Using Data Analytics to Strengthen Monitoring and Surveillance of Routine Immunization Coverage for Children under One Year in Uganda

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Abstract: Immunization coverage is a traditional key performance indicator that enables stakeholders to monitor child health, investigate gaps, and take remedial actions. It is continuously challenged by validity due to the neglect of unstructured data and process indicators that track small changes/milestones. While empirical evidence indicates digitalized immunization systems establish coverage from structured data, renowned administrative and household survey estimates are often inaccurate/untimely. Government instituted awareness, accessibility, and results-based performance approaches, but stakeholders are challenged by accurate monitoring of performance against Global Vaccination Action Plan coverage targets. This heightens inappropriate strategy implementation leading to persistent low coverage and declining trends. There is scanty literature substantiating the essence of comprehensive immunization indicators in monitoring evidence-based and timely interventions. For this reason, health workers failed to appreciate immunization process indicators and monitoring role. The study aims at developing a real-time immunization coverage monitoring framework that supports evidence-based strategy implementation using prescriptive analytics. The envisaged artifact analyzes a variety of data and monitors immunization performance against comprehensive indicators. It is a less resource-demanding strategy that prompts accurate and real-time insights to support intervention implementation decisions. This study will follow an explanatory research approach by first collecting quantitative data and later qualitative for in-depth analysis.

1 INTRODUCTION

Strong evidence indicates that big data analytics have a positive impact on organization performance (Bogdan and Borza, 2019), decision enhancing, and agility gains (Ghasemaghaei, et al., 2017). In healthcare, big data refers to structured, semi-structured, and unstructured electronic health data sets that are complex and difficult to manage with classical software, data management tools, or internet-based platforms. (Raghupathi and Raghupathi, 2014; Dash et al., 2019). The healthcare industry generates enormous data, scaling from clinical decisions, patient-care, compliance, and regulatory requirements (SoleimaniRoozbahani, et al., 2019; Liang and Kelemen, 2016). The United States health system alone by 2011 had generated 150 exabytes soon reaching yottabyte (Raghupathi and Raghupathi, 2014; SoleimaniRoozbahani et al., 2019). A substantial amount of data in the health industry are stored in hard copy form, however, rapid data digitization trend, for example, Digital Health Management System (DHIS2) in Uganda, Electronic Immunization Registries (EIR) piloted in Zambia, Tanzania (Dolan, et al., 2020; Villagereach, 2020), Immunization Information Systems (IIS) in Mexico (Derrough, et al,, 2017), and Online Real-Time Immunization System (OTRIS) among others, generate volumes of data that can facilitate extracting useful insights to support decision making for efficient operations. Big data in healthcare is overwhelming not only because of its volume but also because of the diversity of data types and speed at which it must be managed (Dash et al., 2019; Palanisamy and Thirunavukarasu, 2017).

In public health, big data encompasses patient information gathered from electronic health records and participatory surveillance systems, as well as mining of digital traces like social media and internet

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searches (Bansal et al., 2016). Driven by the potential to improve quality of healthcare delivery while reducing costs, these massive quantities of data hold the promise of supporting a wide range of healthcare functions such as clinical decisions, gaining valuable insights in monitoring and surveillance of disease prevention strategies like immunization. (SoleimaniRoozbahani et al., 2019).

Immunization is a cost-effective public health intervention guaranteeing the safety of children against preventable diseases and a right for every child (Karami et al., 2019; Wariri et al., 2019). It has numerous activities grouped into service delivery, programme management, surveillance and monitoring, advocacy and communication, vaccine supply, quality and logistics components (WHO/IVB/08.05, 2008). Immunization deters 2–3 million deaths yearly and an additional 1.5 million could be avoided if immunization coverage is improved worldwide (Bhatti, et al., 2017).

Immunization coverage (IC) is a cornerstone of Primary Health Care and a key immunization programme performance indicator that shows how far a country is from preventable disease outbreaks (Roux, et al., 2017; Derrough, et al., 2017). Coverage is calculated as the percentage of persons in the target age group who received a particular vaccine dose by a specified age and is globally the most closely followed indicator annually tracked (Sodha & Dietz, 2015). Indicators like the third dose of diphtheria-tetanus-pertussis (DTP3) coverage is used to measure the strength & reach of routine immunization (RI) (Mihigo et al., 2016). RI ensures that children below one year receive recommended vaccination on time, at the right age, in accordance to the recommended schedule by age, gender and with ease of access to the point of vaccination (MOH-UG, 2017).

It is important to note that, the 194 GVAP member states including Uganda have instituted accessibility and awareness strategies like free immunization, outreaches, traditional leader engagement, mass campaigns among others to increase IC (Bhatti, et al., 2017; Malande, et al., 2019). Additionally, development partners like GAVI, global fund, master card, Orange, have subsidized vaccine costs and supported private health facilities to ease community service accessibility (Villagereach, 2020). Similarly, technological strategies like IIS monitor vaccine coverage and effectiveness (Derrough, et al., 2017); EIR are capable of child enrolment at birth, unique identifition, structured data aggregation, among others (Dolan, et al., 2020; Villagereach, 2020).

However**,** an estimated 19.7 million children under the age of one year never received basic vaccines according to the global immunization coverage 2019. Correspondingly, Uganda at 73% DPT3, 88% BCG (WHO/UNICEF, 2020) and 55% of fully immunized children coverage (MOH-UG, 2017) lag below the GVAP 90% national coverage target by 2020 (Mihigo et al., 2016). Awareness/accessibility strategies target caretakers while digital interventions known to reduce health worker data burden are a replicate of the current paper-based system (Dolan, et al., 2020; Villagereach, 2020) aggregating structured data only. Currently, government and development partners are concerned about Uganda's immunization declining trends (WHO/UNICEF, 2020) as illustrated.

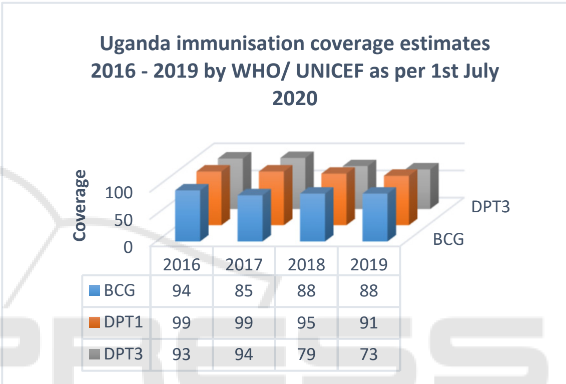

Figure 1: Current immunization coverage estimates.

The achieved IC gains were reversed due to reported high infant mortality rate attributed to Vaccine-Preventable Diseases -VPD (MOH-UG, 2017) and sporadic measles and rubella 2018 outbreaks in 55 and 13 districts respectively (Opendi, 2018). In fact, 100% IC is still the target to avoid further mortality (Bhatti, et al., 2017) which is hard to achieve without constant monitoring.

Monitoring is a systematic and continuous process of examining data, procedures and practices to measure progress, identify problems, develop solutions, and guide policies. It is an important tool for mid-level managers to improve the quality of the immunization programme by ensuring that: (1) all infants are immunized; (2) vaccines and safe injection equipment are delivered in correct quantities and on time; (3) staff are well trained and adequately supervised; (4) information on disease incidence and adverse events following immunization (AEFI) are collected and analyzed, (5) community has confidence in the vaccines delivered and immunization service they receive (WHO/IVB/08.05, 2008).

African ministers collectively and individually committed themselves to monitor progress towards achieving the goal of the global and regional immunization plans having recognized that Africa despite the progress, was largely off track compared to the 2020 90% target (Desalegn, 2016). At national and subnational levels, monitoring and assessment of coverage rates are critical for countries to prioritize and customize strategies or operation plans to address immunization gaps and reach life-saving vaccine to every child (Dicko, 2020; Derrough, et al., 2017).

However, IC validity is continuously questionable as different tools report differing coverage for the same population and time (Liu, et al., 2017; Murray, et al., 2018). Known coverage determination methods of administrative overestimate or underestimate coverage while surveys are costly and provide untimely information to guide programmes (Sodha & Dietz, 2015. This is attributed to low-quality data. Surveillance and monitoring data is largely captured passively from structured DHMIS2. These traditional passive monthly reports do not capture much information on the advocacy and communication, and programme-management components of the immunization system (WHO/IVB/08.05, 2008. Active supervision like physical supportive visits is the instituted way to collect uncaptured data. It is known to increase reporting of measles, rubella, and hepatitis in demonstration projects but is generally too expensive to be performed routinely (Roush, 2017), notorious for severe time lags and challenged when aggregating variety of data (Bansal et al., 2016). WHO asserts that monitoring requires a combination of passive and active data collection measured against indicators.

"Additional indicators that describe immunization system functioning in real-time can provide managers with essential information to guide their actions for improving IC. Process indicators like a micro plan, supervision, outreach conducted among others have long been proposed but not highly valued by health personnel or promoted as useful tools for management" (USAID_MCSP, 2018). As the need for evidence-based policies grows, big data hold the key to rapid improvements to promote health/prevent disease (Gall and Suzuki, 2019).

A new era is dawning where monitoring/surveillance systems are strengthened by big-data streams, from legacy systems and non-traditional digital data sources, like social media (Bansal, et al., 2017). Big data analytics technologies and techniques can analyze large, diverse and dynamic data sets intended to enhance firm decision making/performance (Al-Shiakhli, 2019). They discover associations, understand patterns and trends within the data to improve care, save lives and lower costs (Raghupathi and Raghupathi, 2014). "The impact of big data in healthcare lies in identifying new data sources such as wearable devices in addition to the data in legacy sources". Coupling analytics and all data sources provide valuable insights for researchers to attain novel health care solutions (Palanisamy and Thirunavukarasu, 2017). Big data analytics is beneficial to public health by turning large amounts of data into actionable information that can be used to identify needs, provide services, predict and prevent crises especially for the benefit of populations (Raghupathi and Raghupathi, 2014). Big data analytics has been mainly used to predict (Heart Attack, Disease Outcome/Outbreak), on fewer occasions diagnosis and vaccine development. (Das et al., 2018). Using prescriptive analytics, Performance of public health intervention can be monitored in real-time.

"Prescriptive analytics includes functions as a decision support tool that explores a set of possible actions and suggests decision based on descriptive and predictive analysis of complex data" (Liang & Kelemen, 2016). Using tools like optimization, simulation, business rules, algorithms, and machine learning (Al-Shiakhli, 2019), prescriptive analysis conducts real-time analytics using point-of-care data to present immediate and actionable information to providers (Liang and Kelemen, 2016).

1.1 General Research Question

How can data analytics strengthen monitoring and surveillance of routine immunization coverage?

1.2 Research Questions

1. To what extent does data analytics influence immunization coverage validity?
2. How can big data analytics enhance comprehensive indicators monitoring?
3. What components must the immunization coverage monitoring framework have to support evidence strategy implementation?
4. How will the developed coverage monitoring framework be evaluated?

1.3 General Objective

To develop a real-time routine immunization coverage monitoring framework that supports evidence-based strategy implementation to improve coverage, uptake and completion of routine immunization.

1.4 Research Objectives

1. To establish the extent to which data analytics can influence immunization coverage validity.
2. To determine how big data analytics can enhance comprehensive indicators monitoring.
3. To design a real-time immunization coverage monitoring framework.
4. To evaluate the designed framework.

2 LITERATURE REVIEW

2.1 Immunization Data Quality

Immunisation programme performance management must be built on a foundation of accurate and complete data collection. Data checks and management are crucial to improving performance management, evaluation and form the basis of evidence-based advocacy to politicians and donors. (Stokes-Prindle et al., 2012). Poor quality and underuse of data remain a persistent problem, affecting the ability of countries and partners to monitor progress against the GVAP goals as well as supporting optimal changes to immunization programmes (SAGE, 2019). The lack of adequate skills in data collection, analysis, interpretation and use among health workers are key factors limiting the quality and use of data (SAGE, 2019).

In Uganda, vaccine dose administration data are often not available or low-quality to optimally plan, monitor, evaluate program performance (Ward, et al., 2017) and target missed populations (Carnahan, 2020). Optimal immunization coverage relies on high-quality immunization data, which are a prerequisite for effective and efficient public health action to improved population immunity against VPDs (Ward, et al., 2017; Nzaji, et al., 2019). Administrative IC estimates enable programme managers to monitor, investigate gaps and take remedial action. However, population denominator used in the computation is often inaccurate (Ward, et al., 2017).

In-accurate IC estimates are evident in many countries like; inflation in administrative coverage data in 2013 according to national data quality self-assessment (DQS) in Uganda attributed to sub-optimal data quality. Similarly, in Nigeria, administrative data were indicated as unreliable to accurately represent RI coverage levels hence difficulty to evaluate programme performance (Stokes-Prindle, et al., 2012). Overestimation and underestimation occur in rural and near urban areas districts respectively, therefore national coverage estimates may not accurately reflect the true situation (Wetherill, et al., 2017). In Democratic Republic of Congo over-reporting on the administration of third-dose of the pentavalent vaccine was identified in Tshiaba, Mukeba and Ditalala and measles antigen in Tshiaba and Tshibombo health facilities, while under-reporting was evident in Ditalala and Mukeba (Nzaji, et al., 2019). Surveys that never depend on census population as dominator are known to be more reliable. However, they are costly and provide untimely (after 3-4 years) information to guide programmes (Sodha and Dietz, 2015; Cutts et al., 2016). Unreliable estimates undermine national and international investments, prevents accurate monitoring of global immunization initiatives, and can increase the risk of VPDs outbreaks. (Wetherill, et al., 2017).

2.2 Performance Indicators Monitoring Strategies

2.2.1 Results-based Approaches

Results-based Approaches (RBA) and Results-based financing and incentives (RBF) are government tools to disburse a portion of its health budget in cash or goods conditional on measurable actions taken or performance target achieved by health workers (Naimoli and Brenzel, 2009; Pearson, et al., 2010). For example, GAVI funded programs receive results-based funds after two years of an initial investment (Stokes-Prindle, et al., 2012). RBF implemented in Rwanda, Zambia and Ghana, between 2009-2014 indicated improved health services (Naimoli and Brenzel, 2009; Stokes-Prindle, et al., 2012).

Conditional Cash transfer programs targeting users of services began in Latin America/Caribbean region in the 1990s; where a cash transfer to household conditional on completing certain actions statistically indicated significant IC increment in Mexico and Nicaragua (Naimoli and Brenzel, 2009).

These strategies, however, have unintended pitfalls like non-remunerated services neglect, falsify reporting, propagating a culture of monetization among health workers, sustainability and cost-effectiveness challenges (Stokes-Prindle, et al., 2012). Pearson asserts that there is a risk of these schemes to focus on results that are measurable instead of important (Pearson, et al., 2010).

2.2.2 Other Approaches

The Reach Every District (RED) approach implemented since 2002, emerged from WHO and partners in an attempt to devise an innovative strategy to improve stagnating immunization coverage in Africa. It offers planning for better management of resources, supportive supervision, link communities with service delivery and ensures monitoring for action (Mahigo, 2009). RED's passive monitoring tools like drop out chart, timeliness and completeness reports, and data analysis increased IC. However, RED is challenged by funding, lack of qualified staff and immunization declining trends.

2.3 Comprehensive (Process and Basic) Indicators' Role

The capacity to attain and sustain recommended IC is a great challenge facing expanded programs on immunization (EPI). Bicaba et al. indicated that full immunization coverage (FIC) is sufficient neither to evaluate EPI performance nor to help identify the broad strategies that must be implemented to improve performance. The study asserts that FIC is a restrictive process that only accounts for several vaccines received, but not the age of the child at the time of vaccination and adherence to schedule. They recommended a tripartite performance view including FIC, the adherence to vaccination schedule and status of children not completely vaccinated. It yields better-targeted interventions, inequity reduction and vaccination accessibility. Conversely, the study never investigated the reasons underlying performance deficiencies (Bicaba, et al., 2009).

Similarly, Naimoli and Brenzel indicated there is need for a comprehensive approach in monitoring the immunization programme to draw attention to low performing areas instead of the classical coverage indicators (Naimoli and Brenzel, 2009). To emphasize, Better Immunization Data (BID) prioritization exercise team arrived at four challenging areas that could be informed by EIR data analysis namely**:** Denominators and population movement, Missed opportunities, Continuum of Care and Continuous quality improvement (CQI). CQI is "an iterative data-driven process of empowering health care workers to improve health service delivery by identifying challenges, trends, consistencies, outliers in coverage and dropout rate". BID is meant to share findings with stakeholders (Carnahan, 2020). This approach, however, lasts for a period, never informs stakeholders in real-time and emphasis is put on basic performance indicators.

2.4 Big Data Analytics

The success of public health big data applications entirely depends on underlying architecture and utilization of appropriate tools. Data curation plays a vital role in transforming big data into actionable knowledge (Palanisamy and Thirunavukarasu, 2017). Big data generate more revenue while reducing risk and predicting future outcomes with greater confidence at low cost. Big data management cycle includes capture, organize, integrate, analyze and act (Hadi, et al., 2015). However, validation, interpretation, and visualization are crucial in extracting actionable knowledge for decision making (Liang and Kelemen, 2016). Besides, real-time big data analytics is a key requirement in healthcare to address the lag between data collection and processing (Raghupathi and Raghupathi, 2014).

Information systems design theory (ISDT) underpins this study. ISDT's strength is the theoretical basis of "vigilance denoting the ability of an information system to help an executive remain alertly watchful for weak signals, discontinuities and opportunities". (Walls, et al., 1992). ISDT indicates how to design an artifact on principles of function, methods and justificatory theoretical knowledge.

3 METHODOLOGY

Pragmatism will form the basis of the study. It integrates both inductive and deductive research and accepts concepts to be relevant only if they support action (Ågerfalk et al., 2008). The explanatory approach will be used because it provides a greater depth and breadth of information. (Venkatesh et al., 2013). The research strategy is both qualitative (useful to provide a detailed description as it occurs in context) and quantitative methods (searches for significant relationships, patterns or correlations between variables) (Nowell and Albrecht, 2018) following design science.

Table 1: Case study population.

Particular	Kampala region details	Kampala attributes
Unit of Analysis	Hospitals: 22 General hospitals, 2 National referrals, 3 Regional referrals, 13 Health Centre IV and 48 Health Centre III. **Total : 88** (MOH Uganda, 2018)	-Kampala covers 189.3 square kilo meter. -Divisions/strata: Kawempe, Rubaga; Central, Nakawa, Makidye, -Parishes 96 and 1285 villages. (UBoS; 2019). -74,913 births per year. -6,242 children immunized (UNICEF-Uganda, 2015) per month(formula indicated by (WHO/IVB/08.05, 2008)).
Unit of inquiry (per Health Facility)	-Key informants: In charge (health facility), Head of immunization department, Community personnel (Village health team), Head immunization outreaches, Records officer, Nurse/vaccinator; Total study population: 528 -Representative sample size : 226 (Krejcie & Morgan, 1970). -Sampling techniques: Stratified, simple random, purposive. -Methods: Interview, questionnaire, focus group and document review -Data analysis: Epinfo for quantitative Text for qualitative	

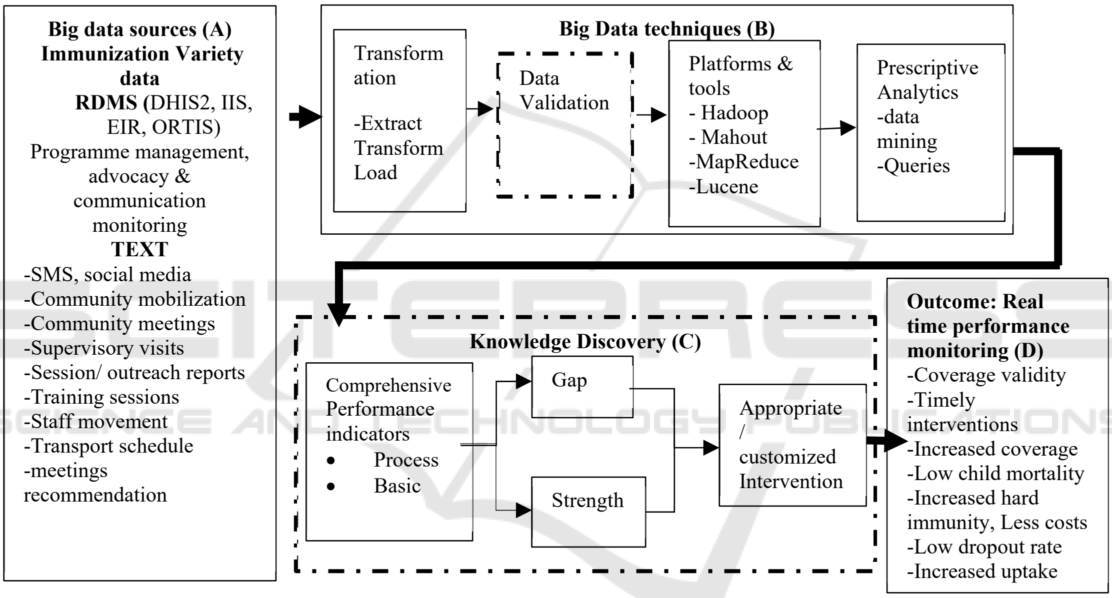

Figure 2: Envisaged Artifact (Adapted from "Applied conceptual architecture of big data analytics" by (Ravikumaran and Vimala, 2016)).

4 ENVISAGED ARTIFACT: ROUTINE IMMUNIZATION COVERAGE MONITOR FRAMEWORK

The Routine Immunization Coverage Monitor Framework in Figure 2 is an extension of Ravikumaran and Vimala, 2016 applied architecture of big data analytics. The adapted framework initiates at a big data layer (A) by pulling/integrating structured data from legacy systems and unstructured data from immunization generating activities (data curation) in real-time. These raw data are transformed and validated at component (B). The transformed data is subjected to big data tools and platforms like Hadoop a "NoSQL" open source distributed data processing technology. MapReduce provides the interface for the distribution of sub-tasks and tracks processing of each server/node. Mahout generates machine learning algorithms while Lucene supports text search and analytics. Using prescriptive analytics, data mining and querying will generate performance reports. The reports are fed into a data discovery component (C). This component houses variables like performance indicators. Comparing immunization performance indicated by insights from reports against set process and basics indicators, strength and gaps are easily identified to inform conclusion and support decisions for appropriate customized child health intervention. It is this intervention that is implemented national or subnational level to attain/sustain recommended immunization coverage preserving optimal validity.

5 EXPECTED RESEARCH LIMITATION AND MITIGATION

The researchers anticipate self-reporting to limit the study, especially for selected key informants. This will be mitigated by verifying given information with doses administered in reports, unique child identifier from Vital records management systems and National Identification Regulatory Authority(NIRA) records.

6 CONCLUSION

Monitoring and surveillance of IC rates are critical at national and subnational levels for countries to prioritize and customize strategies to address immunization gaps and reach life-saving vaccine to every child. The study suggests that the success of the immunization programme lies in real-time monitoring of its performance against all set targets. This study indicates that the envisaged framework integrates structure and unstructured immunization data to generate real-time programme performance actionable knowledge to guide child health interventions using prescriptive analytics. Monitoring these insights against comprehensive health facility indicators like micro-plans, process and national basic indicators, is important in identifying evidence-based gaps/strengths that inform conclusion and support customized remedial action/interventions in real-time to eliminate VPDs. This artifact also strengthens monitoring and surveillance of IC with greater validity confidence. Empirically establishing the extent to which data analytics influences immunization coverage validity will be the next step in our research.

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