

Guidelines for developing geographically sensitive mobile health applications

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Abstract

Background

Seventeen (17) Sustainable Development Goals (SDGs) were promulgated in 2016 following the end of the Millennium Development Goals (MDGs) era. SDG 3 aims to ensure health lives and promote well-being for all ages. Increasing use of geo-enabled mobile health applications can positively contribute to realisation of SDG 3 targets. Health facilities and the communities that require health care are connected by geography. Digital technologies are increasingly becoming an important resource for health services delivery and public health. However, there is a need for a framework that guide the development and deployment for context relevant location based digital technologies. This paper presents recommendations for guidelines that can be adopted for developing geographically sensitive mobile health applications. These guidelines were formulated based on experience from the RoadMApp project in Kwekwe District of Zimbabwe. RoadMApp is an mHealth location aware application that reduces the negative effects of long travel times to health care facilities by pregnant women.

Results

The guidelines for developing geographically sensitive mobile applications developed starts with user requirements assessment followed by geographic information systems data needs and modelling, database development, and finally frontend mobile application development.

Conclusions

In line with the new global health policy drive for locally driven and context relevant health interventions, the guidelines present new opportunities that take advantage of the ubiquity of mobile telephony and could be adopted in health policy formulations to contribute to SDG3.

Introduction

Despite efforts made globally to improve health, there is much concern about the high disease burden in Low- and Middle-Income Countries (LMICs). The Millennium Development Goals (MDGs) 4 and 5 aimed at reducing the maternal and child adverse outcomes rates by the year 2015. Although the global rates showed improvement, the in-country rates showed inequality in the improvements, with LMICs lagging. The more stringent Sustainable Development Goals (SDGs) were drafted to address the gaps in the MDGs, with the focus turned on improving preventative measures to alleviate adverse outcomes by the year 2030. The 2030 Agenda is a central United Nations (UN) platform for achieving 'integrated and indivisible' goals and targets across the three characteristic dimensions of sustainable development: the social, environmental and economic [1]. Non-clinical strategies that offer solutions for improving health are particularly important in realising SDGs targets. One of the targets under SDG 3, "Ensure healthy lives and promote well-being for all at all ages", is to "achieve universal health coverage, including financial risk protection, access to quality essential health-care services and access to safe, effective, quality and

affordable essential medicines and vaccines for all”. Geographical access, which includes a combination of factors such as distance, terrain and climate is the first barrier to access health care services. The policy drive within the SDGs heavily embraces digital technologies. Practically all the SDGs have a digital component included[2], unlike in the predecessor MDGs.

Health facilities and communities are connected by the physical geography, with travel time to health facilities being affected by the distance [3]. However, distance is not the only factor that affects travel time. Long travel times due to poor road infrastructure and adverse weather conditions remain key geographic barriers to seek healthcare [4]. The condition of roads in rural regions in most LMICs deteriorates during the wet season due to precipitation and flooding, leaving many pregnant women more vulnerable to poor health outcomes as a result of delays in seeking care. To help alleviate these poor outcomes, an innovative technology platform, Road Mobile Application (RoadMApp), that seeks to offer solutions to the challenges associated with the physical access to health care was designed and implemented. RoadMApp is a technological enabler that improves access to healthcare for pregnant women. It takes advantage of mobile health technologies, providing information on weather conditions as well as linking pregnant women to local transport and options to finance it. This is in tandem with the SDGs policy formulation that is driven by digital technology.

Mobile digital technologies are increasingly becoming an important resource in support of health services delivery and public health[5] through mobile Health (mHealth). mHealth refers to the use of wireless communication devices to support public health and clinical practice[6]. Geo-enabled mHealth applications are therefore tools with a location aware component playing an integral part in improving access to healthcare services. Thus, they ride on mobile wireless technologies which are easy to use, have broad reach and wide acceptance over a wide range of communities. There has been an upward trend in mobile phone technology adoption all over the world. The rate of mobile technology usage is even more in LMICs. By the end of 2018, there were 456 million unique mobile subscribers in Sub-Saharan Africa – an increase of 20 million over the previous year and representing a subscriber penetration rate of 44%[7]. More households in developing countries own a mobile phone than have access to electricity or clean water, and nearly 70 percent of the bottom fifth of the population in LMIC own a mobile phone[8]. There is no doubt that mobile technology is easiest and one of the most affordable means of communication presently[9]. The RoadMApp platform has taken a strategic advantage of the ever-increasing adoption of digital technologies in resource poor settings.

Some geo-enabled mHealth applications have been developed in the past. For example, Validating European Mobile Alarm Services for Inclusion and Independent Living (MobilAlarm) project was executed in 2004–2005 with the aim of bringing together mature technologies into a simple, low-cost geo-enabled emergency response service to be offered to European customers[10] using a mobile device with GPS capabilities. Complete Ambient Assisted Living eXperiment (CAALYX), a two year project between 2007 and 2008, was aimed at developing a location aware service capable of monitoring the health status of aged users 24 hours a day, seven days a week, for the purpose of predicting and detecting any unfolding adverse health conditions or medical emergencies, including falls, and preventing complications before

they developed, all while respecting users' privacy and personal life needs[10], [11]. The Mobilisation and Accessibility Planning for People with Disabilities (MAPPED) project which ran from 2004 to 2007 consisted of a route planning and navigation system using a personal digital assistant(PDA) or mobile phone device from which users could plan a route and also follow it up through the built-in GPS subsystem[10].

Most, if not all the existing geo-enabled mHealth applications have been designed and implemented at a large scale and assume uniform characteristics of the users. The aim of RoadMApp is to improve antenatal care (ANC) seeking behaviour and facility deliveries, by providing the pregnant women at highest risk the important information and guidance throughout their pregnancies, and most importantly providing them with affordable transport to seek antenatal care and deliver in health facilities. The RoadMApp solution uses a bottom up approach, being driven by local knowledge, practices and experiences, resulting in context relevant interventions that use geographic information systems (GIS) as a tool, to contribute to global health policy formulation.

This article introduces a set of guidelines for creating geo-enabled mobile health applications based on the experiences from the RoadMApp project, implemented in a mix of urban, peri-urban, and rural settings in a developing country. Considering the SDG to broaden healthy lives and wellbeing for all at all ages, our guidelines will potentially provide quicker avenue to those with interest in developing location aware applications for healthcare services.

Development Of The Guidelines

The application development guidelines were formulated to enable creation of geo-enabled mHealth applications that fulfil expected objectives using the RoadMApp project as a case study. The integral part of the RoadMApp application is anchored on 5 components i.e. the identification of pregnant women in the communities, recruitment and registration of the pregnant women at the health facilities, the pregnant woman's savings towards her transportation, prompts and advice on travel risk and travel options respectively, and transportation of the women to health facilities, as shown in Fig. 1. In this project, a process from preparatory work, through data gathering to developing the geo-enabled mobile health application included: 1. user requirements assessment, 2. GIS data needs assessment, data gathering and modelling, 3. database design and development and 4. the front-end mobile application development.

The agile approach to mobile application development was adopted in this project. These processes are described in detail below.

1. User requirements assessment

User requirements assessment involves discovering and assessing the needs of users in order to meet those needs[12]. To

develop a phenomenally successful geo-enabled mobile health application, a user-centred design method should be adopted. User expectation is the most fundamental part of the designing stage, to discover the potential application's behaviour and usage. The user-centred design method allows for direct end-user engagement throughout the design process, facilitating the development of a tool that can provide the most beneficial outcome possible[13].

As part of user-need assessment context, a literature search through a scoping review study was carried out to gain evidence about the possible implementation of the application in a developing country perspective. The scoping review mainly focused on transport options and travel times to seek healthcare implemented elsewhere in the world. A scoping study's main aim in this context was to rapidly map the key concepts underpinning a research area and the main sources and types of evidence available[14].

A qualitative study was then carried out to gather contextual information from the study site to identify key community perspectives on the RoadMApp application intervention to understand the characteristics of target population, that is the cultural, demographic, social and economic characteristics. These characteristics were factored into the development of RoadMApp at a disaggregated spatial level, to produce an equitable platform that would prioritise the most vulnerable, whilst being an efficient and effective tool for the least vulnerable. The study, under the *RoadMApp- Improving Access to maternal care* -project was carried out in the Kwekwe District, Midlands Province in Zimbabwe. The study area had a mix of urban, peri-urban and a rural setup. Of the 49 health facilities in the district, 2 hospitals (rural and urban), 4 rural health centres, 2 peri-urban clinics, and 2 urban clinics were selected. The qualitative study included focus group discussions (FGDs), key informant interviews and community engagement. The key informant interviews encompassed traditional chiefs, local government authorities, midwives, fire brigade and ambulance personnel and other players offering maternal services. FGDs were used to collect data from focus groups made up of pregnant women, women of childbearing age, spouses, and other community members. For the RoadMApp, it was crucial to identify the transport options available for all the pregnant women in the study area. Instead of assuming that every woman could be driven from their locations to the facilities, like most existing applications have, the study revealed that if we had proceeded with that assumption and only modelled driving in the application, the most vulnerable women would have been unable to reap the benefits of the application. The qualitative study revealed that some remote areas are not accessible by vehicular transport, as the road conditions were not suitable for driving regardless of the season. Considering this, other modes of transport, like walking, ox driven carts, wheelbarrows, bicycles, etc, given by the community members as the modes of transport they use where cars cannot reach, were factored into the model as transport that links the woman and the drivers at the beginning of a road segment suitable for cars. The visualisation of the expected functioning of the combined transport systems within the application is shown in Fig. 2.

2. GIS data needs assessment, data gathering and modelling

One of the major problems that the development of GIS applications is facing today is data acquisition[15]. In high income countries (HIC), access to GIS data for healthcare utilisation is more

readily available than in LMIC, albeit in different formats. In LMIC countries, most of the data is collected directly from primary sources such as surveys and mapping exercises, as there are few secondary sources of data available as either open or proprietary sources. Even when the data is available as secondary data, its use for new applications is often hampered by poor documentation, obscure semantics of data, diversity of data sets, heterogeneity of existing systems in terms of data modelling concepts, data encoding techniques, storage structures, access functionalities, etc [15]. When it comes to collecting framework/base data for GIS modelling, a systematic way to check data availability is to carry out a data inventory and evaluation. A nine step approach, which is a documented framework for gathering and creating framework GIS data was used[16]. The most critical GIS datasets needed for the creation of geo-apps are shown in Table 1. After following guidelines proposed in [16], GIS datasets required for the mobile application back-end processes were prepared using online open source resources, OpenStreetMap (OSM) and Google maps. Defining the location of health services in relation to the communities they are intended to serve is the cornerstone of health system planning[17]. Lists of health facilities were obtained from the provincial health ministry offices were geocoded using google maps and OSM. The road dataset was also initially extracted from existing vector data using OSM. The gaps in the dataset were filled through digitizing, using OSM resources. However, the accuracy is often questionable as most of this data is made available through crowdsourcing[18]. Crowd sourced geographic data is an opensource collection of geographic data contributed by lots of non-professionals and provided to the public[19]. As a result, data directly obtained from crowdsourced resources should be checked for accuracy. Using ArcGIS software, the road dataset was then cleaned to correct for any topological errors. The roads were classified into highway, paved major, paved minor, unpaved major, unpaved minor and trails.

Two important geographical perspectives on health care service access can be distinguished as accessibility and utilisation[20]. Modelling potential geographical access to health services is the main application of GIS in maternal health research[21], [22]. Our modelling approach was focused on accessibility i.e. the availability of the health facility and the means of reaching it to promote and improve facility utilisation. GIS data gathering and preparation preceded the creation of road network dataset in ArcGIS. Wet and dry period access models were produced using “Modelbuilder in ArcGIS”, using the closest facility and the route layer tools. The process for producing these models is highlighted in detail in [4].The location of the pregnant woman and that of the driver would be initiated from the mobile application where it is determined in real-time using the mobile inbuilt “Global Positioning System”. The access model was published as a service on the ArcGIS Server hosted on “Microsoft Azure” cloud services. This model was accessible to the mobile application through the “ArcGIS REST API” service.

Table 1

Datasets required and their use in Geo-enabled mobile health applications development

Dataset	Gathering process	Role in App development
Road network Feature lines in Esri shapefile format.	The initial road network is adopted from Open Street Map. The dataset is comprised of mainly highways and major roads. Missing roads and paths in the dataset are digitised from high resolution Bing Maps satellite image service to fill the data gaps. These roads are classified into highways, major paved roads, major unpaved roads, minor paved roads, minor unpaved roads and trails done in ArcGIS. Quality of the dataset is be monitored by checking GIS topology. Speed limits were assigned to each road segment depending on the road type, precipitation level and flood extent.	Road dataset is needed to create a road network data in GIS environment. The road network is used to create access model used in the mobile application for navigation to health facilities from home and for the driver to pick the woman from a certain location.
Health facility (Point features in Esri shapefile(.shp) format)	GPS coordinates of the health facilities were collected from google earth, OSM.	Health facilities are needed as facilities in the modelling process
administrative boundaries, polygon features in (.shp) files	Administrative boundaries up to ward level were downloaded from DIVA-GIS.	These represents locations where women live. Community boundaries are used for sending prompts to pregnant women ward-based.
Precipitation and floods Raster images (.TIFF)	Historical data records of precipitation stretching from the previous 5 years was downloaded from CHRS Data Portal.	These datasets were integrated with data from roads to assign speed limits on roads, adjust on travel time to seek care and predict and inform travel risk on a weekly basis.

3. Database Development for the Mobile Application

The term database embraces many different approaches from paper records to vast computerised collections of data. However, in our context a database is a large collection of data in a computer, organized so that it can be expanded, updated, and retrieved rapidly for various uses[23]. The database is an essential part of the application as it holds the GIS data to be utilised by the mobile application. Data in a relational database is stored as tables which are related to other tables within the database. Structured Query Language (SQL) allows for information manipulation from the database. Two categories of datasets stored in the database can be identified which are datasets that are relatively static in nature such as administrative boundaries, health facilities and roads as well as datasets that are

collected in real-time such as location of pregnant woman and the driver. Information collected by facilities using the health facility and CHW components of the application is also stored in the database.

In the case of RoadMapp intervention, standard database development processes were followed as: requirements elicitation, conceptual modelling, logical modelling and physical modelling as described in [24]. The database uses client-server architecture, which entails establishing a system with 'n' number of clients (application users) who interact with a server. The database is particularly important as it is used for storage of data generated and used by the mobile application. The database designing was done in open source "Postgres/PostGIS" database system. PostGIS is an extension of Postgres allowing storage of location aware data such as health facilities location, roads, and administrative boundaries.

4. Front-end Mobile Application Development and Testing

Mobile application development is the process of building application software for mobile devices. Through the use of mobile apps, the user is provided with various features that will enable him/her to fulfil all his/her needs and much more[25]. The front-end mobile application development process or cycle utilised the Agile philosophy through the Scrum framework. Agile is a model for developing software applications where project implementation is done iteratively or incrementally[26]. In others words, the framework offers an answer to the eager business community asking for lighter weight along with faster and nimbler software development processes[27].

The Scrum framework provides the processes to implement the Agile philosophy through iterative and incremental agile software development process cycle. Its focus is on "a flexible, holistic product development strategy where a development team works as a unit to reach a common goal"[28].

The process of front-end mobile application development started with Agile requirements-gathering through the development of User Stories by the Product Owner. User stories were based on the qualitative data collection from the intervention area, the scoping review and original ideas of the Product Owner. Each User Story described the behaviour and characteristics of each specific feature of the mobile application. The developed User Stories were then evaluated by means of INVEST criteria before being entered in the project tracking tool. The INVEST criteria are Independent, Negotiable, Valuable, Estimable, Small, and Testable characteristics.

In this agile approach, the development team and the client or product owner met regularly to discuss progress in the development of the application. Any problems arising in the absence of the client during development would quickly be solved in regular meetings. The feedback received from the Product Owner was then used to improve the app until the final product was ready for use. The Agile application development process employed in this approach gives the mobile application developers a chance to work with geospatial scientists to create a robust product. The geospatial scientists were responsible for the behaviour of the whole application as well as supplying all the necessary required resources for the GIS-based back-end processes of the application.

The front-end mobile application had 4 main interfaces i.e. Community Health Worker (CHW), health facility, the pregnant woman and the driver interfaces. The CHW interface enables community/village health workers to capture basic information of the pregnant woman including the coordinates of the household where the woman resides. The coordinates are important for follow-up to the woman in case she misses registration at the facility or misses any ANC visit. The health facility interface integrates data from the CHW interface with additional information that enables the pregnant woman to be registered in the database for ANC. The driver application interface enables the driver to receive requests for transport from pregnant women. The woman and the driver interfaces are linked to the back-end access model with navigation capabilities. The driver is also able to locate position of the woman and pick her up to the health facility using the shortest route possible. The driver interface also receives notifications of payment into their mobile wallet accounts for transport services offered from the pregnant woman's micro savings account once she has been delivered at the health facility. The pregnant woman's interface enables the woman to select the closest driver and request for transport services. The pregnant woman's interface comprises of a payment gateway, funds balance checking, receiving notifications about antenatal visits and transport risk and the general information about pregnancy.

After the initial development of the application, user application testing was conducted. User application testing evaluates the usability, functionality, user experience, and design of the application by involving the end-user. It involves a situation where product faults are reported, tracked, fixed and re-analysed until it conforms to the requirements of the objectives. For RoadMAApp application, testing was performed by both the client and the end-user. Client testing involved both functionality and usability testing to check the application's functionality and compare with the user's requirements. The end-users testing basically involved usability testing to check the application's link validation, multiple browsers' support, screen resolution[29]. A sample of women, hospital facility personnel, drivers, community health workers was used in the end-user testing of the application.

Discussion

This article proposes guidelines summarised in Fig. 3 that can be adopted in the development of location aware applications for improving access to health care. To our knowledge, no guidelines of this nature have been documented anywhere so far. In line with the new global health policy drive for locally driven and context relevant health interventions, the guidelines present new opportunities that take advantage of the ubiquity of mobile telephony and could be adopted in health policy formulations to contribute to SDG3. These locally driven and context relevant health interventions are driven by the concept of primary health care that takes a comprehensive, systems-driven approach aligned with a set of strong values around equity, participation, and community-driven, bottom-up action for health and well-being[30].

Improving physical access to healthcare is one of the issues envisaged to greatly increase facility utilisation which ultimately enhances the success of SDG3. Global health policy should emphasize digital infrastructure that supports mobile technology considering the ubiquity of mobile phone technology even in remote communities around the world. The availability of location aware applications alone will not

solve the issue of access to health care. They should be augmented by better road and transport infrastructure. Therefore, there is need for collaboration between health policy makers, urban and regional planners, and transportation experts that could lead to creative solutions that address transportation barriers to health care access while considering patient health, cost, and efficiency [31]. There has been increased recognition that improving health and achieving health equity will require broader approaches that address social, economic, and environmental factors that influence health[32]. SDG 3 can only be realised if global health policies use a holistic approach through considering other social determinants of health.

Health interventions, through riding on geospatial applications, present a unique way of contributing to global health. The main thrust of RoadMApp intervention in global health is to improve community level health following precision public health principles. Central to the notion of precision public health is the concept of identifying specific risk factor profiles that confer vulnerability to poor health[33]. Identifying that long travel times to seek health care is a risk factor motivated the development of the RoadMApp and subsequent guidelines. However, technology is not a panacea for the world's health problems[34]. Successful implementation and sustainability of geo-enabled applications especially in LMIC is associated with potential difficulties. Cost, wider economic effect, challenges of distribution, human resources, and energy supply are all factors that determine whether a technology can be deployed in a resource-poor setting[34]. In the RoadMApp intervention site, some parts of the rural areas lack basic transport, electricity, and mobile phone infrastructure. The road infrastructure is also poor, and this is further exacerbated during the rainy season where some sections of the road network become impassable due to flooding and slippery surfaces. Improved physical access to primary health care is required for the successful attainment of SDG3. Mobile phone is a technology that is already available in resource-poor settings and should be used as a platform for health interventions.

Quantitative data collection methods such as user surveys involve administering written questions to a sampled population of users to determine their needs[35]. User surveys can be an effective and quicker way of gathering information from users. However, quantitative data collection was not part of the RoadMApp project.

Conclusion

The use of Geo-enabled mobile health applications is increasing. Organisations should therefore adopt standardised Geo-enabled mobile health applications development guidelines to speed up the development process in the healthcare sector. Health policy should also be informed by these guidelines to positively contribute to sustainable development goals.

Abbreviations

LMIC: low to medium income countries; HIC: high income countries; SDG: Sustainable Development Goals; MDG: Millennium Development Goals; mHealth: mobile health; GIS: Geographic information

systems; RoadMApp: Road Mobile Application; SQL: Structured Query Language; ANC: Antenatal care; UN: United Nations; FGDs: Focus Group Discussions, CHW: community health workers.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

NN conceived and designed the guidelines, as well as drafting the first version of the manuscript. All authors contributed in findings and read and approved the final draft.

References

1. Nunes AR, Lee K, Riordan TO, "The importance of an integrating framework for achieving the Sustainable Development Goals: the example of health and well-being," 2016.
2. Novillo-Ortiz D, De Fátima H, Marin, Saigí-Rubió F. The role of digital health in supporting the achievement of the Sustainable Development Goals (SDGs). *Int J Med Inform.* 2018;114:106–7.
3. Factors Influencing the Accessibility of Maternal Health Service in Cambodia

- Hwang WJ, Park YM. "Factors Influencing the Accessibility of Maternal Health Service in Cambodia," 2020.
4. Makanga PT, et al., "Seasonal variation in geographical access to maternal health services in regions of southern Mozambique," *Int. J. Health Geogr.*, vol. 16, no. 1, 2017.
 5. Organization WH, "mHealth, use of appropriate digital technologies for public health.," *Seventy-first World Heal. Assem. - Provisional agenda item 12.4*, vol. 28, no. March, p. 26 March, 2018.
 6. Kahn JG, Yang JS, S KJ. 'Mobile' Health Needs and Opportunities in Developing Countries. *Health Aff.* 2005;2(1):699–706.
 7. Intelligence GSMA, "The Mobile Economy Sub-Saharan Africa," London, 2019.
 8. Bank W. "DIGITAL DIVIDENDS," 2016.
 9. Qureshi SS, Afzali FM, "Role of Mobile Phone Penetration and the Health Index in Human Development," no. November, pp. 0–10, 2017.
 10. Boulos MNK, Anastasiou A, "Geo-enabled technologies for independent living: Examples from four European projects Author ' s final version as accepted in September 2010 for publication in : Journal : Technology and Disability Publisher : IOS Press Volume 23, Number 1 / 2011 Pages," *Technol. Disabil.*, vol. 23, no. January, pp. 7–17, 2011.
 11. Boulos MNK, et al., "CAALYX: a new generation of location-based services in healthcare," vol. 6, pp. 1–6, 2007.
 12. Working Group on Planning (GTplan). "Spatial Data Infrastructure (SDI) Manual for the Americas," 2013.
 13. Dykes PC, et al., "Participatory Design and Development of a Patient-centered Toolkit to Engage Hospitalized Patients and Care Partners in their Plan of Care," *AMIA Annu. Symp. Proc.*, vol. 2014, no. 8, pp. 486–495, 2014.
 14. Arskey H, O'Malley L. Scoping Studies: Towards a Methodological Framework. *Int J Soc Res Methodol Theory Pract.* 2005;22(1):29–49.
 15. Devogele T, Géographique I, Cogit N, Saint Mandé F, Parent C, Spaccapietra S. "O n s p a t i a l d a t a b a s e i n t e g r a t i o n," vol. 12, no. 3, pp. 1–20, 1998.
 16. Makanga PT, Schuurman N, Sacooc C, Boene H, von Dadelszen P, Firoz T. Guidelines for creating framework data for GIS analysis in low- and middle-income countries. *Can Geogr.* 2016;60(3):320–32.
 17. Maina J, et al. A spatial database of health facilities managed by the public health sector in sub Saharan Africa. *Sci data.* 2019;6(1):134.
 18. "QUALITY ANALYSIS OF OPEN STREET MAP DATA
Ming W, Qingquan LI, Qingwu HU, Meng Z. "QUALITY ANALYSIS OF OPEN STREET MAP DATA," *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.*, vol. XL, no. June, pp. 155–158, 2013.
 19. See L, et al. Crowdsourcing, Citizen Science or Volunteered Geographic Information ? The Current State of Crowdsourced Geographic Information. *Int J Geo-Information.* 2016;5(55):23.

20. Mokgalaka H, "Measuring Access to Primary Health Care: Use of a GIS-Based Accessibility Analysis," in *Planning Africa 2014 Conference*, 2014, no. July.
21. Makanga PT, Schuurman N, Von Dadelszen P, Firoz T. A scoping review of geographic information systems in maternal health. *Int J Gynecol Obstet*. 2016;134(1):13–7.
22. Ebener S, et al., "The geography of maternal and newborn health: the state of the art," ???, 2015.
23. Data H, et al., *Health Data in the Information Age*. 1994.
24. Baynon-Davies P. Database systems. 3rd ed. New York: Palgrave Macmillan; 2004.
25. Baktha K. "Mobile Application Development: All the Steps and Guidelines for Successful Creation of Mobile App : Case Study," vol. 6, no. 9, pp. 15–20, 2017.
26. Agile vs. Traditional," no. December
"Software Development
Stoica M, Mircea M, Ghilic-micu B. "Software Development: Agile vs. Traditional," no. December, 2013.
27. Abrahamsson P, Salo O, Ronkainen J, Warsta J. Agile software development methods: Review and analysis. *VTT Publ*. 2002;no. 478:3–107.
28. Rajput GS, Litoriya R. "Corad Agile Method for Agile Software Cost Estimation," pp. 1–13, 2014.
29. Amen BM, Mahmood SM, Lu J. "Mobile Application Testing Matrix and Challenges," 2015, pp. 27–40.
30. Organisation PAmericanH, "Health in all Policies. From the Global to the Local," Washington DC, 2009.
31. Syed ST, Gerber BS, Sharp LK. Traveling Towards Disease: Transportation Barriers to Health Care Access. *J Community Heal*. 2013;38(5):976–93.
32. Artiga S, Hinton E. "Beyond Health Care: The Role of Social Determinants in Promoting Health and Health Equity | The Henry J. Kaiser Family Foundation," *Kaiser Family Foundation*, no. May. 2018.
33. Olstad DL, McIntyre L. Reconceptualising precision public health. *BMJ Open*. 2019;9(9):1–9.
34. Howitt P, et al. Technologies for global health. *Lancet*. 2012;380(9840):507–35.
35. Maguire M, Bevan N, "User requirements analysis: A review of supporting methods," in *Proceedings of IFIP 17th World Computer Congres*, 2002, no. August, pp. 133–148.

Figures

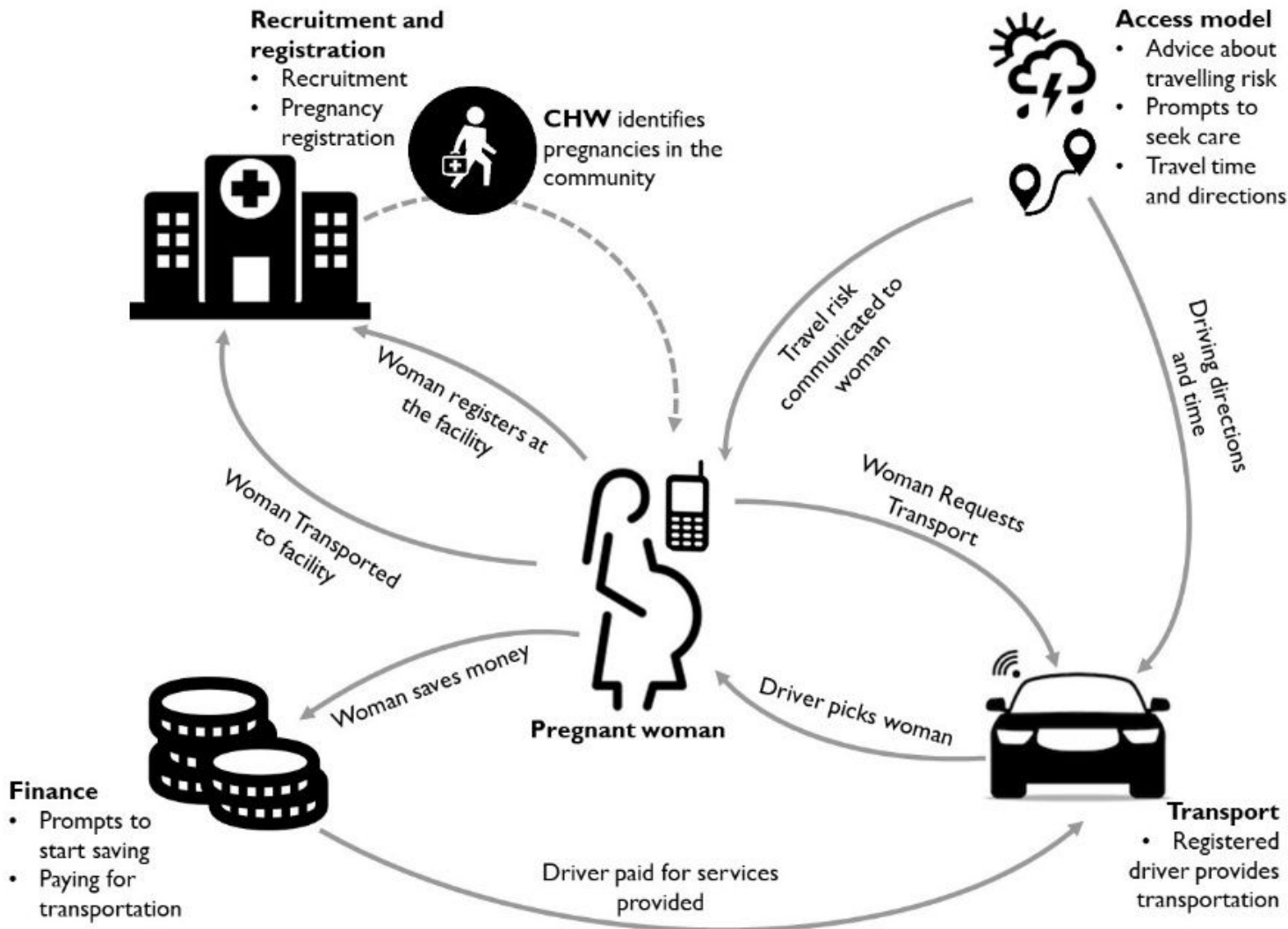


Figure 1

RoadMApp geo-enabled application development architecture.

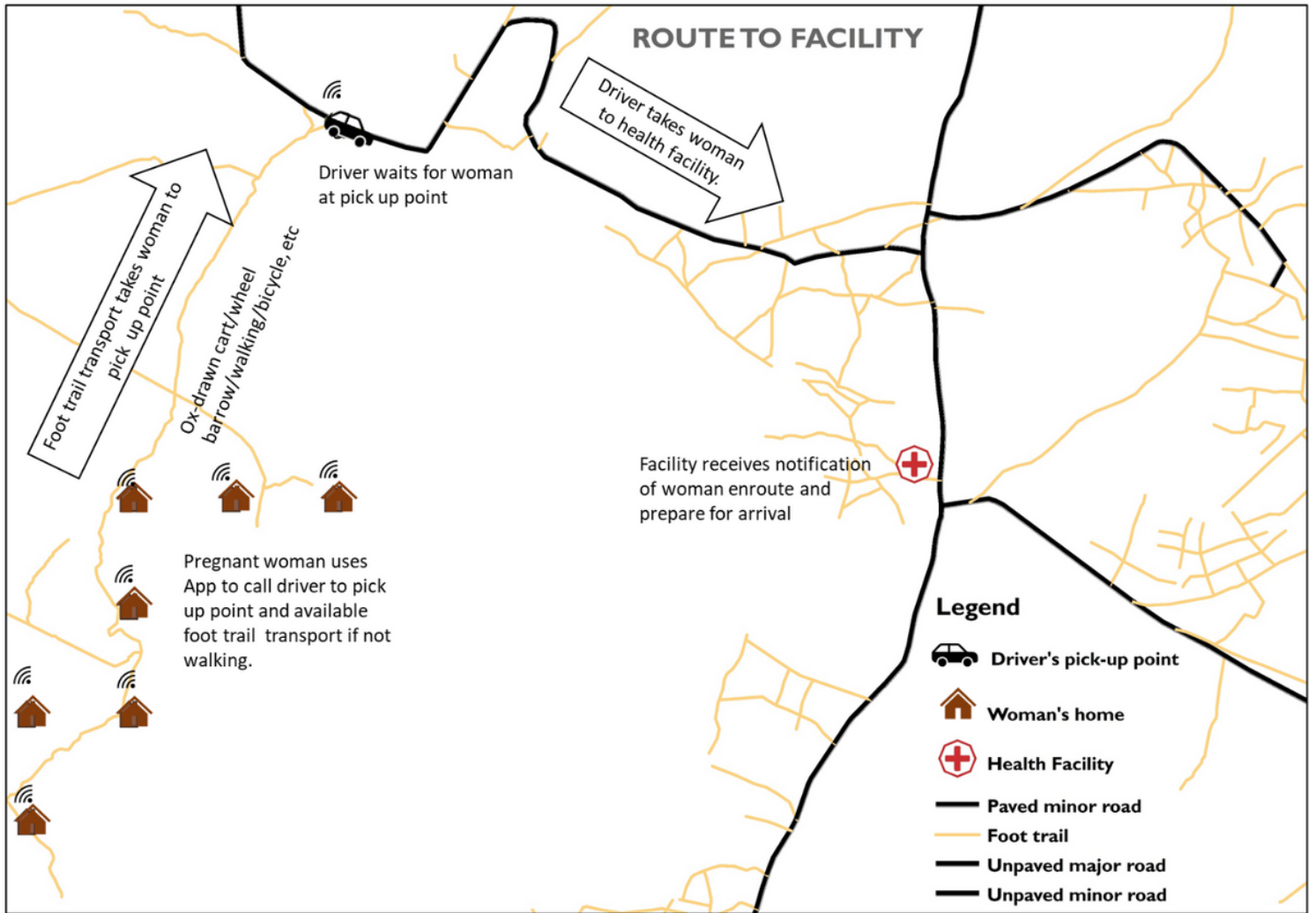


Figure 2

Visualisation of functioning of the combined transport systems.

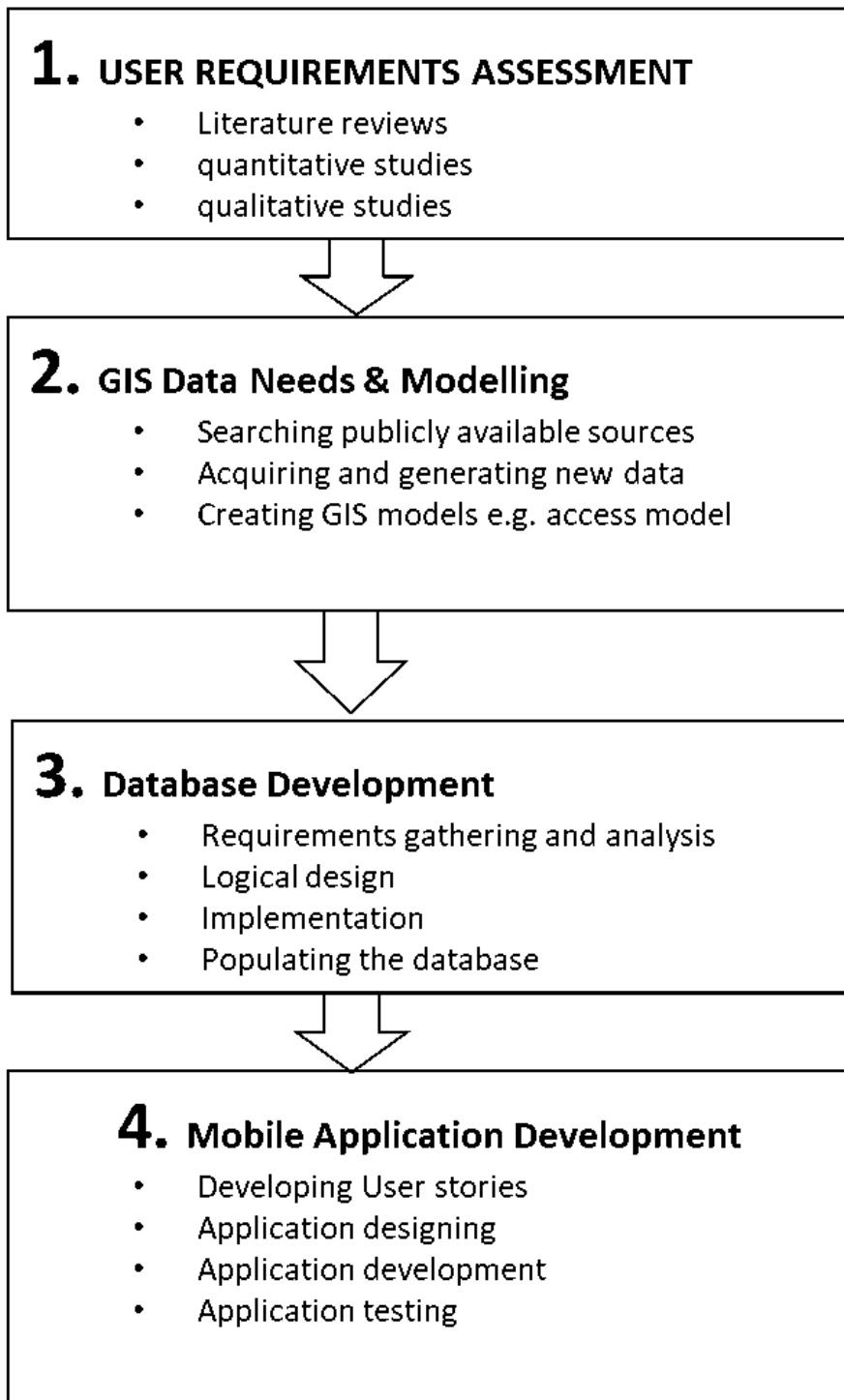


Figure 3

Proposed simple guidelines for creating location sensitive mobile applications.