Lean and Green Modelling in Healthcare Supply Chains: The Case of Massive COVID-19 Vaccine Distribution

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Abstract

In more than 100 years, the first global pandemic COVID-19 has proliferated all over the world at an unprecedented speed. The biopharmaceutical industry is moving fast to discovering a vaccine while governments scaling up to overcome the complex task of a global vaccination program. Now the race is on to organize supply chains to distribute billions of vaccines around the world. The logistic of the distribution vaccine requires a huge amount of people, transportation equipment, and storage equipment for low temperatures to handle the highly perishable vaccine. The process requires a just-in-time environment to get the population as fast as possible, in the right conditions for each one of the individuals that need to take the vaccine. This is huge shipping, transportation, and distribution challenge. It inspired us to reflect on the requirements of a massive COVID-19 vaccine distribution; and to contribute to the process improvement, adapting previous research work on lean and green supply chain modelling. Considering the high number of challenges, this work intends to develop a lean and green model for the healthcare supply chain. An overview of developing the coronavirus vaccine supply chain, identifying and systematizing recent trends, and the impact of COVID-19 on global supply chain management is considered. How lean and green supply chain practices can help in the vaccine supply chain.

Keywords
COVID-19 vaccine, COVAX Facility, Healthcare, Lean-Green Supply Chain Management, Lean

1. Introduction

The ongoing pandemic situation, the coronavirus disease 2019 (COVID-19) has spurred severe disruptions across the world and in the entire supply chains (Govindan *et al.,* 2020), especially pressing companies to reorganize the strategies behind their deliveries. The development and clinical release of various vaccines was the remarkable success story of 2020 and the distribution of these vaccines to a critical mass of people will be the challenge of 2021 (World Economic Forum, 2021). Vaccinations began in December 2020, and the vaccine rollout presents a huge and unprecedented challenge in terms of both logistics and geopolitics actions. As a logistical operation, transporting and distributing the vaccines quickly and efficiently to those who need them all around the world, is unprecedented in terms of scale, and in terms of urgency. The challenge is not just in quickly putting together a global supply chain for billions of vaccines but the fact that it must be stored, shipped, and transported at temperatures of minus 70 degrees Celsius (-94 Fahrenheit), otherwise it will go bad.

As countries start to emerge from the immediate health crisis, COVID-19 highlights the need for global cooperation to address global challenges. The COVID-19 pandemic's overall impact has forced organizations to rethink their supply chains and their resilience for an uncertain future. While in the past, the discussion has focused mainly on cost efficiency, the recent history reveals that future supply chains will need to worry about resilience and adaptability. All stakeholders must urgently come together to minimize its impact on public health and further disruption to lives and economies all over the world. Bearing this in mind, on 24 April, the World Health Organization (WHO) launched the COVID-19 Vaccines Global Access (COVAX) Facility, a new global platform collaboration to accelerate development, production, and equitable access to COVID-19 diagnostics, therapeutics, and vaccines. Governments can benefit from a wide portfolio of COVID-19 candidate vaccines, assuring, at the same time, a greater market than governments can support by their own, using a range of technology platforms, which provides an insurance policy through economies of scale and portfolio diversification.

Challenging the impact of COVID-19 on the global supply chains should consider multilateralism collaboration, international and national policies, trade wars, investment in technology, and sustainability. The key is to have a holistic approach on the organization´s decisions which should not only focus on the supply side patterns but must also consider the demand patterns. Different types of logistics and distribution plans have been considered. The supply chain considers different perspectives, between entities and within the companies. Indeed, several priorities to fight this disease include the development of potential vaccine candidates to provide protection and interrupt the transmission of COVID-19 and to ensure enough supplies for hospitals and their homogeneous distribution among the countries (Perez and Abadi, 2020). Vaccines are small volume, high margin products that are extremely sensitive to the environment temperature and must be maintained under restricted temperature control to preserve their efficacy (Ferretti *et al.*, 2018). Now, there are several candidates for a vaccine in different stages of development. Some are in the final stage of the tests, others at the beginning of their mass production or starting their administration (e.g. Moderna and BioNTech/Pfizer). It remains the understanding of how the supply chain will behave with the specific characteristics of the new vaccines. Most vaccines may require at least two doses, possibly the second one to be administered after a certain number of days, which increases difficulties in logistics and supply. According to Govindan et al. (2020), the healthcare supply chain is, probably, the most affected by the pandemic situation. Also, governments are defining their plans and processes for the distribution of vaccines, considering the infrastructure and organizations in place to adequately manage the administration of the vaccine in people (Krishnan *et al*., 2020).

Recent studies revealed that healthcare organizations are adapting lean practices within the supply chain to remove the non-value-added activities improving their supply chains (Khorasani *et al.,* 2018). In addition, the integrative lean and green supply chain eliminates non-value-added activities and at the same time reduces environmental impacts and risks throughout the supply chain activities (Duarte *et al.*, 2011; Duarte *et al*., 2020). However, the lean and green paradigms in the healthcare supply chain are not well developed, especially about COVID-19 vaccine distribution. Therefore, several characteristics from a lean and green paradigm in Industry 4.0 perspective should be considered in the vaccine distribution. For example, digital technology can help manage distribution once the products have included sensors placed on every box/pallet (Duarte and Cruz-Machado, 2017) and this is considered in this product. Other, is the waste resulting from the millions of vaccines administration and the waste management and elimination of the disposal. Production, transportation, and stock picking time are a top discussion relative to this issue and is an attribute from a lean and green point of view.

This study aims to explore how lean and green modelling will help healthcare supply chains in a massive COVID-19 vaccine distribution effort. The purpose of this paper is to make a relationship between the lean and green supply chain and the COVID-19 vaccine distribution. To the author’s knowledge, this is one of the first documents making this kind of analysis. This can help to open avenues to explore how lean and green paradigms are managed in this era of pandemic situation.

2. Supply chain and lean and green paradigms

Supply chain management (SCM) is a system that needs continuous improvement in its activities to deliver a product with higher quality, at the right time, and in the right place (Duarte and Cruz-Machado, 2017). A supply chain is defined as a network of entities that are involved in the different processes and activities to provide the right products and services. The main purpose is to satisfy the customer needs, at the right place and at the right time, with the right quantities and with the required specifications. Therefore, it is important to ensure a continuous flow-through synchronization between companies (upstream and downstream linkages), considering material flows, information flows, and cash flows. The management of the supply chain must be viewed as a system. The healthcare supply chain is slightly different compared to other industries because of its impacts on human health, which requires exact medical supplies according to the needs of patients (customers) (Alexandrea and Dewa, 2020). But, from a general point of view of practices implementation, healthcare supply chains have both similarities and differences from other industries (Zhu *et al.*, 2018). The authors Alexandrea and Dewa (2020) proposed a relationship between the healthcare supply chain and the manufacturing supply chain. Several characteristics are similar as follows: inventory control, procurement processes, information sharing, and supplier relationship (Alexandrea and Dewa, 2020; Craighead *et al*., 2020; Francis, 2020). These characteristics are of extreme importance in a lean and green supply chain. Examples are the minimization of inventory levels, high levels of capacity utilization, increased information frequency and sharing, and integration level with suppliers and customers, the decrease in the production and transportation lead time (Carvalho *et al*., 2011). The main practice and the starting point of a lean and green supply chain is the elimination of

wastes (Duarte *et al.*, 2011). Based on the works of Carvalho *et al*. (2010) and Campos and Vazquez-Brust (2018), other lean and green supply chain practices are compiled in Table 1.

Table 1. Lean and Green supply chain practices
Adapted from Carvalho *et al.* (2010) and Campos and Vazquez-Brust (2018)

SCM Level	Lean and green practices
Upstream	-Cooperation with the supplier to anticipate and resolve problems -Just-in-time deliveries -Outsourcing -Procurement consolidation/ Green procurement -Supplier certification/evaluation -Supplier relationship/long-term commitment -Supplier training and development -Delivery materials directly at the point of use -Use of green/less packages/take back the packages -Cooperation between companies to minimize the logistical impacts of material flow regard to purchase products -Materials from ethically sourced -Use logistics guidelines -Use recycle pallets/boxes to deliver materials -Collaboration on products recycling with industry peers -Profit-sharing
Focal Company	-Information shared through the chain or information system -Design for Manufacturability -High involvement work systems -Just-in-time -Multifunctional work -Work standardization -Continuous improvement/Kaizen -Use barcoding and radio frequency identification (RFID) -Use standard or bar-coded containers -3Rs (reduce, reuse, and recycle) for materials and packages -Waste reduction -ISO systems certifications (or other systems) -Pollution prevention -Emission reduction -Reduction of hazardous/materials/resources consumption -Use of green technology -Use lesser resources in getting the tasks done -Value stream map or focus/ Green-VSM
Downstream	-Customer relationship/interaction -Cross-docking approach for great distances -Use thirty-party logistics for transportations -Order/shipment tracking -Inventory reduction -Capture the demand of the customers in real-time -Reverse logistics -Environmental risk sharing with customers

3. Future of Healthcare

Healthcare topic is not only related to improving health; many types of healthcare may impact other aspects of a person's welfare, housing services, unemployment, and lifestyle. Health economists may therefore be interested not only in the cost of treatments but in the impact that this has on the quality of life and prospects of survival of the population (Cabrita and Cabrita, 2013). COVID-19 brought some challenges, besides those, including preparing for

and responding to epidemics similar events, to a tipping point. New health priorities, approaches, and new agenda will be on the table of the global platforms and initiatives as mentioned in Figure 1: i) healthcare technology to support healthy behaviours (Cabrita et al., 2019); ii) preserving health programs; iii) enabling access to healthcare; iv) sustainability of healthcare systems; v) global and national approaches, and; vi) preparing for and responding mechanisms and tools to epidemics.

Increasing numbers of infectious diseases, including HIV/AIDS, SARS, and Ebola, have demonstrated that a lack of universal response has left billions of people, including in rich countries. Healthcare supply chain collaboration and cooperation are key to prepare a healthy and green recovery, reducing wastes, preparing for and responding to sustainable solutions. Healthcare firms include biomedical research organizations, medical equipment manufacturers, pharmaceutical firms, surgical material makers, immunology experts, and pharmacies distributing COVID-19 rapid tests. All these stakeholders have to act decisively, together, in an orchestrated way, to make the necessary changes.

Figure 1. Future of Health and Healthcare

Adapted from World Economic Forum (2020)

4. The supply chain for COVID-19 vaccines

Vaccines are urgently needed to control the pandemic. The supply chain going further to be resilient and be foster transilience (Craighead *et al*., 2020). This concept represents the ability to simultaneously restore some processes and change radically others to address pandemic-induced challenges (Craighead *et al*., 2020). There is a need to overcome major supply chain challenges. Indeed, a product involves many steps before it reaches its destination: raw material extraction, manufacturing, packaging, transportation, distribution, and retail. Also, reverse logistics makes the supply chain become a closed-loop, after customer use, by taking reuse, recycling, and remanufacturing materials into new materials (Duarte and Cruz-Machado, 2017). Each of these steps may be managed internally by a company or involve multiple levels of suppliers and sub-contractors. The authors Kumar *et al*. (2020) indicate several challenges that supply chain and retailers faced with the pandemic, for example, the balance in supply and demand, safety of employees, trust between retailer and consumer, distribution and transportation capability, storage space capacity

constraints, information exchange and viability. Viability is considered a combination of resilience, adaptability, and sustainability (Kumar *et al*., 2020).

The vaccination plans must consider a sustainable supply chain. Transportation is very important to analyse sustainable issues. Economic, social, and environmental sustainability are important topics due to the fact that vaccine should arrive at all people. Active information sharing throughout the supply chain is an important practice. Technologies such as RFID and blockchain can accelerate information sharing and improve visibility into inventory positions and logistics flows (Van Hoek, 2020). According to DHL (2020), the supplying of vaccines must consider innovative packaging solutions, as well as recycling opportunities and optimal waste management in the case of one-way packaging. Another example is the barcoding to track vaccines from manufactured to patients, in vaccine vials, and packages (Jarrett *et al*., 2020) to help the distribution. Also, the product temperature is needed through continuous control and monitor. Vaccines are destroyed by storage and transport at the wrong temperature. Therefore, transport and storage must take several considerations especially packaging, precise temperature, and humidity management. Lin *et al*. (2020) confirm that the lack of vigilance, inadequate training, and equipment failure are the reasons for cold chain management breakdowns, and these will make vaccines defective.

The supply chain for the COVID-19 vaccines is defined as a cold supply chain. Indeed, all vaccine candidates require temperature and humidity management. This means that the vaccine needs to be packed to ensure that the required temperatures are maintained throughout the supply chain journey (from the manufacturing to the patient). The need to be stored and transported, until the vaccine administration in the patient must be at lower temperatures. These temperatures are different according to the types of vaccine and three main temperature ranges in the world of the cold supply chain: i) the chilled (+2 to +8 degrees Celsius); ii) frozen (minus 20 degrees Celsius); or even iii) minus 70 degrees Celsius. The first two can be handled with a normal refrigerated (water ice), but the third to keep the shipment cold is required dry ice (Leonard, 2020; Bryant, 2020). The European Commission has given conditional marketing authorization for the vaccines developed by BioNTech/Pfizer on 21 December, and Moderna on 6 January (EU Commission, 2021). The vaccine developed by BioNtech/Pfizer has to be stored and transported at temperatures of between minus 70 and minus 80 degrees Celsius, and the vaccine from Moderna has to be stored and transported at temperatures minus 20 degrees Celsius.

Packaging is an important issue in the supply chain. Cooling boxes are used to transport the vaccines, first in pallet shippers through air and road modes and then in parcel sized when transport by road to the point of use (e.g. Hospitals or vaccination centers) (DHL, 2020). The geographic reference of vaccines and transport mode is very important to control the distribution operations and can be controlled through the GPS tool. GPS can be used as a tool of the traceability system in shipping processes and in combination with IoT technologies and other components of cyber-physical systems (Al-Refaie *et al*., 2020). Traceability across the supply chain and daily reporting of execution of deliveries, reservation status, and vaccine conservation are considered. Technology devices are used for operations control and are important tools that allow real-time assessment and monitoring of the quality of the product such as IoT, Sensors, RFID, and Barcode. These will contribute to increased product handling efficiency. The data obtained through these devices are connected to the information system and providing real-time visibility into all aspects of the supply chain. Therefore, Information systems are used to share the information through the chain and help monitor and control the operations. However, there is a demand for significant levels of investment in equipment and infrastructure (Kigali, 2020). This also includes emissions from energy consumption and refrigerant escape from storage and transportation which leaves high greenhouse gas (GHG) emissions (Ferretti *et al*., 2018). Kigali (2020) mentioned that several issues must be analysed in this cold supply chain: i) production capacity; ii) vaccine storage and distribution; iii) data management and monitoring, and iv) reverse waste logistics. The reverse waste logistics and waste management are issues that must be handled. By waste the author Kigali (2020) refers "Alongside vaccines, disposable syringes, personal protective equipment and other vaccination supplies will be items that demand more volume in transport and storage."

In their research Al-Refaie *et al*. (2020) considered six characteristics of a cold supply chain: i) Information Technology to supports collaborative processes and enhance its performance during various stages of product life cycle and applying to the processes several different IT tools; ii) Available of qualified and skilly staff to work with IT tools; iii) Human resources to generate new ideas and share knowledge with partners; iv) Operational Cost which controls the costs from the raw material stage until the finished product is delivered to the customer, and v) Maintenance management which is very important to guarantee that does not fail or break down unexpectedly. According to SNS (2020) to ensure the storage, distribution, administration, and acquisition of new vaccines, real-

time information, and management system will be needed to monitor the execution of the operational component of the logistics plan. Table 2 aggregates several referenced characteristics for the COVID-19 vaccine supply chain.

Table 2. COVID-19 cold supply chain characteristics

SCM topics	Characteristics
Sourcing	-Response with the quantities needed for production -Supplier certification and qualification -Vaccination supplies
Production	-Mass production -Relationships and networks with suppliers -Create a safety stock of critical supplies in advance
Distribution and Storage	-Continuous temperature monitoring -Multimodal transport -GHG emissions
Equipment	-Vaccine product packages/boxes -Cooling equipment
Traceability	-Sensors in the boxes for batch tracking -Real-time information -Detect counterfeit vaccines
Digital technology	-Sensors in cold boxes to monitor temperature -IoT; RFID; Barcode -GPS
Information sharing	-Information Technology Systems -Real-time information -Transparency
Waste management	-Disposal/recycle of packaging materials -Disposal/recycle of medical waste -Solid waste -Reverse waste logistics
Sustainability	- Energy use (e.g. spillage of refrigerant) - Pollutants from cooling equipment - Investment in equipment - Eco-friendly packaging materials - Appropriate people training

It is possible to consider different stages in the supply chain for COVID-19 vaccines: i) from supplier to pharmaceutical (vaccine producer); ii) from pharmaceutical to hub distribution or country warehouse; iii) to hospitals or vaccine centers, and iv) to patient. Also, the material used on these stages must be managed to be recycled or disposed.

The EU Commission (2021) claim that all member states must work to develop a vaccination strategy considering logistics and transportation as a key issue. Each of the member states is responsible for the vaccination of their population: management of human and technical resources, monitoring capacity, storage capacity, and transport of vaccines in ideal and safe conditions. Vaccines are received in a single central warehouse, at a saved cold temperature, and are transported in a road-based distribution.

According to DHL (2020) five pillars can define the successful crisis management to meet supply chain challenges: i) developed a clear emergency response plan; ii) built a partnership network; iii) ensure access to required physical logistics infrastructure; iv) established IT-enabled supply chain transparency, and v) create a structure to coordinate the plan considering partners, infrastructures, resources, and IT.

Therefore, it is important to develop detailed logistical plans and tools to support effective vaccine production, transport, storage, continuous temperature monitoring, and waste management (DHL, 2020). The supply chain can be worked well if a framework for the supply chain structure is available for data collection here.

5. Lean and green modelling for COVID-19 vaccines

The application of lean and green paradigms throughout supply chain networks help to respond faster to customer/patient (Shokrani *et al*., 2020; Duarte and Cruz-Machado, 2017). In a lean and green approach, several challenges must be considered as cost reduction, on-time delivery, quality improvement, reduced emission, and solid waste (Thanki *et al.,* 2016). A crucial challenge is the reduction of waste. Lean and green transportation waste have outcomes as travel and packaging scrap (Choudhary *et al*., 2019). Also, satisfying the customer needs is an important issue in a lean and green environment. These are challenges in COVID-19 vaccine distribution.

Therefore, customer satisfaction due to the vaccine administration must be made on the date and schedule. So, just-in-time practice is a crucial practice in the administration process. Inspired by the COVID-19 cold supply chain characteristics studied above, the vaccine cold supply chain integrates both lean/green characteristics and digital supply chain, as depicted in Figure 2.

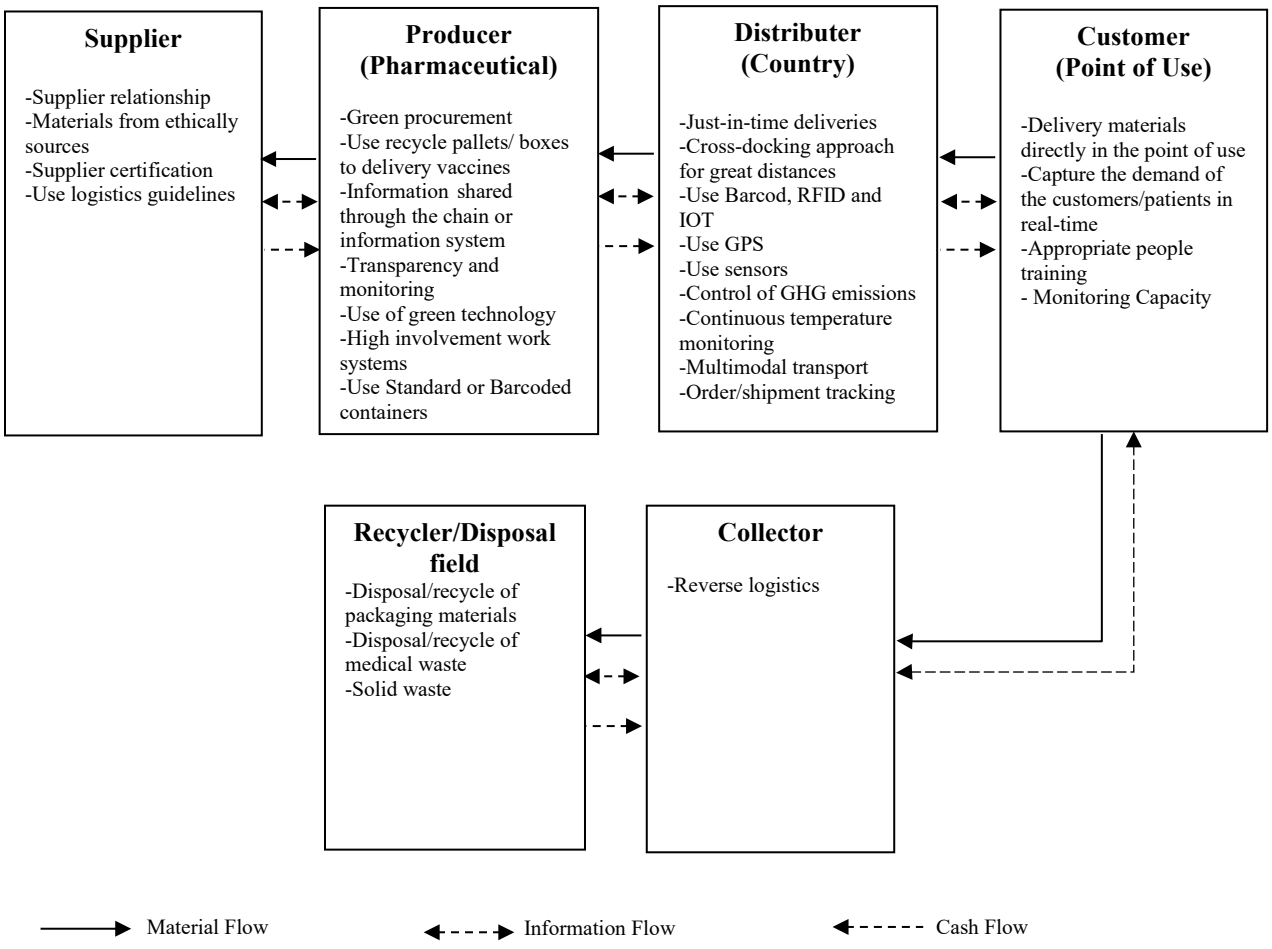

Figure 2. Lean and Green COVID-19 vaccine distribution

6. Conclusions

COVID-19 is the greatest global shock in the last decades. Responding to the COVID 19 pandemic requires global cooperation among international organizations, governments, and local communities. Technology solutions shared between governments, logistics providers, and healthcare providers are needed to reach the end of this pandemic and move towards the "next normal" (World Economic Forum, 2021). Collaboration at an unprecedented level among all parties involved in the development and distribution of COVID-19 vaccines is critical to success. As we move into the future, it is vital to use what has been learned from recent events to prepare for the future. Our study stresses that to deliver vaccines, all parties involved – pharmaceutical companies, logistical partners, and governments – must work together to create a "cold chain" of freezers and temperature-controlled shipping methods that ensures vaccines are kept at a precise temperature. Both the Moderna and BioNTech/Pfizer vaccines need to be kept frozen and must rely on the cold supply chain to get anywhere. Only wealthy countries have the resources to implement an adequately developed cold chain, leaving back the poorer countries and the remote parts of the world where electricity is unavailable or spotty to provide mechanisms to keep vaccines at low temperatures.

A conceptualization between the fields of action lean and green supply chain and Covid-19 supply chain was presented in this study. The lean and green supply chain practices help to define the massive Covid-19 vaccine distribution. This contributes to the discussion of how modeling lean and green supply chain to help to get a massive vaccine administration.

Several new research can be developed around this topic. Understand which practice is more important in the vaccine distribution and which has a high impact to respond faster to the vaccination need, can be the next step around this research.

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