A Blockchain Approach to Support Vaccination Process in a Country

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Abstract: Vaccines are important means to prevent diseases and save lives. Data related to vaccination process, such as vaccine identification and number of vaccinated people, is critical to the production and distribution of vaccines in a way to achieve the desired immunization in a country. We propose a reliable approach based on Blockchain to manage vaccination data. We describe the roles played in a vaccination process as well as their relations. Aiming to validate our approach with a prototype, we present the data required in two scenarios, including the registration of a vaccine administration and the visualization of the vaccination history of a citizen. We discuss the potential of our proposal, by indicating analysis that can be conducted with the vaccination data, as well as challenges to be addressed in further investigations.

1 INTRODUCTION

Vaccines are an essential instrument used for life preservation and protection of people against different and harmful diseases. Vaccines train the immune system to create antibodies without the person come into contact with the diseases. To get vaccinated is critical not only to protect the own individual, but also to help reduce the spread of diseases (WHO, 2021). In many countries the vaccination process is a human right for any citizen. A government has concerns about vaccination control, distributed batches and immunized people. There is then a particular way to manage the vaccination process of population (Brazil, 2020). To accomplish its goals, a common practice is the creation of strategic vaccination plans (Anderson et al., 2012).

However, just having a vaccine is not enough; traceability is required in order to know production location, storage locations, warehouse conditions, manufacturer, and other information. This data provides a way to ensure vaccine quality and safety in vaccine supply chains (Yong et al., 2020). With data about population and vaccination, it is possible to improve the vaccine management and medical resources (Anderson et al., 2012).

By analyzing short periods of time, vaccines prevent disease dissemination and decrease the mortality. When considering long periods of time, it is possible to identify people that tend to have better health conditions, high rate of life expectancy and reduced spends on medical care with a specific disease that has a vaccine (Yong et al., 2020). Vaccines have an important function to society in the immunization process, since they aid to eradicate or control diseases that injury people through years, being a cost-effective way to protect people.

In a pandemic case, a vaccine can be the best option as a countermeasure. Individuals are in general prioritized to receive the vaccine based on their risk profile and transmission rates. A good strategy is essential for the success of an immunization process (once the disease generally affects more specific groups of people), always considering an effective use of vaccine resources (Özaltın et al., 2014). The used strategy is evaluated with behavioural mathematical models (Brazil, 2020). Nevertheless, data regarding vaccination is needed in order to have foundation for accurate analysis and strategic plans. Obtaining such data can be a problem to many countries (Palacio et al., 2017). A common issue is to register vaccines on a paper of each individual, without any backup record. The main challenges in vaccination process is then regarding traceability, lack of information, and lack of patterns.

In this paper, we describe a reliable approach to support the vaccination process of a population, by registering vaccination data in Blockchain. Blockchain consists of distributed ledgers, well-know by the cryptocurrency Bitcoin, but that also has the attention of many different industries. In Blockchain, data is distributed across the network, which makes

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difficult a data tampering attack. There is also a consensus mechanism among network nodes to decide which blocks are stored in chains (Malik et al., 2019)(Nofer et al., 2017). In our proposal, we detail the existing roles in the vaccination process and their relations. Roles are described considering their responsibilities in recording and accessing data.

In the next section, related work is presented. In Section 3, we describe a prototype that implements the proposal, by focusing on vaccine administration. In Section 4, there is a discussion about the implications regarding the proposal. In the last section, we present concluding remarks and indicate future work.

2 RELATED WORK

Traditional vaccination methods consist of a technique called number labelling (Yong et al., 2020), which does not allow accurate vaccine traceability. Using number labelling, there is only estimated numbers of a situation, without a confirmation if these numbers represent the reality. For instance, a government knows the vaccine doses number per region and used doses; however, they do not know who is vaccinated in a given neighbourhood or city.

Vaccination process faces challenges. For instance, records can be forged in order to hide the real numbers of vaccinated people or vaccines dosages can be stolen (Yong et al., 2020). In the cases of large amount of immunizations with no centralized data, it is faced difficulties on data computation (Peng et al., 2020). With a data tampering attack, it is possible to lose relevant data (Peng et al., 2020). There can also be cases in which people travel to another region to get the vaccine, impacting the resource allocation (Queiroz et al., 2020). It is important to have a coordination between vaccine transportation and production, providing vaccine distribution supervision (Hu et al., 2019). Furthermore, the lack of registered records can make more difficult a vaccination campaign (Eisenstadt et al., 2020).

Yong et al. (2020) proposes a work that uses Blockchain and machine learning in the management system for the supervision of vaccine supply. The main concern is to provide a reliable mechanism where it is possible to trace problems during the vaccine production, such as vaccine expiration and vaccine record fraud. The mechanism also suggests a vaccination recommendation, allowing to identify the better vaccine in a given scenario. Despite of presenting an architecture, the authors do not describe roles or protocols to be adopted by the tool.

Peng et al. (2020) present a work centered on a safe vaccine production, using Blockchain method for supervision. The idea is to keep private enterprise data and public information with product records and vaccine information (e.g. vaccine name, expiration date). The work presents an initial application of Blockchain; however it does not present details of the roles in the suggested process.

Eisenstadt et al. (2020) describe an approach to certification, using Blockchain and mobile devices. The work aims to improve the development phase of an antibody or a vaccine, in order to provide data to the certification process (by preserving privacy). The authors present briefly the roles when using their tool.

Due to Covid-19, Brazilian government created the “Conecte SUS” app to have a digital record of vaccination. It aims to trace the vaccination in public and private institutions (Brazil, 2021). The work describes and discusses usability and scalability of Blockchain on mobile devices platforms. It provides an explanation of the vaccination registry using a smartphone, but the system as a whole is not detailed.

3 A BLOCKCHAIN APPROACH FOR VACCINATION

Here we describe our digital approach to aid the vaccination process in a country. We present a scheme with roles and their relations, considering the process since the production of a vaccine until its inoculation. The goal is to address problems related to lack of registration records and standardization of records, which in turn can aid the definition strategic vaccination plan, as well as the coordination of vaccine production and distribution. As a digital platform, we use of Blockchain mainly due to its reliability characteristic. So, it is possible to eliminate the lack of records (since information about the vaccine is registered), to avoid data tampering and to mitigate cases of forged records.

It is known that vaccination is a complicated process, which can be different in distinct countries. In this paper, we detail a general and reliable protocol. Figure 1 shows the proposed approach. Roles are needed to be defined in a way to control data manipulation in the Blockchain. In order to control data consistency, we delimit what kind of data each role is allowed to register or fetch.

Government refers to the entity that controls and coordinates processes around a society. *Government* is the main role and it is allowed to access almost all data. *Person* represents any individual in a society. A *Person* can receive a vaccine. *Enterprise* is responsible to develop, test and distribute vaccines. *Vac-*

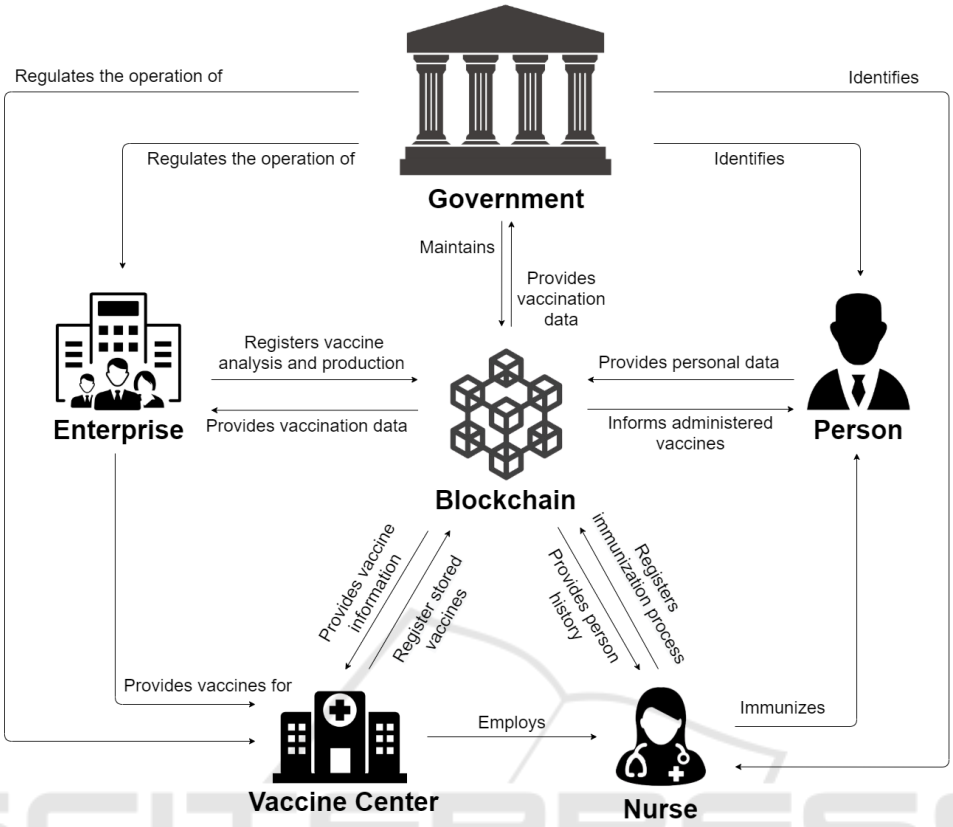

Figure 1: Blockchain approach for vaccination with roles and relations.

cination Center is any medical center authorized by *Government* to vaccinate people. *Vaccination Center* receives and stores vaccines. It has *Nurses* who can immunize *Person* using vaccines. *Nurse* refers to any professional allowed to immunize people, who is registered in a *Vaccination Center*.

Blockchain represents the network that *Government*, *Enterprise* and *Vaccine Center* access and where data is stored. Data is classified into public and private data. The main reason of using Blockchain technology is because it is a decentralized public ledger system and it has intrinsic consensus protocols (Saito and Yamada, 2016). An attack to this network requires a considerable cost and time, which so discourages the attack. At the same time, by using decentralized records, it can be easy to access information in a reliable way (Yang et al., 2019).

3.1 Roles in Detail

Here we better specify the roles of our approach, by describing the expected interactions and permissions.

3.1.1 Government

Government plays a crucial role in assuring veracity and integrity of data (stored in Blockchain) related to other roles. The main reason is that governmental entities must regulate processes regarding the approval of vaccines, the registration of citizens, and the operation of companies.

We assume that there is only one *Government* in this approach, including its various levels of hierarchy. Since everyone in society needs to follow rules, the *Government* may have access to all the information about the vaccine test and composition. It allows fast analyses and accurate answer in many cases, such as a pandemic case, or to create strategic vaccinations plans.

Government accesses the following data: vaccine to be certified, vaccine information, vaccine analyses, vaccines stored in a *Vaccination Center*, and *Person*'s history. *Government* has privilege to register the following data: *Person*'s identification, *Vaccination Centers*, *Enterprises*, strategic plan, certified vaccines, *Enterprise* inspection, *Vaccination Center* inspection, and *Person* inspection.

Such information characterizes the core data used

by other roles, allowing the system to work properly. The majority of this information needs to be public, in a way to provide data visibility to everyone on eligible legal places. Information regarding *Person* identification needs to be private in order to keep individual rights of privacy. Moreover, private data is all those that can be linked and later used to identify a *Person*, for instance, the information about who takes a given vaccine.

3.1.2 Person

Person has its identification provided by *Government*, which is used to access its personal history. It is expected to have cases where a given person has more than one role, for instance every *Nurse* is also a *Person* in society.

Person registers only its personal information, such as telephone and address. It verifies in the system all the administrated vaccines in his/her life history. *Person* accesses the public information about the vaccination process, for instance: certified and stored vaccines; inspections in *Enterprise* and *Vaccination Center*; and vaccines' information and analysis. The goal is to provide means to *Person* to find relevant information about vaccines and to choose places to be immunized.

3.1.3 Enterprise

Enterprise is responsible for documentation, research and production of vaccines. It is expected that a country has many authorized *Enterprises*, including national and foreign ones. Each *Enterprise* has its private data (such as a detailed description of business rules, and scientific methods) and contributes to public data (such as tests and vaccine information) in Blockchain.

Regarding the privileges for data registry, *Enterprise* can provide data about vaccines considering distinct phases as: research, development, test, and certification. The objective here is to give to society knowledge about the implications of the use of some vaccines, mainly if a vaccine has side effects on a determined group of people.

For *Enterprise*, it is specifically important to access *Person*'s inspection, in a way to support a market analysis and start a vaccine production. The *Enterprise*'s private data needs to be accessible only by itself. In case of audit or vaccine certification, *Government* can access some critical data provided by *Enterprise*.

3.1.4 Vaccination Center

Vaccination Center has access to all the *Enterprise*'s public data and the *Person*'s data. *Vaccination Center* provides immunization records only of vaccines approved by Government. *Vaccination Center* accesses the *Person*'s information in order to provide the correct diagnosis for vaccine application.

Data that *Vaccination Center* can access includes the certified vaccines. Besides, data regarding the *Vaccine Center* inspection is useful to provide feedback for vaccine usage based on data statistics. As privileges for data registry, *Vaccination Center* registers contracted *Nurse* and stored vaccines. The information about stored vaccines needs to be public, since it can be valuable to a citizen to search where vaccines are available.

3.1.5 Nurse

Nurse has access to the vaccine's public information and the *Person*'s information, since *Person* provides a identification to receive a vaccine. *Nurse* registers in the system the vaccines administrated to *Person*. In this way, *Person* has its vaccination history available at any time.

Nurse is responsible for administrating only the necessary vaccines, given the provided *Person*'s history and diagnosis. As well, *Nurse* has the compromise to keep all the *Person*'s data secure, aiming to preserve privacy. *Nurse* also reports to *Vaccination Center* about the consumed supplies and immunized people.

3.2 Blockchain Data

In order to describe the needed data to be kept in Blockchain, we consider a specific phase of the vaccination process: the vaccine administration, which means when someone is immunized with a vaccine. The vaccine administration is an essential phase, since it supports the extraction of accurate information to make vaccination analysis.

The Blockchain data needed to the vaccine administration is the following:

1. **Patient Identification:** a record to identify a person. All the person history is linked to this identification.
2. **Vaccination Center Identification:** a record to identify a medical center. With this data, it is possible to identify the flow and demand for vaccine supplies.
3. **Nurse Identification:** a record to identify each nurse.

4. **Vaccine Identification:** each vaccine needs to have its identification (e.g. vaccine for COVID).
5. **Vaccine Manufacturer:** identification of manufacturer, since *Enterprise* who produces the vaccine needs to be specified.
6. **Vaccine Batch:** each vaccine has a batch, being possible to have many batches of the same vaccine. *Enterprises* should inspect all vaccines batches and store their data.
7. **Location:** place where the person was immunized, since it is necessary to know the correct location given that *Vaccination Center* can change its address later.
8. **Date of Administration:** the date when the person received the vaccine.
9. **Vaccine Expiration Date:** the date in which the vaccine is still valid.

All data stored in Blockchain network can be used by approved governmental entities, which can conduct specific studies and analysis, in benefit of all roles. For instance:

- Number of people immunized by a given vaccine: It provides evidences about preference or usage of a specific vaccine type.
- Number and location of people immunized by a given vaccine: It helps *Enterprises* to plan vaccine production. Besides, it assists *Government* and *Vaccine Centers* to predict new purchases, and to create distribution plans considering logistics cost-benefit.
- Number of people, location and vaccine identification: It aids the creation of a new vaccination campaign, the prediction of second pandemic waves, and the distribution of medical suppliers.
- *Person*'s identification and vaccination history: It is used to identify vaccines that need to be administrated to an individual.

Give all data stored in Blockchain, several data combinations can be made to extract information and knowledge regarding vaccination in a country. We presented only some examples above. The exploitation of other combinations has potential to be addressed in future research.

4 PROTOTYPE

This section describes an implementation of a prototype that enacts the approach to manage the vaccination process. We implemented smart contracts related to vaccination administration in Ethereum (a Blockchan platform), using Solidity as programming language. We used Remix (an Ethereum IDE) to implement and deploy the smart contracts on a private local Blockchain.

The private local Blockchain was supported by Docker containers. Docker containers are considered due to their easy usage and possibility of project scalability, being more practical than working with virtual machines. The Blockchain network has three mining nodes. There was also a third party service for network monitoring, named as *Ethereum Network Status* (shown in Figure 2). The mining nodes were accessed through a Remote Procedure Call (RPC) interface exposed to the host by the service containers. The *Ethereum Network Status* was exposed through the HTTP protocol on a host port.

The front-end layer was based on Next.js (a React Framework) and used the smart contracts exposed by the Blockchain network through RPC, in a way to provide data storage and retrieval. The prototype has mainly two functionalities: to register a vaccine administrated to a patient, and to provide visibility of a patient's vaccination history.

Figure 3 illustrates the usage of the vaccination registration form, responsible to input data into the Blockchain when a given vaccine is administrated to a given individual. The following fields are required: patient name (as 'James Miller'), vaccination location (as '297 Grant Avenue, Auburn NY 13021'), vaccination center (as 'IVI - International Vaccine Institute'), nurse (as 'Patricia Williams'), and vaccine identification (as 'AZD122-Pfizer').

Through the front-end application, it is also possible to check all vaccination history of a given patient, which is illustrated in Figure 4. It is shown the patient information: individual ID in the country (as '324-53-9801'), and patient name (as 'James Miller'). Later, there is a table for each received vaccine. In this figure, there is one vaccine with the following information: type (as 'AZD1222'), manufacturer (as 'Pfizer'), batch (as '100'), expiration date, application date, application location (as '297 Grant Avenue, Auburn NY 13021'). There is also data about the vaccination center related to that vaccination, including: name of the center (as 'IVI - International Vaccine Institute') and nurse identification (as 'Patricia Williams').

5 DISCUSSION

Using Blockchain to support the registration of vaccination data, we propose a reliable approach to coordinate vaccination. It can solve or mitigate problems in

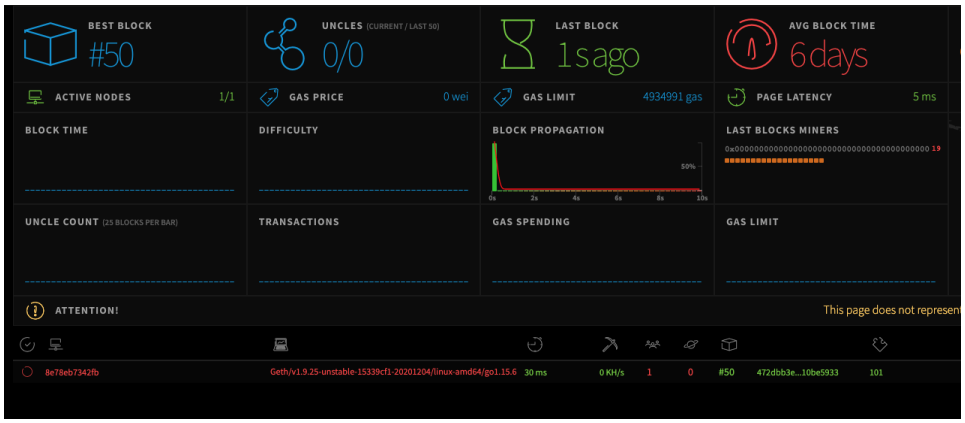

Figure 2: *Ethereum Network Status* monitoring the application.

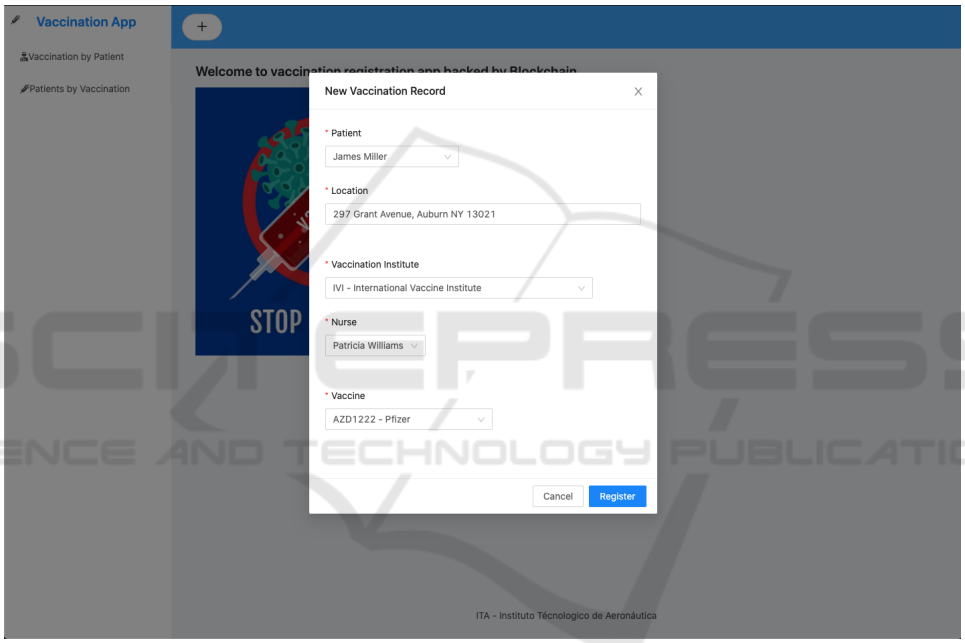

Figure 3: Form to registry a vaccine administration.

the entire vaccination cycle, mainly related to the lack of data. All vaccines of a given person are available to improve diagnosis in cases of a disease.

All stored data can be used by specialists to create strategic vaccination plans to better assist population, using only the required resources. By controlling inventories based on vaccine expiration date and associating it with vaccines' distribution, it is possible to avoid wastes. In cases of problems in a vaccine batch, *Government* or *Enterprises* can coordinate the detection and removal of such a vaccine; while people who took the vaccine can be identified and warned.

Following the proposal, new opportunities related to vaccination arise. Supposing that a certified vaccine has a recent study that unfortunately shows that it can be nocuous to children, so such a vaccine needs to be suspended. With a Blockchain system, the vaccine certification is revoked by *Government* and all roles have the updated information about the vaccine, for instance the system can alert *Vaccination Centers* that they are not allowed to use this vaccine any longer to that specific public.

As limitations of the proposed approach, we highlight the need of cooperation among partners, including *Government*, *Enterprises* and *Vaccination Centers* to implement and maintain this service correctly.

Distinct strategies can be established to add people in the Blockchain system. Hospitals can register newborns and their initial vaccines just when they are born. After that, their profiles are updated in a regular

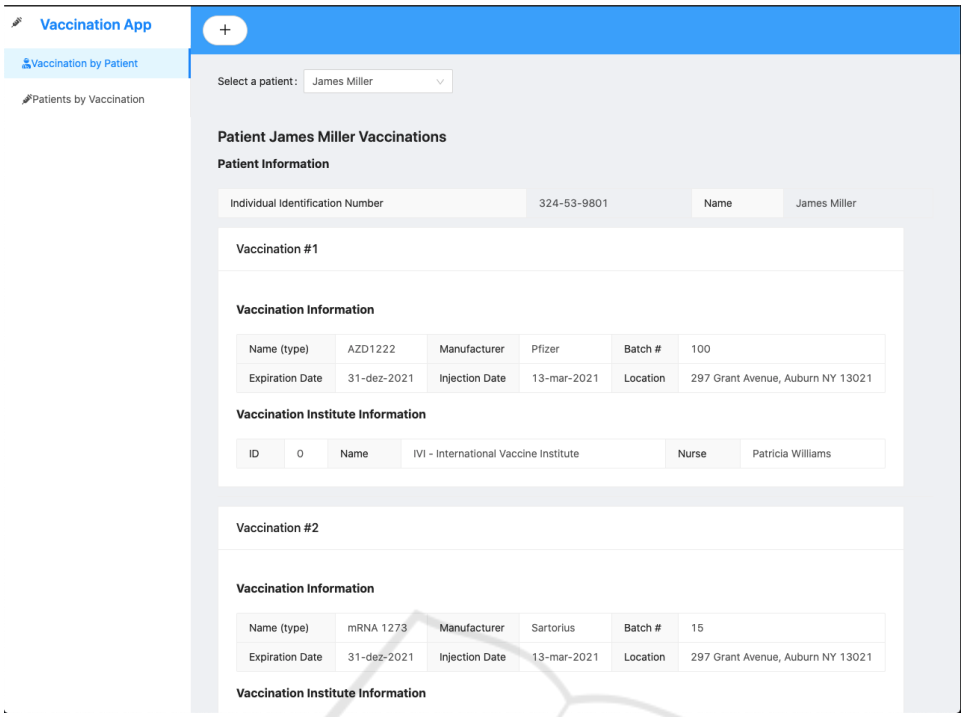

Figure 4: The vaccination history of a patient.

way when they need further vaccines. Other citizens can be included by *Government* and requested to go to a *Vaccination Center* with their paper vaccination cards in order to update the system. Other possibility for unregistered citizens is to have their vaccines computed in the system only when they take a new vaccine.

As a future implication, if a person needs to travel to other country that requires a vaccine inspection, he/she can retrieve his/her vaccination identification from the system, since it is already certified by *Government*. Other possibility is to include in the system a specific role to other countries or embassies, so they can verify in the system the vaccination history of the traveller. In the same way, any person (with his/her vaccines records) can verify if it is possible to go to a specific country, considering that the countries' entrance requirements are already defined in the system.

6 CONCLUSIONS

We propose an approach, based on Blockchain, to store and maintain data around the entire vaccination process. The main goal of the approach is to provide correct and updated data for aiding citizens (for instance, in cases of disease diagnosis or vaccine inspection in a travel) and for supporting institutes (for example, with the creation of strategic plans for vaccine distribution and population immunization).

Blockchain provides a reliable structure for the approach due to its proof-tamper characteristic, so data can not be corrupted, and also the entire track of data is available. In the approach, we describe roles in the vaccination process and their relations and privileges. Considering the vaccine administration (the procedure of registering a vaccine administration in a person), we present the required Blockchain data, including patient identification and vaccine information.

Aiming to validate our approach, we developed a prototype using Ethereum Blockchain. We implemented a contract to register a administered vaccine and other to access patient history with all received vaccines. We understand that, depending on the desired functionality or analysis, other data can be considered in the approach. For future work, we intend to specify other scenarios related to vaccination in order to improve the definition of the required data. Investigations need to be conducted with existent institutes (such as medical centers and enterprises) in order to identify their expectations and needs, to support more relevant analysis.

An additional study should consider data privacy and authorization, which will provide details to classify data and refine roles' privileges. Other important work is to create a basis to store information regarding the research and development process of a vaccine,

which is essential in the certification process. Evaluation with real users playing all the proposed roles is also of interest. The definition and development of the entire approach is a challenge, however the expected benefits are enormous, arising then interesting opportunities of future work.

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