A Blockchain-Based Approach for COVID-19 Vaccine Lifecycle

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Abstract. Vaccination is a cost-effective health practice that prevents or reduces patients' hospitalization, illness, and death. In case of a pandemic as the COVID-19 outbreak, vaccination is a more challenging situation due to the urgency in controlling the spread of a high infecting disease. Public acceptance of vaccines is critical to the success of immunization campaigns, being affected by the poor knowledge about vaccination and the existence of fake news. People need to know who needs to be vaccinated, which vaccines exist, when they should get vaccinated, and where to get vaccinated. Governments and health agencies need to approve, acquire, distribute, and administer the vaccines in a short period. Information related to the vaccine lifecycle is important for decision-makers to deliver vaccines effectively and equitably, through the development of immunization programs and their continuous improvement. Blockchain is a technology that stores data in blocks chained together in chronological order and replicated over a network. Blockchain data is decentralized, encrypted, and cross-checked, which in turn ensures security, immutability, transparency and trust. Such characteristics make Blockchain a reliable platform to address COVID-19 vaccine lifecycle. We investigate how the lifecycle of the COVID-19 vaccine can benefit from an approach based on Blockchain. We discuss the scenarios of vaccine research, production, distribution, and administration, as well as monitoring of disease cases. The main goal of the proposed Blockchain-based approach is to offer a transparent and trustable platform for all stakeholders that take part in the scenarios related to COVID-19 vaccines, including government entities and citizens.

Keywords: Vaccination · Blockchain · Scenarios · COVID-19 · Vaccine · Pandemic

1 Introduction

Vaccination is a fundamental health practice, preventing people from illness, disability, and death. Based on the principle that prevention is better than treatment, vaccines provide the human immune system with the capacity of combating diseases [1,2]. Vaccination has contributed significantly to global health. Important infectious were eradicated or controlled, including smallpox, rinderpest, and measles. There are also efforts toward vaccines to prevent or modulate non-infectious diseases, such as cancer, hypertension, and Alzheimer [3].

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Vaccines are considered cost-effective tools for improving health. Investments in immunization programs can affect positively incomes when considering aspects as worker productivity, children's education, savings, and demographic structure. Healthy workers are more productive and miss less work due to illness. Health supports the cognitive development and the ability to learn of children, while aids school attendance. Sickness leads to medical expenses, reducing people's savings. Population age structure changes with low mortality, resulting in positive economic implications [4,5].

Among the vaccination programs, mass immunization campaigns are complex due to the large number of doses administered in a short time. National Immunization Days is an example of a mass immunization campaign. Fortunately, there are guidelines to support the advanced planning and orchestration of mass campaigns, considering aspects as target group directives, vaccine delivery strategies, and program evaluation [6,7].

Pandemic is a more challenging situation due to the urgency in controlling the spread of a high infecting and unknown disease. It is the case of the COVID-19 outbreak, a disease caused by the coronavirus SARS-CoV-2 [8]. Up to 10th September 2021, there have been more than 220 million confirmed cases of COVID-19 and more than 4.6 million deaths in the world [9]. The developments of COVID-19 vaccines have been an extraordinary success [10]. The safety of vaccines is assured by a rigorous process with tests and licenses, before being introduced into immunization programs [11]. Regulatory authorities are the bodies that approve the use of vaccines. They need to handle issues and communicate consistently during vaccine research in a timely manner. It is also important to keep the monitoring of adverse events following immunization, in order to detect possible abnormalities in vaccines [10,11].

Even with the rapid development of COVID-19 vaccines, public acceptance of vaccines is essential to vaccinate the population properly [10]. Vaccine lack of confidence is a problem that goes beyond scientific rationale, being impacted by social, political, and moral aspects. In order to keep public trust in vaccines, national healthy authorities and governments have to deal carefully with the communication regarding vaccines in case of adverse effects or changes in immunization programs [12]. The causes of vaccine hesitancy include poor knowledge about vaccination, bad experiences with vaccination services, and inadequate perceptions about vaccination importance. So people need to be aware of who needs to be vaccinated, which vaccines exist, when to vaccinate, where to get vaccinate considering accessibility and convenience, and the overall benefit to vaccinate [13].

Beyond communicating the benefits of vaccination and the details of the immunization program, governments have to be able to deliver vaccines effectively and equitably. Governments need to establish principles and processes to guide decisions and actions in vaccine procurement, distribution, prioritization, and administration [10]. Analysis considering vaccine inventories and vaccine distribution is especially of interest for decision-makers to support vaccination programs. Some useful information includes vaccination facilities, human resources, patients arrivals, and patients served [14,15]. The continuous monitoring of a immunization program is also useful to identify errors and adjustments in a way to improve campaigns. For instance, to allow enhancements

in logistics aiming to access population (specially the hard to reach communities), and to identify the need of extra doses to ensure a maximum protection [11].

Besides the inherent difficulties of the vaccination process, the work is aggravated by the spread of fake news. Fake news is news or stories created to deliberately misinform or deceive readers. Usually, fake news is created to either influence people's views, push a political agenda or cause confusion. The fake news spread during the first six months of the COVID-19 pandemic in Brazil was characterized by misinformation about the number of cases and deaths and about prevention measures and treatment [16].

Other aspect that affect negatively the immunization efforts is the erosion of trust in democracy, experienced by many countries in the past few years. For instance, the online voting system with electronic voting hardware, one of the main pillars of democracy widely used in some countries, have not earned unambiguous trust due to security and administrative issues [17]. Shin [18] and Racsko [17] consider that Blockchain technology is a tool for restoration of trust.

It is then of interest an approach to support every lifecycle step of the COVID-19 vaccination in a transparent and trustable way. In a previous work [19], we present a Blockchain-based approach to aid the vaccination process for any type of disease. We highlighted the main actors involved in the vaccination scenario as well as their responsibilities, focusing mainly on the vaccine administration. We did not cover the entire lifecycle. In this article, we focus on the COVID-19 vaccination and consider the overall lifecycle.

Blockchain is a technology that stores data in batches (called blocks) that are then chained together in chronological order. Since Blockchain data in replicated over a network, there is not have a single point of failure nor the control by a single entity. Any node on the network is able to download the Blockchain and verify new data using a block's hash value, providing transparency to data. Additionally, the Blockchain data is practically immutable since it is required huge amounts of computing power to alter data on the Blockchain. There is also a consensus mechanism among network nodes to decide which blocks are stored in chains, contributing to trust in data [20,21]. To summarizing, Blockchain technology allows transparent, incorruptible, and trustable data, making it potentially an ideal platform to address the COVID-19 vaccination lifecycle.

In this paper, we investigate how the lifecycle of the COVID-19 vaccine can benefit from an approach based on Blockchain. We discuss the main scenarios of the lifecycle that include research, production, and distribution of the vaccine. We also detail the Blockchain scheme in the vaccine administration process and in the monitoring of COVID-19 cases. The main goal of the proposed Blockchain-based approach is to offer a reliable, transparent, and trustable platform with COVID-19 related data for all stakeholders, including government entities and citizens. The approach supports regulatory agencies to make more informed decisions by accessing data about the stages of vaccine development. The approach is useful for decision-makers to improve the vaccination campaign with up-to-date knowledge about the availability of the produced vaccines, the logistic of distribution in the country, and the tracking of new and re-incident cases of the COVID-19 disease. The advantages for citizens include information about vaccines' characteristics and immunization locations, as well as the provision of a vaccination certificate.

The paper is organized as follows. Section 2 presents the background of our work. In Sect. 3, we present the scenarios, supported by Blockchain, of vaccine research, production, distribution, administration, and monitoring. Section 4 discusses the advantages of our approach and some concerns related to security and data privacy. Section 5 concludes our work and indicates future investigations.

2 Background

COVID-19 changed many facets of the healthcare environment. Global collaboration was established to share data, aiming to identify treatments and to develop a vaccine. The widespread outbreak led to more agile vaccine research, for example with accelerated clinical trials and quick adjustments in vaccines to respond to virus variants [22]. Government entities received the collaboration of the private sector to combat COVID-19, for instance, the initiatives of Google [23] and Amazon [24] to aid vaccine distribution. The need to monitor COVID-19 vaccination fomented the development of new strategies, such as the V-safe [25], which is a mobile application when US citizens can notify side effects after vaccination.

Distinct works are being developed to propose and validate strategies to aid society and governments in the combat of the COVID-19 outbreak. Singh et al. [26] discuss how technologies can be used in situations, such as testing, contact tracing, spread analysis, sanitization, and protocol enforcement. They suggest that autonomous vehicles (aerial or grounded) can transfer samples to labs, while Blockchain can record the test details. They explain that IoT and smartphone apps can identify people that have contact with someone infected, while Blockchain can register such tracing data. Blockchain is also mentioned to record places with proper sanitization, and transactions of protocol violations.

Peng et al. [27] propose to use Blockchain in the supervision of vaccine production. Nowadays, enterprises control entirely the vaccine production record, and they send information to health regulatory agencies only in the approval phase. The idea is to stimulate enterprises to submit production records in a timely manner, assuring data reliability and privacy. Antal et al. [28] focus on applying Blockchain the COVID-19 vaccine supply management. They outline a general scheme for vaccine distribution and administration and provide an implementation of smart contracts. Omar et al. [29] propose a smart contract to handle vaccines' procurement, in a way to promote transparency and minimize purchase timeline.

Musamih et al. [30] discuss a Blockchain-based solution for distributing COVID-19 vaccines, aiming to automate traceability and to guarantee trust in the process. The vaccine distribution in future pandemics is studied by Verma et al. [31]. They consider Blockchain to record checkpoints from vaccine production to destination, and unmanned aerial vehicles to assist such delivery. Ricci et al. [32] investigate how Blockchain can aid the COVID-19 combat in areas as contact tracing and vaccine passport provision. They also comment about cryptographic techniques to preserve security and privacy. Eisenstadt et al. [33] developed a mobile application, using Blockchain

in the architecture, to emit certification of test results and vaccinations. They consider aspects as tamper-proof and privacy preservation, explaining the use of public/private key pairs and digital signatures in the solution.

The related work considers distinct Blockchain projects and solutions that are emerging to address COVID-19. Each work deals with specific scenarios of the vaccine lifecycle. Our proposal provides a complete vision of how Blockchain can support the COVID-19 vaccine scenarios, including research, production, distribution, administration, and monitoring. Our goal is to detail the interplay of actors and their responsibilities, always indicating the benefits of a Blockchain-based solution.

3 Blockchain Scenarios Related to COVID-19 Vaccine

A vaccination program is a complex endeavor and can vary in implementation depending on the country. Motivated by the COVID-19 outbreak, here we bring a general approach that can be customized according to specific demands. We present the main actors that participate in the vaccine scenarios. Later, we detail the scenarios related to a vaccine, including research, production, distribution, administration, and monitoring. The actors considered are: *Government*, *Health Regulatory Agency*, *Person*, *Research Institute*, *Manufacturing Site*, *Purchasing Entity*, *Vaccination Centers*, *Nurse Team*, *Health Entity*, *Officer*, *Testing Sites*, and *Hospitals*. Each actor is responsible for accomplishing specific tasks. Each actor can retrieve data and/or insert data in the Blockchain.

Government refers to the entity that controls and coordinates the overall vaccination processes of a country. *Health Regulatory Agency* protects the country and the population from health, safety, and security threats. It is responsible to assure vaccination safety, by regulating and monitoring *Research Institute*, *Manufacturing Site*, and *Vaccination Centers*. *Person* is a citizen of the country who has a registry provided by *Government*. The person actor can access her/his vaccination history and public information related to the vaccines. *Research Institute* refers to institutes that research and develop a vaccine. It is responsible to conduct and register all the stages of vaccine development, as well as vaccine quality control. *Manufacturing Site* produces, trades, and delivers the authorized vaccines. A country can host national and international *Manufacturing Sites*. *Purchasing Entity* buys the vaccine produced by a *Manufacturing Site* and delivers it to *Government*.

Vaccination Centers are the places that immunize the citizens, following the authorization of *Health Regulatory Agency*. Each *Vaccine Center* has its vaccine stock and *Nurse Team*. *Nurse Team* is the group of professionals who interact directly with the citizen in an immunization campaign. The team has professionals to identify if the person is entitled to the vaccine, check the availability of the vaccine, and apply such vaccine. *Health Entity* is an entity of *Government* that organizes the vaccination campaigns in different levels as federal, state, or municipal. Its goal is to guarantee vaccines' distribution and to define directives for *Vaccination Centers*' operation. *Officer* represents an individual in a society who controls access of persons to facilities depending on the inspection of vaccination certificates. An example is the safety & security officer of an airport. *Testing Sites* are places that conduct testing to verify if a person is infected or not. *Hospitals* are locations responsible for treatment when infected people require medical assistance.

Blockchain is the platform where data is stored reliably. The data can be classified as private or public. Such classification is important to define to which data the actors can have access. We consider that the COVID-19 Blockchain is public and it should be maintained by all the stakeholders. We envision that additional stakeholders can be considered, such as news agencies, legislative and judiciary powers, and non-governmental organizations.

In order to explain the benefits of using Blockchain in the vaccine lifecycle, we employ sequence diagrams to describe how the actors interact in the various scenarios. The diagrams present the main flow of the processes. Eventually, some alternative flows are considered. The vaccine research diagram is shown in Fig. 1. During the vaccine development, *Research Institute* must register in the Blockchain the useful information to support the decisions of *Health Regulatory Agency*. These data are related to the stages of vaccine development. The stages include exploratory, pre-clinical and clinical development (with 'Phase 1', 'Phase 2' and 'Phase 3'). Details on the purpose of each stage of development can be found in [34].

The support given by Blockchain in Fig. 1 allows making the vaccine approval or disapproval faster and reliable since *Health Regulatory Agency* follows the updated data directly. *Health Regulatory Agency* is then instrumented to make decisions of granting license to the clinical stage and approving the vaccine. The registering of vaccine information is critical to *Health Regulatory Agency* anticipate the interactions with *Health Entities*, in order to plan the entire immunization program. After the vaccine approval, *Research Institute* decides the start of the 'Phase 4' of vaccine evaluation. Moreover, *Health Regulatory Agency* can continuously monitor the quality control conducted by *Research Institute*. For instance, *Health Regulatory Agency* can be informed of possible side effects or the need for extra doses to complement immunization.

Figure 2 presents the diagram of vaccine production. The vaccine production is performed by national or international enterprise, here named *Manufacturing Site*. *Manufacturing Site* accesses the information about the production of approved vaccines in Blockchain, previously provided by *Research Institute*, for instance, the raw materials and the required storage conditions. The production itself starts with a purchase contract between *Purchasing Entity* and *Manufacturing Site*. Such a contract (with price and payment conditions) is out of the scope of our proposal, being negotiated and registered out of the chain.

Manufacturing Site in Fig. 2 records data about production requests in Blockchain (for example, vaccine type and quantity), the estimated delivery date, and the start of production. The information is useful for auditing reasons by *Government*, for instance, who needs to manage the provision of vaccines in a country. *Manufacturing Site* can experience anticipations or delays in production, due to particular situations with suppliers. In this case, *Manufacturing Site* updates the delivery estimation in Blockchain. It is important to observe that *Purchasing Entity* can be a private entity or a governmental entity. For example, in Brazil, only federal entities can purchase COVID-19 vaccines during the crisis [35].

Purchasing Entity follows the purchase information in Blockchain, in a way to improve planning and to adapt vaccination campaigns. At the end of production, *Manufacturer Site* registers the shipping of vaccines and *Purchasing Entity* confirms the

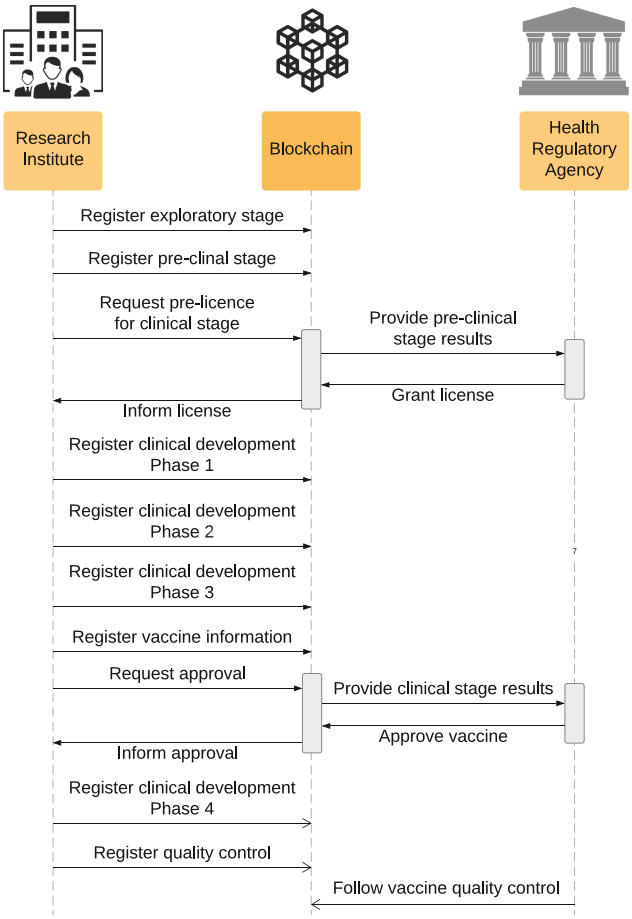

Fig. 1. Vaccine research supported by Blockchain.

receipt in Blockchain, allowing the detection of intentional or non-intentional cases of misplacement. Additionally, this diagram can be extended to include the suppliers of *Manufacturer Site*, which provide inputs, such as active pharmaceutical ingredients, to manufacture COVID-19 vaccines.

The diagram in Fig. 3 presents a vaccine distribution case, considering an integrated scenario where *Government* controls the purchase and the distribution of vaccines. In Brazil, for example, we have a hierarchy of command regarding the healthy administration that includes *Federal Health Entity* (responsible for the entire country), *State Health Entity* (in charge of a given state), *City Health Entity* (responsible for a given city). *City Health Entity* manages *Vaccination Centers* in its jurisdiction. In order to understand the vaccines' demand and organize their distribution, we follow a bottom-up strategy, where *Vaccination Centers* reports their demands to *City Health Entity*; *City Health Entity* reports its demand to *State Health Entity*; and *State Health Entity*

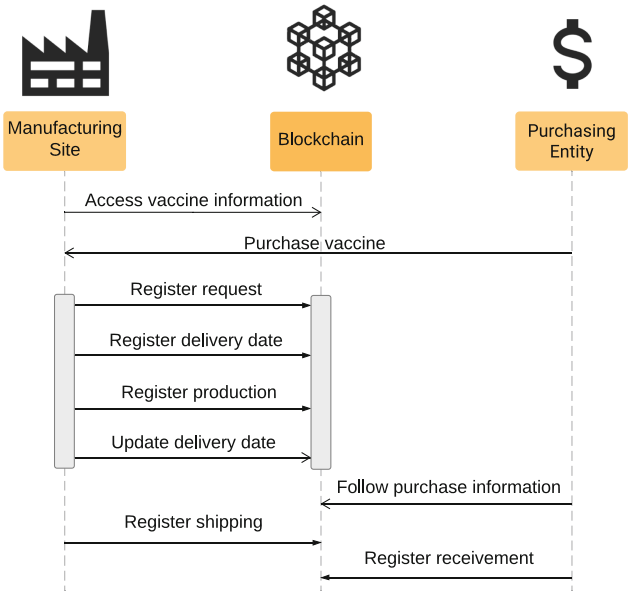

Fig. 2. Vaccine production supported by Blockchain.

reports its demand to *Federal Health Entity*. The report includes information such as the number of people to be vaccinated, storage capability, current stock, available transport conditions, and geographical restrictions. The goal is to have enough information to elaborate a complete vaccination plan. The vaccine delivery proceeds in a top-down way, where *Federal Health Entity* deliveries vaccines to *State Health Entity*, and so on until reaching the citizens in *Vaccination Centers*. Each shipping and receipt step is stored in Blockchain, in order to enable the proper tracking of vaccines.

The diagram in Fig. 4 refers to the vaccine administration. Using Blockchain, *Person* can access her/his vaccination history (i.e. the vaccines already received), check information about the approved vaccines, and find vaccination centers to receive a vaccine. When the person arrives in a *Vaccination Center*, he/she presents the identification to *Nurse Team*, who is responsible to check the identity in Blockchain. *Nurse Team* accesses the vaccination history of *Person*, in a way to verify if it is possible to proceed with the vaccination. For instance, the influenza vaccine requires an interval before the administrations of other vaccines. In case of no impediments, *Nurse Team* informs *Person* about the administration, *Person* authorizes it and receives the vaccine. Blockchain keeps the information in two perspectives (of the nurse and of the beneficiary), avoiding cases of disrupted information, such as mismatch between the number of used doses and the number of immunized people. The information about the applied vaccines is also useful for controlling the stock in *Vaccination Center*. After receiving a vaccine, *Person* obtains the vaccine certification. Vaccine certification is a document that proves that a person is immunized with a vaccine. The verification of a vaccine certification, made by a *Officer*, is useful to allow access to places as restaurants and arenas, as well as to travel

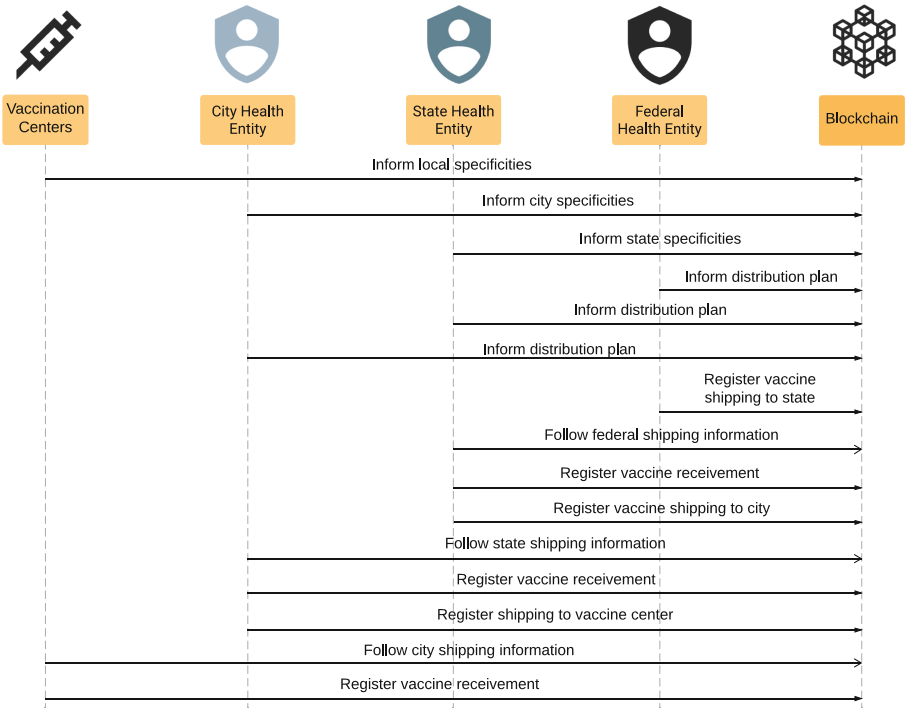

Fig. 3. Vaccine distribution supported by Blockchain.

abroad. The diagram can be extended to support the booking of vaccine appointments. In this work, we restrict to a case of COVID-19 vaccination. However, the diagram can include activities to coordinate the vaccines needed by a person, in compass with the other existing vaccination programs.

The scenario regarding vaccine monitoring includes two situations: testing (shown in Fig. 5) and hospitalization cases (shown in Fig. 6). According to Fig. 5, *Person* desires to perform COVID-19 testing, in order to check if he/she is infected. The team in *Testing Site* is responsible to validate the person's credential, performing the testing, and register in Blockchain the result and other data related to the test (such as the date and test type). The diagram in Fig. 6 considers a *Person* with COVID-19 symptoms, who needs medical assistance. The team in *Hospital* identifies the patient and analyses her/his medical history. The vaccination history is important to know if the patient is already vaccinated. The testing history informs if the patient was previously infected. In case of no recent testing confirmation registered, new testing can be conducted in *Hospital*. Other steps in the diagram consider that the person really is infected. So, the doctor informs the diagnosis and conducts the patient's treatment. *Hospital* record in Blockchain information about the case that is relevant to the disease monitoring, for instance, if the patient is a new or recidivist, severity (i.e. moderate, severe, or critical

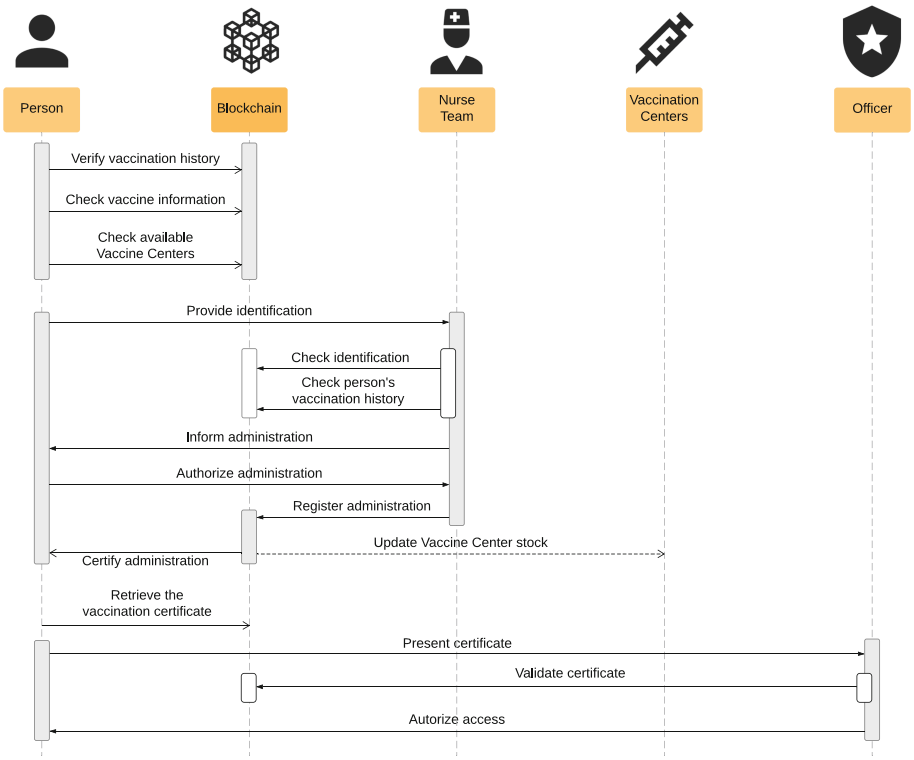

Fig. 4. Vaccine administration supported by Blockchain.

symptoms), and hospitalization finalization (by patient death or discharged from the hospital).

The monitoring information, available in Blockchain, can benefit *Research Institute* to conduct the quality control of the vaccine, by exploring the effectiveness of the vaccine especially in recidivist cases and severe hospitalization situations. The monitoring information in Blockchain aids *Government*, together with its *Health Entities*, to understand the spread of the disease, to identify critical areas with more infected people, to propose new treatments, to adjust the vaccination campaign, and to improve the vaccine distribution plan. Other technological solutions can be created to anticipate the identification of new COVID-19 cases, by tracking the contacts of people with confirmed infections.

4 Discussions

Our proposal is an initial step towards the incorporation of Blockchain as the technological platform to support the vaccine lifecycle. We highlight the scenarios of vaccine research, production, distribution, administration, and monitoring, explaining the benefits of having vaccines' information stored in a reliable way. The reliability of

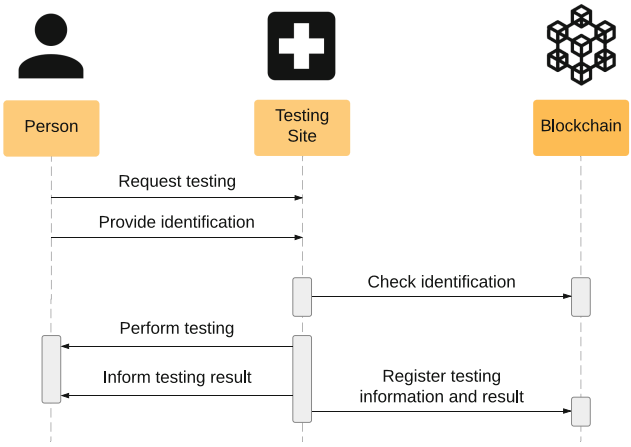

Fig. 5. Testing monitoring supported by Blockchain.

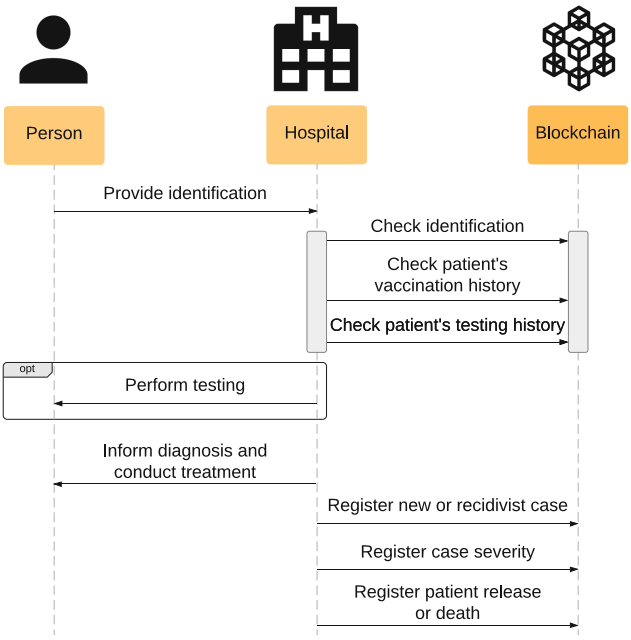

Fig. 6. Hospitalization monitoring supported by Blockchain.

Blockchain is associated with the fact that it uses distributed ledgers to record data. The information is replicated in computers or systems across a network. Besides, only read and write operations are authorized, avoiding the elimination or modification of transaction records.

Two concerns are of paramount importance in the approach: data privacy and cybersecurity. To deal with data privacy, one needs first to classify the Blockchain data into public or private data. Public data refers to any data that does not need protection and is intended to make the Blockchain transparent and trustable. Private data is any information that can be sensitive or valuable for a person or entity. Considering the privacy aspects, data must be stored in a way to avoid linkability, detectability, and identifiability. Linkability of two items of interest allows an attacker to distinguish whether these items of interest are related or not, for instance, the link between the person and her/his hospitalization. Some people may prefer not to disclose that they were hospitalized. Detectability of an item of interest means that the attacker can sufficiently distinguish whether such an item exists or not, for instance, if the person is not vaccinated. Some people prefer not to make public the fact that they are not vaccinated. The identifiability of a subject means that an attacker can sufficiently identify the subject associated with an item of interest, for instance, the attacker might identify the vaccinated people that have comorbidities. A person may prefer not to disclosure that he/she has comorbidities for professional reasons. This may pose a challenge if the campaign has exclusive dates for vaccination of people with comorbidities and the date of vaccination is made public in the certification.

The process of vaccine research has very sensitive information, for instance, those related to vaccine components and tests before its certification. Such data can be valuable for other companies and generate undesired competition among *Research Institutes*, impacting negatively the market. The private data generated by *Research Institute* can be accessed by *Health Regulatory Agency* anonymously, under permission, for license analysis and final approval of the vaccine. *Research Institute* also contributes with public data for citizens with the information related to a vaccine, for example, efficacy, common side effects, and the interval between doses. Another example of private data is personal identification. The person registration is of the responsibility of *Government*, but the person needs to keep updated data (such as address and telephone number). The vaccination history, the testing history, and the eventual medical records are all sensitive information since they can expose a person.

Besides dealing with data privacy, it is also desired to ensure the cybersecurity of the information in the vaccine lifecycle. Considering the cybersecurity aspects, the system in our approach must offer an authenticated and confidential channel for sending information, where only authorized users can access or edit the data. For instance, in production and shipping operations, although such data is important for managing and tracking purposes, it can be used by attackers to steal the vaccines during storage or transportation. Besides identifying all data required for the scenarios in the vaccine lifecycle, a dedicated effort is needed then to classify and protect data, aiming to avoid data leaks and security breaches.

A major concern about people immunization is to guarantee equal access to the vaccine for every citizen, so every location needs to receive the right quantity of vaccines. To solve this problem, in Brazil, the vaccines are distributed according to the percent of the population for each state and city, so the immunization process occurs at the same speed for the entire country. This strategy requires *Government* to have the updated population number. In Brazil, the population number is controlled by a census

that is carried out in 10 years. As ten years is a long period, it can generate a disequilibrium between the needs and the offer. In our proposal, as each person is responsible for updating her/his personal data in Blockchain, it is possible to have the same result as a decade-long census in just a few minutes. *Government*, in possession of more accurate information, can improve vaccination's strategic plans.

The system that implements the proposed Blockchain-based approach should consider accessibility and usability aspects. Accessibility refers to offer a diversity of technological interfaces, for instance, web applications and smartphone applications, in order to address more diverse users, including disabled citizens. Regarding usability, the system needs to be used by the distinct public, including teenagers, adults, and elderly people. The system needs to consider easy navigation, visual clarity, engagement, and error tolerance.

The great challenge for the adoption of the proposed approach is to manage the orchestration of operations of all actors, ensuring security and data privacy, and at the same time providing transparency and trust. Nowadays, we lack a pattern to store and share information among actors. With a *Government*'s regulation, it is possible to establish such pattern and to benefit the entire vaccine related network.

5 Conclusions

The vaccine is a global tool to stimulate the body's immune response against diseases, being a cost-effective solution to improve human life expectancy. The vaccine lifecycle has several stages, including research, production, distribution, administration and quality control. Such stages need to be controlled by stakeholders and supervised by healthcare authorities. The information associated to every step is critical for studies regarding vaccine efficiency and for managing vaccination campaigns. In this paper, we proposed an approach, supported by Blockchain, to handle the interplay among distinct actors in the vaccine lifecycle. We consider that Blockchain technology is ideal to implement the COVID-19 lifecycle transactions because it provides immediate, shared and completely transparent information stored on an immutable ledger that can be accessed only by authorized users. We consider that the platform should be maintained by all the stakeholders to avoid the control of single entity.

For each stage in the vaccine lifecycle, we present a sequence diagram with the main actors, their interactions, and the relevant data to be stored in Blockchain. The proposed approach aids actors to anticipate information regarding vaccines' development, in a way to foster approval and adoption of vaccines. Entities that are responsible for acquiring and distributing vaccines, can develop more informed plans in order to conduct better vaccination campaigns. Citizens can benefit from the proposed approach by accessing the vaccine's transparent information and her/his vaccination history, and by identifying available locations to be vaccinated. Hospitals can record data related to testing, hospitalization, and treatments. These data can support the monitoring of the effectiveness of vaccines. It also helps the creation of strategies regarding treatments, disease tracking, and pandemic control.

As future work, we intend to explore the specific data required in each scenario, as well as to study how to guarantee data privacy in the scenarios. It is needed a further investigation regarding security aspects, in order to identify the mechanisms to be

added in the solution to mitigate security threats. It is of interest the development of Blockchain smart contracts to implement the proposed scenarios and test them in practice. A continuous field of investigation is the integration of the Blockchain with other technologies (such as IoT), in a way to improve services and the overall vaccination program.

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