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Tracing and measuring the COVID-19 Colombian vaccination network

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Abstract: The COVID-19 vaccination process in Colombia has been a major challenge not only in terms of public health but also in terms of supply chain management and logistics processes. To support the monitoring of these processes and associated decision-making, a dashboard was designed in Google Data Studio focused on analyzing the progress of COVID-19 vaccination and its logistics efficiency. This article describes the design and implementation of the dashboard using a design science approach and discusses the main lessons learned. During its development, four major challenges were identified: the search for and availability of data sources, the definition and standardization of metrics, the extraction of data in different formats; and finally, the validation of the metrics. Despite these challenges, the dashboard became a source of information for different stakeholders in the Colombian COVID-19 vaccination network, facilitating the monitoring of key performance indicators (KPIs), supporting decision-making, and policy evaluation. This reaffirms the importance of having open information to generate knowledge for both public and private entities as well as for the public. The main contribution of this work is the definition and standardization of the KPIs and it is therefore expected that this experience will serve as an insightful input for designing mass vaccination strategies.

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1. INTRODUCTION

The COVID-19 pandemic has had a broad impact, highlighting the inequality in access to health care, especially in developing countries. In Colombia, the National Vaccination Plan (PNV by its name in Spanish) began on February 17th of 2021. It established the goal of fully vaccinating 70% of the population by December 31st of 2021, as the main strategy of the Colombian government not only to prevent COVID-19 deaths but also to enable economic reactivation (Gaus, 2021) and seek timely and equitable distribution of vaccines throughout the country.

To achieve this objective, the availability of vaccines is not the only requirement; it is also necessary to define the logistics process for their allocation and distribution. Thus, the PNV stipulated the macro-logistics along the vaccination network to distribute vaccines throughout the country, defining the design of the cold chain, distribution to the main territorial entities, transportation, and storage at different nodes of the network such as collection centers (Bae et al., 2021). However, it fell short in specifying the micro-logistics in the vaccination network (i.e., the process in which vaccines will be dosed to people). Especially, in aspects related to the recording and collection of information on the vaccines administered and, in general, with open data management, which is especially important during a health emergency such as a pandemic.

The importance of having open information lies in the fact that it promotes transparency, efficiency, and effectiveness of the services offered to the population while allowing working on

decision support models and generating knowledge for both public and private entities (Xue, 2021). On the other hand, actors in the healthcare sector can control quality and cost through the design of key performance indicators (KPIs), for which the implementation of Business Intelligence (BI) tools and data visualization techniques is recommended (Díaz-Piraquive et al., 2021).

The purpose of this research is to design and implement a COVID-19 vaccination dashboard using the design science research (DSR) approach to produce valuable information on the vaccination progress and its logistic efficiency in Colombia, thus supporting public health decision-making. The dashboard uses structured and unstructured data with different update periodicities and the main contribution is the definition and standardization of the key indicators to be implemented. This paper is organized into four sections plus this introduction. The second section presents a brief literature review, followed by the description of the DSR approach defined to design the dashboard in section three. Then, the results are described in section four and finally, section five presents the discussion and conclusions of this paper.

2. LITERATURE REVIEW

COVID-19 vaccination has posed a logistics problem for which different organizations have designed types of monitoring and tracking dashboards that have been published online and in academic articles. For this research, the COVID-19 dashboards were organized and classified into three groups: a) patient tracking dashboards throughout the phases of vaccine development (Shrotri et al., 2021); b) global, regional

or local vaccination progress dashboards (Wang, 2021, Mitra et al., 2021, Berry et al., 2021, Xue, 2021, Bae et al., 2021, Mathieu et al., 2021, De Moura Pereira et al., 2021, Shaheen et al., 2021); and c) dashboards to simulate the operation of vaccination centers (Pilati et al., 2021). This research focuses on the second group since these types of dashboards allow exploring and visualizing the large and complex amount of data, formulating possible policies and strategies regarding vaccines as scarce resources (Xue, 2021, Mathieu et al., 2021), identifying vulnerable populations (Xue, 2021), supporting decision making (Xue, 2021, Berry et al., 2021) and keeping the population informed (Xue, 2021).

The literature review was conducted using the following query: ((COVID OR COVID-19 OR pandemic) AND (dashboard OR dash) OR indicators OR “data visualization” AND vaccin*) in Web of Science and Scopus. As a result, 10 articles were found that discuss the use of dashboards to monitor the progress of COVID-19 vaccination for a specific geographic location (e.g., city, region, country, or global progress). This review showed the importance for both, decision-makers, and the population of having accessible, rapid, and reliable information on COVID-19 vaccination as a tool for decision-making. It also revealed multiple representations to visualize the fulfillment of governmental objectives, such as graphs, geographical elements, performance statistics, and comparative forecasts. In addition, the review showed that the data collection can be daily (Berry et al., 2021, Mathieu et al., 2021), weekly (Shrotri et al., 2021), and can be either automatic or manual (Mathieu et al., 2021).

Additionally, the literature review identified key metrics that measure progress in terms of population coverage for a specific geographic location such as population fully vaccinated, population with one dose, population vaccinated by age, among others. However, no metrics focused on tracking the efficiency of the COVID-19 vaccination network were found, being this the main objective of this paper. The approach chosen to develop the work is described below.

3. DESIGN SCIENCE RESEARCH APPROACH

To design and implement the dashboard, we followed the DSR approach that has proven to be useful in this type of context (Pestana et al., 2020). DSR is a problem-solving paradigm that seeks to construct a working artifact (i.e., the dashboard) and its relevance is based on the artifact’s applicability in practice (i.e., monitoring of the vaccination process allowing for a faster response) (Holmström et al., 2009). It is divided into 6 stages (Pestana et al., 2020), which are presented below:

Stage 1 - Problem identification and motivation: Colombia’s population is 51 million (DANE, 2018) plus 1.6 million legally registered migrants (UAEMC, 2020a), the latter population was included in the PNV at the beginning of October of 2021. Departments, municipalities, and districts territorially organize Colombia. The main districts are Bogotá, Cartagena, Barranquilla, Santa Marta, and Buenaventura, which stand out for their national importance and where the country’s population is concentrated, while the most rural departments are Vichada, Vaupés, Cauca, Nariño, and Chocó, located mostly on peripheral areas, as shown in Figure 1.

The COVID-19 vaccination should be viewed as a supply network since it involves a set of entities that participate directly in the upstream and downstream flows of products, services, finances, and information from a source to a client or user (Mentzer et al., 2001). In the Colombian COVID-19 vaccination network, the macro-logistics process to allocate and distribute the vaccines was defined in the PNV. The arrival is via air transport in batches from different countries (Figure 1 and Figure 2 - orange arrow). Then, vaccines are received at the central warehouse, located in Bogotá, from where they are allocated and distributed according to the resolutions issued by the Ministry of Health and Social Protection (MSPS by its name in Spanish). Distribution is made in smaller lots to the main cities (Figure 1 and Figure 2 - black arrows), generally using air transport. Once the vaccines arrive in the cities, the departmental health secretariats allocate smaller batches to the municipalities and to the Health Service Provider Institutions (IPSS by its name in Spanish) (Figure 1 and Figure 2-blue arrows), which distribute smaller batches to their vaccination centers.

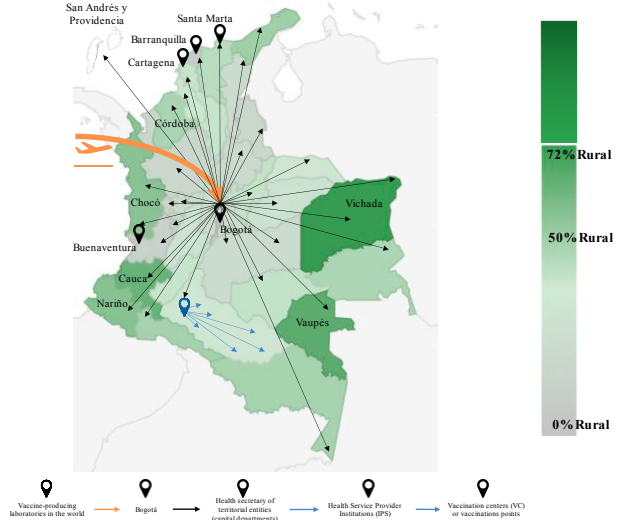


Figure 1 Colombian COVID-19 vaccination network

IPSS bear the costs of distribution to COVID-19 vaccination centers, as well as the costs associated with resources such as personnel, technology, and supplies required to carry out the vaccination. These costs are compensated by the MSPS once the information is registered and verified in the vaccination national information system PAIWEB2.

The vaccination network described above presents additional challenges compared to other countries and vaccination networks. In the Colombian case, the information could not be recorded in real-time, due to limited Internet access in certain regions and the low capacity and scalability of PAIWEB2 to support simultaneous registrations. These circumstances generated a bottleneck in the official registration, resulting in a backlog of 20.4 million records as of December 31st of 2021 (MSPS, 2021f). To overcome this delay and be able to monitor the progress of vaccination, the national authorities defined additional records triggering manual reports for both IPSS and local authorities that had to be added to the workload.

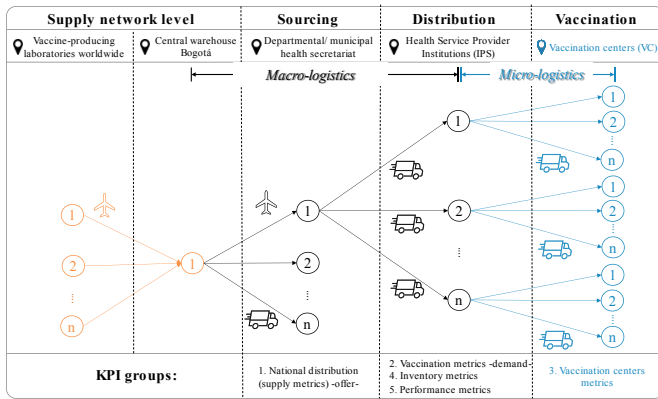


Figure 2 Stakeholders and users of the KPI groups in the Colombian COVID-19 vaccination network

On the other hand, there were no standardized metrics to measure the progress and efficiency of the vaccination network, in other words, the KPIs and data requirements varied among organizations. Additionally, as there was not enough related open and structured data in Colombia, the possibility of implementing an efficient BI tool to manage information and support real-time decision-making was very low. The dashboard designed in this research was launched and validated with some key actors in the health sector before the MSPS launched its dashboard in Power BI. In addition, for the dashboard to provide the greatest possible value, metrics related to the progress and efficiency of the COVID-19 vaccination network in Colombia were included to monitor compliance with the goal established by the government.

Stage 2 – Goal definition and solution: this phase was divided into two parts. Firstly, defining a standardized set of key indicators to measure both progress and performance along with the supply network: *sourcing*, *distribution*, and *vaccination* (see Figure 2). This required information at the *supply level* on scheduled arrivals (i.e., number of vaccines allocated by brand and geographic location) (see Table 1); at the *distribution level* on vaccine allocation to departments (i.e., potential supply); and at the *vaccination level* on vaccine demand, measured as the daily vaccination rate (e.g., number of vaccines administered by geographic location). Likewise, to maintain an optimal vaccination rate, it was necessary to consider the balance between available and required capacity in the vaccination centers. The available capacity corresponds to the average number of people vaccinated per day at a vaccination center. While the required capacity is the average number of people to be vaccinated daily to meet the established target (70% of the population fully vaccinated) by December 31st of 2021. In addition, the inventory reflects the relationship between supply and demand and is the subtraction between vaccines supplied and administered in each territorial entity. Finally, overall performance metrics were defined, including throughput (number of vaccines distributed / administered) and the percentage of the population fully vaccinated. These KPIs were organized into five groups shown in Table 1 along with some examples of specific metrics. These five groups allow differentiating among national and department metrics; vaccination progress and vaccination

capacity; and resources availability and performance (see Figure 2).

Secondly, once the metrics were predefined, possible data sources were identified and the metrics were refined according to the available information to build the data model for the dashboard. These data sources included both structured and unstructured sources (see Table 2). The structured sources included open data from some of the organizations in charge of consolidating and tracking data on vaccination progress; and unstructured sources included news, tweets, and information collected in infographics, as also found in the literature. The latter was included due to the lag of registration in the PAIWEB2 platform and the absence of official structured sources. However, this information had to be typed manually. The dashboard was updated daily, and additional reports were produced as part of the validation and evaluation of the dashboard, as discussed in step five.

Table 1 KPIs for the Colombian COVID-19 vaccination network

KPI groups	Indicator
1. National distribution (supply metrics) - offer	Number of vaccines allocated by brand (Xue, 2021)
	Number of vaccines allocated by geographic location (country, department) per day (Xue, 2021, Mathieu et al., 2021, De Moura Pereira et al., 2021, Shaheen et al., 2021, Berry et al., 2021)
	Total doses allocated (Mathieu et al., 2021, Berry et al., 2021)
2. Vaccination process metrics - demand	Total doses administered per time unit (day, month) (Mathieu et al., 2021, Shaheen et al., 2021)
	Number of vaccines administered by geographic location (Berry et al., 2021, De Moura Pereira et al., 2021)
	Total vaccinated population by geographic location (Berry et al., 2021, De Moura Pereira et al., 2021, Xue, 2021)
3. Vaccination capacity centers metrics	Total number of vaccination centers by a territorial entity (Wang, 2021, Shrotri et al., 2021)
	Capacity used in vaccination centers
	Capacity required at vaccination centers
4. Inventory metrics	Inventory level per time unit (day, month)
	Inventory level per geographic location
	Inventory level per-10,000 people
5. Performance metrics	Percentage of execution by the territorial entity
	Percentage of the population fully vaccinated (De Moura Pereira et al., 2021, Shaheen et al., 2021)

Table 2 Data sources

Data Source	Periodicity	Source description
Demography	Once	Structured open spreadsheet to download (DANE, 2018)
Vaccination centers	Once	Structured open spreadsheet to download (MSPS, 2021d)
Vaccine purchase agreements and information on arrivals in the country	According to the periodicity of arrivals	Structured open online spreadsheet (MSPS, 2021c), and also unstructured official information from Twitter.
Vaccine allocation resolutions by territorial entities (supply)	Weekly	Unstructured information regarding resolutions in PDF format (MSPS, 2021e) and structured open information in JSON format (MSPS, 2021a)
Infographics on the progress of the PNV	Daily	Unstructured data on Colombian progress in COVID-19 vaccination by the territorial entity, and total population (MSPS, 2021b)
Infection	Daily	Structured open online database using JSON format filtered by Colombia (GCCL, 2020)
Regional report of vaccination progress	Daily	Structured open Google sheets (MSPS, 2021c)
Migratory flows and immigration	Monthly	Structured data filtered and downloaded from Tableau (UAEMC, 2020b, UAEMC, 2020a)

Stage 3 – Design and development: this stage was also divided into two parts: the selection of the tool and the definition of the data model, and the techniques to be used. For the former, several tools were evaluated and Google Data Studio was selected, as it is an online tool for converting data into reports and dashboards, offering a free version for small teams, which suited the needs of the project. This tool also allows loading information from various formats and additionally uses Google's geocoder, so the maps are made quickly and easily. For the latter, a snowflake data model was selected (see Figure 3). “The snowflake schema represents a dimensional model which is composed of a central fact table and a set of constituent dimension tables which can be further broken up into subdimension tables” (Levene and Loizou, 2003) and is widely used. Specifically, in addition to the fact table, nine-dimension tables along with their attributes were defined and manually loaded. The dimension tables are maintained in a standardized form to reduce redundancy. The advantage is that these tables are easy to maintain and save storage space. However, it also means that more joins are needed to run queries. The fact table is drawn in the data model as a "time series", where the metrics and calculations are at the bottom with the minimum necessary granularity.

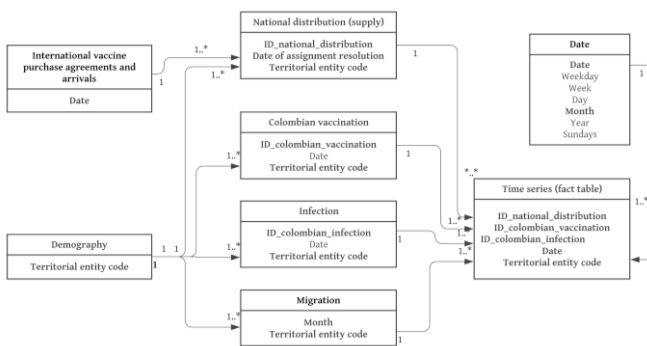


Figure 3 Snowflake dashboard data model

In addition, the literature on COVID-19 vaccination dashboards, on which this research focuses, states that they are designed to support decision-making by visualizing data, forecasting, and classifying information using statistical techniques, classification algorithms, and supervised and unsupervised learning (Xue, 2021, Mathieu et al., 2021, Wang, 2021, Berry et al., 2021). Specifically, the dashboard proposed in this research uses a moving average to forecast the PNV compliance as it does Mathieu et al. (2021).

Stage 4- Demonstration: before officially launching the dashboard, we conducted a three-week pilot test. The pilot consisted of presenting the dashboard to various stakeholders, including public and private healthcare organizations. Some of the main outcomes of the pilot were (1) to organize the dashboard in a way that gave more importance to the logistic indicators, (2) to show explicitly the relationship between typical health indicators and logistic indicators, and (3) to socialize the dashboard with departmental and municipal health secretariats.

Stage 5– Evaluation: for this stage, experts from both the MSPS and the IPSs were invited. This group of people was

sent a monthly report designed based on the information in the dashboard (see <https://colev.uniandes.edu.co/resultados>). This group of experts sent us comments and proposals each month to refine or create metrics that they considered useful, which helped us to evolve the monthly report from reporting four key logistical indicators to seven.

Stage 6– Communication: both internal and public mechanisms of socialization of the presented dashboard were carried out. In the first group, the University, to which the researchers of this project belong, used the dashboard, to keep the community informed about the progress of the COVID-19 vaccination and to make decisions about returning to the campus. In the second group, articles were published in national newspapers discussing particular indicators based on the dashboard information (COLEV, 2021), and finally, it was also socialized through social media.

4. RESULTS

The COVID-19 vaccination network has particular characteristics such as the fact that vaccines are a scarce resource with special storage conditions and uncertain demand. On the other hand, its value is difficult to calculate in terms of its impact on the prevention of deaths and the economic reactivation of the country making it an interesting case to be studied.

The standardized set of KPIs facilitated the implementation of a BI tool (see <https://colev.uniandes.edu.co/2-uncategorised/58-avance-nacional-de-vacunacion>). This dashboard is used to visualize the metrics of progress and efficiency of the COVID-19 vaccination network in Colombia. The dashboard is divided into three parts: PNV population progress indicators, logistic indicators, and capacity analysis. The dashboard made it possible to identify behaviors associated with the design of the PNV. For example, the shortage of vaccines led the PNV to be designed in stages (i.e., the stages were defined mainly by age groups) to control demand and at the beginning of each stage, there was an over-demand due to the expectation of the age group to be vaccinated. This over-demand began to regulate as the days went by without this behavior being directly associated with the level of available inventory. Given this behavior, at the end of the last stage, the application of boosters was enabled. The average daily COVID-19 vaccination rate for the PNV was 211 thousand doses.

The fact that supply and demand are out of balance causes inventories to increase. In October, the inventory reached 9 million vaccines. With such a high inventory, the Colombian government decided to include migrants in the PNV. However, demand did not increase as expected and during that month, there was an oversupply of all the vaccines brands. The average monthly vaccine inventory was 3.2 million doses. The decline in demand towards the end of the year meant that the goal of 70% of the population vaccinated by December 31st of 2021 was not achieved. However, Colombia surpassed countries such as Russia, Poland, Bulgaria, Bolivia, Venezuela, and Nicaragua (GCDL, 2020). It is important to mention that there is a hidden variable that could be called “willingness to be vaccinated” that should be included in

further vaccination forecasts. This willingness may be affected by factors such as the phenomenon of misinformation, religious beliefs, or anti-vaccine movements.

As of December 31st of 2021, the PNV had to vaccinate 70% of the population, which means 35.7 million people. By the same date, 82.2 million doses had arrived in Colombia, 35.4 million double-dose vaccines composed of AstraZeneca 17%, Moderna 17%, Pfizer 22%, and Sinovac 30%, and 11.5 million single-dose vaccines (Janssen 14%). This indicates that Colombia could have reached the PNV target and vaccinated 46.9 million people. However, only 64.6 million doses were administered reaching 28.3 million people fully vaccinated, equivalent to 56% of the population, and 4.7 million people with only one dose (MSPS, 2021b). In addition, to achieve this figure, the population had to be progressively expanded from 75.2% (16 years and older), then 81.5% (12 years and older), and finally 95.4%, the latter corresponding to children between 3 and 11 years of age. The 1.6 million migrants were also included in the population (UAEMC, 2020b).

The dashboard also shows that the territorial entities with performances above 75% in their order were Barranquilla (88.67%), San Andrés and Providencia (82.83%), Boyacá (82.77%), Risaralda (77.79%), Bogotá (77.45%); and those with lower performance were Vichada (27.66%), Vaupés (33.84%), Chocó (39.06%), Guainía (39.91%) and Buenaventura (40.23%). It was also identified that territorial entities that are efficient have low inventories, high vaccination speed, and a high percentage of vaccinated population, while those that are inefficient have high inventories, low vaccination speed, and low percentage of vaccinated population.

The dashboard also generated a forecast based on the vaccination rate calculated as the moving average of the last week. This metric calculated the days remaining to meet the target by each territorial entity and for the whole country. Specifically, the numerator was the number of doses needed for each territorial entity minus the number of doses assigned and the denominator was the moving average of the vaccination rate. This metric showed that the territorial entities with the best performance were San Andrés and Providencia, Amazonas, Boyacá, Barranquilla, and Bogotá; on the other hand, those with the lowest performance were Putumayo, Buenaventura, Cauca, Vichada, and Chocó (see Figure 4).

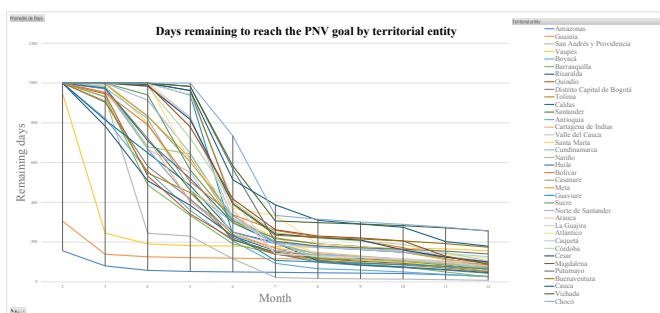


Figure 4 Forecast by territorial entity - Days remaining to reach the PNV goal

The Colombian health system was able to vaccinate between 80 and 120 people in each vaccination center, exceeding this indicator on some days up to 150 people. The average percentage of capacity utilization could not be calculated since the granularity of the data did not allow it, however, it could be stated that to take advantage of the maximum capacity it would be necessary to implement strategies to increase demand and to estimate, as identified, the population's willingness to be vaccinated.

Finally, this experience allowed us to build another dashboard that was created to measure and track three vaccination centers in Bogotá as part of the CoVIDA project "La vacuna es de todos", which administered more than 110 thousand doses in 75 days (COVIDA, 2021).

5. DISCUSSION AND CONCLUSION

In Colombia, even in the age of data and information, a huge number of reports are published in spreadsheets or are manually constructed from unstructured data sources such as Twitter or newspaper news. Particularly in the health sector, a lot of information is handled in spreadsheets, which are not the most appropriate tool for data analysis or visualization, especially when handling large volumes of data. Additionally, much of the valuable information for decision-making is confidential despite the existence of an open data policy in Colombia (República de Colombia, 1991), which hinders the implementation of data analytics tools for decision-making and the formulation of public policies, especially in the health sector.

Seeking to promote the use of BI tools, which are effective tools for assessing, comparing, and communicating complex situations such as a pandemic, this article has discussed the importance of standardizing metrics and making data available to users and decision-makers to minimize the time to deliver information to users compared to operationalizing and visualizing data in spreadsheets.

The COVID-19 pandemic has imposed challenges in the improvement of health services delivery, specifically in vaccination, opening opportunities to work on technological innovations that can evaluate the effects of established policies, the management of logistic operations, and the good management of information. In this direction, the development of the presented COVID-19 vaccination dashboard revealed the following challenges:

- The importance of strengthening the physical, technological and connectivity infrastructure in rural areas, as well as the capacity and flexibility of the mechanisms for uploading information to the central registration platforms. The above, to avoid both the delay in the availability of information and the duplication of tasks.
- The importance of having open, available, accessible, and structured information available to support decision-making in the health system
- In a mass vaccination scenario the key variables for the design of an analytical and visualization tool are: a) the global vaccine supply; b) the criteria for vaccines allocation and

distribution; c) the distribution (supply) in a geographic location d) the actual demand for vaccines in a geographic location; and e) the capacity of the vaccination points (manpower, facilities, vaccination speed).

- To make decisions or formulate policies that need to compare performance or efficiency between processes, actors, sectors, or geographic locations, it is necessary to validate metrics and standardize their calculation. These metrics should be available to the general public and, of course, to the health sector stakeholders.

- In mass vaccination scenarios or general massive health services, the health metrics are important, but these metrics mixed with logistics metrics could provide decision-makers ideas about how to improve the supply chain to accomplish the health objectives efficiently.

Finally, one of the factors to consider when selecting a visualization tool is the cost. Many tools have a high licensing cost, however, the data visualization tool selected in this research -Google Data Studio- is a free and accessible tool that handles several ways of loading information, so it easily fits the requirements of a project like this one.

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REFERENCES

- BAE, J., SUKUMARAN, R., SHANKAR, S., SHARMA, A., SINGH, I., NAZIR, H., KANG, C., SRIVASTAVA, S., PATWA, P. & SINGH, A. 2021. Mobile Apps Prioritizing Privacy, Efficiency and Equity: A Decentralized Approach to COVID-19 Vaccination Coordination. *arXiv preprint arXiv:09372*.
- BERRY, I., O'NEILL, M., STURROCK, S. L., WRIGHT, J. E., ACHARYA, K., BRANKSTON, G., HARISH, V., KORNAS, K., MAANI, N. & NAGANATHAN, T. 2021. A sub-national real-time epidemiological and vaccination database for the COVID-19 pandemic in Canada. *Scientific Data*, 8, 1-10.
- COLEV. 2021. Colombia necesita varios ajustes en el sistema de información de vacunas. Grupo COLEV-Universidad de Los Andes. *El espectador*, August 22nd.
- COVIDA. 2021. *Vacunación gratuita en tres localidades de Bogotá* [Online]. Available: <https://uniandes.edu.co/es/noticias/salud-y-medicina/vacunacion-gratuita-en-tres-localidades-de-bogota> [Accessed October 1st 2021].
- DANE. 2018. *Proyecciones de población. Proyecciones y retroproyecciones de población departamental para el periodo 1985-2017 y 2018-2050 con base en el CNPV 2018* [Online]. Available: <https://www.dane.gov.co/index.php/estadisticas-por-tema/demografia-y-poblacion/proyecciones-de-poblacion> [Accessed February 3 2021].
- DE MOURA PEREIRA, D. A., DOS SANTOS, M. & DE OLIVEIRA COSTA, D. 2021. Análise da distribuição de vacinas contra o covid-19 no Cariri Paraibano a partir do desenvolvimento de um dashboard em power BI. *Archives of Health*, 2, 430-441.
- DÍAZ-PIRAQUIVE, F. N., DE JESÚS MURIEL-PEREA, Y. & ORDOÑEZ-DÍAZ, M. S. Implementation of the Management System of Knowledge for the Process Management of a Sterilization Central. In: UDEN, L., TING, I. H. & WANG, K., eds. *Knowledge Management in Organizations, 2021// 2021 Cham*. Springer International Publishing, 280-291.
- GAUS, D. 2021. COVID-19: vacunas. *Práctica Familiar Rural*, 6, 1-5.
- GCDL. 2020. Global Change Data Lab, Coronavirus (COVID-19) Vaccinations. *Daily*. Global Change Data Lab.
- HOLMSTRÖM, J., KETOKIVI, M. & HAMERI, A. P. J. D. S. 2009. Bridging practice and theory: A design science approach. 40, 65-87.
- LEVENE, M. & LOIZOU, G. J. I. S. 2003. Why is the snowflake schema a good data warehouse design? 28, 225-240.
- MATHIEU, E., RITCHIE, H., ORTIZ-OSPINA, E., ROSER, M., HASELL, J., APPEL, C., GIATTINO, C. & RODÉS-GUIRAO, L. 2021. A global database of COVID-19 vaccinations. *Nature human behaviour*, 5, 1-7.
- MENTZER, J. T., DEWITT, W., KEEBLER, J. S., MIN, S., NIX, N. W., SMITH, C. D. & ZACHARIA, Z. G. J. J. O. B. L. 2001. Defining supply chain management. 22, 1-25.
- MITRA, A., SOMAN, B. & SINGH, G. 2021. An Interactive Dashboard for Real-Time Analytics and Monitoring of COVID-19 Outbreak in India: A proof of Concept. *arXiv preprint arXiv:09937*.
- MSPS. 2021a. *Asignación de dosis de vacuna contra COVID-19* [Online]. Available: <https://www.datos.gov.co/Salud-y-Proteccion-Social/Asignacion-de-dosis-de-vacuna-contra-COVID-19/sdvb-4x4j> [Accessed December 31st 2020].
- MSPS. 2021b. *Infografía Plan Nacional de Vacunación (PNV) contra COVID-19* [Online]. Ministerio de Salud y Protección Social. Available: <https://www.minsalud.gov.co/salud/publica/Vacunacion/Paginas/Vacunacion-covid-19.aspx> [Accessed August 30th, 2021 2021].
- MSPS. 2021c. *Llegadas de vacunas por laboratorio y dosis aplicadas por entidad territorial* [Online]. Ministerio de Salud y de Protección Social. Available: <https://docs.google.com/spreadsheets/d/1N4V-qqp6q8exuYAZgZ79GT9GazsSCHUK/edit#gid=625217412> [Accessed December 31st 2021].
- MSPS. 2021d. *Ministerio de Salud y Protección Social. Cantidad de prestadores con puntos de vacunación - Registro especial de prestadores de servicios de salud - REPS - Ministerio de Salud y Protección Social* [Online]. Available: <https://minalud.maps.arcgis.com/apps/dashboards/e12f9e426dba423cab76c981af7a5791> [Accessed July 17th 2021].
- MSPS. 2021e. *Normativa resoluciones - Año: 2021* [Online]. Bogotá D.C. (Colombia). Available: https://www.minsalud.gov.co/Paginas/Norm_Resoluciones.aspx [Accessed August 29th 2021].
- MSPS. 2021f. *Rezaço en el registro de dosis aplicadas contra COVID-19 en PAIWEB* [Online]. Available: <https://app.powerbi.com/view?r=eyJrjoiNThmZTJmZWYtOWFhMy00OGE1LWFiNDAtMTJmYjM0NDAsNGY2liwidCI6ImJmYjdlMTNhLTdmYjctNDAsNi04MzBjLWQzNzE2ZThkZDhiO CJ9> [Accessed December 31st 2021].
- PESTANA, M., PEREIRA, R. & MORO, S. 2020. Improving Health Care Management in Hospitals Through a Productivity Dashboard. *J Med Syst*, 44, 87.
- PILATI, F., TRONCONI, R., NOLLO, G., HERAGU, S. S. & ZERZER, F. 2021. Digital Twin of COVID-19 Mass Vaccination Centers. *Sustainability*, 13, 7396.
- REPÚBLICA DE COLOMBIA 1991. Constitución Política de Colombia [Const]. Art. 20 y 74. (Colombia). Colombia.
- SHAHEEN, A. W., CIESCO, E., JOHNSON, K., KUHNEN, G., PAOLINI, C. & GARTNER, G. 2021. Interactive, on-line visualization tools to measure and drive equity in COVID-19 vaccine administrations. *Journal of the American Medical Informatics Association*.
- SHROTRI, M., SWINNEN, T., KAMPMANN, B. & PARKER, E. P. 2021. An interactive website tracking COVID-19 vaccine development. *The Lancet Global Health* 9,e590-e592
- UAEMC 2020a. Estatuto temporal de protección - Estatuto Temporal de Protección - Prerregistros. *Monthly*. Unidad Administrativa Especial Migración Colombia (UAEMC) - Migración Colombia.
- UAEMC 2020b. Flujos migratorios - 2020 *Monthly*. Unidad Administrativa Especial Migración Colombia (UAEMC) - Migración Colombia.
- WANG, Z. 2021. Equitable Distribution of Covid-19 Vaccines: Can Data Visualization and Optimization Help?
- XUE, M. 2021. *Visualization of the distribution of COVID-19 vaccines in Norway*. Høgskolen i Molde-Vitenskapelig høgskole i logistikk.