Dashboarding Vaccine and Routine Immunization Data Services for Selected Healthcare Centers: A User-Centric Evaluation

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Abstract

Poor data quality resulting from routine immunization (RI) that is centered on a registry-based reporting approach can influence improper management of resources which hampers the data value of vaccine monitoring and RI services at primary healthcare centers. The present study has attempted to address these data-related predicaments by examining selected primary healthcare centers within Edo State for their mode of RI and vaccination data. It has proposed an architectural framework for dashboarding data services for vaccines and RI. A qualitative research approach was employed for data gathering and the prototype software development methodology was adopted for engineering the dashboard solution. To trace users' experiences on the solution for vaccine and RI data integration services, user-centric evaluation was simulated upon request/response for both mobile and desktop platforms to mimic real primary healthcare workers while assessing the performability of the prototype dashboard solution. The evaluation results and analysis further established that the implemented and evaluated dashboard solution is user-centric and highly supportive of integrating data and information on vaccine and RI services across primary healthcare centers and local government areas towards quality data and efficiency in service delivery. Thus, the study underlines the architectural framework as an integral component of the National Primary Healthcare Development Agency to ensure quality data-driven decisions while improving on the centralized registry-based approach of the national immunization initiatives.
Keywords: routine immunization, vaccine monitoring, primary healthcare centers, data quality, user-centric, performance

Introduction

In Nigeria, a crucial part of vaccination service delivery involves estimating vaccine needs (vaccine forecast), ordering vaccines, storing vaccines, monitoring vaccine use, and reducing vaccine wastage (Ophori *et al*., 2014; Ameen *et al*., 2016; Oluwatuyi, 2020). The use of vaccination and immunization as public health tools help to reduce the infectious disease burden as vaccine-preventable Diseases (VPDs) account for 22% of child deaths: representing about 200,000 avoidable deaths a year (Ameen *et al*., 2016). In some primary healthcare centers (PHCs) within Nigeria, the vaccine records, usage rates, supply, and coverage of immunization are inadequately managed because a registry-based data pipeline is evident in the way data is reported from the tertiary to the grassroots level. As a registry-based data pipeline, vaccine and immunization data is weighed down by the enormous burdens of an intensive manual approach, as well as poor visualization, which causes a poor

quality of the data and thus, impedes data-driven decision-making.

The authors of Ophori *et al.* (2014) explicated key barriers to the realization of effective vaccine monitoring and quality data reporting to poor routine immunization. This assertion was also dominant in the 2014 report of the National Health Agency for Primary Healthcare Centers – NPHCDA (Ado, 2015). This among other factors was also examined by Akwataghibe et al. (2019) emphasizing the effect on the quality of data in these healthcare centers and their associated local government (LG). For LGs, tracking and managing immunization data from all health centers under their jurisdiction has become increasingly challenging, and the quality of data remains also a challenge both for primary and state healthcare facilities with recourse to the ability of making data-driven decisions (Akhere *et al*., 2021).

Monitoring is the systematic and continuous process of examining data, procedures, and practices. It is a way to measure progress, identify problems, develop solutions and guide policies and interventions. In Nigeria, PHCs have a poor or passive reliable approach to vaccination and RI monitoring and management (Etamesor *et al*., 2018; Akhere *et al*., 2021). Most often, the approach relies heavily on register-based monitoring of vaccine information which restricts quality analysis of vaccination data to predict or monitor trends toward informed decision-making and planning. Consequently, poor data quality from PHC influences improper management and planning of resources, and thus, technology can play a bigger role in primary healthcare systems if a platform with a data-centric framework is designed to synchronize and streamline the administrative activities associated with RI.

Vaccination and routine immunization data management is mostly register-based across PHC facilities, and as a result, makes it difficult to monitor underperforming facilities on vaccination and routine immunization data for proper planning and effective coverage. In addition to the number of PHCs under a particular LG, it is hard to synchronize and improve the nature of data and information gathering towards a sustainable and reliable provision of health services as observed also in Oluwatuyi (2020) and thus, the aforementioned challenge is a problem that motivated this study with the aim to propose an architectural framework to dashboard and manage vaccine and RI information across PHCs and LGAs. Further objectives were to: investigate the mode of managing vaccine and RI data by PHC caregivers from the supply chain and identify the need for a proposed data services solution; mimic healthcare users in evaluating the architectural solution via an automated user-centric evaluation tool. In doing so, the study is hereafter piloted with the significance of the study, then background information on theoretical concepts, a review of preliminary studies and related literary works. The proposed architectural framework and its workability was presented in section 2. The architecture solution was evaluated with result analysis in section 3. Section 4 concluded the study with future recommendations for the study.

The study attracts significance both in literature and healthcare practice by further establishing that the proposed dashboard is highly supportive of integrating data and

information on vaccine and RI services across PHCs and LGs towards improved efficiency in service delivery with user-centricity. It has contributed to the study through advancement in leveraging technologies to promote quality assurance in sustainable data management for vaccine and RI services.

Background information and preliminary studies

In Nigeria, the NPHCDA provides technical and programmatic support to states, LGAs, and other stakeholders in the functioning, planning, implementation, supervision, and monitoring of primary health care services in Nigeria (Ado, 2015). At birth, RIs are scheduled for children globally according to the world health organization's schedules for immunization (WHO, 2020). A child is considered fully vaccinated if, according to the Nigerian Federal Ministry of Health, they have received a BCG vaccination against tuberculosis, three doses of the DPT vaccine against diphtheria, pertussis (whooping cough), and tetanus, at least three doses of the polio vaccine and one dose of the measles vaccine. These vaccinations should be received during the first year of life, over five visits (including the doses delivered at birth); thus, children aged 12-23 months ought to have completed their immunizations (Ophori *et al*., 2014; Ekundayo *et al*., 2016). Immunization records are kept to properly track measures of ensuring sustainable resource management and vaccine monitoring processes.

At the PHCs, a monthly report is generated manually by the healthcare workers about vaccine usage and immunization coverage data. Related studies exposed that, the lack of reliable vaccination coverage data at the operational level (i.e., LGA), makes it challenging to monitor and remediate RI service delivery in achieving uniformly high vaccination coverage. Thus, a review is paramount for clarity on data quality challenges.

This study recognizes the work of Abdulkarim *et al*., (2011); who ventured into the past, present, and future of vaccines and immunization in Nigeria. Their emphasis was centered on the advisement of more funding towards simplified, inexpensive, and valid methods for obtaining crucial data to have enough evidence to make informed health policy decisions.

Aside from the valid methods of mining quality data, Placzeck *et al*., (2011) added that registry-based data affect vaccine effectiveness studies. Their review showed that central immunization registries can be useful tools for evaluating the impact of immunization programs by measuring vaccine effectiveness as a response and preventive measure in a variety of population study contexts. Automation may counter the challenges of registry-based reporting.

In Merrill *et al.* (2013), the effects of automated immunization registry reporting via an electronic health record were discussed, stating that it can help public health officials better determine who in the patient population has been adequately immunized – quality vaccination and RI records, providing easy access and reliable immunization histories.

The rate of RI was discussed in Ophori *et al.* (2014), and Nigeria was reported to have had some of the lowest immunization rates

in the world and these rates could be attributed to several reasons. One of those reasons is the ineffectiveness of primary health care services as well as their poor management of existing resources.

Poor data quality has been emphasized by Ado (2015) as one of the causes of poor RI performance in Nigeria resulting from the monitoring and reporting approach. In the agency's report, it was statistically observed with reviews to recent times, that several aspects of the monitoring system need improvement, some of which included: archiving, recording practices, use of data to spur action, accurately defining the population, tracking indicators, etc. The report consequently stressed that the effective use of accurate, reliable, and timely data is paramount to managing the immunization program. These constituents of quality can be visualized by an integrated dashboard.

The importance of the quality of available healthcare data was pointed out in several literary works (Etamesor *et al*, 2018; Omole *et al*., 2019; Oluwatuyi, 2020). Akhere *et al.* (2021), also advised the improvement of data quality. The rate of inconsistencies in the data monitoring and reporting from the various platforms was exposed and consequently, a dashboard was advised to strengthen routine immunization towards achieving success in vaccination and immunization programmes in Nigeria. However, data reliability and availability are somewhat relevant and also a milestone to achieve in this study.

Summarily, the review of literary works was paramount to studying existing research efforts, their challenges, platforms, and suggested solutions on vaccination and RI information monitoring to enable a conceptual framework capable of contributing toward a viable dashboard for vaccine and RI information management for PHCs with associated data-endpoints. The next two sections systematically describe the methodological approach to achieving the objectives of the study.

Conceptual framework

This section provides a conceptual framework for understanding, visualizing, and validity of the study. The conceptual framework aligns with a software development methodology that outlines the various steps and techniques unutilized in the field of study. The software development methodology is a framework that is used to structure, plan, and control the process development of an information system. Thus, the present study adopted the prototype software methodology depicted in Figure 1.

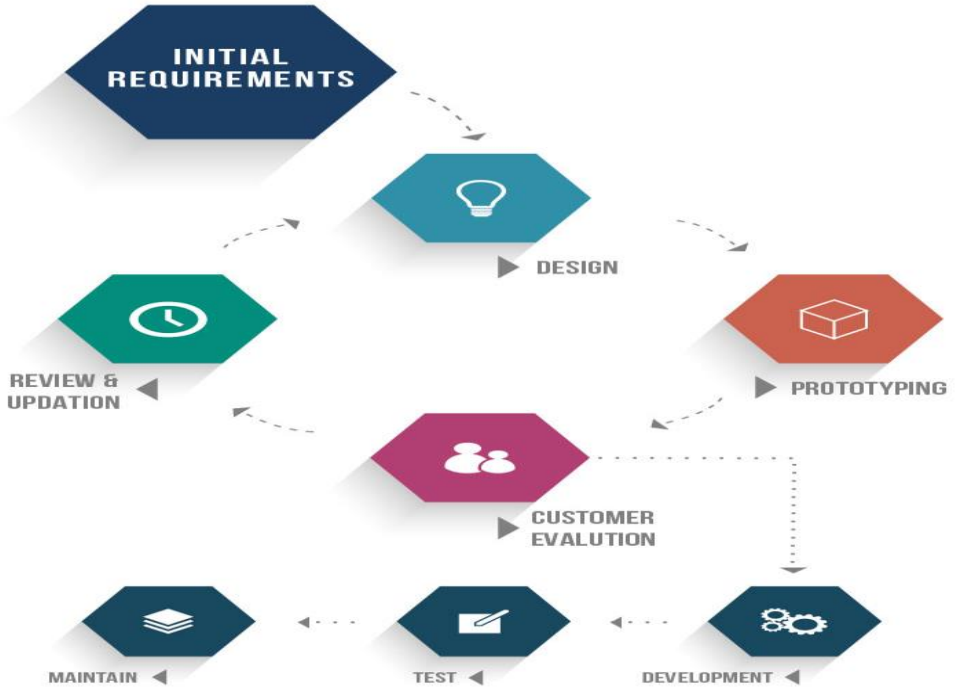


Figure 1. Research Software Development Methodology – Prototype Approach

This model follows a series of activities to attain a targeted objective by allowing the development of a prototype solution in order to demonstrate the feasibility of the end product. It gives a clear understanding of the problem and ensures a greater level of customer satisfaction while refining the scope to accommodate changes in requirements. The series of activities were implemented accordingly.

Requirement engineering: System investigation and data gathering

The qualitative approach was used as a technique for data gathering adopting the observation and interview methods with structured questions that intended to elucidate information on the mode of operations and RI data reporting available at selected PHCs and LGAs.

Nigeria is a country made up of 36 states, with a total of 774 local governments. System investigation was carried out for PHCs in three selected LGAs – Ikpoba-Okha, Egor, and Oredo in Edo state of Nigeria. Investigation findings revealed that:

- Edo state consists of 18 local governments with a combined total of 634 primary health centers with major LGAs such as Ikpoba-Okha, Oredo, and Egor
- Ikpoba-Okha: has 129 health centers; 32 public-owned PHCs, 1 public-owned secondary health center (SHC), 85 private-owned PHCs, and 11 private-owned SHCs
- Egor: which has 80 health centers; 12 public-owned PHCs, 2 public-owned tertiary health centers (THC), 53 private-owned PHCs, 12 private-owned SHCs, and 1 private-owned THC
- Oredo: has 148 health centers; 22 public-owned PHCs, 5 public-owned SHCs, 83 private-owned PHCs, 35 private-owned SHCs, and 3 private-owned THCs.

- the investigation also revealed a register-based mode of operations for reporting RI data

From the investigation, it is alarming that the number of PHCs in the LGAs is overwhelming to be dependent on a registry-based approach for their data service. The procedural steps ensure that the data from these registers are reported back to the LGs headquarters at the end of every month. A photocopy is made for the health center keeps, while the original is submitted to LG. However, report generation is inefficient with no assurance of data quality data PHCs. The summary of the investigation serves as a tool to propose a design framework capable of assuring the quality of vaccine and RI data, hence, the study proposed an architectural dashboard depicted in Figure 2.

The designed architectural framework

In the prototype methodology, requirement analysis is veritable for proffering solutions to a system under study. Figure 2 is the proposed architecture design for dashboarding vaccine and RI information across the selected PHCs and LGAs.

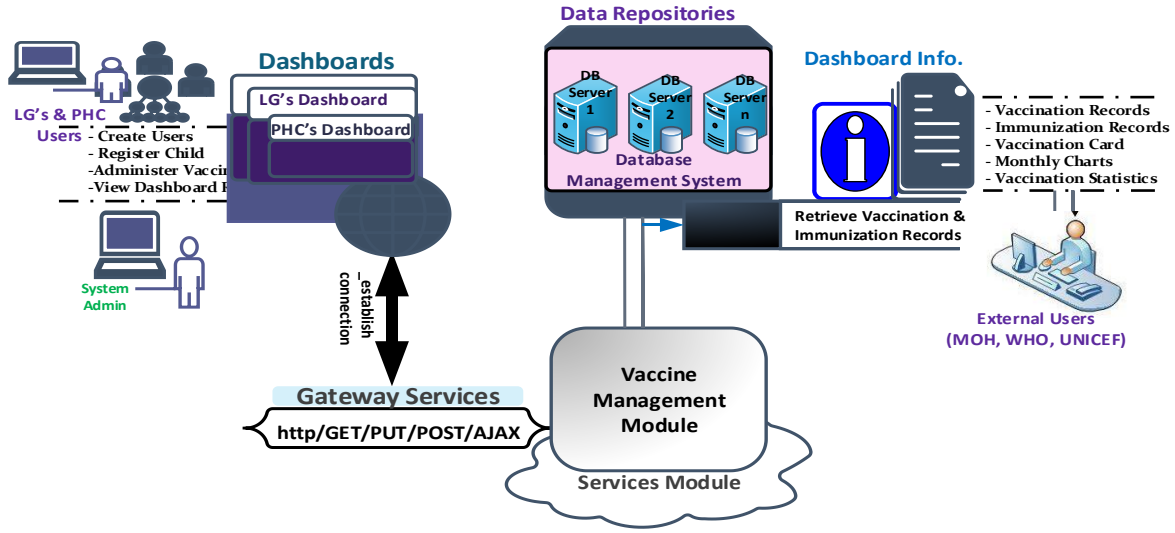


Figure 2. Architectural Framework for Dashboarding PHCs Vaccine and RI Data Services.

Figure 2 is an architectural framework of a dashboard for vaccine and immunization data monitoring and reporting. It adopts features of web service technology as gateway services to provide a platform that synchronizes and integrates vaccine and immunization data services for and from different health centers. Webservices adoption facilitates the implementation of real-time synchronization of non-platform dependent PHCs data repositories for effective querying, retrieval, and visualization of quality information. The framework is architectural and allows the implementation of an automated vaccine monitoring system as highlighted in Merill *et al*. (2013), for PHC workers to document and report their weekly vaccination reports across PHCs in a particular LG. This initiative is viable for multiple PHCs, LGs and also, the proposed framework provides support for administrative access to healthcare information for LGs, PHCs, Ministry of Health (MOH), UNICEF,

WHO, NPHCDA, and other external users via the integrated management module that uniquely supports repositories for warehousing children vaccination records, vaccine routine distribution, querying vaccine records, viewing of child and vaccine records, viewing the statistics via the dashboard in consonant with Etamesor *et al.* (2018). The proposed framework is architecturally conceptual for the implementation of a prototype solution to justify the feasibility and quality assurance of monitoring and reporting services.

Prototyping phase

This phase involved the combined activities of the prototype, development, and test phases. The practicability of the proposed architectural framework was demonstrated with an implementation of a prototype solution. Figure 3 – Figure 6 tested and validated the functional aspects of the architecture solution as Figure 3 is a snapshot depicting the dashboard for vaccine monitoring with codename VMID – Vaccine Monitoring and Immunization Dashboard.

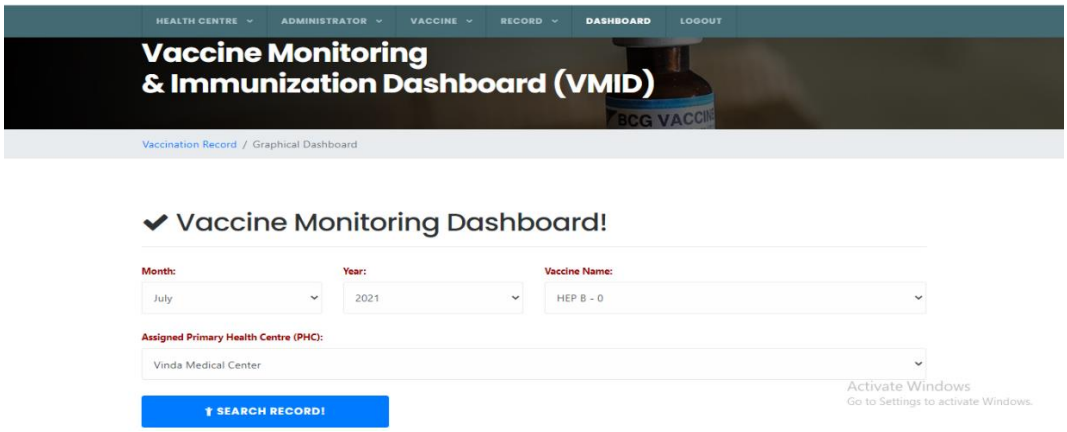


Figure 3. Dashboard Interface for Vaccine Management.

Figure 4 captured PHCs under the control of Ikpoba-Okha LGA. It shows that the architectural framework supports implementation that caters to LG registration and sub-registrations for constituent PHCs. Figure 5 is a snapshot of children with vaccination records. Figure 6 represented the health record sheet with details of the vaccination history of every vaccinated child. A similar card is generated for every vaccinated child across PHCs with unique vaccination and certificate number in line with NPHCDA.

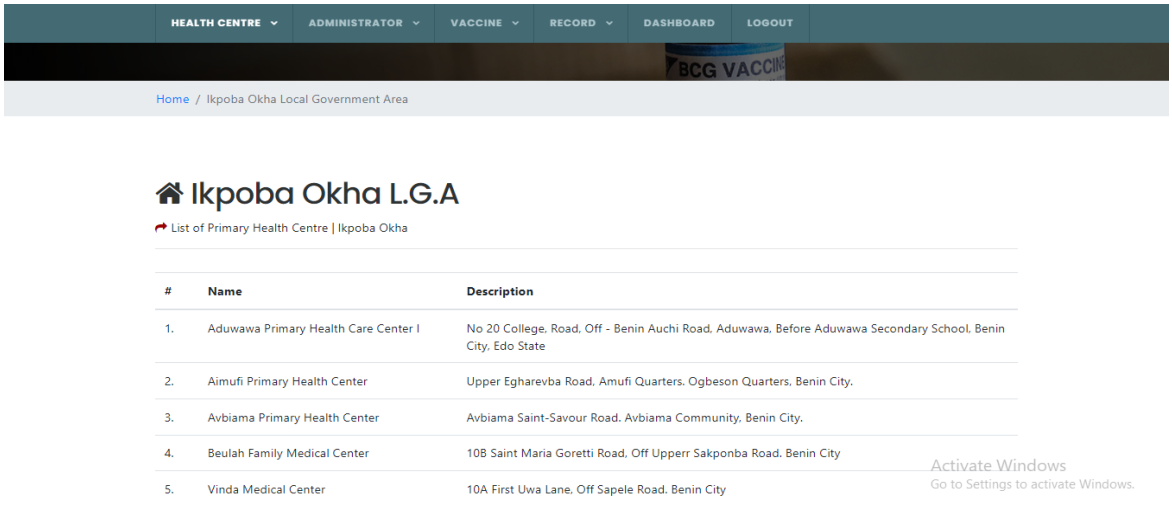


Figure 4. LG and its Constituent PHCs.

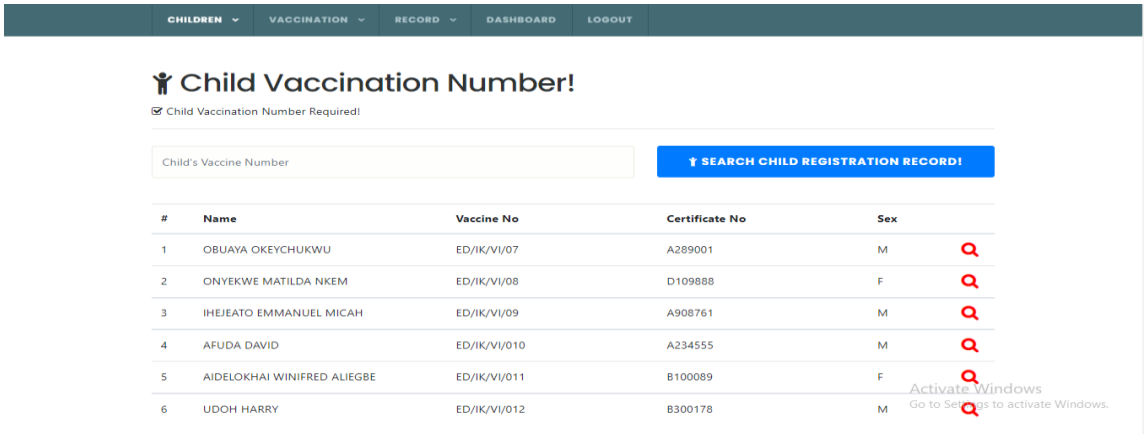


Figure 5. Vaccination Records for Immunized Children.

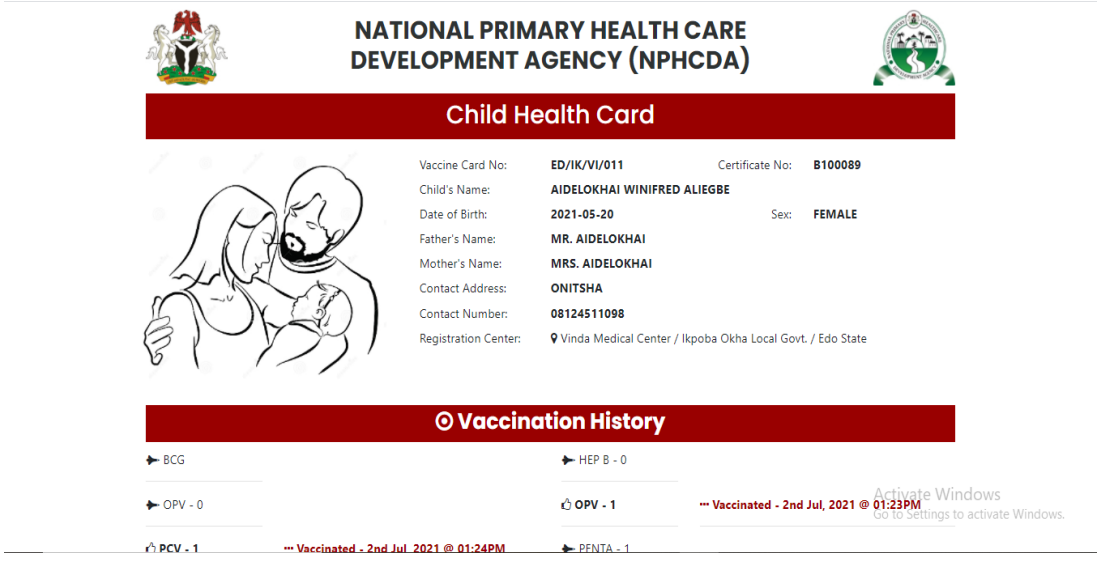


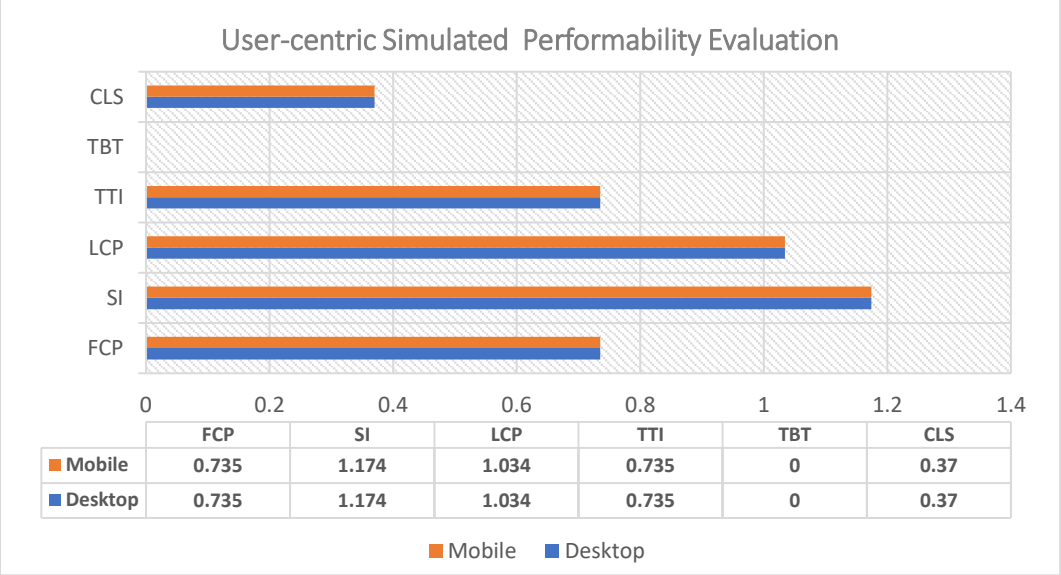
Figure 6. Health Record Card for a Vaccinated Child.

The majority of vaccine and RI-related services are supported for digitalization by the proposed framework because it synchronizes people, technologies, and processes to realize a common objective for NPHCDA and Nigeria at large. For the non-functional components. A user-centric evaluation of the architecture prototype solution was paramount to ascertain its performability in terms of efficient service delivery, user-friendliness, and performance.

User-centric performability evaluation – A non-functional approach

This phase evaluates users' opinions on the implemented architectural dashboard. Users' experiences were automated for the study via a user-centric evaluation to test the performability of the prototype architectural dashboard for PHC modules across the selected healthcare centers. This performability approach has been identified with performance and usability evaluation in literature (Oliha, 2020; Oliha, 2021; Oliha, 2022; Oliha and Iyoha, 2023) The evaluation simulated the user's experience with real-life usage. The selected evaluation tools were Dareboost and Google PageSpeed Insight due to their capabilities in assessing automated user-friendliness and performance features (Oliha, 2023) while checking if the architecture solution supports ease of use for all categories of users (mobile, aged, disabled, and assertive technologies).

The user-centric performance evaluation of the prototype architecture solution was characterized by event-timing attributes of six user-centric metrics: first contentful paint (FCP), speed index (SI), largest contentful paint (LCP), time to interactive (TTI), total blocking time (TBT), and cumulative layout shift (CLS). The metrics have substantial effects on users' experiences with software usability. The experimental results were captured for desktop and mobile users' simulations. Figure 7 represents the evaluation of the architecture solution for performability simulations for both platforms, while Figure 8 and Figure 9 captured the weighted performance score for the simulated experiments on both platforms.



	FCP	SI	LCP	TTI	TBT	CLS
Mobile	0.735	1.174	1.034	0.735	0	0.37
Desktop	0.735	1.174	1.034	0.735	0	0.37

Figure 7. User Responsiveness Simulations for Desktop and Mobile Users.

In Figure 7., there was a matching similarity in responsiveness to user requests for both the desktop and mobile versions from the evaluation results. Both application versions were excellent in TBT as it has no latency in responding to user inputs or requests on mouse clicks. However, usability construct in terms of layout shift was a common challenge for both versions of the architecture solution with the indication that the CLS may need more improvement in order to suit and scale on both the desktop and mobile platforms.

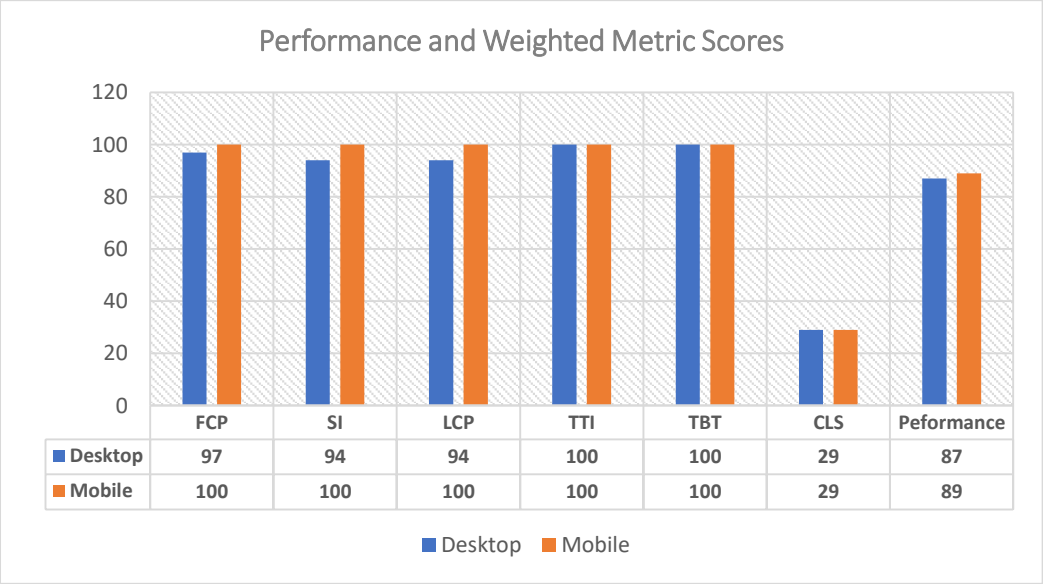


Figure 8. Performance Evaluation Result for Desktop and Mobile Dashboards.

In Figure 8., a performance-weighted score of 87 was reported for the desktop version of the experiment. It was obvious that the performance weight amassed from the attributes of TTI and TBT was about 40% of the scored performance as shown also in Figure 9. The construct of FCP, SI, and LCP aggregated at 19% each with weighted metric scores ranging from 94 to 97 depicted in Figure 8. However, in both figures, the CLS metric displayed poorly with a metric score of 29(6%) which is far below the expected average score. With an overall weighted average score of 88%, the indicated performance for the tested architecture solution is moderate (orange) and acceptable.

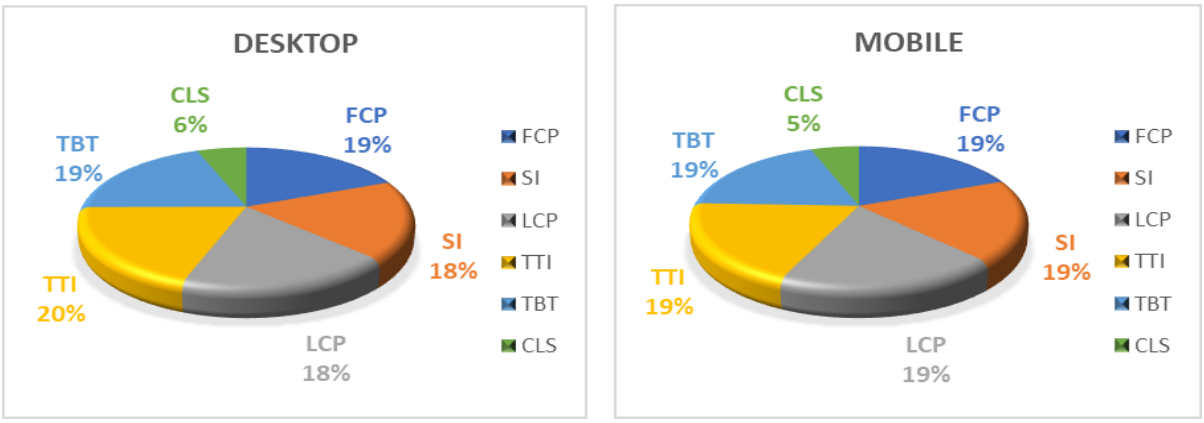


Figure 9. Construct Impact on Performance for Desktop and Mobile.

For compatibility, the performance of the architecture solution was matched with excellence on the attributes of FCP, SI, LCP, TTI, and TBT except for CLS with below 30. This again, drags attention to the layout shift responsiveness for both experiments as shown in Figures 8 and 9. However, the results for both simulations showed that the proposed dashboard is and will be compatible with mobile and desktop devices in rendering service support for records and information management across PHCs and LGs with good performance and improved productivity.

Discussion

The prototype software development methodology was adopted with various steps and techniques utilized to validate the conceptual framework of the study. The study adopted the interview and observation methods as qualitative data-gathering techniques and requirement analysis to formulate a base of information for the proposed architectural dashboard. Modern web technologies were employed in terms of web services and API integration to provide connections between PHCs application modules with support for improved vaccine and RI data exchange.

To ascertain the performability of the proposed architecture dashboard, a prototype solution was built on the framework and the functionalities were demonstrated with data quality in vaccination and RI records for each PHC for every registered and vaccinated child. User-centric and performance evaluations were simulated to mimic real PHC workers and assess the solution's loading performance upon user requests/responses while tracking their usability experiences with affiliation to Oliha (2023). The evaluation simulated two user experiments via the assessment tools based on six request-response-timing metrics associated with the responsiveness of a target solution:

i. FCP user-centric performance indicator is a metric that marks the timing for web browsers to render the first text or image after a user navigates to your page. The FCP score compares a web solution's page based on data from the HTTP archive. The required FCP load time is 1.2 seconds at 99^{th} percentile performance and the FCP scores for both versions were evaluated at 735ms (0.7s) with metric scores of 97 and 100. The FCP metric indicates a good weighted score averaging +9.85% of the weighted 10% allocated for FCP in standard practice.
ii. SI shows how quickly and visibly populated the page contents are during a page load. A range of 0 - 3.4 seconds indicates green (fast), 3.5 - 5.8 seconds indicates orange (moderate), and over 5.8 seconds indicates red (slow). The resultant SI score for both versions was capped at 1,174ms (1.2s) with metric scores of 94 and 100. This indicates a very fast content load for the architecture solution with a weighted score of +9.41% of the standard 10%.
iii. LCP measures the time it takes to paint or render the largest content DOM element in the viewport to the browser. A range of 0 - 2.5 seconds indicates fast, 2.51- 4 seconds indicates moderate, and over 4 indicates slow. The LCP score for both versions was overlaid at

1,034ms (1.0s). With a weighted score of 24.25% (97) of the standard 25%, the architectural framework implements an integrated solution with fast responsiveness to users.

iv. TTI measures how long it takes a page to become fully interactive when the page responds to user interactions or requests. A range of 0 - 3.8 seconds indicates green (fast), 3.9 - 7.3 seconds indicates orange (moderate), and over 7.3 seconds indicates red (slow). The resultant TTI score was evaluated at 735ms (0.7s) with a weighted score of 10% (100) of the standard 10%. This indicates that the architecture solution is timely and interactive.

v. TBT measures the amount of time that a page is blocked from responding to the user input, such as mouse clicks, screen taps, or keyboard presses. The required time is < 50ms and anything more than 50ms is the blocking portion, over 400ms is considered slow. The architecture solution is with an excellent score of 100% (30% of the standard 30%) in responding to user inputs.

vi. CLS is an important user-centric performance metric that measures the visual stability that helps quantify how often users may experience unexpected layout shifts. A low CLS helps ensure that the page is delightful. The required CLS score is between 0 - 0.1s which measures the 75th percentile of page loads segmented across mobile and desktop devices. A CLS of 0.1 – 0.25 needs improvement while above 0.25 is poor. The resultant evaluation score for the prototype architecture solution was averagely poor at a weighted percentage of 29% (0.37). Users may be disoriented by unexpected shifts in layout; thus, an improvement is required for the prototype solution to meet the required standard practices for better experiences with users.

The findings revealed a loading performance rating of 87% for users' experiences with the desktop simulation and 89% for the mobile experience. Explicating these findings, the six user-centric performance indicators exposed good user experiences with FCP, SI, LCP, TTI, and TBT in responsiveness to user requests. However, the layout shift revealed an unexpected experience and requires improvement to ensure continuous usability and performance in reporting and monitoring vaccine and RI data. The evaluation results and analyses further established that the proposed dashboard is highly supportive of integrating data and information on vaccine and RI services across PHCs and LGs towards improved efficiency in service delivery with user-centricity, extending on the work of Etamesor *et al*. (2018). Thus, better quality of data and information management on vaccine and RI service is achievable with the proposed dashboard and methodology which agrees also with the pilot study of Akhere *et al*. (2021).

Conclusion

The quality of data associated with the vaccine and routine immunization management at various PHCs within the selected LGAs has become an analytical tool for effective planning and

improvement for NPHCDA. An architectural framework has been introduced, designed, and prototyped to facilitate the dashboarding of vaccination and immunization records at selected primary healthcare centers. The dashboard cuts across NPHCDA initiatives on national immunization programmes for promoting reliable vaccine utilization, monitoring, and report management with graphical interfaces supportive of relevant performance indicators for quality data services such as charts, factsheets, and trends. The collective emphasis from the Federal Ministry of Health and other Health organizations should be geared toward RI services to improve the quality of data gathered and reported by PHC workers in general. Although, the resultant performance evaluation outcomes are not a sufficient yardstick to ascertain the architectural workability in reality but, it is an advancement in leveraging technologies to promote quality assurance in sustainable data management for vaccine and RI services. The proposed dashboard is supportive of PHCs and LGs services limited to the selected state, future effort is required to amalgamate state and national repositories for effective vaccine monitoring in Nigeria.

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