Optimization Model for Planning the Logistical Response to COVID-19 Vaccination.

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Abstract

The health crisis that our country is going through is very difficult to manage and vaccination is of utmost importance to counteract it; however, the logistical process of purchasing and distributing vaccines is very complex. Objective: Therefore, the present research article aims to design a predictive model that influences the logistic response planning for COVID 19 vaccination in the district of San Juan de Lurigancho. Methods: This can be achieved using geographic information systems technology and the implementation of mobile vaccination centers. Results: The results obtained showed the lack of vaccination sites in the district and how this measure generates a great benefit in the most vulnerable population of the study district. In addition, it is positive the results obtained compared to the results of other articles. Conclusions: It is confirmed that the logistic process of vaccination can be improved from the implementation of mobile vaccination centers.

Keywords
Vaccination, Humanitarian logistics, Optimization, GIS technology, Mobile vaccination center.

1. Introduction
At present, the countries with the highest rates of infection and deaths in the world generally have a poorly equipped and infrastructurally poor health system. The governments of the world are taking measures to slow the advance of the epidemic and reduce the effect it is causing on the world economy (García Monsalve et al. 2021). Therefore, a series of measures have been implemented to combat this pandemic: First, oxygen plants have been acquired to avoid dependence on other countries. Secondly, more beds were implemented in the intensive care unit for the care of people. Lastly, the vaccination process has been carried out to avoid the increase of contagions and the saturation of hospitals. The latter is one of the most effective methods to control the spread of epidemics / pandemics (Sinha et al. 2021). The global hope of controlling the disease rests on the effective and universal distribution of available vaccines (Herrera-Añazco et al. 2021). In addition, it is important that the logistical process for vaccine distribution is as efficient as the efficiency of the vaccines, where effective cooperation between government, health plans, hospitals, and frontline care, particularly during emergencies, helps facilitate the vaccination process (Rosen et al. 2021).

The logistics required for vaccination in San Juan de Lurigancho are complex due to the rugged geography. Also, the COVID-19 vaccination program must address challenges related to the cold chain and vaccine distribution system, as well as vaccine acceptance by citizens (Nugraha et al. 2021). Consequently, access to vaccination sites is a major problem to solve. Moreover, achieving vaccination of the entire population is a great logistical challenge, especially because of the limited availability of vaccines and strict conditions of their storage and distribution (Krzysztofowicz and Osińska-Skotak 2021). Also, it is necessary to consider that shipping, storing, and delivering vaccines in a cost-effective manner, remains a major challenge (Yang et al. 2021). Therefore, it is necessary to come up with a logistical response that can help us to improve the distribution of vaccines to the neediest population in the district; since, it is the most vulnerable population. This problem leads us to ask the following research question: To what extent does an optimization model influence the planning of the logistic response to vaccination against COVID 19 in the district of San Juan de Lurigancho?

In this research article, mobile vaccination centers will be proposed as an emergency response to increase the number of vaccination sites that already exist in the district. These will be equipped with the necessary facilities for the vaccination process to take place. These facilities are intended to be temporary and are designed to meet an immediate need (Klise and Bynum 2020). In addition, the temporary vaccination centers will be located at strategic points in the district. Using a GIS, disease "hot spots" could be identified. It is concluded that the integration of GIS into routine epidemiological surveillance in the field can provide a real-time quantitative method to identify and track the geospatial spread of infectious diseases (Cascón-Katchadourian 2020). The key factor could be data on the place of residence of people in a specific age group (Krzysztofowicz and Osińska-Skotak 2021). The proposed analyses could be added in more detail, considering information on the transport accessibility of a given vaccination site, understood as the distance and time needed to reach it on foot, by car or by public transport. This is especially important in the context of limiting social contacts and thus the risk of contagion. The best solution is the shortest possible route to the vaccination site or using your own transport vehicle. To achieve this goal, it would be necessary to use network analysis that can also be performed with the use of GIS technology.

1.1 Objectives

The following objectives are sought for this article:

- To design a predictive model that influences logistical response planning for COVID 19 vaccination in the district of San Juan de Lurigancho.
- Simulate the implementation of mobile vaccination centers in the 8 main areas of the district and the use of geo-referencing technology.

2. Literature Review

Vaccination has been shown to be the most effective method of preventing disease, disability, and death from infection (Yang et al., 2021). However, vaccination is not a method that eliminates disease. Despite the development of effective vaccines at an unprecedented speed and high vaccination rates in some countries, vaccine availability remains low and vaccination rates remain low in many countries (Kim et al. 2021; Stein-Zamir and Rishpon 2021). Humanitarian logistics is a field of study that faces the complexity of a multi-linked supply chain at the same time that must be implemented under a systemic approach and with metrics in the sub-processes that comprise it (Jhare et al. 2021), to solve this complexity various modeling techniques can be used such as mixed integer programming (Malmir and Zobel 2021), linear programming (Rastegar et al. 2021) In many cases due to the complexity of implementing the logistics needed to meet urban demand in conditions of temperatures that can be in the range between -15 to -25 °C for periods of two weeks, which makes the challenge of maintaining a cold chain requires technology and infrastructure for areas close to the city (Acharya et al. 2021).

Reducing crowding and vaccine allocation coverage also represents a particular challenge in this type of complex supply chain (Gessler et al. 2021). Governments of countries that carried out vaccination processes very rapidly highlight the importance of implementing technology and data that prioritizes segments of the target population such as older adults (Cylus et al. 2021; Green et al. 2021) even though there was uncertainty in generalizing policies that might work for one country, but in another country the same result was not evident (Freed 2021; Marchildon 2021; Munguía et al. 2021; Perry et al. 2021). Therefore, it is necessary that the population be vaccinated with full and booster doses before the disease has a greater impact than we are already having. In addition, it is necessary that the acquisition of vaccines be from laboratories that can transmit confidence (Johnson 2021; Sbarra et al 2021). Similarly, for Herrera-Añazco et al. (2021) this would not be an impediment to vaccine resistance; therefore, it is necessary to disprove conspiracy theories and provide relevant information on the efficacy of vaccines (Cuenca Jaque et al. 2020; Wentzell and Racila 2021).

In this work we will use the simulation technique through a geolocation software with a Python programming language, which will help us in the mapping to find the most effective routes, as well as collection points studied where it will be easier for the population to approach for the distribution of the vaccine against covid-19. GIS technology will be used which will help us to obtain the most convenient routes and this model has no restriction on the level of territorial division here, it can be a district, province of any country. If there is a need for analysis of another type of administrative area, for example, medical districts, it can also be implemented quickly (Krzysztofowicz and Skotak 2021). Geographic Information System (GIS) is software that allows us to manage, collect and analyze data. This tool has been very useful for research on vaccination plans against infectious diseases. This system is focused on planning vaccination campaigns, identifying unvaccinated populations, and evaluating the progress of vaccination campaigns. In addition, the objective of using GIS technology has been to help not to collapse health care telephones, hospitals and health systems, both during the upswing phase of the disease, as well as the de-escalation phase, in addition to avoiding new outbreaks and allowing a gradual return to normality (Cascón-Katchadourian 2020), this approach is widely used in disaster response systems (Warnier et al 2021).

There have been a number of existing health services that do not offer people the guarantee of having a good a healthy life especially for people living in a rural area, as access is limited for them (Zain Rashid et al. 2019) .This software will be of utmost importance to perform the mapping in the district of San Juan de Lurigancho, to achieve the level of collective immunity as quickly as possible, it is important that the vaccines reach the individual vaccination sites in the optimal number, taking into account the needs, but also minimizing the risk of spreading the virus in the population.

3. Methods

The goal is to identify what number of mobile vaccination modules can be purchased to meet the vaccine demand of COVID-19 patients while minimizing the total cost of COVID-19 vaccination candidates driving to an existing or temporary COVID-19 vaccine facility and the total cost of constructing temporary facilities. This example shows how a mixed-integer programming (MIP) model of facility location can help health care providers make decisions on how to best use their capacity, whether to build temporary vaccination facilities for COVID-19 patients and how COVID-19 vaccine candidates should be allocated from one area to several vaccination sites to ensure that the sites have the capacity to provide the vaccines to patients. The goal of the model is to minimize the total cost of transporting potential vaccinees from an area to a vaccination center while motivating them to get vaccinated by facilitating the process. Figure 1 shows the summary of the design of the response model.

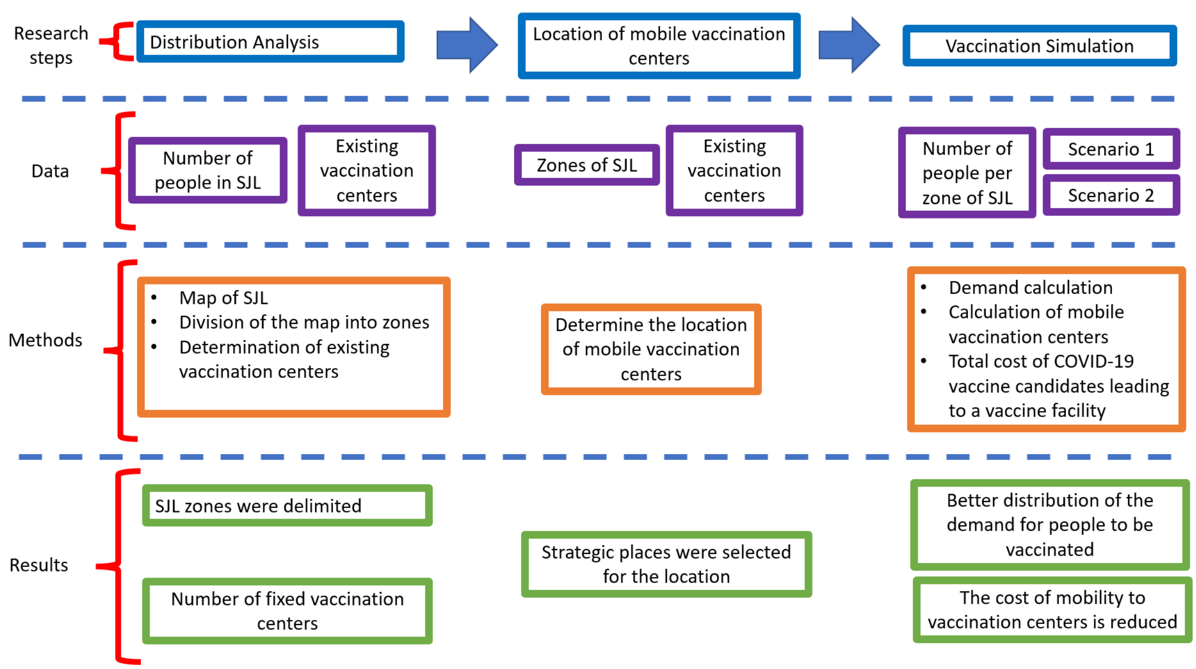

Figure 1. Response design model (Krzysztofowicz and Osińska-Skotak, 2021)

The following scenarios are used for the evaluation. Scenario 1 tests whether the existing vaccination centers can supply the citizens of the area under study (San Juan de Lurigancho) with the necessary vaccines. On the other hand, we have scenario 2 of a 10% increase in demand to calculate the necessary logistical supply capacity and at the same time the increased cost of this new situation.

In the present work we use the geolocation coordinates of the aid points and the centroids of the demand areas, which will help us in the mapping to find the most effective routes, as well as studied collection points where it will be easier for the population to approach for the distribution of the vaccine against covid-19. For the application of these techniques and instruments, it will be necessary to review and analyze documentary data on the population, such as age range, territorial location, population density, etc.

To achieve the level of herd immunity as quickly as possible, it is important that vaccines reach the individual vaccination sites in the optimal number, considering the needs, but also minimizing the risk of virus spread in the population. For this purpose, Geographic information System (GIS) technology can be used. This is a broad term that refers to several methods related to all components of geographic information systems, e.g., data or analysis. It offers the possibility to perform various types of spatial analysis to inform the decision-making process, whenever the spatial aspect is important. This technology is widely used in analyses related to the assessment of the accessibility of various types of natural, semi-natural and anthropogenic objects by inhabitants of cities or other areas.

Sets
L: Set of all facilities locations
L^e: Set of existing facilities locations
L^P: Set of potential locations for new facilities
C: Set of counties
I^+: Set nonnegative integers

Parameters
$D_{c,l}$: Distance between county c and facility location l
M_c: Number of people could receive aid
R_l: Number of people can be served by a facility al location l
P: Maximum number of new facilities

Variables
y_l: Number of new facilities to place at location l
$x_{c,l}$: Number of people from county C served by a facility at location l

Formulation

$$\sum_{c \in C} \sum_{l \in L} D_{c,l}\, x_{c,l}$$

s.t

$$M_c = \sum_{l \in L} x_{c,l} \qquad \bigvee_c \in C$$

$$R_l \geq \sum_{c \in C} x_{c,l} \qquad \bigvee_l \in L^e$$

$$R_l y_l \geq \sum_{c \in C} x_{c,l} \qquad \bigvee_l \in L^P$$

$$\sum_{l \in L^P} y_l \quad \leq P$$

$$y_l \ \in \ I^+ : \ \bigvee_{l} \in L^P$$

$$x_{c,l} \ \geq 0 \qquad \bigvee_{c} \in C \ , \bigvee_{l} \in L$$

4. Data Collection

The main data to be collected are the centroids of each zone of the district of San Juan De Lurigancho and the population density, which complements the research (Medina et al., 2019). The scope is descriptive correlational, associating 2 or more variables (Hernández et al., 2014). The variables used in the study are the model with combined integer and linear optimization techniques and the Logistic Response for vaccination against COVID.

The district of San Juan de Lurigancho is one of the largest and most populated in our capital. Its total population, according to the projection made by peruvian national statistics office, for the year 2019, amounts to 1`159,987 people and a density of 8,838 inhab/Km2 (figure 2.A) (Medina et al, 2019). In this case, we will focus on the 8 zones of the district of San Juan de Lurigancho (figure 2.B). In addition, it has only two vaccination centers in the entire district, which makes the logistical process difficult to provide. For this reason, we are considering creating mobile vaccination sites that have the necessary equipment. In addition, we will use coordinates of the center of each area of the study district and an estimate of the demand of people who are not yet vaccinated. For the estimation of this demand, we consider the total population of San Juan de Lurigancho distributed by age. In addition, the coordinates of each vaccination center in San Juan de Lurigancho will be used. The capacity of the existing facilities is calculated as 50% of the total population of the district. A table containing the coordinates and capacity of a trailer truck for vaccination will be used. The cost of these temporary trucks with a capacity of 1000 people is $75,000. The coordinates of the three tables are in tens of kilometers. We assume that each 10-kilometer increase in distance to a COVID-19 vaccination center results in an $8 increase in driving costs per potential COVID-19 vaccinee.

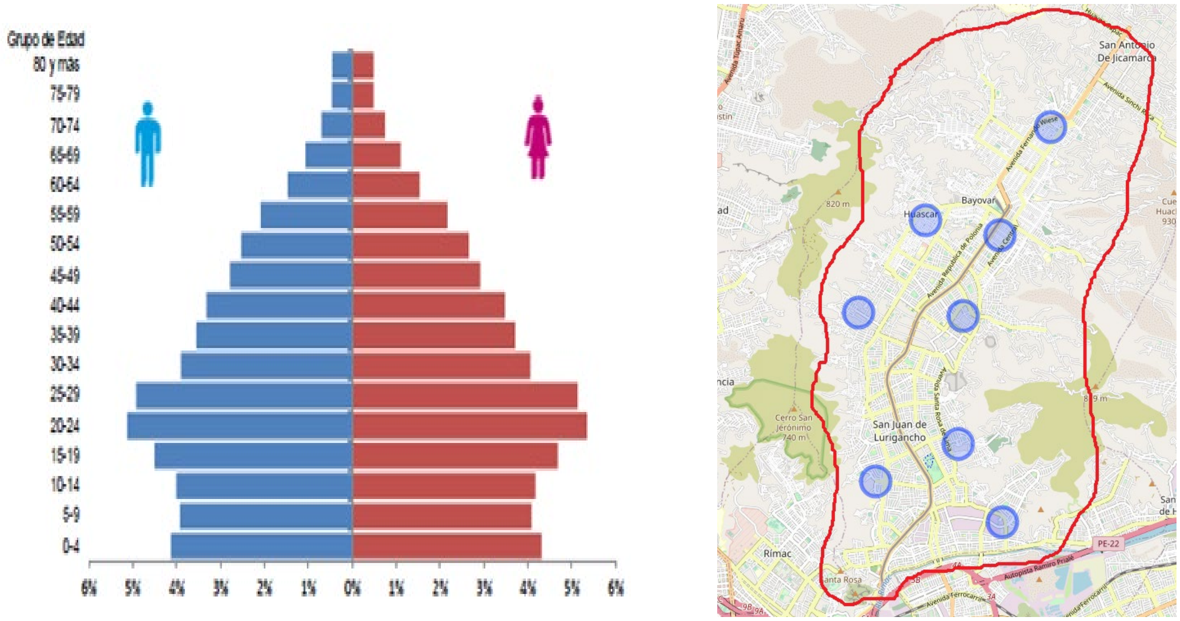

Figure 2. A) Population age density; B) Geographic centroids of sector locations

Table 1. –Counties Centroids

Centroid	Coordinates	Demand
County 1	(-12.02041090650846, -76.98682723839352)	140000
County 2	(-12.012108811940337, -77.01340809215701)	140000
County 3	(-12.004557753780183, -76.99609518328666)	140000
County 4	(-11.977959888615478, -77.01713789970691)	140000
County 5	(-11.978744417664782, -76.99514041576899)	140000
County 6	(-11.962380911089127, -76.98734964024925)	140000
County 7	(-11.959466758129297, -77.00293119137194)	140000
County 8	(-11.940523998191479, -76.9768091797424)	140000

Table 2. – Existing vaccination centers

Existing	Coordinates	Capacity
Parque Zonal Huriacocha	(-12.008956592382392, -77.00070501851573)	560000
IPD BAYOVAR	(-11.95654073397045, -76.98823599589338)	560000

5. Results and Discussion

5.1 Numerical Results

In the first scenario, it could be seen that the fixed vaccination centers can meet the expected demand for vaccinations in San Juan de Lurigancho. However, both vaccination centers would not have the capacity to serve more people than expected. In addition, the cost of assigning patients to health facilities would be $95,450.00, a fact to consider when comparing it with the second scenario. In the second scenario, a 10% increase in the demand of people requiring vaccination was proposed. It became evident that, with the increase in demand, the fixed locations do not have the capacity to meet the total demand. Implementing mobile centers, could be seen that they are of great help in meeting the increase in demand. It was also possible to obtain the costs of assigning patients to sanitary facilities $95,205.00 and of implementing the mobile vaccination centers $600,000.00, giving a total cost of $695,205.00.

Considering both scenarios, it can be concluded that the implementation of mobile vaccination centers is of great support for the logistical process of vaccination. This can be seen in scenario 2, where, despite the implementation of mobile centers, the cost of assigning patients to health facilities is lower than in scenario 1, where the existing localities work at maximum capacity without having the option to accommodate more people. In addition, it gives people the option to use the mobile vaccination center closest to their homes, reducing mobilization and distance costs. It should also be noted that being a new modality in our territory would generate that people are attracted to go to these centers.

Table 3. Scenarios

Scenario	Facilities	Cost	Total
First Scenario	Existing	$ 95,450.00	$ 95,450.00
Second Scenario	Existing	$ 95,205.00	$ 695,205.00
	Mobile	$ 600,000.00	

5.2 Graphical Results

The district of San Juan de Lurigancho is divided into 8 zones, of which a proposed mobile vaccination centers will be placed in each of them. In addition, it already has 2 existing vaccination centers (Figure 3).

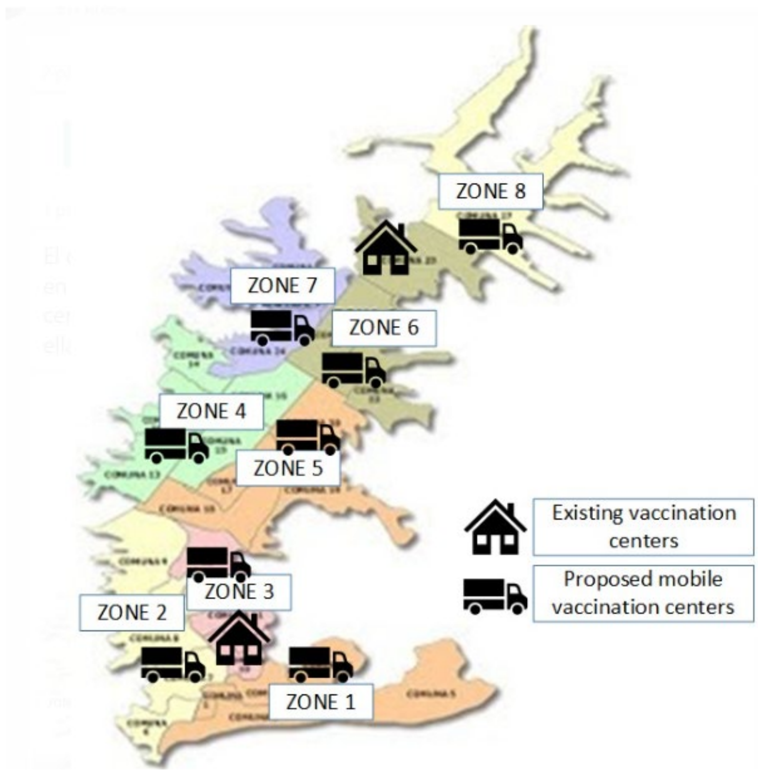

Figure 3. Location of vaccination centers

5.3 Proposed Improvements

In scenario 1, we found positive results since the total demand is met and satisfied according to the turnout of the citizens of San Juan de Lurigancho. In the model proposed, the existing vaccination centers are able to meet all the demand, but we were told that with an extension of vaccination points the process would be more efficient and faster compared to the initial scenario. Mobile vaccination centers should be implemented to speed up and cover a possible increase in demand in each critical situation. This increase in efficiency would save many lives by the simple fact of good management of available resources in our country.

In scenario 2 of the 10% increase in demand compared to the model of Krzysztofowicz and Osińska-Skotak (2021) in our context it would not be possible to meet the full demand of required inoculations of people in an acceptable timeframe, necessarily an increase of vaccination centers would be required to meet the demand in a reasonable time (Klise and Bynum, 2020). Therefore, the implementation of additional mobile vaccination centers is necessary to be able to efficiently respond to the additional demand presented by this scenario. In addition, it is important that the mobile vaccination centers have a modification that allows transporting a larger quantity of vaccines, new refrigerators can be implemented, and the increase of trained personnel can be implemented.

5.4 Validation

This method is repeatable so that it can be successfully applied in other cities or local government units. There is no restriction on the level of territorial division here, it can be a district, province of any country. If there is a need for an analysis of another type of administrative area, for example, medical districts, it can also be implemented quickly. According to this simulation in GIS it is possible to parameterize the maximum number of people vaccinated per day or the availability of vaccines from different companies. The key factor is data on the place of residence of people in a specific age group. The proposed analyses could be added in more detail, taking into account information on the transport accessibility of a given vaccination site, understood as the distance and time needed to reach it on foot, by car or by public transport. This is especially important in the context of limiting social contacts and thus the risk of contagion. The best solution is the shortest possible route to the vaccination site or using your own transport vehicle. To achieve this goal, it would be necessary to use network analysis that can also be performed with the use of GIS technology.

6. Conclusion

We have demonstrated that the implementation of mobile vaccination centers is a more economical alternative to conventional centers. In addition, any logistical plan should always have several alternatives or options that help the process to be optimized. It was also possible to determine the ideal location of these mobile vaccination centers and their capacity to meet the demand. This can be seen in the scenarios that were proposed to determine whether it is possible to meet the district's demand and how the implementation of vaccination trucks can have a significant impact on economic and logistical issues.

The scope of the positive impact of the vaccination campaign extends to more indirect aspects such as the motivation people must go to vaccination centers due to the ease with which they can travel and obtain vaccines. Different incentives that facilitate vaccination, such as the low cost of transportation or the speed of the process, can make a significant difference in protecting the population.

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Biographies

Miguel Arellano holds a bachelor's degree in Industrial Engineering from Universidad de Lima. Winner of the first place for the best productive process in the program "The Company" Junior Achievement. With experience in the area of purchases and contracts in the mining company Southern Peru Copper Corporation during the period January-September 2021. Currently, in preparation for a Master's Degree in International Business at CBS International Business School in Germany.

Fabrizzio Cobos holds a bachelor's degree in Industrial Engineering from Universidad de Lima. Experience in the area of operations in the company EAGLE CONSULTING, working in bids with Chinalco Mining of Peru, Volcan Mining Company and management in maritime-port training. Currently working on a safety audit project for a transportation company (materials and concentrates) in the mining sector.

José Antonio Taquía is a Doctoral Researcher from Universidad Nacional Mayor de San Marcos and holds a Master of Science degree in Industrial Engineering from Universidad de Lima. He is a member of the School of Engineering and Architecture teaching courses on quantitative methods, predictive analytics, and research methodology. He has a vast experience on applied technology related to machine learning and industry 4.0 disrupting applications. In the private sector he was part of several implementations of technical projects including roles as an expert user and in the leading deployment side. He worked as a senior corporate demand planner with emphasis on the statistical field for a multinational Peruvian company in the beauty and personal care industry with operations in Europe and Latin America. Mr. Taquía has a strong background in supply chain analytics and operations modeling applied at different sectors of the industry. He is also a member of the Scientific Research Institute at Universidad de Lima. His main research interests are on statistical learning, predictive analytics, and industry 4.0.