Child Vaccination in Peru: How to Support it Using Cloud Computing and Blockchain

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Abstract: Childhood vaccination is an important pillar for a country's public health system. However, in Peru there was no adequate tool or technology that could be used by parents or guardians of children to monitor or control the process. In this work, a technological solution based on Cloud Computing and Blockchain that is implemented in the childhood vaccination system of Peru will be presented based on a diversity of previous studies. Which focused on the analysis of the processes involved in vaccination, the system used, and the main actors to provide the best possible solution. The presented solution seeks to support the increase in the rate of childhood vaccination in the national healthcare system. We developed a system with functionalities that enhance the weak points in the current process, it is deployed in the cloud for the operation and connection with various services, and which takes advantage of Blockchain technology to ensure the protection of information that is managed in the process. The results obtained in the validation tests were satisfactory, obtaining a minimum compliance percentage of 99%. In this way, the system with the Blockchain network complies with the pillars of security such as confidentiality, integrity, and availability. On the other hand, the non-technical aspects to safeguard the security of the system that have to do with the processes and actors involved in vaccination were also considered. With this, the fundamental pillars of security ("CIA") can be ensured to provide a solution according to the context of the protection of transactional and medical data in Peru.

1 INTRODUCTION

Currently, the Covid19 pandemic (ONU, 2020) has affected childhood vaccination around the world (Unicef, 2021). This also affected Peru since there is a reduction in the number of vaccines applied (Andina, 2021) and the rate of the complete regimen (INEI, 2021) received by children in the first years of life. Added to the current context are other factors that do not favor the childhood vaccination process, increasing the chances of generating new infectious foci, collapses in the health system, and deaths from infections (WHO, 2021). In the studies of Ekouevi et al. (2018) and Garcia et al. (2021), where information on the vaccination of children between 12 and 24 months of age is collected, some of the reasons for not following the schedule of vaccinations are observed, such as the lack of an electronic card, the lack of knowledge about the process, the absence of a guide from a medical professional to guide them. This point is very representative in the Peruvian reality since there is not a massive public system for the national childhood vaccination program. Peruvian parents must use a physical card that the nurses stamp or sign each time they go to vaccinate their children. There is no efficient way for them to follow up on the vaccination schedule and remember all the appointments to schedule to immunize your children. At the same time, they must take care of a fragile element that is also easy to lose (physical vaccination card), so that they can vaccinate their children following the vaccination program stipulated by the government. On the other hand, there are studies likeof Di Giuseppe et al. (2022) and Lewandowska et al. (2020) that seek to know the opinions and knowledge that parents have about preventive vaccination issues and the willingness they would have to apply them to their minor child. In these, it is found that most parents are willing to apply preventive vaccines to their children, however, they do not follow the vaccination schedule and due to ignorance, they are afraid of the adverse effects

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that the vaccines could have. Finally, studies of Getman et al. (2018) and Arede et al. (2018) show the influence that social networks have on the opinion of vaccines, specifically the pro- or anti-vaccine publications with which parents can interact and contract more doubts about vaccination. These points are important to emphasize in the context of Peruvian society, since this paper focuses on finding solutions that best fit to this context. The level of basic academic studies in Peru is deficient, therefore the studies mentioned above have more importance since they are based mostly on the level of ignorance that parents have and how easily they are influenced by any unverified information mostly found on social media nowadays. Due to the ways are being sought to counteract these factors and increase the rate of children vaccinated with the complete schedule. The studies of Trumbo et al. (2018) and Clarke et al. (2019) provide an analysis of the health systems implemented in different countries, including Peru. In this you can see the weak points, strengths and lessons learned to implement these systems, and how it improves the data collection process.

In Section II, the related work about using Blockchain and Cloud Computing in healthcare is described. In Section III, the architecture and the solution are explained. In Section IV, it is described how validate the solution against the CIA Triad. In Section V, the results are shown through tables and graphs. In Section VI, we conclude about the most important findings of the results, limitations, and future work.

2 RELATED WORK

The research carried out resulted in works like the developed solution, which are systems based on Cloud Computing and Blockchain technologies. This is due to studies of Yang et al. (2018), based on Cloud development, Pawar et al. (2022) and Shanthapriya et al. (2020), based on Blockchain, where systems are developed in the health sector using these technologies independently and evidencing their individual benefits. On the other hand, there are studies such as of Omar et al. (2019), Mahajan et al. (2020) and Mubarakali (2020) that combine these two technologies in a single system to offer a solution for the treatment of adequate medical records. The latter focus their research on providing a solid and robust system in terms of the security of medical data protection, but which in turn is deployed within a service in the cloud. These systems, however, are oriented towards a more general approach within the health sector. In addition to these studies, there are works such as of Haque et al. (2021), Hernández-Ramos et al. (2021) and Biswas et al. (2021) that focus on the use of Blockchain technology to develop solutions related to COVID-19 vaccination. These seek to create a system that can globally certify the vaccination of a person through unique certificates using Blockchain technology and that can circulate between countries without major inconvenience when there were greater requirements for migratory transit. Finally, there are solutions that apply functionalities like those developed in our work. This is the case of studies of Obi-Jeff et al. (2021) and Cheng et al. (2020), which offer messaging systems to improve the vaccination process in some countries and thus increase the rate of vaccination. The latter are developed based on the cloud and the functionality of text messaging is very present in our work as it is an effective reminder method within the vaccination process.

3 METHOD

3.1 Architecture

The solution to be developed is based on the physical architecture shown in Figure 1. The two main technologies that will be used in the proposed system are the Cloud Computing and the Blockchain, these are represented by the yellow box that encloses most of the development components, and the blue box connected to the Rest API, respectively. This is because Cloud Computing technology will provide the infrastructure to be able to deploy the system that will be created and services that will be helpful to enhance our solution with great capabilities. Through this, it is possible to save on hardware components and adjust the capacity according to the need for requests, so that the economic section will be covered in a staggered manner. Some of the technologies that will be deployed in the cloud will be the Reminder & Notification Scheduler, which will be in charge of sending reminders by mail and text message; the web application, which will allow the end user to interact with the entire solution; the MySQL database, which will store the data used in the system; Finally, the Rest API, which works as the core of the system, processing the information and connecting all the components. On the other hand, Blockchain technology will be used for the robustness it can provide in transactional data security that is managed in the core activities of our solution.

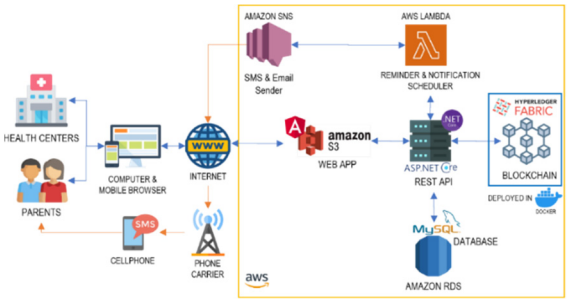

Figure 1: Physical Architecture.

In this way, the aim is to provide sufficient functionalities and characteristics to the vaccination system to improve the experience in the process of vaccinating children and thus support the increase in the vaccination rate. The Rest API will contain all the logic that you want to process in the system, while the web application allows the user to interact with all the functions offered in the system to offer a user-friendly experience. The database is the one that will contain all the data that is managed in the system, while the Blockchain will manage the critical transactional data of the vaccination process. Finally, the Amazon SNS and AWS Lambda components work together to provide email and mobile text message reminders automatically.

Some advantages that have this architecture are modularity, scalability, and versatility of the components. This allows to add or change things with a minimal configuration.

3.2 Web App

The web app allows to the users to access to the functionalities of the system for the vaccination process. The functionalities of this web app are divided in two groups: for the parents and for the health personnel.

In the group of functionalities for parents are the following functionalities:

Visualization of Vaccination Card: the objective of this functionality is that the parents can see the status of completion of their children's vaccination scheme. With this functionality, they will be able to immediately know what vaccines their children have already had, when, where and who gave them those vaccines, and what vaccines are still to be given as can be seen in Figure 2. Parents with this functionality will not need to have the current physical vaccination card that deteriorates over time or can be lost, by having this vaccination card digitally they will be able to know the status of their children within the vaccination process at any time and thus have better control to comply with the entire vaccination schedule for their children.

Figure 2: Visualization of Vaccination Card.

Next Dose Reminder: this functionality allows parents to know the next doses that can be administered to their children. With this functionality, parents do not need to be aware of their children's next vaccinations since they will receive reminders, as can be seen in Figure 3, days before the date on which the next vaccine can be given and thus comply with their children's vaccinations on time and boost their health at the right time.

Figure 3: Next Dose Reminder.

And in the group of functionalities for health personnel are the following functionalities:

Visualization of Child Health Information: The objective of this functionality is that the health personnel can immediately view and at any time the remaining and administered vaccines of a child. With this functionality, they do not need to request the vaccination card from the parents, since it would be only enough to search for the child's health information, like is shown in Figure 4, and view the vaccines that must be given, and which ones have already been given.

Registration of Dose Administration: This functionality is focused on health personnel can quickly and easily record the doses of vaccine that have been administered. With this functionality, the children's vaccination information will be recorded so

that both parents and health personnel can consult it later and thus know the real completeness status of the children's vaccination scheme. Figure 5 shows the form that is filled out once the dose to be vaccinated has been selected.

Figure 4: Visualization of Child Health Information.

Figure 5: Registration of Dose Administration.

Besides of the explained functionalities, the web app also has the following: Visualization of Vaccine Information, Vaccination Appointment Scheduling, Vaccination Appointment Reminder, Registration of Vaccination Campaign, Vaccination Campaign Notification, Registration of Vaccine Inventory, Visualization of Vaccine Inventory.

On the other hand, as part of the processes that are involved in the functionalities provided to the parents of the children who will be immunized and the health personnel, it is sought that they have the least possible access to information that does not correspond to them or use a simple interface that allows the entry or modification of data as little as possible. In addition to protecting the data in terms of integrity and reliability, there will not be an excessive use of computational resources to load the different views and functionalities of the service, which also ensures its availability.

3.3 Blockchain

The Blockchain Platform developed with Hyperledger Fabric and its API developed with Node.js allow to the solution to record the transactional data of the vaccination process in a decentralized and secured way, also allow to the different Health Organizations access to the same information from the same data source. Internally, the Blockchain Platform has 3 peers, as can be seen in Figure 6. One smart contract written in JavaScript that is used to register and query the doses, one certificate authority to authenticate and authorize the agents, and one orderer peer to manage the transactions and the Vaccination channel where all the information of the vaccination process flows.

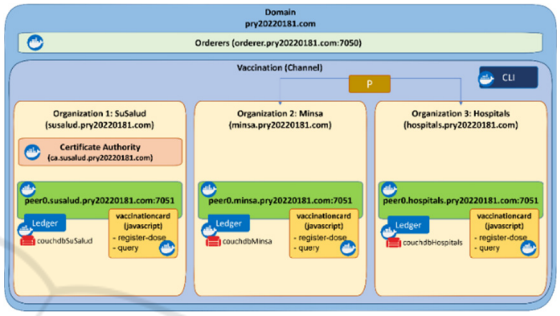

Figure 6: Blockchain Diagram.

The information of the administered doses is recorded in the Blockchain when the doctor registers a dose administration in the web app and this information is retrieved from the Blockchain when the parent or the doctor query the health information of the children. Internally, the REST API made with ASP.NET Core calls the Blockchain´s API made with Node.js to get or save the records. The Blockchain´s API communicates with the Blockchain via the Smart Contract and then returns the response to the REST API; this one processes the info and finally returns the response to the web app for the users.

4 EXPERIMENTAL SETTINGS

4.1 Calculation of the Experimental Sample

According to the INEI, in 2022 there are 33 million 396 thousand 700 inhabitants in Peru, through the following formula an approximate of the sample of users that will be used for the test cases will be calculated:

$$n = \left(\frac{xy}{zv}\right) \times \left(1 + \frac{1}{w}\right)$$

Figure 7: Sample Formula.

Where:

- The sample (n)
- Total population (x): 33,396,700
- The percentage of children from 0 to 11 years old (y): 22%
- The total number of health facilities (z):8148
- Number of children per user (v): 2
- Number of patients per health center (w):230

The result that was obtained using the previous formula is 453 users, with whom the validation tests will be carried out. This amount is an approximate calculation of users that there would be in a medical center for the test cases.

4.2 Test Cases

For the validation of the security triad of the technological solution based on Cloud Computing and Blockchain for the child vaccination process, a proof of concept (PoC) was carried out, with the following test cases:

- Test Case Nº1: Confidentiality of vaccination records: This validation test consists of evaluating the relationship between the number of tests that accessed unauthorized information and the total number of requests made.

$$\%Confidenciality = \left(1 - \frac{\#\ of\ successful\ tests\ HW + \#\ of\ successful\ tests\ P}{\#\ of\ total\ test\ requests}\right) \times 100$$

Figure 8: Formula for % Confidentiality.

- Test Case Nº2: Integrity of vaccination records: The test case for this scenario is the verification between the records that are entered and those that are consulted to observe that there have been no changes. This check relates to the total number of tests performed.

$$\%Integrity = \left(\frac{\#\ of\ successful\ comparisons\ R\&O}{\#\ of\ total\ comparisons}\right) \times 100$$

Figure 9: Formula for % Integrity.

- Test Case Nº3: Availability of vaccination records: The availability test seeks to generate requests for consultation of vaccination records and vaccination cards. Availability effectiveness is measured by the ratio of successful queries to the total number of queries made.

$$\%Availability = \left(\frac{\#\ of\ successful\ queries\ VR + \#\ of\ successful\ queries\ VC}{\#\ of\ total\ queries}\right) \times 100$$

Figure 10: Formula for % Availability.

The Blockchain network, of our system, is configured with 3 organizations where each one has a content peer. In this, the information of 453 users between parents and health personnel will be placed. With this, we will be able to validate the security triad in our technological solution. Each test scenario has been designed to validate an item of the security triad, and thus, the correct functioning of the system will be verified, fulfilling the success factors established for the proof of concept.

Table 1: Success factors of PoC.

Test Case	Success Factor
Nº1: Confidentiality of vaccination records	Validate that at least 99% of the data has not been accessed by unauthenticated or authorized users.
Nº2: Integrity of vaccination records	Validate that at least 99% of the data have not been modified when making the comparison.
Nº3: Availability of vaccination records	Validate that at least 99% of the data is available to authorized users who request it.

5 RESULTS

5.1 Confidentiality

As shown in Table II, the records of doses administered, and the vaccination card information could not be accessed by unauthenticated users without the respective permissions.

Table 2: Extract of the results of test case N°1.

	Users	
	Could access the information	Could not access the information
Obtaining medical records as an unauthenticated user	0	460
Obtaining a vaccination card for children who are not your children	0	460

5.2 Integrity

According to table III, the records of administered doses were recorded and compared satisfactorily.

Table 3: Extract of the results of test case N°2.

	Requests	
	Correct	Fail
Register of Administered Doses	456	0
Obtaining and comparing DosesAdministered	456	0

5.3 Availability

In relation to the availability of the system, table IV shows that the records of doses administered and the information on the vaccination card could be obtained satisfactorily in all requests.

Table 4: Extract of the results of test case N°3.

	Requests	
	Correct	Fail
Obtaining Immunization Records	453	0
Obtaining Vaccination Card	453	0

In summary, a minimum of 906 interactions per test have been carried out, simulating the 453 users established in the calculation of the experimental sample, carrying out the 2 interactions per test case. In all the tests, as can be seen in Figure 13, a satisfactory result was obtained, meeting the minimum required of 99.9% effectiveness for the proposed test case. This result, added to the controls of the system itself for the protection of accounts, data, and transactions ensures a robust system not only against its technical aspect but also against the processes and people involved in the child vaccination system.

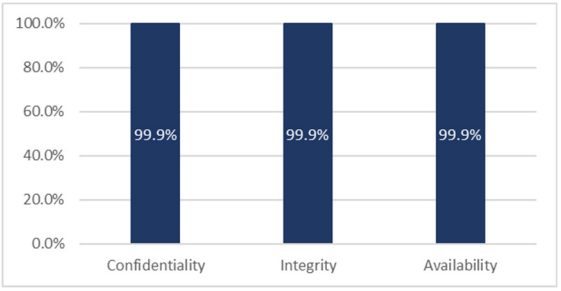

Figure 11: % Confidentiality, Integrity, and Availability of vaccination records.

6 CONCLUSIONS

The research carried out in this work concludes with the functional and technical validation of the developed system. First, an investigation has been carried out to clearly understand the cause of the problem of low childhood vaccination. Through this, functionalities have been designed to adapt to the proposed system and to work in the context of the Peruvian reality. With functions such as the SMS reminder, it is considered that not many parts of the country have a smartphone with an internet signal so that they can be notified by email, specific application, or social network. In addition, an attempt is made to reinforce the idea that vaccines are beneficial for the healthy growth of children and that they are available free of charge and available to parents in the medical centers listed in the system according to the vaccine and location of the child. Therefore, the functional proposal of the solution has several edges considered according to the investigation carried out on the problem and possible similar solutions. Then for technical validation, through the various tests and experiments, the level of effectiveness for the protection of vaccination records that the web application has with the use of Blockchain technology was recorded. These tests sought to verify that the solution complies with the security triad such as Confidentiality, Integrity, and Availability in data protection. After the tests, as can be seen in Figure 13, the developed solution meets the minimum established as a success factor with 99.9% authenticity of information in all the tests carried out. It can be concluded that the Blockchain network integrated in the system complies with security standards and protects vaccination records. This added to the controls in the process that must be carried out by the national health entities such as the designated personnel who should have access to the system and the important nodes described in the architecture for the verification of the chain data, among others. These considerations will allow the solution to comply with the security standards proposed in this work. Another type of research that may arise because of the work carried out is the definition of the implementation within the national system and how it should be coupled to the laws or requirements that exist within the Peruvian state. This research could address other technical, legal, and social aspects for the adoption of the proposed solution. Finally, the research carried out solves the latent problem of the lack of information for the vaccination process and the safety of these in its transmission, that is, a system that informs parents in real time, being supported in the process. And encouraged to follow the childhood vaccination schedule, and at the same time provide protection in

the security of highly critical data that is handled, such as health records.

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