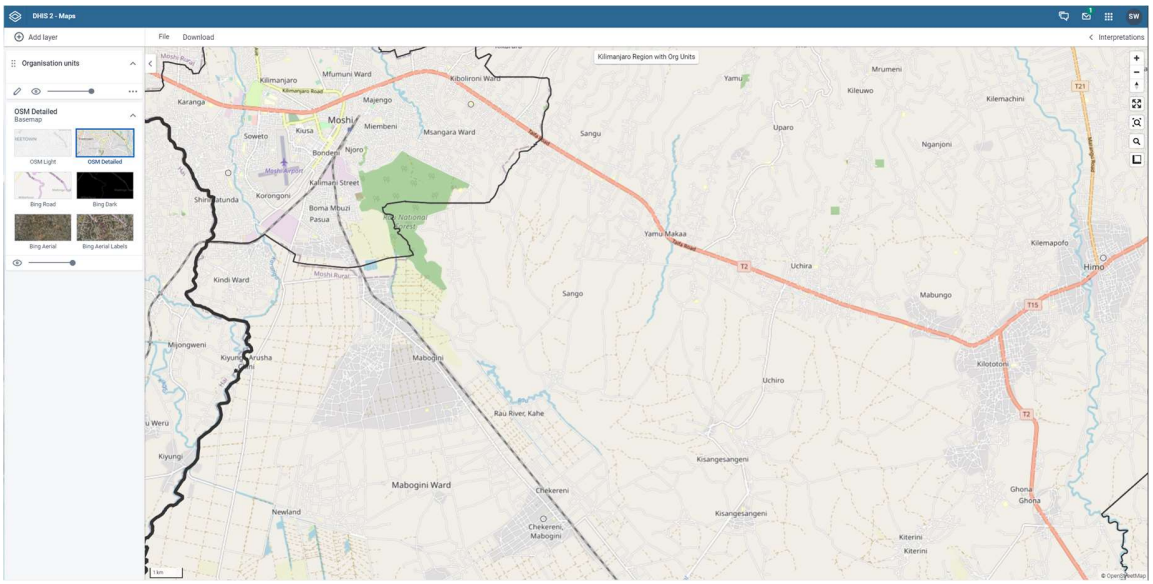

Figure 1: Moshi Urban and Rural Areas

To support the ULTRA application, a technology stack has been implemented as follows:

- A Dell PowerEdge server with 4 cores, 64GB RAM and 2TB of RAID SSD storage. This server provides redundancy in both its power supplies and its solid state disk storage.
- The Ubuntu 2204 LTS operating system
- A virtual machine, also running Ubuntu 2204 LTS. Backup images of this virtual machine are taken several times a day.
- Java JDK 11, installed on the virtual machine.
- Tomcat 9, installed on the virtual machine.
- PostGRES 12, installed on the virtual machine.
- The DHIS2 2.38 application, installed on the virtual machine. DHIS2 is directly dependent on software items 4, 5 and 6. See https://dhis2.org/ for information about DHIS2 itself.
- The Kilimanjaro ULTRA Registry, a specific configuration of DHIS2 with its own specific metadata. This is comprised of several software and configuration components, all part of the DHIS2 application.
- The DHIS2 Capture app, installed on an Android smartphone or tablet.

This technology stack is visualized in Figure 2.

The ULTRA application software comprises several sets of metadata and configurations within DHIS2:

- Data elements are derived from the relevant current MTUHA books. These directly copy MTUHA variables. Some text variables are directly replaced with option lists to eliminate ambiguity and inconsistency in their use.
- A Multi Event With Registration (MEWR) Tracker Program, which facilitates entry of data on pregnant women from the first antenatal visit, for subsequent antenatal visits, at delivery and for the postnatal visit within 42 days post-delivery. This Program is the core of ULTRA and presents the relevant MTUHA variables for completion at the appropriate stage.
- An organisational structure reflecting the structure of the health system in the Kilimanjaro region.
- Geographic data which maps that hierarchical organisation structure into the Kilimanjaro region.

All of the software on which the Kilimanjaro ULTRA Registry relies is open source with no licence costs. ULTRA itself is fully portable and may be easily moved to another DHIS2 server by transferring all the metadata associated with the components in the four innermost grey boxes in Figure 2.

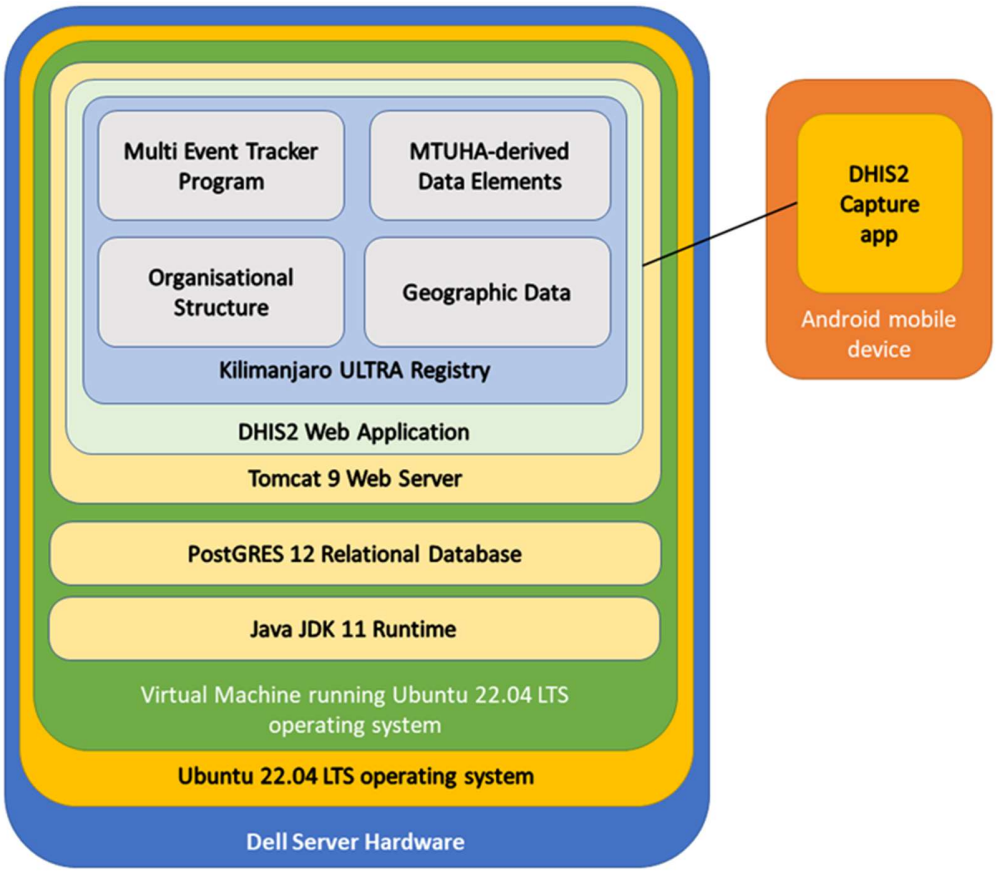

Figure 2: Ultra Technology Stack

Using a virtual machine architecture permits development, test and production copies of ULTRA to be run alongside each other without interference among them. It also permits rapid configuration changes and a higher degree of isolation between the environment in which ULTRA runs and the outside internet. The virtual machine provides 16GB RAM and 100GB of disk storage on which to run ULTRA. This is in line with the server specifications for the DHIS2 application.

The server is secured on KCRI's and KCMC's network by means of a firewall. All network traffic to and from the virtual machine on which ULTRA runs is encrypted. The physical Dell server hardware is not accessible from the outside internet. The server is protected with an uninterruptible power supply.

Most users of Kilimanjaro ULTRA will use it via the DHIS2 Capture app, which runs on an Android smartphone or tablet. The mobile app provides for online and offline data entry with manual and automatic synchronisation of data when a cellular or WiFi network is available. The app provides for a substantial amount of customisation to make sure that data entry fields are suitably formatted for mobile usage. The app is available in Swahili and English.

Designing the workflow

The ULTRA app variable content is a straight copy of all the data entry fields contained in the MTUHA books. No extra data are asked for and no data are omitted. In this respect, ULTRA is a "*paved cowpath*" implementation of an existing paper-based system, with no overall process changes (Becker and Janiesch, 2007). This is intentional; the initial role of ULTRA is to be an electronic equivalent of the existing MTUHA system. The overall patient care pathway is not being redesigned.

Nevertheless, the workflow will change. The initial ULTRA form design reflects the assumption that the MTUHA books are completed in a linear sequential fashion. This has turned out not to be the case in reality. Observations were made of an antenatal consultation to determine the exact sequence of questions and answers that is used to fill in all the required data. Since ULTRA permits rapid form reconfiguration, the data entry sequence is being amended to reflect what was observed. The high degree of standardization of data gathering imposed by the MTUHA books, plus comments received from healthcare professionals at four clinical sites, allows some optimization and resequencing of data gathering to be implemented. It is important that nothing will be omitted from or added to the MTUHA data set at this stage of the project.

The MTUHA books by their nature do not restrict certain forms of data entry. The most constrained fields are tick boxes. If the user is expected to select an option from a list, the options are presented, and the user writes down the option selected. There is no protection against other items being written in that particular field in the book. Additionally, there is redundancy in the data gathered in the MTUHA books.

An exact electronic copy of the MTUHA books would be similarly unrestricted and could ultimately present problems with data cleanliness. Therefore, where possible, option sets and yes/no options are presented in the ULTRA app rather than enabling a free text response. This is expected to reduce confusing or contradictory data entries. The DHIS2 system upon which ULTRA is built also allows for reasonable value ranges and consistency checks to be specified. Additionally, values outside certain defined ranges may be notified to another DHIS2 user (such as a supervising clinician) as possible areas of concern.

A qualitative study is being designed to fully map existing and future workflows in health facilities where ULTRA is being deployed. This study relies on mapping techniques such as information flow mapping as devised in Adam (1995) and the Integrated Patient Journey Map as described in McCarthy *et al* (2016). Figure 3 illustrates part of the workflow as implemented in the ULTRA app; the sequence of questions is designed to follow that of the MTUHA books as well as the workflow observed at antenatal visits.

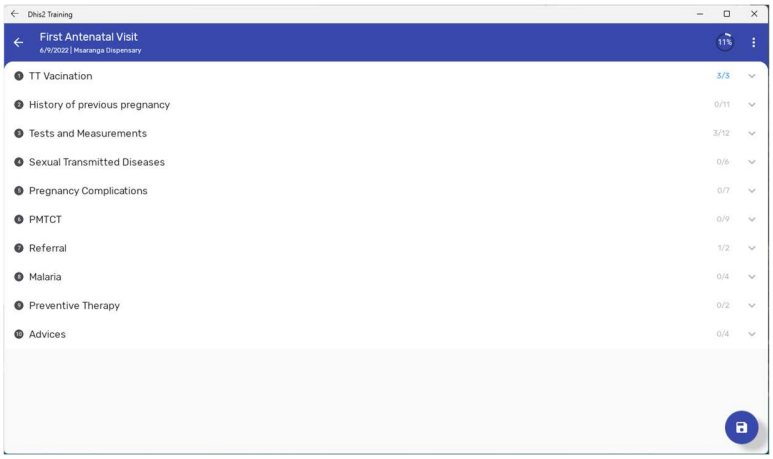

Figure 3: A screenshot of part of the ULTRA app

Innovation

An innovation is defined as *"a new or improved product or process (or combination thereof)"* (Eurostat, 2018). In this context, the ULTRA application may be regarded as a "*business process innovation"* in the area of "*information and communication systems"* (Eurostat, 2018). As described already, ULTRA changes the existing processes around the recording and communication of data related to antenatal care, childbirth and postnatal care. These changes are subtle in that they optimize workflow to reduce data duplication and to omit data recording steps which are not needed. However, ULTRA also introduces some new features that a paper system cannot provide. These are:

1. Automatic notifications, dependent on rules that can be defined in the ULTRA application.
2. Permanent or temporary referrals from one health facility to another.
3. A system of controls governing who may enter, read and search for data and to what organizational unit such privileges are scoped.
4. Email and SMS notifications to other users or to pregnant women registered in the system.

This takes ULTRA beyond a straightforward data gathering platform for research purposes only. It provides sufficient workflow support that parallel running of the existing MTUHA system will not be necessary beyond the early stages of the project.

ULTRA is therefore an *incremental* innovation in that it introduces small but significant changes to the existing workflows for antenatal care, delivery and postnatal care. However, its *innovative* nature may also be regarded as *radical* in that it permits instant access to a large body of data previously unavailable, *disruptive* in that it completely replaces one technology with another and *sustaining* in that it seeks to support and enhance the ability of the health system to improve patient care and determine policy (Ridley, 2020; Shestakov, 2019).

There are other innovations to consider: ULTRA is based entirely on open-source software and is designed to be portable to other settings. There are no license costs to consider. In line with Tanzanian data transfer rules, all data resides on a server within the jurisdiction, although it is possible to save the data on the cloud somewhere else. Tanzanian researchers retain ownership and control of that data. Finally, ULTRA is innovative in that it offers a means to provide a single obstetric history for a woman across multiple pregnancies.

Analytic Approaches

The DHIS2 platform affords data reporting, aggregation and analysis across multiple cases. It also supports longitudinal data reporting over a single case. DHIS2 contains substantial reporting facilities including pivot tables and mapping. Nevertheless, it will be desirable to apply statistical and analytic techniques not native to DHIS2. Accordingly, ULTRA data may be exported in CSV format for analysis in other statistical packages.

Future data analysis techniques, novel or otherwise, have yet to be determined and will to some extent be driven by the research objectives of any future study relying on ULTRA data. However, ULTRA has the advantage that a corpus of real-world birth data is being built up reasonably quickly after deployment in the Kilimanjaro region. The development of descriptive analytics will begin shortly, guided by the needs of pregnant women, clinical staff and the local health ministry. Predictive analytics will follow when sufficient data are available for model building.

Future work

ULTRA will require the ongoing support of the Tanzanian Ministry of Health if it is to sustainably replace the existing MTUHA HMIS. The current project is funded by the Irish Research Council and Department of Foreign Affairs to the end of 2024. The enthusiasm of the regional medical office is notable and has hugely accelerated the project's rollout. This is likely to lead to expansion of the project's coverage subject to resource availability. A national review of the MTUHA HMIS is planned for late 2023; organizing this will be a joint effort by the ULTRA project team and staff in the regional medical office.

Conclusions

The ULTRA project, which started in October 2021, has progressed rapidly in its first year. A conservative project plan which allowed time to eliminate as many problems as possible with the technology stack, has yielded a fairly robust mobile electronic implementation of Tanzania's existing MTUHA HMIS and a very good understanding of the landscape of the regional maternal healthcare system. Enthusiasm from local ministry of health officials means that project progress is likely to accelerate. This brings attendant risk, not least potential technological failure risks and also issues with user acceptance and scaling. The success of the project will be carefully monitored and evaluated using published WHO guidelines.

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