

A CONCEPTUAL DATA MODEL FOR DISEASE SURVEILLANCE, MONITORING AND PREDICTION IN NIGERIA

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Abstract: Despite the fact that Sub-Saharan Africa is a region characterised by high rates of several deadly diseases, there is relatively little consistent or reliable data that can be used for surveillance, monitoring and management of these diseases in the region. In order to alleviate the problem of patchy and inconsistent epidemiological data, a well structured, interoperable spatial data model for diseases surveillance and monitoring is proposed in this paper. The model is motivated by HIV/AIDS monitoring and prediction in Nigeria. We initially review some of the existing health data models which we modify and extend to develop a conceptual data model for disease surveillance, monitoring, management and, potentially, prediction. The data model captures information required for the development of diseases surveillance systems. The model is developed using the Unified Modelling Language and we aim to make the model an open standard in order to promote collaboration and encourage researchers in developing nations to contribute to the maintenance of the data model. The model will be implemented in XML, and will be applied to a system using service oriented architecture with a focus on HIV/AIDS surveillance and monitoring in Nigeria.

1 INTRODUCTION

Currently, there are almost no easily accessible, open data standards for disease surveillance, health monitoring and management in developing countries. In this paper, we describe a proposed data model for disease surveillance, monitoring, management and prediction for Nigeria, a country which has high incidences of diseases such as Human Immunodeficiency Virus/Acquired Immuno-deficiency Syndrome (HIV/AIDS), malaria, tuberculosis, etc. It is designed such that it can be adopted by any country within sub-Saharan Africa. Indeed it has the potential to be used globally.

HIV/AIDS has been a destructive epidemic and threatens to continue to create health, social, economic and developmental problems for developing nations. This incurable disease is one of the major causes of poverty in Africa, which, with around 10% of the world's population has over 75% of the people living with HIV/AIDS (UNAIDS,

2004), and 72% of the world's mortalities from HIV/AIDS. An estimated 2.8 million Africans became infected with HIV in 2006 alone - more than all other regions of the world (UNAIDS, 2007). Since the first case of HIV/AIDS in Nigeria was reported in 1986, the prevalence rate has increased steadily from 3.8% in 1991 to 5.8% in 2001 (Pyke and Ali-Akpajiak, 2003) with a slight decline to 4.4% in 2007. Despite the decline, Nigeria still has the largest HIV/AIDS epidemic in sub-Saharan Africa. According to latest statistics on HIV/AIDS, Nigeria, now ranks second in the world with disease counts of over 3.0 million (UNAIDS, 2007) and almost half a million annual deaths (Adegoke, 2008). Some Nigerian states have a prevalence rate as high as 10% (Federal Ministry of Health Nigeria, 2006; Utulu & Lawoyin, 2007) but epidemiological data is patchy and inconsistent (Lawoyin & Adewole, 2004).

Coping with recent HIV/AIDS increases in Nigeria is consuming a large portion of the national health budget, and threatens the health sector (FMH and NACA, 2002). In 2000, Nigeria overall health care system performance was ranked 187th out of

the 191 World Health Organisation (WHO) member states (WHO, 2000) and this shows that the Nigerian health care system is weak. ICT facilities such as email, Internet, and electronic surveillance systems are vital for healthcare management and exchange of information. ICT has been identified as the backbone of health services to prevent, diagnose and monitor diseases (WHO, 2004) and reduce the cost of running hospitals (Remlex, 2007). However, there is almost no existing ICT infrastructure in any Nigerian hospital. The country faces a number of obstacles in the use of ICT and its implementation in the health sector, including an 'epileptic' electric power supply, inadequate telecommunication system, high cost of ICT equipment and the lack of reliable Internet facilities (Idowu et al, 2008).

The control of any disease, in any country, requires that the spatial and temporal rates and trends of the disease must be determined. This information will assist public health officials and stakeholders to determine the locations and areas on which to focus their attention (Myers et al, 2000). In Nigeria at present, there is neither an electronic surveillance system nor any electronic national database for disease monitoring. As in most other African nations, the monitoring and surveillance of disease especially HIV/AIDS in Nigeria is limited to biennial sentinel surveys at less than 100 sites which focus on pregnant women between the ages 15 to 49 years attending antenatal clinics in health facilities across the country (FMOH, 2006). The absence of a reliable national database on HIV/AIDS compounds the challenges facing the management of HIV/AIDS in the country (USAID, 2002).

There is therefore a need for an effective and efficient spatio-temporal health data model which can be used as a guide for the systematic capture of health related data, to provide the impetus for the development of a national database that can be used in the monitoring and management of disease, especially HIV/AIDS in Nigeria. This is the focus of this paper.

2 SCOPE OF DATA MODEL

A central requirement within any disease surveillance system is the effective management of patient information, diseases and location, for which a good data model is imperative in order to capture useful information. The immediate scope of the data model is to:

- identify different types of information needed for disease surveillance activities and the

corresponding entities

- represent and document the information required for disease surveillance activities and entities
- develop a formal Unified Modelling Language (UML) description to show the relationship and association between the entities
- provide enhanced support for flexible spatial and spatio-temporal data

The future scope is to develop a disease surveillance database system from the data model that will allow easy query of pattern and distribution of diseases based on geographical location such as city/town, local government area and states and to make the model open standard so as to encourage other researchers to contribute, use, modify and extend the system in order to have a standard disease surveillance model for sub-Saharan Africa.

To achieve the immediate intention of the model, we hope to build on existing data models that are relevant to diseases surveillance and introduce enhanced spatial support into the model. The model is developed in UML, with the intention to automate the generation of the XML schema, allowing easier maintenance of the data model. An interesting issue is the governance model for the data model. In the Geospatial domain a strong governance mechanism is provided by the Open Geospatial Consortium, however in the health field it is less clear.

3 REVIEW OF EXISTING DATA MODELS

A data model may be defined as a formal structured representation of real world entities, focused on the definition of an object and its associated attributes (BIS, 2004). There are a number of existing health data models such as EHR (Electronic Health Record) and openEHR (Open Electronic Health Record), DICOM (Digital Imaging and Communication in Medicine); and Health Level 7 (HL7). Some of the models however, are not without problems: both EHR and open EHR are still not fully developed though EHR has made a significant contribution to health data models by introducing archetypes. DICOM, though fully developed, focuses on medical imaging which is out of context of the proposed data model. HL7 is also fully developed and widely used by many vendors. HL7 is an extensive, comprehensive data model that focuses on general health care system, with a unique specification of messages between health care

application systems. The HL7 messaging protocol is widely adopted and implemented by several health data models. Several health data models have built parts of their model on HL7 not only because of the messaging protocol, but because it is a widely recognised and supported standard and many commercial software vendors actively orient their product development efforts to this model. In addition, most international health data model development organisations are using HL7 to harmonize their standards effort. Two particularly relevant data models built on HL7 are the Public Health Conceptual Data Model and the Canadian Conceptual Health Data Model which are reviewed in the following section.

3.1 Summary of Existing Health Data Models

In this section we present a summary of our review based on scope, strengths and limitations of the most relevant data models. The Public Health Conceptual Data Model (PHCDM) focuses on data needs for public health at all levels generally, while Canadian Conceptual Data Model (CHDM) focuses on data concepts that must be captured to meet the needs of key stakeholders in the Canadian health system. The two models develop conceptual models to encapsulate the data needs of the health activities they represent. PHCDM aims to develop a high level process model that can be used in public health while the CHDM aims to develop a process to maintain and refine the Canadian model in order to influence international health data models.

The two models support interoperability but neither of the models is an open standard. CHDM incorporates governance data which allows the building of mechanisms to support accountability for the use of data and for the processes that use the data. CHDM does not include relationships and associations between the entities in the model nor does the specification discuss details of the attributes of the classes that make up the data model, in contrast to the PHCDM. The major inadequacy in the two models, with respect to our requirements is lack of formal support for spatial features. The major contribution of this proposed model to existing health data models is to provide a more structured representation of the spatio-temporal aspects of health data. We adopted, modified and extended the PHCDM because it is more relevant to our proposed model and focuses on public health systems and diseases surveillance.

3.2 Geography Markup Language

Geography Mark-up Language (GML) is an XML based language used to describe spatial and spatio-temporal objects (Lake et al, 2004). GML is an Open Geospatial Consortium (OGC) specification that defines an XML encoding for geographic information. GML is an international standard designed to represent common spatial features and describe spatial objects (including their geometry), map projections, topology, time, etc (OGC, 2007). It uses XML schema to define the geometry elements needed to encode the geographic features.

GML is used to allow the interoperable exchange of geographic data. It is mostly used in web feature services as a mechanism for interaction with a geospatial database (that is to send features between servers and clients). In this work we employ GML to provide the spatial embedding of the data. The use of GML facilitates easy use of the data in a GIS system, making the data more easily interoperable with existing web GIS models. We note that in this work we do not propose our model as a GML application schema, since the primary issue we wish to capture in the model is the health data, however it seems likely that such an application schema would have a potentially large impact, and allow much easier interoperability with existing GIS systems. The existing data model would require quite significant revision to formulate as a GML application schema.

4 THE PROPOSED MODEL

A conceptual data model gives the representation of the real world phenomena in the context of a database. The conceptual data model is designed to describe relevant features and attributes of the information, the methods from the user perspective that will be stored in the database. The success of any information system based project depends on efficiency and effectiveness of conceptual data model. There are different approaches that can be used in developing conceptual data model including semantic, entity relationship, and object oriented approaches. In our model, we use an object oriented approach encoding entities and relationships in the domain. The main advantage of an object oriented approach is that it allows representation and definition of objects which provides a clearer understanding of the conceptual data model. It also allows easy representation of spatial information. The formal language of the object oriented design is

typically UML (Hay, 1999).

4.1 Modelling using UML

UML is a standard, graphical language for object modeling. UML is a general-purpose tool and industry standard modelling language for specifying, visualizing and documenting the artifacts of a system intensive process. It offers standard methods to create data models, database schemas, and reusable software components amongst other things. UML is used to develop the proposed data model for diseases surveillance and monitoring in Nigeria.

4.2 Core Components

This model comprises of a number of classes and the classes are grouped into three core components or subject areas namely party, location and health activity. These core components deal with health activities, parties that are involved in the health activities and the location where the parties reside and health activity takes place. The core components of the model are discussed below.

4.2.1 Party

This contains information about a person, groups and any features that are of interest to the health system. Examples of parties include physicians, epidemiologists, public health workers, hospitals, laboratories, patients, association of laboratory scientists, people living with HIV/AIDS. All these

interact within the health system. The party component of the model also captures information about relationship within the parties. For example, physicians employed in a particular hospital, laboratory scientists in a particular hospital receiving treatment in another hospital or the same hospital or group of sex workers being counsel by public health officers. It may also represent public health workers telling people in a particular location how to prevent disease in their locality. The classes that form the party component of the model are shown in Figure 1.

4.2.2 Health Activity

A health activity is the provision of a specific health service to a health service recipient by a service provider at a given place during a particular period of time. It often intends to affect, or report on, the health of a person or group. A health activity component contains information about all the activities that occur between patient and health provider. The core health activities in this data model include observation, diagnosis, laboratory test, treatment, (which may result in admission or referral) and intervention. For example, it can capture information on how a patient is diagnosed by a physician with a blood or urine sample. Intervention which is a means of preventing diseases or providing care is also part of the model. Intervention includes educational and media campaigns about the spread of diseases and how to prevent this. For example, the distribution of

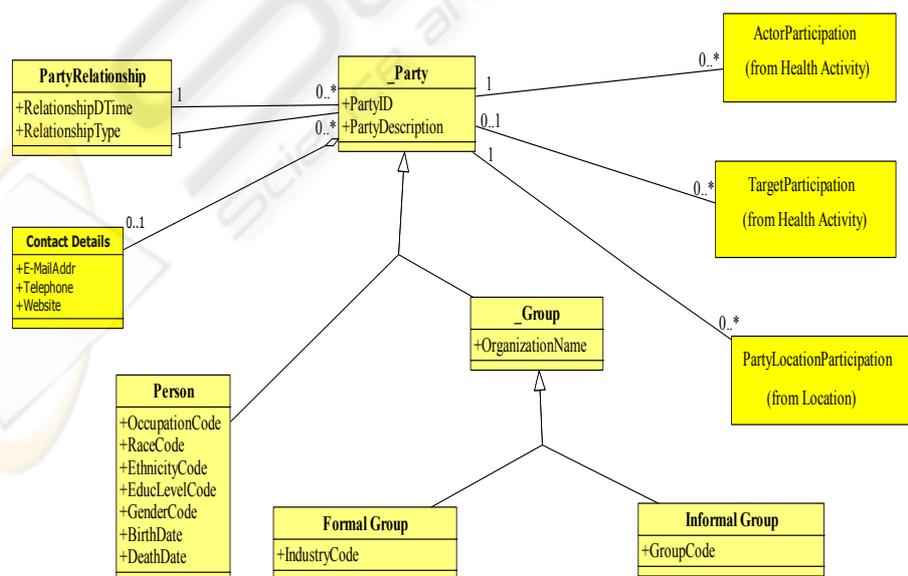


Figure 1: The party component of the data model. Classes begin with an underscore represent abstract classes.

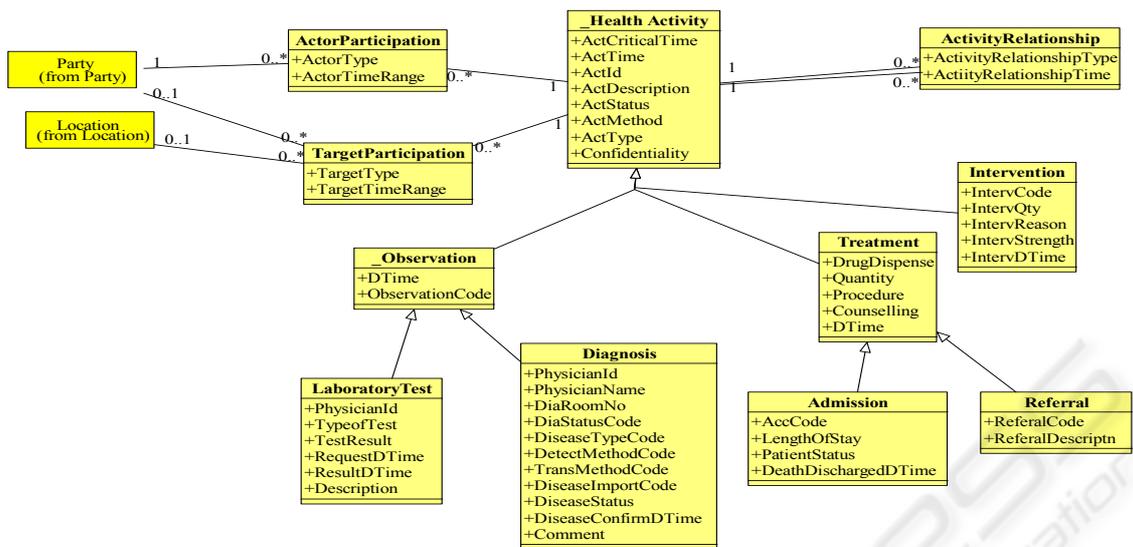


Figure 2: The health activity component of the data model.

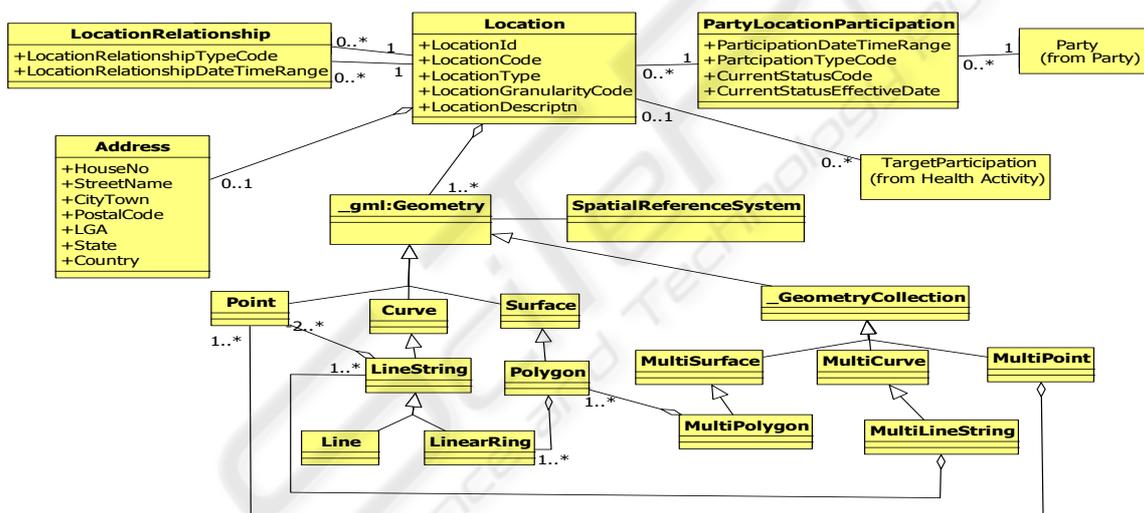


Figure 3: The location component of the data model.

condoms by public health workers or diseases agencies among some groups of people (such as sex workers, bus drivers, etc) and encouraging them to avoid unprotected sex can be represented as a health activity.

4.2.3 Location

The location component contains information about the addresses and spatial positions associated with the other two core components (Party and Health Activity). Figure 3 below shows different types of geometry that can be used to represent location in the model. Location may be used to represent the

position of a range of parties and activities including, for example, hospitals, buildings, cities, or local government areas where patients reside. Address (which contains information such as House No, Street Name, City/Town, Postal Code, logical government area, etc) and geometry are aggregated to location. Geometry is represented using the GML abstract geometry base element, which is substitutable for a wide range of geometry types and will allow easy query of diseases based on geographical location.

4.3 Structure Of The Model

In our proposed model, we adopt, modify and extend PHCDM as it is applicable to the need of diseases surveillance in order to represent the data needs of diseases surveillance.

Figure 1 above depicts party component which provides information about data required in party component. Party component contains information about person and group. In order to provide useful information for the database designer, it is important to provide information about what to be stored within the party component. Party components store information about persons, groups, and, contact details. A person include patient, physician, diseases agent and person may be a member of more than one group without necessarily knowing. For example, a physician that just contacted AIDS and contact details are aggregated to party in order to provide more information about the parties such as website address, e-mail address and telephone number. Patients, physicians, hospitals, group of people may have website that provide more information about them and or their interest, for example National Agency for the Control of AIDS in Nigeria (www.naca.gov.ng).

The group party represents formal and informal organization; it is formal when the group has an administrative and functional structure with common objectives such as Association of Midwives, Nigeria Association of Resident Doctors. It is informal group when the group is casual such as group of sex workers.

In health activity of our model, classes like notification or outbreak are not included as in PHCDM because the model aims to be used by diseases agent to query the pattern and distribution of a particular disease based on spatial location and other demographic data. So, there is no need to notify any party about any disease, the stakeholder will fetch necessary data about any disease from database. Diagnosis, laboratory report and treatment are included in our model since we focus on diseases surveillance and it will assist the stakeholders to know the type of disease that is prevalent in a particular location, at a particular period of time. For example, a particular location may be prone to a particular disease in a particular time of the year such as case of malaria during raining session.

Location is an important component in any disease surveillance system because the occurrence of any diseases will be based on location and the stakeholders will query the diseases surveillance database based on location so as to know the pattern

and distribution of any diseases and where intervention is needed. Location component of this model is unique as shown in Figure 3 compared with location in PHCDM or any other health data models because a spatial feature is included and aggregated to location.

In order to show the relationship between the three core classes or components, we use class relationship methods so as to give clear understanding of the model and the methods are super class/sub class relationship, relationship association and participation association.

Super class is a class from which other classes are derived. It is also known as parent class and sub class inherit from super class. The three core components in the model have super class and the sub class associated with them. The relationship association is used in the model to show the relationship between the super class and the sub class. The symbols 1, 0..1 and 0..* on the association line shows the multiplicity of the association between the main class and relationship class. A single health activity may be associated with zero or more activity relationship relating it to another health activity. For example diagnosis of chronic typhoid fever in a particular patient may lead to admission of such patient.

The participation association is used to show the relationship between the main classes. Each of the main classes has a many to many relationship to other main classes and each of the class has attributes that describe data items that can be collected for a given class in the model. For example roles play by physician in diagnosis HIV/AIDS and role play by public health workers in distribution of condom.

In the model, we use party relationship, actor participation, target participation, party location participation, activity relationship, and location relationship to describe relationship between the components.

Party relationship gives information about the relationship that exists between parties in the health activity. Example of party relationship includes a relationship between health worker and patient, health organization and a particular community, disease agency and people living with a particular disease such as relationship between National Agency for the Control of AIDS (NACA) and Network of People Living With AIDS in Nigeria (NEPWHAN).

Actor participation is the major roles played by a party in health activity. Examples include roles played by a physician in order to diagnose a

particular disease, or role played by NACA to distribute condom to hotels in Nigeria. Target participation on the other hand is the minor roles played by a party in health activity. For example, if a person identified as a potential carrier of a disease (which is a target) is unable to speak or express himself/herself to a physician probably because of language barrier, or the intensity of the illness or is an infant, the person that speak for the potential carrier (may be interpreter, parent or relative) is an activity target.

Party location participation shows the relationship between a location and a party. For example, a hospital may have different health facilities such as laboratories, consultation room, female ward, etc. It may also be diseases agency that have offices in all the states within the country. The participation role would be that of the disease agency that have office at a particular location.

Activity relationship is the relationship between health activities, for example relationship between observation and diagnosis, relationship between diagnosis and treatment. Location relationship deals with the relationship that exists between locations and this relationship is important in diseases surveillance. For example, relationship between ward and operation room, or relationship between X ray room and consultation room.

In addition, the model makes use of codes in order to allow extensibility and flexibility. Codes are alternative to using free text to describe an attribute or features of a class. The use of code facilitates data validation by the system when entered by the users. Codes are used to allow each of the classes to be more useful by allowing the class to have type codes instead of defining new class for minor differences in the properties of party, health activity or location.

4.4 Model Discussion

The purpose of this model is to document the information needs of an information system for effective diseases surveillance, monitoring, management and prediction.

In the location component of this data model of which we are aware that explicitly supports geometry which is represented using the widely accepted, open GML standard. The GML representation of the hospitals and party features allows different geometries such as points, curves, surfaces and geometry collections which provides flexibility of encoding.

With GML, user can query a point of interest on a map in order to ascertain the pattern and

distribution of HIV/AIDS in the vicinity of that location. A Web Feature Server could also be used query to fetch the name of locations which has more than certain prevalent rate for a particular disease, for example, to fetch the name of state(s) with more than 5% prevalent rate for HIV/AIDS.

This proposed data model will aid in capturing comprehensive information about diseases, carriers of the disease and their location. The model will assist in developing an understanding of the basic data required within the health care system in order to build disease surveillance systems to aid effective management, monitoring and surveillance of diseases. It will assist the country to have a good and reliable epidemiological data and increase the efficiency of health record unit and this will help the health policy maker in making favourable health policies and decision. The model in future may give birth to electronic health record which will eventually increase the confidentiality and security of health record.

This data model will be used to develop a prototype system which aims to allow users to spatially query and view data on any diseases in order to ascertain the patterns, distribution and prevalent rate of any disease such as HIV/AIDS, malaria, tuberculosis, etc in any location in Nigeria. When the system is developed, users will be able to click on particular point or select a polygon on the map and the features of the point or polygon such as the name of the state(s), population at risk and prevalence rates will be displayed. The prototype will use aggregated data and focus on HIV/AIDS because it is only aggregated HIV/AIDS data based on state level that is currently available for this research.

It is hoped that in the future when the diseases surveillance system is fully developed, the physicians in the hospitals will input patient information such as demographic data, diseases associated with each patient and information about geographical location of each patient into the system so that epidemiologists, disease agents, policy makers, and any other authorised users will be able to query, analyse, view, predict and generate diseases information based on street, town/city, local government area, year, population at risk, total number of cases, prevalence rate, sex, marital status, educational status and age distribution of disease carriers in the country.

This system will hopefully aid effective and efficient intervention in outbreaks of any disease, which eventually will improve the population health and reduce the expense on health service provision.

This will also reduce poverty, which has characterised the sub-Saharan Africa region. Also, the system will serve as a means to regularly publish the patterns and distributions of diseases such as HIV/AIDS, malaria, etc down to street, town/city, local government, and state levels and produce weekly, monthly, bi annual and annual reports as the case may be on any disease for the use of researchers, policy makers and stakeholders in hard copy and on the Internet as against the report which is published every two years and which only focuses on sentinel survey in selected centres across the country.

The process of developing the prototype will be completely based on open standards, and the future diseases surveillance system is aimed to be fully open standard, and open source, so that researchers and anyone interested in developing, using and evaluating the system will be able to do so at minimal cost.

5 CONCLUSIONS

This conceptual data model will aid the development of national database which can be used in management, monitoring and surveillance of diseases in Nigeria. The model constitutes a basic pattern for the design of database structure for disease surveillance that can be queried easily. The physical implementation of the data model using PostgreSQL will be discussed in the future.

We hope that the proposed model will form the basis for the collaboration among researchers interested in developing health standards for developing nations and serve as a guide for development of a standard health data model, diseases surveillance system, and electronic health record in Nigeria and sub-Saharan Africa as a whole.

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REFERENCES

Adegoke, R., 2008. HIV/AIDS Killed 400,000 in 2007. Nigeria Tribune (online), Available from <http://www.tribune.com.ng/22042008/news/news10.html>

(Accessed 22 April, 2008)

Business Intelligence Solution, 2004. Data Model, Data Standards and XML, January 2004. Available from <http://www.knowledge-integrity.com/columns/bi2004-01.htm>, (Accessed on June 12, 2008).

Federal Ministry of Health Nigeria, 2006. The 2005 National HIV seroprevalence sentinel survey among pregnant women attending antenatal clinics in Nigeria: summary position paper, Abuja.

FMH and NACA, 2002. HIV/AIDS: What it means for Nigeria (Background, Projections, Impact, Interventions, and Policy) 1st Edition.

Hay, David C. 1999., *A Comparison of Data Modelling Techniques*, Essential Strategies, Inc

Idowu, P. Cornford D. and Bastin L., 2008. Health Informatics Deployment in Nigeria. *Journal of Health Informatics in developing Countries*, 2(1) p.20-21.

Lawoyin T., and Adewole D., 2004. Predictors of maternal HIV/infection at the primary care level in inner city Ibadan. *International Journal of STD and AIDS*, 15(3) p.165-168

Myers M. F., Rogers, D. J., Cox J., Flahault A. and Hay S. I. 2000. Forecasting Diseases Risk for Increased Epidemic Preparedness in Public Health. *Advances in Parasitology* 47 p. 309-330

Open Geospatial Consortium (2007): OpensGIS, Geography Markup Language (GML) Encoding Standard. Available from http://portal.opengeospatial.org/modules/admin/license_agreement.php?suppress_headers=0&access_license_id=3&target=http://portal.opengeospatial.org/files/index.php?artifact_id=20509 (Accessed June 12, 2008)

Pyke T. and Ali-Akpajiak S., 2003. *Measuring Poverty in Nigeria*, Oxfam, Oxfam Working Papers.

Remlex O., 2007. Information and Communication Technology in chronic diseases care. *Medical Care Research and Review*, 64(2) p 123-147.

UNAIDS 2004. *Report on the Global AIDS Epidemic*. Geneva.

UNAIDS 2007. *AIDS Epidemic Update: December 2007*. UNAIDS/07.27E/JC1322E, Geneva.

USAIDS, 2002. HIV/AIDS in Nigeria: A USAIDS brief. Available from <http://www.aegis.com/files/synergiaids/nigeria.pdf> (Accessed 7 June 2008)

Utulu S, and Lawoyin T., 2007. Epidemiological features of HIV infection among pregnant women in Makurdi, Benue State, Nigeria. *Journal of Biosocial Science*, 39(3), p.297-408.

WHO, 2000. World Health Report Geneva.

WHO, 2004. eHealth for health-care Delivery: Strategy 2004-2007. Geneva. Available from <http://www.who.int/eht/en/Backbone.pdf> (Accessed 7 June, 2008)