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Thematic Section - Resilient and innovative operations management

Logistics of Covid-19 vaccines: main challenges in theory and practice

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Abstract

Paper aims: This paper presents the literature findings of the Covid-19 vaccines supply chain, its main challenges and best practices, which are compared and verified empirically.

Originality: The questionnaire developed in this study provides new empirical data about the Covid-19 vaccines supply chain, especially regarding the impacts of the Covid-19 pandemic in the chain, as these events are still recent.

Research method: A questionnaire was sent by e-mail to specialists working with the Covid-19 vaccine supply chain in South America. Each response was compared to the literature findings.

Main findings: Despite the challenges faced by vaccination programs, some countries have achieved good results due to strategies adopted at the beginning of their immunization campaigns. The empirical research confirmed that literature findings match business reality, although some empirical results vary depending on the scenario of the country regarding the impacts of the pandemic.

Implications for theory and practice: This paper summarizes the Covid-19 vaccine supply chain and its challenges, best practices of the most successful countries regarding the immunization process, providing a better understanding of the pandemic scenario. Some empirical data corroborate the literature, and some discrepancies allow the formulation of suppositions that may be tested in future studies.

Keywords

Pandemics. Covid-19. Vaccination. Cold chain. Supply chain.

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1. Introduction

On March 11, 2020, the global pandemic of Covid-19 was declared by the World Health Organization (WHO) (Liu et al., 2020). Over 198 million cases and 4 million deaths were officially confirmed until August 2021, leading to a current fatality rate of 2.1% (Our World in Data, 2021a). The disease may cause fever, cough, and fatigue, similar to other severe respiratory infections (Velavan & Meyer, 2020). Most people who fall sick with Covid-19 will experience mild to moderate symptoms, recovering without special treatment. However, some will become seriously ill, requiring medical attention. The disease tends to have greater severity and mortality rate in the elderly population (Zhou et al., 2020) and immunodeficiency or chronic disease patients (Brasil, 2020).

Covid-19 characteristics make herd immunity harder to be achieved. A natural herd immunization process would require a large portion of the population to be affected, triggering millions of deaths and overloading the healthcare system. In this way, mass vaccination programs emerge as a critical element for achieving sufficient immunization coverage to end the global pandemic (Randolph & Barreiro, 2020). Global vaccine accessibility relies on the transport of doses to the last mile through distribution chains, strict quality controls, complex production processes, and raw material availability (Smith et al., 2011). Thus, its efficacy depends not only on

the supply chain that distributes the final product but also on all the supply chains that support the whole manufacturer (Golan et al., 2021).

In the health context, the cold chain is a temperature-controlled supply chain with procedures and rules that ensure the proper storage and distribution of vaccines to national and local health services. The current immunization cold chain and its operations have been key elements in intensifying the provision of daily immunization services, allowing more people to be protected from vaccine-preventable diseases. Also, the importance of the cold chain is given as most of the vaccines must be at a specific temperature from its manufacture to its inoculation to maintain the expected efficacy and safety. In this sense, the cold chain needs to be flexible, as each vaccine has its temperature requirement.

Natural disasters that arise from the external environment are intrinsically challenging to manage and respond (Oliveira et al., 2019). Some of them are tough to predict, as in the case of the COVID-19 pandemic, an unprecedented event. As consequence, actions to respond to a disaster such as the COVID-19 pandemic are complex. The Covid-19 vaccine cold chain is multifaceted and highly challenging, mainly due to the global-scale demand. For months, the main challenge with the Covid-19 vaccine roll-out was that demand significantly outstripped supply. Furthermore, challenges in the production, distribution, and even the acceptance of the vaccine also emerged as barriers to the immunization process. This paper aims to present and discuss the main challenges and aspects of the Covid-19 vaccine supply chain, comparing the findings in the literature with the ones found in practice. Thus, the question posed in this study includes: Do the challenges of the Covid-19 vaccine supply chain found in the literature correspond to business practice? For this purpose, we designed two specific objectives:

- Comprehend the state of the art of the Covid-19 vaccines supply chain and its main challenges and best practices;
- Verify the aspects of the Covid-19 vaccine supply chain and its challenges empirically, comparing these findings with the ones found in the literature.

To verify and validate the literature findings, we conduct empirical research through a structured questionnaire with experts working in the Covid-19 vaccine supply chain in Brazil, Argentina, and Peru. Thus, this research endorses the academic discussion about the cold chain of vaccines, especially the Covid-19 vaccine supply chain, and contributes to practitioners to better comprehend the main challenges in theory validated in practice. The remainder of the paper is structured as follows. We begin by reviewing the theoretical grounds for the Covid-19 vaccine supply chain. Section 3 describes the research methodology, while Section 4 presents the main research findings and discussions. Finally, Section 5 summarizes the conclusions and limitations and raises future research on the field.

2. Covid-19 vaccines supply chain

The Covid-19 pandemic gathered the attention of a large audience, especially researchers worldwide, who have been targeting efforts toward the development and distribution of a safe and effective vaccine. Usually, vaccine development occurs linearly in eight distinct phases (World Health Organization, 2020), as shown in Figure 1. This type of development reduces the stakeholders' risk and the installed infrastructure once the effectiveness, the feasibility of production, and clinical studies must be validated before proceeding with each phase (Golan et al., 2021).

The development of the Covid-19 vaccine, in turn, had to follow an accelerated schedule due to the pandemic severity. The phases needed to overlap to accomplish the accelerated development schedule (World Health Organization, 2020) (Figure 2). With the global demand for vaccines, this acceleration overloaded the supply chain (Golan et al., 2021), inherently complex.

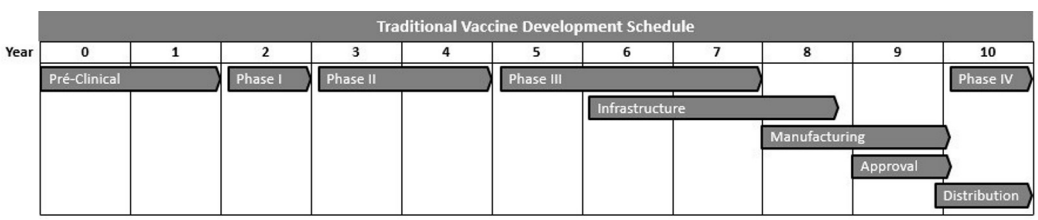

Figure 1. Traditional Vaccine Development Schedule.

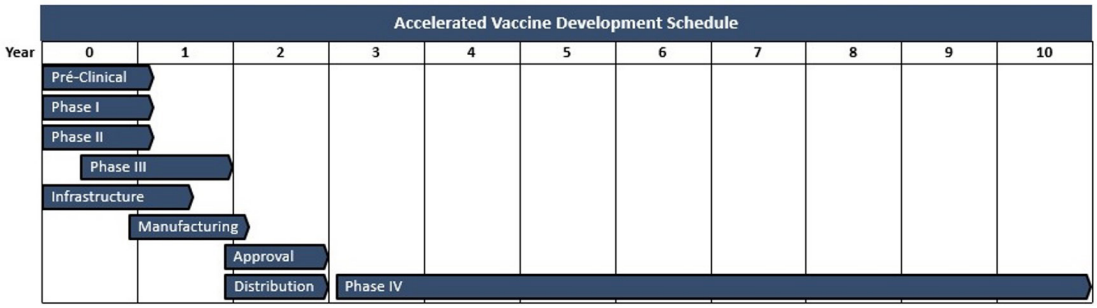

Figure 2. Accelerated Vaccine Development Schedule.

To understand the entire vaccine supply chain, from manufacturing to the last mile, it is essential to model the whole network and consider its interactions (Golan et al., 2021). The US Centers for Disease Control and Prevention (2021a) segregates the vaccine cold chain into 5 stages, named: vaccine manufacturing, distribution, vaccine arrival at the provider facility, vaccine storage and handling at the provider facility, and vaccine administration (see Figure 3).

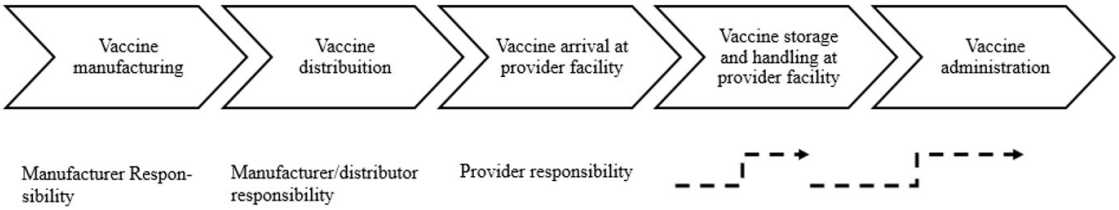

Figure 3. Cold Chain Flowchart.

Vaccine manufacturing is a complex and multistep process. These steps involve the virus culture, purification and inactivation, vaccine formulation, packaging, and shipment. This entire process usually takes from 6 to 36 months, being 70% of this time dedicated to quality tests done by different authorities worldwide (Sanofi, 2019). Regulatory licenses are not limited to biological entities, but also the entire production and testing process. Therefore, significant changes to the manufacture, such as raw material or equipment changes, will demand new regulatory requirements to ensure that the vaccine is still effective and comparable to its prior version. The regulatory licenses configure an obstacle to optimizing and improving the production process, with the manufacturers having to choose between reaching the market earlier or having a manufacturing optimization process. The former has been advantageous to the short term and the latter to the long term (Plotkin et al., 2017).

Covid-19 vaccine manufacturing proved to be very challenging, as it needed to be rapid and on a large scale. For mRNA vaccines, challenges were more remarkable. These vaccines use novel technologies, and no preexisting manufacturing infrastructure that could be utilized was ready (Amanat & Krammer, 2020) as this was the first time mRNA technology has been authorized outside of clinical trials (Smith et al., 2011). At this stage of the supply chain, main challenges include (i) a long and complex multistep manufacturing process (Sanofi, 2019); (ii) strict regulatory licenses (Plotkin et al., 2017); (iii) global demand for Covid-19 vaccines production (Amanat & Krammer, 2020).

The covid-19 vaccine distribution process involves existing networks, processes, and partnerships to make vaccines available worldwide, maintaining product integrity. The proper storage and distribution of vaccines to health services are ensured by the cold chain, a temperature-controlled supply chain. Vaccines are sensitive biological substances that can lose effectiveness and potency if exposed to temperatures (heat and/or cold) outside of the required temperature range for the specific product or when exposed to light (Canadian, 2021). The cold chain aims to maintain vaccines in proper conditions during transport, storage, and distribution until the moment of dose administration (Brasil, 2014). This chain is essential for maintaining the initial characteristics of the product, avoiding changes in the potency, components, and efficacy of the immunobiological. Gunn (2020) reiterates that the main challenges of the cold chain are related to maintaining the vaccines within a constant temperature range, not necessarily low. Too much cold can compromise the integrity of the product.

The most significant risk of losses in the cold chain is related to the freezing of the vaccine and not to the heat (Hubbard, 2020). Failure to adhere to vaccine handling and cold chain requirements can reduce vaccine potency and increase local reactions at the vaccine administration site. The loss of vaccine effectiveness due to cold chain exposures to adverse conditions is permanent, cumulative, and irreversible (Amanat & Krammer, 2020). Thus, at this stage of the supply chain, the main challenges are related to maintaining vaccines at appropriate temperatures and not modifying their characteristics.

Due to the need to keep the product at controlled temperatures, the cold chain presents high operating costs (Costa et al., 2017). The operational cost can be greater depending on the specificities of each vaccine and each country. In Brazil, for example, Covid-19 vaccine distribution is made through land transportation, with a fleet of 100 refrigerated delivery vehicles (Brasil, 2014). Maintaining the vaccines at proper temperatures during land transport frequently leads to a higher freight cost. According to the National Land Transportation Agency (Portuguese acronym: ANTT) (Brasil, 2021), the cost for land transportation of refrigerated cargo is higher than general cargo. The mileage cost of refrigerated cargo is, on average, 19% higher than a general cargo and the cost of loading and unloading is 21% higher.

Challenges in vaccine storage are also common due to the limited storage capacity of providers and the lack of predictability of supply and demand. Customs and regulatory procedures, which vary according to the country, and the import regulations which are frequently changed are also highlighted as challenges. In addition, there is an impasse that suppliers have with obtaining certification and qualifications (DHL Research and Innovation GmbH, 2020).

Regarding the last mile stage - vaccine administration, Gevaers et al. (2011) define it as the final stage of the delivery process, often being the most expensive and least efficient supply chain segment. The last mile is especially important for the vaccine supply chain, as it involves delivering the product to the end user in a medically compliant manner (Golan et al., 2021). For economic reasons, vaccines are usually delivered through multi-dose vials (Schiffling & Breen, 2021). However, it increases the open vial wastage, as there will be more unused spoiled doses in the opened vials. Leftovers are the primary source of vaccine wastage, reaching up to 50% for vials with 20 or more doses (Schiffling & Breen, 2021). Mass vaccination centers allow better supply and demand matching, using open vials more efficiently, as there will be batches of vaccinated people, dwindling this kind of wastage (World Health Organization, 2019).

To overcome the several challenges of the Covid-19 vaccine supply chain, reduce vaccine losses, and make the immunization process more efficient, strategies and best practices had to be developed. The first dose of a fully tested Covid-19 vaccine was administered in December 2020 in the United Kingdom. Thenceforth, several countries have joined the race toward immunization. At earlier vaccination stages, Israel and the United Arab Emirates (UAE) stood out due to their efficiency in conducting the Covid-19 vaccination campaigns, reducing vaccine losses, and developing best practices to overcome the challenges. These countries still lead the current Covid-19 vaccine doses administered per 100 people (Our World in Data, 2021b).

Countries such as Israel, Chile, and the United States of America (USA) used a decentralized strategy, in which several organizations were responsible for each priority group (McKee & Rajan, 2021; TRT World, 2021; U.S. Department of Health and Human Services 2021). In Israel, for example, health workers were vaccinated by their own companies, while people over 60 years old or with pre-existing medical conditions were covered by non-profit health plans (McKee & Rajan, 2021). Israel and the UAE already counted with a robust online registration system for vaccination, which was rapidly adapted to the Covid-19 vaccination campaign, providing real-time data on the vaccine effectiveness, and allowing the follow up of adverse events after the inoculation (McKee & Rajan, 2021; Emirates News Agency, 2020). These countries also developed communication strategies in multiple channels, such as social media, corporate websites, and mass media (Choi et al., 2021; Khaleej Times, 2020), to encourage the population to get the vaccine, which generated excellent adherence. The UAE, USA, and Israel used multiple vaccination sites, which allowed the rapid implementation of the Covid-19 vaccination program by increasing its reach and access (Choi et al., 2021; Syal, 2021; Centers for Disease Control and Prevention, 2021b).

Israel also modified the initial manufacturer's requirements for the transportation, storage, and distribution of Covid-19 vaccines (Choi et al., 2021). The manufacturer's technical specifications pose a significant challenge for vaccinating individuals on a smaller scale, particularly in rural areas. To solve this problem and optimize the supply chain, Israel was authorized by the supplier to repackage the large ultra-frozen pallets into smaller insulated boxes, enabling the vaccine to be distributed in smaller quantities (Choi et al., 2021).

It is important to have well-defined strategies to better respond to the disaster. Lamenza et al., (2019) highlight specific methodologies on purchasing strategies for relief items in humanitarian operations. Countries such as the UAE, Chile, the USA, and Israel developed efficient procurement strategies that contributed to the

good performance of the vaccination campaign in these countries (Syal, 2021; Abramovich, 2021; National Institutes of Health, 2020). The strategy of supplier diversification acquired by UAE, Chile and USA was important since the vaccines available in the market were not proven to be effective yet (Abramovich, 2021). Regarding the early acquisition of the vaccines, Israel was one of the Covid-19 vaccine early buyers, which contributed to accelerating its vaccination process (Abramovich, 2021). Besides, just as necessary as the early acquisition of the immunizer is its use approval. The UAE, Chile, and the USA have fast-tracked the authorization process for the Covid-19 vaccine (Syal, 2021; Abramovich, 2021; National Institutes of Health, 2020). In September 2020, in the UAE, for example, emergency approvals were already issued for the administration of Covid-19 vaccines to frontline healthcare workers (Syal, 2021). Host trials were also performed in the UAE, Chile, USA (Syal, 2021); Abramovich, 2021; National Institutes of Health, 2020). The host of clinical trials facilitates the negotiations, such as acquisition priority, allowing the vaccination program to start earlier than other countries. Finally, the acceleration of Covid-19 vaccine authorization processes proved to be effective in Chile (Financial Times, 2021) and United Arab Emirates (Syal, 2021). Table 1 summarizes the good practices found in the literature.

Table 1. Best Practices Covid-19 Vaccination.

Best Practice	Country	Country
Package Modifications	Israel	(Choi et al., 2021)
Decentralized Vaccination Responsibility	Israel, Chile, USA	(McKee & Rajan, 2021; TRT World, 2021; U.S. Department of Health and Human Services, 2021)
Multiple Vaccination Sites	Israel, UAE, USA	(Choi et al., 2021; Syal, 2021; Centers for Disease Control and Prevention, 2021a)
Promoting vaccine trust through communication strategies	Israel, UAE	(Choi et al., 2021; Khaleej Times, 2020)
Well-structured web-based immunization registry	Israel, UAE	(Emirates News Agency, 2020; Choi et al., 2021)
Multiple contracts with Covid-19 vaccine suppliers	UAE, Chile, USA	(Syal, 2021; Abramovich, 2021; National Institutes of Health, 2020)
Covid-19 vaccine early buyers	Israel, Chile	(Abramovich, 2021; Deutsche Welle, 2021)
Hosting vaccine trials, obtaining commercial advantages	UAE, Chile, USA	(Syal, 2021; Abramovich, 2021; National Institutes of Health, 2020)
Robust primary healthcare system	Israel, UAE, Chile	(McKee & Rajan, 2021; Abramovich, 2021; Embassy of the United Arab Emirates, 2021)
Speed up the authorization processes of the Covid-19 vaccine	UAE, Chile	(Syal, 2021; Financial Times, 2021)

Source: The authors.

3. Research methodology

For results interpretation and discussions in practice, we developed a structured questionnaire based on the results obtained from the theoretical foundation. The questionnaire aimed to bring the empirical foundation of the subject addressed in this research. It was prepared in Survey Monkey Platform and sent to the respondents through e-mail, successfully reaching 3 of the 4 intended respondents. Our sample of respondents included specialists working with the Covid-19 vaccine supply chain in Peru, Argentina, and Brazil. The respondents were identified as A, B, and C, with the following profiles:

- Respondent A: works in the Disaster Risk Management Affairs sector in Peru, handling the *Sinopharm* vaccine. Most of its operations take place through land (80%), followed by air (15%) and water (5%).
- Respondent B: works as a logistic operator in Argentina, with the *Sputnik V, Oxford/AstraZeneca*, and *Sinopharm* vaccines, handling approximately 4 million doses monthly. Its operations are mainly through the land (95%) and the air (5%).
- Respondent C: works as logistics planner with *Sinovac, BioNTech/Fosun Pharma/Pfizer*, and *Oxford/AstraZeneca* vaccines in Brazil. Its operations are mainly through the air.

The questionnaire was available in Portuguese and English, taking approximately 11 minutes to be fully answered. It was composed of closed and opened questions, divided into 3 sections: (i) General information; (ii) Storage, transportation, and distribution; (iii) Logistics challenges. The first section focused on obtaining information about

the respondents and their operations, such as country of operation, area of expertise, and the type of vaccines the respondents work with. The second part was intended to gather information about reasons for vaccine losses during storage and transportation. Besides, the second section also covered questions about the influence of items such as refrigerated load, urgent delivery, specificity of the vaccines on the shipping freight cost, packaging mode, and vehicle security. The third part relied on questions about the challenges related to Covid-19 vaccine logistics. These challenges included: demand planning and inventory management; customs and regulatory procedures; cold chain (transportation and storage), risk of wastage due to product fragility, dose administration (last mile), use of additional personal protective equipment and social distance; shortage of labor/absenteeism (risk groups, confirmed/suspected Covid-19 cases). Finally, the respondents were asked to add potential challenges. Most of the questions followed the Likert scale: Very Low, Low, Medium, High, and Very High. It is important to highlight that these scales are subjective and highly susceptible to variations based on their perceptions.

4. Results and discussions

This section presents the empirical results obtained through the questionnaire with specialists. Tables 2 and 3 present the answers related to vaccine losses during the storage and transportation processes. According to respondent A, vaccine losses occur mainly during the last mile stage. Respondents B and C affirmed there was no vaccine wastage in their operations.

Table 2. Vaccine losses answers - part 01.

Question	Respondent		
	A	B	C
Select the stage with the greatest vaccine loss	Distribution (last mile)	No vaccine loss	No vaccine loss

Source: The authors.

Table 3. Vaccine losses answers - part 02.

What is the impact of the items below on the waste of vaccines during storage/transportation?	Storage		Transportation	
	A	B	A	B
Temperature	Medium	High	Medium	High
Theft	Very High	Very Low	Very High	Low
Process accidents	Medium	Low	Medium	Low
Shelf life	Low	Low	Low	Very Low
Massive vaccination centers	High	-	-	-
Security on transportation	-	-	Very High	-

The questions included in Table 3 measure qualitatively the impact of reasons for vaccine losses. Respondent A added two new items to our previous list: 'massive vaccination centers' and 'security on transportation' in storage and transportation processes. Regarding the storage process, respondent A indicated 'theft' and 'massive vaccination centers' as having a very high and high impact on vaccine loss, respectively, and 'process accidents' as having a medium impact. Only 'shelf life' was seen for respondent A with a low impact on vaccine loss. For transportation, respondent A classifies 'theft' and hence 'security on transportation' as items with a very high impact on vaccine loss.

Despite having affirmed in the previous question that there are no vaccine losses in its operations, respondent B pointed out the main reasons for these losses. 'Temperature' was considered an item with a high influence of vaccine loss by respondent B, whether in the storage or distribution process. In contrast, other items were deemed low or very low in both processes. Respondent C refrained from answering that question since it has been affirmed that there is no vaccine wastage in its operations.

Regarding the freight costs in vaccine distribution, Table 4 shows the influences of the shipping freight cost for respondents A and C. Respondent B did not respond to this question. Respondents A and C stated that their freight cost has a high impact on their operations cost, pointing out items such as 'urgent delivery', 'travel time', and 'mode of transport' as having a high influence on the shipping freight cost. Respondent A also pointed out the' specificity of the product (vaccine)', 'security', and 'cargo packing' as having high influence, while respondent C classified these items as having a medium influence. 'Refrigerated load' was the only item classified as medium for respondent A and low for C.

Table 4. Freight answers.

What is the influence of the items below on the shipping freight cost of your operation?	Respondent	
	A	B
Refrigerated load	Medium	Low
Urgent delivery	High	High
Fragility/specificity of the product (vaccine)	High	Medium
Security	High	Medium
Travel time	High	High
Mode of transport (land, air or water)	High	High
Cargo Packing/Conditioning	High	Medium

Source: The authors.

Table 5 shows the questions and answers related to storage packing; and vehicle escort during transportation. Most of the operations of respondents A and B occurs by the land, with a small part by air, while operations of respondent C occur by the air. For dose storage packing at the distribution center, respondent A selected boxes, and respondents B and C, boxes and pallets. Only respondent B considered refrigerated containers during land and air transportation.

Table 5. Storage packing answers.

Question	Respondent		
	A	B	C
Select the dose storage packing at the distribution center.	Boxes	Boxes and pallets	Boxes and pallets
Select the dose packaging mode during the land transportation.	Boxes	Refrigerated boxes	Boxes and pallets
Select the dose packaging mode during the air transportation.	Boxes and pallets	Refrigerated boxes	Boxes

Source: The authors.

Regarding the main challenges related to Covid-19 vaccine logistics, all three respondents classified difficulties such as 'demand planning and inventory management' as very high or high by all the 3 respondents. 'Customs and regulatory procedures' was considered high for respondents A and C but not considered by respondent B. For respondents B and C, 'cold chain (transportation and storage)' was considered very high and high, respectively, and considered medium by respondent A. Also, 'risk of wastage' was considered high for B and C and medium for A, while dose administration was high for respondent A, and low for C, and it was not considered by respondent B. Finally, 'use of additional Personal Protective Equipment (PPE) and social distance' and 'shortage of labor/absenteeism (risk groups, confirmed/suspected Covid-19 cases)' were considered very high for respondent A, medium for B, and low for C. Table 6 shows qualitative ratings of the challenges. Respondents also had the option to add new challenges they deemed relevant, but none were added.

Table 6. Logistic Challenges answers.

Rank the challenges below related to COVID-19 vaccine logistics:	Respondent		
	A	B	C
Demand planning and inventory management	Very High	High	High
Customs and regulatory procedures	High	N/A (not considered)	High
Cold Chain (transportation and storage)	Medium	Very High	High
Risk of wastage due to product fragility, temperature and shelf life	Medium	High	High
Dose administration (last mile)	High	N/A	Low
Use of additional Personal Protective Equipment (PPE) and social distance	Very High	Medium	Low
Shortage of labor/absenteeism (risk groups, confirmed/suspected Covid-19 cases)	Very High	Medium	Low

Source: The authors.

4.1. Discussions

As previously presented in the literature review, the cold chain is susceptible to losses in all stages, especially in the last mile stage of the supply chain with the highest cost and lowest efficiency. In our sample of respondents, respondent A pointed out the last mile as the part of the chain with the greatest vaccine loss, which can be explained by the open vial wastage discussed in Section 2. Respondents B and C affirmed there were no vaccine losses in their operations. However, these answers do not exclude the fact that there are vaccine wastages. The knowledge of respondents B and C may not cover the entire vaccine supply chain.

Respondents A and B reported a significant influence of temperature on vaccine losses during storage and transportation, classified as medium and high influence for the respondents, respectively. These results are consistent with the literature since vaccines are highly sensitive to temperature, which must be controlled and monitored all along the supply chain.

The main reason for vaccine wastage informed by respondent A is theft. It is worth noting that robberies may be associated with poor socio-economic conditions of the region, requesting, therefore, investments in security. Consequently, this may lead to increases in freight costs. Indeed, respondents A and C pointed out the freight cost as high in their operations. Particularly, respondent A pointed out security as having a high influence on freight costs of its operations. The complexity of the Covid-19 vaccine supply chain impacts the cost of distribution. Refrigerated cargo transportation requires extra resources, such as refrigeration equipment, resulting in additional costs to the companies. In Brazil, for example, the travel cost of land refrigerated transportation is approximately 19% higher than general cargo (Brasil, 2021). However, despite the higher cost of refrigerated cargo, respondents A and C pointed out other items as more significant for the cost of freight, such as urgent delivery, travel time, and mode of transport. This can be explained by the particularities of Covid-19 vaccines compared to other vaccines and refrigerated products. Also, because of the severity and consequences of the Covid-19 pandemic, there is an urgent need for vaccine distribution, impacting the freight cost and possibly diluting the impact of the higher freight cost of refrigerated cargo. All respondents stated that shelf life (when the product can be stored without impairing its integrity) has little influence on Covid-19 vaccine losses. This is consistent with the current reality of supply and demand.

The last part of the questionnaire aimed to measure the impact of the challenges in the Covid-19 vaccine supply chain, qualitatively. All three respondents stated 'demand planning and inventory control' as very challenging, as the lack of predictability of supply and demand is enormous (DHL Research and Innovation GmbH, 2020). A good practice used by Israel (Choi et al., 2021) and the United Arab Emirates (Emirates News Agency, 2020) to better manage supply and demand is developing a well-structured information system, which allows better tracking of the administered doses, enabling a better demand forecasting.

Respondents A and C consider the impact of 'customs and regulatory procedures' as high. It can be induced that customs and regulatory procedures are challenging due to their complexity and lack of agility. However, such impacts can be mitigated by accelerating Covid-19 vaccine authorization processes, proven effective in Chile (Financial Times, 2021) and United Arab Emirates (Syal, 2021).

The respondents had different perceptions regarding the items 'cold chain' and the 'risk of wastage due to product fragility, temperature, and shelf life' in their operations. Nevertheless, these obstacles are existent in all operations, and their intensity may change according to the mode of transport, area of operation, and equipment used. It is noted that respondent B is the only one who confirmed the use of refrigerated boxes in transport operations and pointed the 'cold chain' as being very challenging, which is related to the cargo packaging mode used by company B operations.

The perceptions of A and C were opposite regarding the item 'dose administration (last mile)'. Respondent A ranked it as high and can be explained by the higher incidence of vaccine losses during the last mile, reported in Table 1, which does not occur for respondent C. Making modifications in vaccine packages with the manufacturer's authorization, as done by Israel (Choi et al., 2021), may lead to an optimized supply chain and a potential reduction of vaccine losses in the last mile stage.

The last two items are related to preventive measures, such as the 'use of personal protective equipment/ social distancing' and 'labor shortages and absenteeism' due to suspected or confirmed Covid-19 cases. These challenges are perceived differently in respondents' opinions. This difference may be related to the size, area, number of employees of the respondent's operations, and the pandemic scenario in each country. The questionnaire provided qualitative insights regarding the challenges and logistical aspects of Covid-19 vaccines addressed in the literature review.

It is important to highlight that the small sample does not allow us to draw general conclusions about the subject, but rather discuss different companies' perceptions of the logistics of Covid-19 vaccines. In this way, the results found empirically look for elucidating empirical responses and compare them with the literature findings, allowing researchers to start taking steps toward developing the Covid-19 vaccine logistics.

5. Conclusion

The Covid-19 vaccine supply chain has been complex and highly challenging. Besides the challenges presented in the conventional vaccine supply chain, such as the regulatory procedures involved in developing immunizers and temperature maintenance during the entire cold chain, the Covid-19 vaccine supply chain had to deal with the urgency of a highly contagious disease. The speed with which the disease spread through the world, overloading health care systems, required the development of an urgent vaccine.

Despite the challenges faced by vaccination programs globally, some countries such as Israel, the UAE, Chile, and the USA have achieved goods results due to strategies adopted at the beginning of the immunization schedule, such as decentralizing responsibility for the vaccination program and the purchase of vaccines from diversified suppliers. Also, it is important to highlight that a robust structured healthcare system also contributed to the good performance of the Covid-19 vaccination campaign in Israel, UAE, and Chile, reinforcing the importance of investments and policies in public health.

The objectives proposed in this paper were achieved. Our theoretical foundation summarizes the Covid-19 vaccine supply chain literature, its challenges, and best practices. Then, we compare the literature findings with empirical research. For this purpose, we develop a structured questionnaire and apply it to specialists from Peru, Argentina, and Brazil. Thereby, this work contributes to endorsing discussions about the Covid-19 vaccine supply chain both in theory and in practice. Regarding the empirical results obtained through the questionnaire, we identify discrepancies in the answers, especially regarding classifying the intensity of some items, such as 'cold chain' and 'administration of doses (last mile)', which can be explained due to different perceptions of the respondents and their different areas of operation.

This study also presents some limitations. The small sample of respondents precludes us from raising more robust and confirmatory conclusions about the subject. Also, this sample only encompasses South American countries, which further restricts the insights. The questionnaire is essentially composed of qualitative questions, which are highly based on respondents' perceptions. It is worth mentioning that some partially answered responses and the reduced sample made it challenging to propose more assertive conclusions. Thereby, future complementary works are suggested to explore a larger and global sample, delimiting a quantitative research bias and making it possible to quantify the impact of the challenges. Furthermore, researches are suggested to quantify the good practices found in countries that positively impacted vaccination campaigns, such as Israel, United Arab Emirates, and Chile.

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