UNIVERSITY OF GOTHENBURG

SCHOOL OF BUSINESS, ECONOMICS AND LAW

Master´s Degree project in Logistics and Transport Management

Risks of the Covid-19 Vaccine Supply Chain

Authors:
Viktoria Barany – 19950223-7663
Julia Galus – 19940415-0568

Graduate School

Supervisor:
Prof. Shahryar Sorooshian

Acknowledgements

We would like to show our gratitude to Prof. Shahryar Sorooshian who dedicated his time to guide and support us with his expertise and experience throughout our research.

Furthermore, we would like to thank our research participants for taking their time to participate in our interviews and survey. Their knowledge and experience on the subject have greatly contributed to the outcome of our research. We would further like to thank all contact persons in the LIF network who got us into contact with potential participants.

Last but not least, we would like to thank our families and friends for their continuous encouragement, guidance, support, and understanding before and during our studies.

Abstract

The world is currently facing the Covid-19 pandemic, where the solution relies on the effective distribution of the vaccines. As with every operation, the Covid-19 vaccine supply chain is also facing challenges while the world is attempting to reach immunization coverage. This study aims to identify the risks present in a vaccine supply chain as well as investigates the prioritization of these risks in the Covid-19 vaccine supply chain.

The risks were identified through the prisma systematic literature review which served as a base for ranking these risks by the Analytical Hierarchical Process. The AHP research involved four experts which was conducted through interviews and an e-mail-based survey. As a result of the research, a ranking has been set up where the manufacturing related issues were considered as the most challenging, followed by the R&D, general vaccine supply chain, distribution, economy, stock management and information technology.

It can be concluded that the study provides a deeper insight into risks that are usually experienced under normal conditions and shows how they are prioritized during extreme conditions, which are set by the global Covid-19 pandemic.

Keywords: Covid-19, vaccines, vaccine supply chain, supply chain, risk

Table of Content

Abbreviations

3PL – Third Party Logistics
AEFI – Adverse Events Following Immunization
AHP - Analytical Hierarchy Process
AHP-GDM – Analytical Hierarchy Process – Group Decision Making
AIJ – Aggregating Individual Judgements
AIP – Aggregating Individual Priorities
BDS – Bulk Drug Substance
CDMO – Contract Development and Manufacturing Organizations
CEPI – Coalition for Epidemic Preparedness Innovation
CGMP – current Good Manufacturing Process
CM – Cellular Manufacturing
CMS – Central Medical Stores
CR – Consistency Ratio
CSIR – Council for Scientific and Industrial Research
DC – Distribution Center
DCVMN - Developing Countries' Vaccine Manufacturers Network
EPI – Expanded Program for Immunization
GAVI – Global Alliance for Vaccines and Immunizations
GHI – Global Health Initiatives
GIVS – Global Immunization Vision and Strategy
GSCM - Green Supply Chain Management
GTIN – Global Trade Item Number
GVAP – Global Vaccines Action Plan
HSC – Healthcare Supply chain
KEMSA – Kenya Medical Supply Agency
LIF - Läkemedelsindustriföreningen (The Swedish Association for the Pharmaceutical Industry
LMIC – Low to Middle Income Country
MEDS – Mission for Essential Drugs and Supplies
NRA – National Regulatory Authority
NVIP – National Vaccine Immunization Program
OECD – Organization for economic Co-operation and Development
PEP – Rabies Vaccine
POD – Points of Dispensing
PQ – Prequalification Program
R&D – Research and Development
SCM - Supply Chain Management
SNS – Strategic National Stockpile
TPS – Toyota Production systems
UN – United Nations
UNICEF – United Nations Children´s Fund
VIPS – Vaccine Innovation Prioritizations strategy
VSC – Vaccine Supply Chain
VSM – Value Stream Mapping
VVM - Vaccines Vial Monitor System
WHA – World Health Assembly
WHO – World Health Organization

1. Introduction

A new infectious disease, Coronavirus (Covid-19) (WHO, 2021a), was discovered in Wuhan, China, in the end of December 2019. What were first treated as urgent cases of pneumonia, quickly unraveled into a global pandemic (ProMed, 2019). Today, on the 8th of March 2021, a total of almost 120 million Coronavirus cases have been identified causing the death of nearly 3 million infected people worldwide (Worldometer, 2021). Restrictions have been implemented since the outbreak, with many countries being under lockdown and further limitations on the society, such as closures and reimplemented controls of borders, as well as country-specific regulations on social distance practices and the mandatory utilization of facemasks (Habayeb, 2020; Roser, Ritchie, Ortiz-Ospina, & Hasell, 2020). One of the countries being known for its casual restrictions (Juranek & Zoutman, 2020) and being judged by other countries on its approach to the infection is Sweden (Zayed, 2020; Godin, 2020). The first case was identified on the 24th of January 2020 in Jönköpings county, Sweden, after a person returned from a trip to the epicenter Wuhan, China (SverigesRadio, 2020). Since then, there have been nearly 700 thousand confirmed cases in Sweden, resulting in almost 13 thousand deaths (WHO, 2021d), with elderly homes being affected heavily, as approximately 50 percent of deaths took place there (Regeringen, 2020).

Besides the effects on the society, the economy has been impacted drastically (Statista, 2020). This impact could not only be seen on the global economy, but specifically on the manufacturing industry (Habayeb, 2020; Wuest, Kusiak, Dai, & Tayur, 2020), resulting in disruption on supply chains (WSP, 2020). Probably one of the most important supply chains, which is the base to fight the virus, is the healthcare supply chain (HSC) (Miller, Young, Dobrow & Shojania, 2020). Issues along this supply chain could be identified, due to sudden and unexpected increase in demand for pharmaceutical supplies (Ayati, Saiyarsarai, & Nikfar, 2020; Behnam, Chelala, Gambell, & Galliart, 2020). Rayasam and Mande (2020) further elaborated on the crucial challenges generated by the virus, such as the lack of diagnostic data, care capacity and the absent knowledge about Covid-19. Allen and Mirsaeidi (2020) and Haghani, Bliemer, Goerlandt, and Li (2020) described the pandemic as a global threat to public health, the cultural activities and the economy which further impacts the public health negatively. Furthermore, Haghani et al. (2020) stated that the current pandemic has the largest impact so far on the need for research in several fields such as social and environmental besides the medicine related ones.

Supply chain is a network that incorporates all the steps from the manufacturing to the point of sale and all the functions of storage and transportation and entails the communication, information sharing and technologies throughout the chain (Singh, Dwivedi, & Srivastava, 2020). Supply chain management has the ability to maintain a balance between supply and demand (Jaberdioost, Nikfar, Abdollahiasl, & Dinarvand, 2013) and if disruptions arise in the process, supply shortages and increased costs can occur (Iyengar, Hedman, Forte, & Hill, 2016; Romano et al., 2020).

The healthcare supply chain includes all processes from research and development of a pharmaceutical product to the distribution to the end customer (Dixit, Routroy, & Dubey, 2019). Healthcare organizations contribute to this by ensuring development of high-quality products and access to them (Yadav, 2015). It is highlighted that resources are essential to the efficiency and competitiveness of the healthcare supply chain (Pagliusi, Dennehy & Dcvmn Agm Organizing Committee, 2018) which include finances (Yadav, 2015), people (Fernando, Meyliana, Hendrix Spits Warnars, & Abdurachman, 2020), information systems (Fernando et al., 2015; Pagliusi et al., 2018; Singh, Kumar, & Kumar, 2016), and physical resources (Dixit et al., 2019). The goal of the healthcare supply chain is to provide customers with high quality products that meet the World Health Organization´s (WHO) standards. It is important that safe pharmaceuticals are available to meet demands in any situation (Fernando et al., 2020). Therefore regulations, an efficient supply chain network (Yadav, 2015), infrastructure and planning (Singh et al., 2016) are needed to ensure this. The complex nature of the healthcare supply chain and the characteristics of the products (Dixit et al., 2019; Fernando et al., 2020; Lloyd et al., 2015; Pagliusi et al., 2018; Singh et al., 2016), makes it vulnerable to risks, however an efficient healthcare supply chain is crucial to ensure global health (Yadav, 2015).

Vaccines are having a vital role to play in saving lives through a cost-efficient way (Dellepiane & Wood, 2015; Preiss, Garçon, Cunningham, Strugnell, & Friedland, 2016), which can prevent 2-3 million deaths a year (Yang, Bidkhori, & Rajgopal, 2021). If the immunization rate is high enough, they could have a large impact on erasing the outbreaks of preventable diseases (Hanson, George, Sawadogo, & Schreiber, 2017), but the development of the vaccines is a long and complicated process that can take up to 30 years (Preiss et al., 2016; Rele, 2020). However, in case of emergencies this process can be sped up (Rayasam & Mande, 2020). There are different immunization programs that prioritizes certain groups (Thompson, Duintjer, & Tebbens, 2016) and helps to mitigate the effect of a pandemic (Hovav & Herbon, 2017).

Furthermore, the vaccine supply chain integrates all the processes from the manufacturer to the vaccine recipient and its efficiency is highly important in improving the immunization coverage (Iwu, Jaca, Abdullahi, Ngobo, & Wiysonge, 2019b; Lam, Mccarthy, & Brennan, 2015; Lee & Haidari, 2017). Manufacturing of the vaccines is a complex process in means of production lines, capacity, process, and security (Rele, 2020; Thompson & Kalkowska, 2021). Regarding the distribution of the vaccines, there are special conditions that must be fulfilled because of the heat sensitive vaccines (Anderson et al., 2014; Pagliusi et al., 2018) and a stable cold supply chain is required to reach a high immunization rate and ensure the security of the vaccines (Hanson et al., 2017). Due to the circulation of unsafe vaccination, proper measures must be taken to further contribute to the success of immunization (Dixit et al. 2019).

Currently on the 25th of February 2021, as shown in *Table 1*, there are 255 Covid-19 vaccines under development and from those that reached the clinical development phase, 62 percent of them requires two dosages which could lay higher pressure on the supply chain (Islam, Chowdhury, Qadri, Sur, & Ganguly, 2020; Lee & Haidari, 2017).

Clinical development		73
Preclinical development		182
Dosages	Candidate vaccines/Clinical dev.	
1 dose	**12**	**16%**
2 doses	**45**	**62%**
3 doses	**1**	**1%**
No Data (ND)	**15**	**21%**

Table 1: Dosage Schedule about the candidate vaccines. (WHO, 2021b).

1.1. Problem statement

The immunization through the various types of Covid-19 vaccines, has faced various problems since their introduction. The temperature characteristics of the vaccine, and therefore cold-chain has called for adjustments of logistics processes and the training of employees (Arthur, 2021). Especially the last mile has been affected due to this (Meredith, 2021). So far delays have been identified in various countries due to logistical problems, especially the shipping process (Kennedy, 2020), planning logistic operations and capacity (Mukherjee, 2021), as well as quality concerns of vaccines (Wechsler, 2021). Since vaccine manufacturers are producing the vaccines for various countries at the same time, there have been seen shortages (Aiello,

2021). Due to delivery delays, appointments for vaccinations already needed to be cancelled (Mahase, 2020). It is stated that several vaccine manufacturers have been experiencing production issues and yield changes, further adding to the delay of delivery and vaccinations (BBC News, 2021; The Guardian, 2021). It is therefore uncertain when countries meet their set goals of vaccinations (Miller, 2020).

1.2. Research Gap

Even though the importance of the healthcare supply chain and investments into it has been recognized by governments, researchers, and experts, a thorough and structured understanding of causes for issues in the healthcare supply chain have been lacking (Yadav, 2015). Singh et al. (2016) further add that the complexity, due to its significance to human life and involvement of different stakeholders, of the healthcare supply chain is the cause for the lacking research on this subject. Pagliusi et al. (2018) continue to elaborate, that the scarce research is due to the reason of its benefits not being applicable in all markets. It has rather been focused on supply chain issues in general, however the focus on the healthcare industry is seen to be of high importance due to its purpose of preventing and curing diseases, ultimately improving global health, as highlighted by Yadav (2015).

In order to improve global health and the healthcare supply chain, the risks of the vaccine supply chain need to be known and understood. However, as Yadav (2015) states, understanding the reason for inefficient and underperforming healthcare supply chains, has been identified as a gap in research. Yet the importance of, understanding the risks to find solutions and remedies to eliminate or present them, in order to improve health systems and efficiency is highlighted by Dixit et al. (2019), Jaberdioost et al. (2013), and Yadav (2015). As stated by Jaberdioost et al. (2013), identified risks are essential to the crucial process of supply chain risk management, in which they can be addressed through strategies, in order to decrease uncertainties and vulnerabilities, eventually contributing to efficient and cost-effective healthcare and vaccines supply chain.

1.3. Research Objectives

The aim of the thesis is to present a guideline about the risks occurring in the vaccine supply chain during the Covid-19 pandemics that professionals must be aware of. The objective of the paper is to investigate and set up a list of the risks present in the vaccine supply chain and rank

them according to their priority based on the literature review and the interview results with healthcare professionals. Thus, two research questions have been formulated as:

Research Question 1: *What are the risks of the vaccine supply chain?*
Research Question 2: *How can these risks be prioritized within the Covid-19 vaccine supply chain?*

The paper begins with a detailed systematic literature review regarding supply chain, healthcare supply chain and vaccine supply chain complemented by information about the cold chain. The literature review ends with a list of the major risks revealed from the reviewed articles. The next chapter consists of the used methodology which is followed by the evaluation of the conducted interviews regarding the literature review and the ranking of the researched risks through Analytical Hierarchy Process (AHP) as well as a discussion and ending the paper by the conclusion with future recommendations and limitations of the research.

2. Systematic Literature review

2.1. Organizations

Yadav (2015) stated that Global Health Initiatives (GHIs) actions have significantly contributed to the improvement of the healthcare supply chain by increasing the development and access to pharmaceutical products including drugs, vaccines, materials, and other medical supplies. This was caused by recognition of the increase of bottlenecks in health systems, caused by supply chains. Due to GHIs, additional focus has been placed on improving and developing low-and middle-income country´s supply chains. As a result, alliances and partnerships, as well as introduction of immunization programs and new agencies have contributed to vaccines innovation prioritizations strategy (VIPS) and improved accessibility to pharmaceutical products, with focus on vaccines (Jarrett, Yang, & Pagliusi, 2020).

2.1.1. WHO

The World Health Organization was founded in 1948, by the adoption of the WHO constitution at the International Health Conference in New York (Dellepiane & Wood, 2015). As stated by the WHO (2021e) their goal is to promote health, serve the vulnerable, and keep the world safe. They further state that they want to ensure access to universal healthcare, protection from health emergencies and provision of better health to billions of people worldwide.

Pagliusi et al. (2018) further added that the WHO created a "vaccine price, product, and procurement platform" (p. 7431) with the aim to create policies and strategies for global supply, including the facilitation of affordability and fast access to vaccines during emergencies. It is further stated by Islam et al. (2020) that the WHO works towards access to essential vaccines for various preventable illnesses, especially in developing countries, by assisting policy makers with vaccines licenses and implementing national immunization programs.

As part of their efforts, they introduced the prequalification program (PQ) in 1987 (Dellepiane & Wood, 2015), which according to Yadav (2015), tries to increase the capacity for enforcement of regulations for distribution and retailing of pharmaceutical products. Dellepiane and Wood (2015) further state that the PQ further aims to ensure that pharmaceuticals and equipment meet global standards in terms of efficiency, quality, and safety. This includes transparent and scientific assessment processes, combined with further procurement criteria, which are used by the United Nations (UN), the supply division of the United Nations Children's Fund (UNICEF), and other agencies which have the task to make purchasing decisions of pharmaceuticals. UNICEF is WHO's sister agency (Dellepiane &

Wood, 2015) and concerned with strategies and activities regarding stockpiling, prioritizing, forecasting, financing, and contracting. They are purchasing over 2.5 billion doses of vaccines, that are prequalified by WHO, for approximately 100 countries. Since 2010, they have helped in 90 countries by responding to over 300 humanitarian situations (Pagliusi et al., 2018). As stated by Dellepiane and Wood (2015) especially the vaccine supply of national immunization programs is at focus of the PQ, to ensure global health safety. The PQs' continuous task is therefore to test vaccine shipments, review and approve manufacturing and quality control processes, as well as monitor and investigate reported reactions and complaints. As improvements have been seen, the program will enter a further evolution, with plans of transitioning the responsibility of pharmaceutical´s safety to national levels.

The WHO further launched the Expanded Program for Immunization (EPI) in 1974 to further coordinate national immunization programs (Guignard, Praet, Jusot, Bakker, & Baril, 2019; Kartoglu & Milstien, 2014; Yang et al., 2021). Kartoglu and Milstien (2014) stated that the focus of this program lays temperature sensitive vaccines. Due to this, access to vaccinations of preventable diseases and new vaccine introductions have increased (Guignard et al., 2019). According to Wambura et al. (2019) the National Vaccine Immunization Program (NVIP) is responsible for all routine vaccines that are part of the EPI. They order vaccines through UNICEF while getting assistance with cost estimations, scheduling, purchasing, and delivering quality vaccines. Routine vaccines are financed through the Kenyan government and GAVI.

As an expansion of the EPI, the Global Alliance for Vaccines and Immunization (GAVI) was formed in 2000, in order to improve access to vaccinations in developing countries (Dellepiane & Wood, 2015; Kartoglu & Milstien, 2014; Thompson et al., 2016; Yang et al., 2021). Thompson et al. (2016) explained that GAVI is focusing its work on introduction, and increase of financial input and commitment for vaccines, due to which global health has improved significantly. In order to implement a strategy for global stockpile delivery in epidemic and endemic situations, GAVI has approved funding of $US 115 million (Islam et al., 2020).

Thompson et al. (2016) states that as a part of this, the Global Immunization Vision and Strategy (GIVS) was formed in 2006, which offered a 10-year plan for immunization expansion of preventable diseases through financing plans. This was further expanded by the Global Vaccines Action Plan (GVAP) in 2012, which aimed to eliminate vaccine preventable diseases by 2020, however it was realized that further funds are needed to accomplish this. Guillermet et al. (2015) further stated that GVAP set its objectives to strengthen immunization demand, extend benefits for everyone, and sustain access to programs concerned with high quality vaccines.

Besides the agencies formed through WHO, further national agencies have been introduced, such as the Kenya Medical Supply Agency (KEMSA) as well as the Mission for Essential Drugs and Supplies (MEDS) support access to non-routine vaccines and other medical supplies for health facilities, both public and private (Wambura et al., 2019).

2.1.2. Research and Development Agencies

According to Pagliusi et al. (2018), the Coalition for Epidemic Preparedness Innovation (CEPI) has been launched in 2017 due to gaps in research of the development of outbreak vaccines. They want to accelerate preparations for outbreaks and responses to them. Further, they ensure predictability of the market and access to vaccines. Their goal is to work on the process from identifying antigens to production of 100 million doses within 30 weeks.

Chakravarthy, Priya, and Premalatha (2019) stated that the Council for Scientific and Industrial Research (CSIR) is currently working in national information and forecasting databases to capture scenarios for supply and demand of items needed in the current Covid-19 epidemic. Their goal is to address shortages, black markets, hoarding and faulty forecasting.

2.2. Supply chain in general

The meaning of a supply chain has been widely discussed by several authors in the supply chain literature. Singh et al. (2020) has referred to the supply chain as the network that connects the members participating in the process of delivering and storing the products from the manufacturer to the point of sale and/or consumption which could be for instance medical care institutions and individual patients. The network incorporates the required resources and technologies, contributing organizations into one so called supply chain. Jaberdioost et al. (2013) further expanded the definition by including information as an actor to the network that contributes to transforming the raw materials into products and services. A usual supply chain consists of suppliers, intermediaries, transport providers and consumers. It involves operations such as manufacturing, logistics, marketing, sales, and IT. Furthermore, Derwand (2014) discussed the major challenge faced by international supply chain logistics as the administrative barriers.

Hovav and Herbon (2017) elaborated on the possibility for collaborations in the supply chains which can occur on different levels. These are the operational-tactical level which focuses for instance on the inventory levels and delivery frequency and the other collaboration can happen on the strategic level which maintains the relationship between the parties and considers the

interest and value of the whole chain.

By looking at the supply chain as an integrated system that creates value for customers, consumers, and stakeholders, it is called supply chain management (SCM) which has the possibility to establish an efficient balance between supply and demand (Jaberdioost et al., 2013). Pagliusi et al. (2018) has added to the definition that SCM is a process that plans and handles all the activities that occur in the supply chain. The activities involve the management, control, and design of the supply chain where the people are having an important role in the execution. In the last few decades environmental awareness has been growing around the world. Thus, the green supply chain management (GSCM) has appeared to adapt to people's needs and expectations by implementing more sustainable operations such as recycling, improved reverse logistics etc. Since its emergence GSCM has been adopted by companies to maximize their profits (Singh et al., 2016).

2.2.1. Challenges of the Supply Chain

According to Lemmens, Decouttere, Vandaele, and Bernuzzi (2016) the complexity of the supply chain design is dependent on the number of the involved stages, manufactured goods, and decision levels. Thus, it is relevant to pay attention to integrating the existing decision levels such as the capacity of the production and inventory levels when tackling strategic network design issues.

As it was discussed by Jarrett, Yang, and Pagliusi (2020) challenges can be generated from the lack of sufficient experience and knowledge about global supply chains. Furthermore, Iyengar et al. (2016) was underlying the SC disruptions that could result in supply shortages which for instance was caused by economic and/or political factors, sudden change in demand and arising issues in the manufacturing process such as poor quality, lack of resources and constrained plant capacity. Regarding the political factors, Preiss et al. (2016), and Romano et al. (2020) argued that challenges in the supply chain concerning supply might not be solved by transporting the products from one country to another, as the process may require the repackaging of the products due to the country specific requirements that controls what must be presented on certain labels which adds extra costs to the process. Moreover, Romano et al. (2020) explained that inappropriate supply chain conditions regarding the temperature handling which can cause illnesses and intoxications. Kartoglu and Milstien (2014), and Romano et al. (2020) elaborated on that every party in the chain shares the responsibilities over ensuring the

right conditions for the products to avoid any complications.

Sodhi and Tang (2021) has elaborated on the importance of geopolitical and financial stability throughout the supply chain and about their impact on it in unreliable and unstable conditions. Consequently, the longer the supply chain the more impacted it is, for instance by political conditions regarding climate change, if these conditions are changing frequently the chain will be disrupted. The instability of the financial flow will create a vicious circle where the buyers are cancelling the orders and all the suppliers, manufacturers will postpone the payments and at the same time leaving actors with unnecessary supplies. One of these financial disruptions happened in the 2008-09 financial crisis, however, further extreme conditions could influence these factors such as a pandemic.

In a pandemic setting, the well-being of the transport workers for instance in shipping, air freight or road transport could be impacted by the increased level of stress, longer time spent away from their families in uncertain conditions (Haghani et al., 2020; Sodhi & Tang, 2021). Allen and Mirsaeidi (2020), Habayeb (2020), and Sodhi and Tang (2021) elaborated on the challenges caused by Covid-19 on the supply chains, especially on the medical products flow from China and on the healthcare supply. Pagliusi et al. (2018) further discussed that a global guidance is needed with coordinated strategies and regulations to improve the pandemic preparedness. Sodhi and Tang (2021) presented the challenges the Covid-19 pandemic caused to the supply chains, however it was said that the majority of the issues existed even before, such as uncertain demand and supply which makes the supply chain less efficient, channel instability caused by the lockdowns which means that retailing has moved to e-commerce and loss of labor due to travel restrictions.

2.3. Healthcare Supply Chain

Various researchers describe the supply chain in the healthcare sector as healthcare supply chain, but further terminologies are pharmaceutical supply chain, vaccine supply chain, lean supply chain management in healthcare, or agile supply chain management in healthcare (Dixit et al., 2019). It is further explained that the healthcare supply chain is a specific type of supply chain that is concerned with the production, transportation, and consumption of health care products. Though, the supply chain is envisioned by many as solely being concerned with transportation (Yadav, 2015), according to Singh et al. (2016), it is a whole network of various organizations, operations, processes. Yadav (2015), and Pagliusi et al. (2018) further added

that it includes people, technologies, and resources, which all contribute to the development, design, manufacturing, and distribution of the pharmaceutical product (Singh et al., 2016). The basic function is to deliver the pharmaceutical product which starts at the manufacturer and ends at the customer (Dixit et al., 2019), which can be hospitals, pharmacies, or patients (Singh et al., 2020)

2.3.1. Resources

Pagliusi et al. (2018) highlighted that effective utilization of resources for developing different capabilities plays an essential role in ensuring competitiveness of any supply chain. It is noted by Yadav (2015) that in order to increase transparency of the healthcare supply chain costs, information about costs for operations, transporting, warehousing, and staff need to be available, otherwise it is seen as challenging to convince resource distributors to allocate needed resources for efficient supply chain processes.

Financial flows are crucial for a timely procurement and an uninterrupted flow of pharmaceutical products along the supply chain (Yadav, 2015). It has been stated by various researchers such as Dixit et al. (2019), Pagliusi et al. (2018), Fernando et al. (2020), and Singh et al. (2016), that insufficient funding can cause issues for the efficiency of the healthcare supply chain. It is further added by Dixit et al. (2019) that budget limitations, as well as deficient profits for healthcare companies can further decrease the efficiency of their operations.

People are an essential factor of the supply chain and are included in all its activities (Fernando et al., 2020). Therefore, it is important to have sufficient education and training for staff, and available skilled workforce, however this is a general issue when it comes to the healthcare supply chain (Dixit et al., 2019; Pagliusi et al., 2018; Yadav, 2015; Hovav & Herbon, 2017). Yadav (2015) explained that there is a notable deficiency of talent in the healthcare supply chain, in areas such as technology and leadership. It is further stated that governments should initiate mechanisms that allow skilled and experienced individuals, to be employed in leadership roles that manage the healthcare supply chain. Especially the Central Medical Stores (CMS) experiences limited flexibility when it comes to hiring people that have experience with supply chains and necessary skills, due to low wages and incentives. It is further added that CMS do not have the authority to remove workers that are incompetent for their position. However, moving to an autonomous or semi-autonomous status could increase flexibility when hiring staff and contracting suppliers as well as introducing wages based on performance.

2.3.2. Regulations/Government

The goal is to provide qualitative products according to the standards of the WHO with on-demand quantity as well as fast distribution of the products (Fernando et al., 2020). However, these regulations can affect the processes of the whole healthcare supply chain (Yadav, 2015), therefore good product quality is important for good performance (Singh et al., 2016). Singh et al. (2016) further highlighted that governmental bodies can cause challenges to the healthcare supply chain which according to Dixit et al. (2019) is caused by introducing new policies and as added by Singh et al. (2016), and Pagliusi et al. (2018) by healthcare reforms.
In order to create accountability for the outcome of the supply chain it is explained by Yadav (2015) that strong governance through politicians and policy makers need to be created through mechanisms. The public sector is under pressure of the public, since large amounts of public money are used for procurement of pharmaceutical products.

Depending on specific characteristics in the system such as how healthcare is financed, patients are searching for treatment, as well as healthcare regulations, and geography, the structures of the healthcare supply chain can vary (Yadav, 2015). According to Yadav (2015) most of the population of countries that are part of the Organization for Economic Co-operation and Development (OECD), are insured through either the state, their employer or through private health insurance. However, Singh et al. (2016), and Pagliusi et al. (2018) elaborated that in developing countries pharmaceuticals are paid for out-of-pocket or financed through governmental or international financing. The scarcity of cheap available medicine in developing countries is seen as an issue (Singh et al., 2016; Dixit et al., 2019), which according to Dixit et al. (2019), Fernando et al. (2020), and Singh et al. (2016), can increase the costs for essential medicine and further increase distribution of counterfeit pharmaceuticals.

2.3.3. Temperature sensitive pharmaceuticals

Singh et al. (2020) described that many pharmaceutical products need to be stored and transported at a specific temperature, as a temperature that is too high or too low can decrease their efficiency and make them ineffective. Dixit et al. (2019) explained further, that in order to achieve high efficiency and minimize waste of products that were affected by the wrong temperature, a well-established cold supply chain is needed. Inefficient cold chains have been identified as an issue in the healthcare supply chain, as the importance of its efficiency has been increased rapidly. In order to prevent this, Dixit et al. (2019) stated that trained staff, sufficient

storage, as well as proper vehicles for last-mile delivery are needed. However, lack of equipment for these purposes are seen as a challenge in the healthcare supply chain.

2.3.4. Healthcare supply chain network

It was argued by various researchers (Dixit et al., 2019; Fernando et al., 2020; Lloyd, Mccarney, Ouhichi, Lydon, & Zaffran, 2015; Pagliusi et al., 2018; Singh et al., 2016), that due to changing trends, expansion and development of products, advancements in technology, short product life cycles, globalization, and increased outsourcing, the healthcare supply chain is described as a very complicated and challenging supply chain. It is highlighted by Dixit et al. (2019), and Yadav (2015) that its nature of providing vaccines, drugs, and other healthcare products, makes it one of the most important supply chains and therefore requires a well-performing supply chain network. It is further stated by Yadav (2015), that the healthcare supply chain is identified as an important source of information regarding demand and the consumption of healthcare supplies, which are critical to planners in the healthcare system.

When it comes to healthcare supply chains, Singh et al. (2016) noted, that it is important to design effective planning for all processes, as it improves the whole supply chain to respond quicker and more efficiently. This includes to manage their resources effectively in order to achieve great performance and gain competitive advantage, and according to Fernando et al. (2020) also requires involvement in all societal, environmental, and economical areas. Knowing a company's capabilities is essential for this and includes “physical, financial, organizational, and human resources (Singh et al., 2016, p.245). Further it was mentioned by Pagliusi et al. (2018), and Singh et al. (2016), that flexibility, quality, and costs contribute to their performance. Performance measures are therefore an important part in the healthcare supply chain. According to Dixit et al. (2019), Pagliusi et al. (2018), and Singh et al. (2016), inefficient processes and lack of performance measures in the healthcare supply chain are a risk to be aware of and work against as they, in line with Yadav (2015), allow benchmarking and can be used to create recommendations and can improve the overall performance.

2.3.5. Safety of healthcare supply chain and products

Yadav (2015) stated that especially the healthcare supply chain is vulnerable to corruption, which can happen anywhere in the supply chain. Additionally, an issue mentioned by various researchers (Dixit et al., 2019; Fernando et al., 2020; Pagliusi et al. (2018); Singh et al., 2016),

is concerned with stealing and selling pharmaceutical products. It is therefore essential to have proper processes, infrastructure and IT in place and continuously develop and improve them.

As stated by Pagliusi et al. (2018), counterfeit, illegal, and hazardous pharmaceutical products can seriously harm the safety of patients and the public health and are more common due to globalization. According to Singh et al. (2020) those products can contain incorrect or inactive ingredients, which could result in major health issues and serious side effects. It can be seen that the number of counterfeit pharmaceutical products is increasing, which can submerge at any level of the healthcare supply chain. Dixit et al. (2019), and Singh et al. (2020) identified that most counterfeit drugs can be found in developing countries, however one out ten counterfeit products can be found in developed countries. Singh et al. (2020) highlighted that even though several pharmaceutical companies are trying to prevent the distribution of counterfeit through technologies such as barcoding and holographic technologies, these technologies are still at risk of being cloned.

2.3.6. Supply chain network and plant design

Design planning of the network and plant is an important feature to improve the possibilities for improvements of the supply chain (Pagliusi et al., 2018) and its profitability (Singh et al., 2016). According to Pagliusi et al. (2018), this includes design of the manufacturing process to the distribution to the end customer. It is further elaborated by Singh et al. (2016) that due to trends of globalization, the design of networks became an essential part of the business strategy. Yadav (2015), and Singh et al. (2016) stated that this resulted in the recognition of the need for integrated approaches and information sharing. Fragmentation of the supply chain and insufficient collaboration has been recognized by Singh et al. (2016), to be an issue in the healthcare supply chain. However, the various stakeholders contribute to the complexity of implementing integration. Additionally, the wide variety of products puts even more pressure on the supply chain and therefore requires a well-structured and integrated network. However, Yadav (2015) stated that forcing unsimilar pharmaceuticals into one supply chain can worsen its performance.

2.3.6.1. Integration of the health care supply chain

It has been stated by Singh et al. (2016), that an organization needs to be active in all economic, environmental and social areas. Efficient integration in the healthcare supply chain can reduce operating costs and capital and improve productivity of the supply chain and the service levels,

as well as the responsiveness from businesses. This can, according to Fernando et al. (2020), and Singh et al. (2016), improve a company's competitive competence and contribute to a better overall performance. It has further been found by Yadav (2015) that integration can decrease efforts that are needed to design a network and that the main reason for underperformance derives from the insufficiency of capturing and sharing information. Implementing better supply chain visibility regarding inventory, order habits, consumption, and shipping results in increased accountability in the whole system, however, the behavior of health employees regarding responsibility for weak performance, results in difficulties to implement information sharing. Singh et al. (2016) further explained that, implementing information sharing and integration effectively with external parties, such as suppliers, customers, and other members of the network, can further improve operations. For manufacturers information sharing and integration, can improve product development and quality, responsiveness, reliable delivery, which can positively impact their sales activities. However, Dixit et al. (2019), and Singh et al. (2016) further stated, that the dynamic nature and impreciseness of quantity and quality of products that are manufactured in the healthcare supply chain, can result in further uncertainties due to network issues and insufficient connectivity or infrastructure among the manufacturing countries.

2.3.6.2. Information Systems

In order to create an integrated and coordinated supply chain network, Fernando et al. (2020), Pagliusi et al. (2018), and Singh et al. (2016) stated that it is essential in the globalized era, to have a proper information system infrastructure. Dixit et al. (2019) highlighted that with sufficient information systems it is possible to create connections of internal and external functions within the industry, though in general the lack of information systems is still an issue today.

Additionally, there are issues regarding the implementation of digital health strategies. It is seen as a challenge to implement new integrated information systems that are concerned with immunizations, and traceability as stated by Jarrett, Wilmansjah et al. (2020). Jarrett, Yang, and Pagliusi (2020) further added, that even though there are over 120 countries that have implemented such strategy on the national level, the implementation is challenging due to sustainability concerns, which include the need for leadership, digital infrastructure, integrated frameworks, financial support, and partnerships, according to Jarrett, Yang, and Pagliusi (2020), and Pagliusi et al. (2018). Once health technologies are implemented, new partnerships

between various organizations concerned with telecommunications, knowledge, and health can further disrupt them (Pagliusi et al., 2018).

Jarrett, Wilmansjah et al. (2020) have stated that for successful implementation of integrated technology systems, partners, such as healthcare workers, private health care facilities, and authorized distributors need to communicate. As stated earlier, integration of the supply chain is essential for its efficiency, however it is a challenging task that requires intensive effort, according to Yadav (2015), in order to create transparency and good management, simple technologies that can communicate stockouts, are needed (Jarrett, Yang, & Pagliusi, 2020; Yadav, 2015). Jarrett, Yang, and Pagliusi (2020) further added, that the World Health Assembly (WHA) stated that such implementation of digital services can strengthen the supply chain and health systems, by increasing the quality of services, reducing waste, decreasing mortality rates, increasing security of patients and their health, as well as increase the engagement of the community and families.

Yadav (2015) explained that the information flow in the healthcare supply chain begins when the hospital, pharmacy, or healthcare provider places an order to the wholesaler or distributor, which are then forwarded to the manufacturer when they are in need of replenishing their stocks. Furthermore, the point of sales data that is received from pharmacies and wholesalers are further used for planning the supply chain.

2.3.6.3. E-business

Pagliusi et al. (2018), and Singh et al. (2016) stated that part of the healthcare supply chain is e-business, which changes the traditional ways of business processes by using the internet. These processes can have a major impact on the management of inter-organizational processes, however, can decrease transaction costs, improving efficiency and improving access to information from the supply chain.

Singh et al. (2016) further stated that e-business technologies can further improve procurement, inventory management and distribution, by analyzing demand and available data. However, outdated systems, as seen in hospitals, since it has been focused on improving delivery, rather than integration of information systems for e-businesses.

Dixit et al. (2019), and Singh et al. (2016) elaborated that the challenges identified in the implementation of e-business processes are data inconsistency, poor quality of data, and suppliers.

2.3.7. Outsourcing

Dixit et al. (2019), and Singh et al. (2016) discussed that outsourcing is the act of moving a company's internal activities and responsibilities regarding decisions to one or more outside providers. It can be seen that outsourcing activities and outsourced supply chains are increasing in the healthcare supply chain. Nowadays this is done to increase cost effectiveness and gain share of the global market, which means having access to benefits in production and sourcing. Further, they add that many companies are outsourcing in order to be able to improve their focus, share risks and free resources needed in other areas. These activities are outsourced to specialized suppliers, also known as third-party logistics (3PL). The 3PL have previously only been involved in warehousing and transportation, however, have evolved since, to work in broader functions as well. Companies that are outsourcing can focus on their core competences in the pharmaceutical industry, giving them the opportunity to innovate faster, however they are at the risk of losing their flexibility and control, as well as sharing information that can be used against them, creating possible new competitors (Dixit et al., 2019; Singh et al., 2016).

2.3.8. Research and Development

In order to compete with other companies in the healthcare industry, new innovations need to be created, which requires various important resources. These resources are often provided by the pharmaceutical company, according to Pagliusi et al. (2018), but further through investments from the pharmaceutical industry (Singh et al., 2016). In 2019, the pharmaceutical industry invested US$186 bn on R&D (Mikulic, 2020), which is twice as much, as it was in 2011 (Singh et al., 2016). It is estimated that by 2026, investments will reach a total of more than US$230 bn (Mikulic, 2020). These investments are partly needed due to new occurring health issues (Singh et al., 2016), such as lifestyle diseases and new strains of viruses (Pagliusi et al., 2018), the need for knowledge and innovations, which requires the involvement of the education sector as well as Non-Governmental Organizations (NGOs) (Singh et al., 2016). However, Singh et al. (2016) further added that the time that is spent on drug development, which can take 15 to 30 years, puts a strain in the process and result in a decline of innovation rates.

According to Pagliusi et al. (2018), and Singh et al. (2016), in order to achieve fast and cost-effective methods, pharmaceutical companies often outsource phases of their operations or create joint ventures and mergers. For this, Pagliusi et al. (2018) explained that knowledge of the market and management are essential. The new process development strategy is an

important continuous process including exploratory studies, case studies, formulation of theories, testing phases of products, their development, and the design for commercialization. The process is used for fast and advanced business strategies that are affected by technological advances, increasing costs, and decreased product-life cycles.

Pagliusi et al. (2018) further stated that efficient development of this process can result in lower production costs, better product inventions, manufacturing processes, design, and can further reduce the risks and uncertainties in production regarding quantity and quality, success rate, market uncertainty, estimating production processes, time recovery, and decision making and therefore help to produce defect-free drugs. However, Singh et al. (2016) highlighted that generic drugs and diminishing patent life are increasing the risk of developing new products and their profitability, as new products need manufacturing capacity resources for their production. Therefore, capacity planning for future production is essential for the development of new drugs, as this could affect the healthcare supply chain.

It is mentioned by Pagliusi et al. (2018), and Singh et al. (2016) that capacity planning is regarding all parts of the healthcare supply chain, therefore failures during testing, trials, and commercialization of the product result in major challenges for the pharmaceutical industry. In order to prevent the issue in the development process, they explain that a pipeline process is needed which prioritizes potential drugs to be developed further and therefore decreases issues regarding scheduling. Each product goes through particular sets of tests regarding the need of resources, duration, priority limits and the chance of it being successful. Due to changing market requirements, this however, is a challenging task (Pagliusi et al., 2018; Singh et al., 2016). As part of the product development, Singh et al. (2016) identified that all drugs need to meet specific quality requirements, therefore regulations from national authorities are essential to ensure quality and safety and furthermore prevent the spread of counterfeit drugs. However, this can be challenging, especially in development countries, as resources are limited.

2.3.9. Manufacturing

According to Rele (2020), manufacturing of drugs requires partners from different areas, that assist at different steps of the development and commercial production process. Furthermore, Jarrett, Yang, and Pagliusi (2020) added that costs for manufacturers and their suppliers can be decreased if they share supplier audits, which can ensure the quality of their purchasing activities and acquired supplies.

Rele (2020) stated that contract development and manufacturing organizations (CDMOs) need to increase capacity by utilizing the existing infrastructures and additionally invest in the installment of new equipment that can increase capacity and modify the existing infrastructure and design layout. This will test if the current good manufacturing processes (cGMPs) can ensure quality, readiness of specific platforms, and the knowledge from the different CDMOs, are phase appropriate. It is essential that transfer activities regarding technology, materials, and production and operation processes take place seamlessly (Rele, 2020), as issues along these processes can cause poor product quality (Yadav, 2015).

2.3.10. Waste management

Singh et al. (2016) explained that lean manufacturing has become a vital part in modern manufacturing design to compete globally. The concept is based on the Toyota Production Systems (TPS), which focuses on minimizing waste while maximizing flow. However, the pharmaceutical industry has not adapted to this concept yet, as it is still in the developing phase of implementing lean manufacturing. Yet, lean manufacturing, according to Pagliusi et al. (2018) and Singh et al. (2016), can prevent the seven most common reasons for waste, which are caused by overproducing products, waiting, transport, unsuitable processing, avoidable inventory, and defects. Singh et al. (2016) further highlighted that waste is costly and a threat to the environmental well-being.

Issues with waste and inventory management are known to have a negative impact on the healthcare sector (Dixit et al., 2019; Singh et al., 2016). The different types of waste for pharmaceutical products are caused by patient treatment and due to faulty forecasting and inventory management, as stated by Dixit et al. (2019). This can impact the environment and public health negatively, as according to Singh et al. (2016), improperly disposed pharmaceuticals can reach lakes and rivers through their sewage systems. Additionally, to environmental issues, Dixit et al. (2019) stated that waste disposal can be costly which further lead to the recommendation of lean practices. Singh et al. (2016) added that this problem is additionally caused by the improper disposal of not wanted or expired pharmaceuticals by patients, for example by flushing it down the toilet, or the sink, putting additional stress on the water life cycle. Research has shown that the majority of patients act according to these practices, instead of properly disposing them, by returning them to pharmacies.

Singh et al. (2016) identified that proper waste management, recycling, and waste minimization have therefore, received increased attention through regulations and legislations on national and international levels. It is crucial to introduce restriction and recycling substances for resale into the market, create channels for expired medicines, as well as pharmaceutical waste, to get back to the manufacturer for further use or proper disposal. It has therefore been proposed to add these activities to a manufacturer´s responsibilities as an individual or collaborative task. However, implementing this is seen as complex, due to a high level of uncertainties regarding returns, influencing collection rates and capacities for the production with recycled substances. It has further been mentioned by Pagliusi et al. (2018), and Singh et al. (2016) that creating reverse logistics procedures are expensive and challenging to implement in already existing operations. However, creating such systems would prevent expired or unused medicine from being disposed of in landfills.

Dixit et al. (2019) added that if the waste cannot be prevented through the change of manufacturing practices, appropriate healthcare waste management is essential and must be appropriately adapted by healthcare employees when handling and disposing waste. According to Singh et al. (2016), the department of health has introduced various practices to guide healthcare organizations into meeting environmental standards, such as "´disposal of pharmaceutical waste in community pharmacies and safe management of healthcare waste´" (p. 244).

Therefore, the importance of effective process streamlining and waste reduction or elimination into the strategies of pharmaceutical companies is highlighted by Dixit et al. (2019), Pagliusi et al. (2018), and Singh et al. (2016) in order to create efficient and excellent operations, a clear communication environment, reduction of costs and production time, and further increase product quality. Lean manufacturing processes can further contribute to supply chain agility; however, this is depending on how flexible, responsible, competent, and quick they are operating. Even though lean manufacturing is not yet widely implemented in the pharmaceutical industry, lean manufacturing practices such as value stream mapping (VSM) and cellular manufacturing (CM), have gained attention and are popular and widely accepted tools. VSM is concerned the micro-level analysis of information and material flow along the manufacturing level setups, whereas CM is concerned with the setup of the processes by selecting and grouping manufacturing machines into cells, for better process flows (Dixit et al., 2019; Pagliusi et al.,2018; Singh et al.,2016). According to Rele (2020), errors in forecasting,

lead to issues regarding storage which then impacts inventory management, and therefore increase waste.

2.3.11. Forecasting

Several researchers (Dixit et al., 2019; Fernando et al., 2020; Pagliusi et al., 2018; Singh et al., 2016) stated that in order to forecast accurately, information about consumption patterns as well as epidemiological needs are essential, however, that the ability to forecasting demand is an issue for many pharmaceutical companies. According to Fernando et al. (2020), and Singh et al. (2016), this process is further complicated by increased consumer awareness, the change in customer behavior and preferences (Singh et al., 2016), as well as new product introduction and competition from other actors in the industry.

2.3.12. Inventory management

Inventory management is an essential part for healthcare organization, since large amounts and varieties of drugs are especially needed during emergency situations (Singh et al., 2016). Dixit et al. (2019) stated that insufficient inventory management has negative impacts on sustainability of healthcare and patient safety. However, according to Singh et al. (2016) holding inventory can add additional costs and can be between 10 and 18 percent of a company's net revenue. It further is stated that determining the most suitable level of inventory is a complex issue, yet it is important to increase service levels and prevent stockouts (Singh et al., 2016). Service levels are an essential part of a company's performance, however increased service requirements have caused the need for improvement over the past years (Pagliusi et al., 2018).

According to Gurvich and Hussain (2020), one of the most severe threats to the healthcare system are stockouts and shortages of essential equipment and medicines. During Covid-19 it could already be seen that healthcare providers experienced shortages for ventilators and injectable drugs which are needed for patients on ventilators. Therefore, Rele (2020) marked the importance of having a strategic national stockpile (SNS), from which medical supplies can be delivered to points of dispensing (POD) in emergency situations and stockouts.

Rele (2020) stated that in order to eliminate issues in storage, bulk drug substance (BDS) storage, as well as activities regarding shipping for fill-finish activities need to be carefully monitored, as they can cause bottlenecks and issues with capacities. As most CDMOs are

operating at full capacity, they might not be able to operate in emergency situations, as their capabilities for fill finish operations are already at full capacity. This can lead to bottlenecks, causing major issues in the punctuality of the production process. Further, Fernando et al. (2020), Hovav and Herbon (2017), Pagliusi et al. (2018), and Singh et al. (2016) stated that, issues in storage management have been identified as absence and initiative to maintain stocks and Dixit et al. (2019) added that missing storage systems that are suitable for efficient operation are a further issue for this. Since pharmaceutical products contain compounds that can degrade with time, even when suitable packaging and control storage conditions are implemented, this can add to further issues in inventory and storage, adding further waste to the operations (Singh et al., 2016).

2.3.13. Distribution

The distribution of pharmaceutical products is concerned with the transportation of products from the manufacturer to the end consumer (Pagliusi et al., 2018; Singh et al., 2016). According to Singh et al. (2016), this includes processes such as ordering the products, as well as transporting and storing them, which involves actors such as manufacturers, wholesalers, distributors, and actors which prescribe and dispense the product to the customers. Timely product distribution is of high importance in the healthcare industry; however, it can be heavily affected by issues in the network, connectivity, and the infrastructure. Pagliusi et al. (2018) stated that due to its dynamic environment, a suitable and effective network is essential to its productivity.

Singh et al. (2016) found that timely and efficient delivery of pharmaceutical products has been identified as an essential part of the healthcare supply chain and has caused major interest among researchers. According to Yadav (2015), in countries that are part of the Organization for Economic Co-operation and Development (OECD), well-defined regulations for the distribution of pharmaceutical products have been implemented and are strongly enforced. Due to lack of human or financial resources, limited governance, and corruption, the reinforcement of regulation for distribution and retailing of pharmaceutical products in developing countries is constrained. Pavithra, Kavitha, and Venkatraman (2019) further added that security concerns, damaged packaging and lack of information and communication are the biggest issues when it comes to distribution.

Pavithra et al. (2019) stated that in low-income countries, it is the task of the government to procure pharmaceutical products and distribute them the CMS through a transportation fleet owned by the government, however it is further stated that underperformance in this model resulted in decentralization of the process giving the pharmacies and healthcare providers opportunities to place orders themselves as this makes the process more flexible and faster. It is stated by Yadav (2015) that increased frequencies of replenishment, helps the whole supply chain, but especially the distribution. It is further stated that frequent replenishment is driven by consumption and demand, rather than forecasts which could be inaccurate, however high frequency can increase costs, as more transportation is needed. Another issue regarding distribution mentioned by Yadav (2015), is that an increased number of wholesalers can harm the supply chain performance, as small wholesalers do not have capital to improve distribution efficiency through high frequency deliveries.

Dixit et al. (2019) stated that in order to implement successful distribution processes and operations, a proper infrastructure is needed, however it has been shown that a proper infrastructure is missing in several countries. Due to insufficient infrastructure, especially in developing countries (Singh et al., 2016), the delivery of pharmaceutical products is endangered, causing issues along the distribution systems (Dixit et al., 2019; Fernando et al., 2020; Pagliusi et al., 2018; Singh et al., 2016). It has been stated by Yadav (2015), that effective transportation is a major issue in the healthcare supply chain. Singh et al. (2020) further added that safe transportation is an additional challenge. This is majorly caused by insufficient planning and inappropriate maintenance and use of vehicles (Yadav, 2015). This puts additional pressure on the distribution system and causes an increase of available products that are counterfeited or are not up to global standards (Pagliusi et al., 2018; Singh et al., 2016).

2.4. Vaccines in general

Vaccines in general have specific characteristics compared to other pharmaceutical products in the healthcare industry. Vaccines are having more complex molecules which requires biological processes, while other medical products have smaller number of synthetized molecules (Lemmens et al., 2016). Dellepiane and Wood (2015), and Preiss et al. (2016) discussed the importance and the cost efficiency of vaccines, in saving lives around the world. It has the ability to reduce and prevent the infectious and incurable diseases and takes around two years to manufacture and deliver them, however maintaining enough stock is a continuous problem, especially because of the specific conditions regarding transportation and storage.

Preiss et al. (2016) also highlighted the fact that for an investigational vaccine to reach production takes 10-30 years of collaboration between the government, scientists, and everyone else participating in the process. Guignard et al. (2019), and Thompson et al. (2016) also emphasized that adaptation of a vaccine globally can take a long time and can depend on many factors such as, organized efforts to tackle a disease, international and national conditions, challenges, and costs. Yang et al. (2021) further discussed the efficacy of vaccination by underlying the facts that 2-3 million of deaths are prevented by vaccination and an extra 1,5 million could be averted year by year in case of an improved vaccination coverage globally. Today, there are still 20 million infants who do not receive the vaccines included in the routine vaccination (Derwand, 2014; Iwu et al., 2019b; Thompson et al., 2016, Yang et al., 2021), despite the fact presented by Derwand (2014), that these vaccines are the most efficient ways to improve the health status of the children. However, not all the vaccines have the same importance in each of the countries as it is highly dependent on the available diseases such as cholera and yellow fever and these vaccines can be called as nonuniversal niche vaccines (Thompson et al., 2016).

The collected literature has mainly discussed the specific challenges, risks, development and immunization programs about the seasonal influenza vaccine, the rabies vaccine, the cholera vaccine, and the Covid-19 vaccine. Firstly, the cholera and the rabies non-routine vaccines will be discussed and then the routine influenza and Covid-19 vaccines as they have more similarities regarding the supply chain and usage (WHO, 2020).

2.4.1. Non-Routine vaccines

As it was discussed by Islam et al. (2020) regarding the nonuniversal niche cholera vaccine (Thompson et al., 2016), one of the major challenges in reaching immunization is the global supply shortage in providing enough vaccines to the population of Bangladesh. Even though the production site of the cholera vaccines is in Sanchol, India which is near to Bangladesh, the vaccines are reserved for the WHO stockpile, thus it puts the country into a difficult position when creating immunization. Consequently, this prioritization regarding the WHO stockpile could influence the available global supply to certain countries in a negative or positive setting. Rabies vaccines (PEP) are non-routine vaccines which means that the forecasting system is not as efficient as for routine vaccines (Wambura et al., 2019). It is because the need for PEP is dependent on the bite victims so it cannot be truly forecasted (Changalucha et al., 2019). Rabies vaccine consists of several doses and in several countries, there are no registration kept

centrally about who received all the five doses and who did not, which leads to challenges in fighting against rabies (Changalucha et al., 2019; Wambura et al., 2019). Moreover, it is generally expensive and is producing barriers to governments and victims who were bitten, thus limited supply is kept in stock which can create higher risk of rabies and can have a negative impact on health (Changalucha et al., 2019).

2.4.2. Routine Vaccines

In the following the routine vaccines will be presented including the influenza and the Covid-19 vaccines.

2.4.2.1. Influenza Vaccine

Influenza can be described as a respiratory infection which appears seasonally as an epidemic (Chick et al., 2017). It causes 300-500 thousand deaths annually worldwide (Medscape, 2020) and has a large negative effect on the economy (WHO, 2021c). However, its impact on the economy and on people's lives (Hovav & Herbon, 2017) can be mitigated by a vaccination (Chick et al., 2017; Sun, Chen & Luo, 2019). Dai, Cho and Zhang (2016), and Sun et al. (2019) stated that challenges can arise regarding the composition of the vaccines as its design is decided by the government and/or Drug administration (Hovav & Herbon, 2017), which makes the manufacturing process particularly problematic. Hovav and Herbon (2017) elaborated on the fact that approximately 5-20 % US citizens are getting infected by the flu even though they have been vaccinated. Dai et al. (2016), and Sun et al. (2019) further described that because of this feature regarding the flu vaccines, the manufacturers are at great risks concerning the composition of the flu vaccines as it might be discarded once the design has been published by the government. Thus, it puts a great risk on the supply chain as the manufacturer could lack the motivation for efficient production as the retailer gets the higher profit. Chick, Hasija, and Nasiry (2017) further added that depending on the government and supplier agreement regarding the contracted amount of flu vaccines with low yield, can lead to increased administration and production costs when it causes late delivery.

2.4.2.2. Covid-19 vaccine

There are several types of vaccines under clinical trial such as Sinovac, CanSino Biological Inc., and Sinopharm as reported by Jarret, Wilmansjah et al. (2020). Crommelin, Anchordoquy, Volkin, Jiskoot, and Mastrobattista, (2021) added Moderna, Pfizer-BioNtech and CureVac that are experiencing with different approaches, which slowly moving from Phase I to Phase II then to Phase III, and finally to licensure.

Rele (2020) was discussing the challenges that could arise in a pandemic where the high vaccination coverage is an important goal to tackle the virus. In this means for a 100% coverage according to the two dosages schedule 16-20 billion dosages are needed to be distributed globally. Crommelin et al. (2021) further emphasized the importance of a consistent raw material flow within the supply chain to ensure the right quality of the vaccines.

2.4.3. Immunization Program

Hovav and Herbon (2017) discussed that there are two types of immunization programs applied by countries such as the universal mass vaccination and the prioritized vaccine program whereas the former refers to the whole population. The efficiency of the program can be measured by the rate and timing of vaccination. However, Thompson et al. (2016) stated that every country has their own specific strategy regarding immunization. There are different approaches that can be used in prioritized vaccine programs, for instance, vaccination according to age groups and high-risk groups (Hovav & Herbon, 2017), regular vaccination of a specific group of people, vaccination according to a certain event such as outbreak of diseases close to the country or vaccination by reacting for an outbreak (Thompson et al., 2016). This tailored strategy has a vital role in tackling a pandemic (Hovav & Herbon, 2017). Guignard et al. (2019) discussed that it can be easier or harder to implement new vaccines into the immunization program, but it depends on the selected strategy and vaccine characteristics. Lee and Haidari (2017) further elaborated on the issues regarding not using targeted strategies in vaccination, such as it can cause disruptions in other vaccination programs.

2.5. Vaccine Supply Chain

Lee and Haidari (2017) have defined the vaccine supply chain (VSC) as a system that integrates every step into itself while getting the vaccines to the point of consumption. Thus, it entails transportation, technologies, production sites etc. Lee and Haidari (2017), and Iwu et al. (2019b) elaborated on the role of the vaccine supply chain and it was defined as it has a vital role in creating immunization and provides crucial vaccines for the population. Chen et al. (2014), and Iwu, Jaca, Abdullahi, Ngobo, and Wiysonge (2019a) defined the goal of the VSC as to deliver the required number of vaccines set by each country. Thus, the efficiency of the supply chain must be maintained to be able to provide the sufficient supply at the right time and at the right quality (Iwu et al., 2019b; Lee & Haidari, 2017). It was discussed by Chen et al. (2014) that there are even higher challenges regarding the vaccine supply in the developing

countries because of the scarce resources. Thus, the vaccine supply chain has to consider the whole process from the manufacturer to the vaccine recipient to efficiently organize and control the available resources while considering the specific needs for transportation and storage of each vaccine. Lee and Haidari (2017) emphasized that low to middle income countries (LMIC) have more issues than developed countries, but it does not mean that major issues cannot be identified in developed countries.

2.5.1. Research and Development

According to Dellepiane and Wood (2015) the first list of prequalification by WHO was published in 1987 regarding the BCG vaccine, but later the list emerged to be known as the prequalification procedure. Since then, the total number of suppliers was reduced to specific vaccines because of the quality control. One of the biggest issues faced by WHO was the quality differences between domestic and global standards regarding the vaccines and other pharmaceutical products. Thus, in 2002, there was a decision taken by WHO about the prequalification process in producing countries, whereas a National Regulatory Authority (NRA) must exist and function. It means that there are six regulatory functions that must be fulfilled in order to comply with the international standards. These are: "Marketing authorization and facility licensing, Pharmacovigilance including Adverse Events Following Immunization (AEFI), NRA lot release, Laboratory access, Regulatory inspections, and Authorization and monitoring of clinical trials" (p. 54.). Thus, the vaccine regulations became stronger and more efficient in developing countries.

Additionally, Jarrett, Yang and Pagliusi (2020) stated that manufacturers in emerging countries have a vital role to play in the supply to these countries. Dellepiane and Wood (2015) further elaborated on the post-prequalification procedure which monitors the vaccines after shipping and provides an opportunity for WHO to act if the required conditions are not fulfilled. The largest challenge experienced by the manufacturers regarding the prequalification process is the uncertain response time.

Hovav and Herbon (2017), and Rele (2020) discussed the vaccine development process as a complicated process which takes a long time and requires financial stability, human resources, and knowhow. Preiss et al. (2016) presented the process of how new and improved vaccines are reaching licensure. When launching the vaccine for human trials, there are some important steps that had to be undertaken in advance to convince the involved parties about its secureness

and safety. It involves the carefully investigated vaccine design that suits the supply chain and the current system in means of technologies (Lee & Haidari, 2017), the well-prepared plan for testing, the executed animal testing, and the development of production to provide the needed dosages for human trials. It is vital to provide a reproducible and stable vaccine design as well as the possibility for manufacturing and packaging to get licensure. It is further discussed, once the licensure is given, it usually comes with a broad safety profile, however it is collected continuously after it excessively. It is the responsibility of the vaccine manufacturers to submit their dossier to the European Medicines Agency, who evaluates it from a risk benefit point of view.

In case of emergencies and pandemics, there are alternative solutions to develop and make a vaccine available faster than usual to avoid extreme situations (Preiss et al., 2016; Rayasam & Mande, 2020). Rayasam and Mande (2020) explained the importance of the scientists in developing the drugs and vaccines within a limited time. Moreover, already existing drugs against Ebola and HIV were tested to tackle the Covid-19 in the development process. Honda-Okubo et al. (2017) further discussed the recognized need for innovation in vaccine development at the H1N1 outbreak in 2009. The research and development (R&D) organizations do not have the capability to offer instant solutions against the current pandemic but will provide a template for the future ones (Rayasam & Mande, 2020).

2.5.2. Vaccine Manufacturing

Rele (2020) discussed when manufacturing a vaccine, the capacity and the doses must adapt to the accessibility of the adjuvants to be able to produce the final goods. The development in immunization has created the combined vaccines which means that the vaccines can contain several antigens and serotypes (Thompson et al., 2016). Developed countries have high demand for combination vaccines to reduce the needed dosages because it reduces the overall costs of vaccination. Depending on the ingredients, the combined vaccines can further contribute to the complexity of manufacturing as it requires separate production lines (Thompson et al., 2016; Thompson & Kalkowska, 2021). However, Preiss et al. (2016) argued that the production can be reasonably simpler differing by product. Lemmens et al. (2016), Preiss et al. (2016), and Thompson et al. (2016) also stated that the manufacturing of the vaccines takes considerably long time, 10-26 months from receiving the raw materials, which could result in delays in the delivery. A relevant problem is to increase the production capacity as developing a new production site could take 5-10 years (Preiss et al., 2016). Rele (2020) further discussed the

challenges about capacity in manufacturing which could lead to postponement in providing the vaccine to tackle the pandemic. Uncertainty can be described as a disruption in the supply chain, for instance regarding the flu vaccine which is ordered before the actual start of the season by the retailer and the manufacturer is producing it in advance with an uncertain demand (Thompson et al., 2016) to maximize the profit (Dai et al., 2016; Lemmens et al., 2016; Sun et al., 2019). Especially in the high-income countries the manufacturers are further exposed to specific conditions of the supply chain, and reliant upon suppliers, and external factors can influence them, such as pandemics (Jarrett, Yang, & Pagliusi, 2020). Wambura et al. (2019) highlighted that sufficient influenza vaccine supply at the right time is crucial in seasonal pandemics. Additionally, Preiss et al. (2016) discussed the challenge of the special conditions in manufacturing vaccines, as each production site is usually customized for a specific product. Lemmens et al. (2016) further elaborated on the risks that the manufacturers are exposed to because of the complexity of the production process, as if a failure occurs, the whole process must be authenticated before starting the manufacturing again. Furthermore, Jarrett, Yang and Pagliusi (2020) emphasized that the manufacturers were neglecting technological developments in packaging and deliveries because of the perceived high costs. Likewise, they have conducted research which revealed that manufacturers do not consider the environmental impact of the vaccines as their responsibility but the final customers'. In the case of the manufacturers, the efficiency of their vaccine product has a vital role in fulfilling future orders as their reputation is dependent on it. The manufacturing process stops when the vaccines leave the production site and starts their long journey in the distribution chain filled with obstacles.

Rele (2020), and Thompson and Kalkowska (2021) discussed that large-scale manufacturing has the power to influence the prices of the vaccines as well as the available supply. Thompson and Kalkowska (2021) further added that the prices can be different by countries and stated that the cost of vaccines also can be dependent on the formulation of the vaccine, whereas less expensive or more expensive (Lemmens et al., 2016) products can be used in the production process. Lemmens et al. (2016) further added that beside the internal factors of the production and R&D, external factors such as competition, are having a high influence on vaccine prices.

2.5.3. Vaccine Distribution

Preiss et al. (2016) presented a classification regarding the distribution of the vaccines which includes three categories. The first one is the so-called primary distribution which happens between the manufacturer and the country, the second one is the secondary distribution

facilitated by local authorities and the third category refers to the storage at the point of consumption. Hovav and Herbon (2017) discussed a challenge between the distribution centers (DC) and the clinics, as a conflict of interest can be detected in the distribution process. Both parties' goal is to minimize the costs on transportation and inventory holding, therefore the clinics are aiming to have frequent deliveries, however the DC's goal is lower the cost of transportation which cannot be reached by frequent deliveries to certain clinics.

According to Yang et al. (2021), a four-tier hierarchical distribution network is used in LMICs. It means that for instance EPI vaccines are bought in large amounts one or two times a year and then shipped to large cities. From there, the required number of vaccines are transported to regional DCs quarterly by a temperature-controlled truck. From the regional DCs, the vaccines are distributed to the closest neighborhood centers and lastly, it is transported to the point of consumptions or to local clinics by any mode of transport in cooler boxes. Regarding the private sector's distribution in LMICs, Yadav (2015) discussed the challenges associated with it. It is stated that the number of wholesalers is limited, and the distribution of the products performed by their own fleet weekly, which means that small pharmacies in rural areas are forced to solve their transportation to the pick-up point which results in high costs. Dellepiane and Wood (2015), and Guignard et al. (2019) elaborated on the challenges experienced in LMICs connected to new vaccine introductions, such as in logistics where increased number of products requires higher capacity transportation. Furthermore, despite the continuous introduction of vaccines, immunization remains a challenge in these countries. Guignard et al. (2019), and Kartoglu and Milstien (2014) added that there are even harder challenges to overcome in LMICs in vaccine distribution, especially regarding the cold storage conditions, such as the lack of access to electricity.

Dellepiane and Wood (2015) discussed the change in distribution of vaccines in 1974 when the EPI was established, whereas the vaccines were purchased by national or multinational vaccine producers to ensure the right quality standards are applied. Yadav (2015) highlighted that wholesaling is concentrated to a limited number of players in the OECD countries because of the high economies of scale, who has the power to influence the prices, thus the profits which puts a great risk on the manufacturers (Thompson et al., 2016). Dellepiane and Wood (2015) elaborated on the procurement of the vaccines as it can be bought by countries without production through international tenders. Jarrett, Yang, and Pagliusi (2020), and Pagliusi et al. (2018) stated that the Developing Countries' Vaccine Manufacturers Network (DCVMN)

ensures that vaccines are good quality with low costs. Anderson et al. (2014), and Chen et al. (2014) highlighted the vaccine distribution because of the different vaccine characteristics as a logistical challenge in ensuring the sufficient supply at each of the health facilities. Islam et al. (2020), and Lee and Haidari (2017) further elaborated on that many vaccines consist of several doses which must be given according to a specific dosing schedule. This creates further logistical challenges regarding the delivery of the vaccines to enable all the patients receiving their second dosage in the right time.

According to Chakravarthy et al. (2019), issues related to the cargo forwarders can originate from the nature of the specific requirements related to vaccine transportation as well as the required high security of the transportation. Pavithra et al. (2019) discussed a research that was conducted to identify the main challenges for the carriers in the supply chain through a survey. It was identified that the main challenge is the inaccurate usage of the Vaccines Vial Monitor System (VVM) as well as the unpreparedness for emergencies are causing disturbance in the cold supply chain. Anderson et al. (2014), and Pagliusi et al. (2018) elaborated on that delivery is dependent upon the required handling of the specific vaccines during the transportation. There are several vaccines that can be transported outside of the traditional cold chain, whereas the vaccines need to be stored and transported between 2 °C and 8 °C. However, the vaccine's suitability for non-traditional transport modes could be connected to specific days and temperatures that a vaccine could spend without the optimal temperature. Guillermet et al. (2015), and Lee and Haidari (2017) highlighted that prefilled syringes provide an advantage in the supply chain as the delivery is easier because of the less complicated handling processes and at the same time it can reduce the waste and the stock outs as there is no need for further material. However, a challenge could be placed on the cold chain as it requires higher capacity for storing the syringes which is difficult in the developed countries and even more difficult in the developing countries (Guignard et al., 2019; Guillermet et al., 2015).

2.5.4. Vaccine Stock Management

According to Iwu et al. (2019a), stock management has a vital role in supporting the vaccine supply chain as their effectiveness is highly dependent on each other. The event of vaccine stockout refers to the lack of specific vaccines (Anderson et al., 2014; Iwu et al., 2019b). Iwu et al. (2019b), Jarrett, Yang and Pagliusi (2020), and Thompson et al. (2016) emphasized that vaccine stock outs have a negative impact on the HSC as well as on the population and can impact the routine immunization. Thus, Anderson et al. (2014), Iwu et al. (2019a), Iwu et al.

(2019b), Jarrett, Yang, and Pagliusi (2020), and Thompson et al. (2016) discussed that stockpiling of the vaccines can offer support in managing immunization and a solution for the shortages experienced in the supply chain by the poor stock management which can entail, for instance unpredictable events, forecasting and inventory recording failures. Dessouky, Ordóñez, Shen, and Jia (2017) elaborated on the advantages of the stockpiles as it can prevent and control epidemics (Jarrett, Yang & Pagliusi, 2020) and ensure future preparedness for outbreaks (Pagliusi et al., 2018) and prevent biological attacks on countries by using the right allocation of the vaccines and resources. However, Jarrett, Yang, and Pagliusi (2020) discussed the manufacturers concern about the stockpile whereas the storage costs and financial risks of perishable products are high. Thompson et al. (2016) highlighted that the stock of the preventable disease vaccines should be kept at least on the level that equals the expected birth rate and harmonized to the current immunization program in order to reach higher efficiency regarding the vaccines.

As claimed by Iwu et al. (2019b) stock management faces difficulties in vaccine introduction in LMICs as their VSC has not been developed over the years. Anderson et al. (2014), Iwu et al. (2019a), and Iwu et al. (2019b) elaborated on the vaccine stock outs which leads to less immunization coverage as the children can be also impacted by it.

Thompson et al. (2016) explained when an outbreak happens there are two approaches that can be used such as the preventive and reactive method whose conflict of interest generates shortages of certain vaccines. Furthermore, Hovav and Herbon (2017) said that shortages can happen because of the limited capacity of healthcare facilities and distribution centers which are balanced out by backlogs. However, backlogs are having a higher cost in terms of reputation, and losses. Additionally, it was argued by Iyengar et al. (2016) that it can be related to the immediate demand, production issues, political and economic factors and all the related topics can provide a cause that can be connected to medicine and vaccines. Thompson et al. (2016) referred to shortages as it can be generated if a manufacturer has a large market share, and the supply chain cannot provide solutions for the issues in the chain. However, manufacturers might hold some stockpile to manage these arising issues, but it cannot be solved on a large-scale issue. Guillermet et al. (2015) added that stock outs can be reduced or mitigated by using innovative solutions in vaccine packaging that provides easier handling and requires less storage capacity as well as by efficient stock management (Iwu et al., 2019a).

Yadav (2015) underlaid the two approaches used in stock management, the pull, and the push

system. The latter uses the allocation method of distributing the vaccine from the regional stores whereas the pull system is processing the information at the health facility and sets an order to the regional store. Which system is used is dependent on the efficiency of communication between the facilities as well as on the level of development in stock management. Rele (2020) highlighted that the storing conditions are having a vital role in determining the stock units by considering the shelf life of the vaccines if it is frozen or not which provides a guideline for manufacturing and stocking.

2.5.5. Vaccine IT

Reporting systems and stock monitoring initiatives could provide the backbone of reliable data while reducing the shortages caused by untransparent operations (Iwu et al., 2019b; Iyengar et al., 2016). Iwu et al. (2019a) suggested that monitoring the stock level in real time can further reduce the possible stockouts. Anderson et al. (2014) has mentioned the Cold Chain Equipment Manager that is used by several countries to manage the inventories and the stockouts. It could further improve the response time and the availability of the vaccines (Iwu et al., 2019b). It is also included in the Sustainable Development Goals to provide the right to use of vital health technologies (United Nations, n.d.). However, Rele (2020) stated that until the advanced platform technologies have the capacities to efficiently function in a quick vaccination campaign, more advanced technologies continue to be experimental. Lee and Haidari (2017) emphasized that the forecasting system can only be truly useful if the bottlenecks in the supply chain are resolved and in-time deliveries are secured.

Singh et al. (2020) proposed a system called the blockchain system where the data can be stored in every node in the supply chain which are representing blocks and connected to all the nodes throughout the chain. It can be accessed by anyone which creates trust among the supply chain partners and provides real time data while increasing security towards counterfeiting and the quality of the products as it records the inside temperature of the package with the help of a QR code. It is further explained when using a blockchain system, the distribution from the manufacturer to the recipients are recorded in every step of the supply chain, making a product history available to the final consumer.

2.5.6. Traceability

The following section will discuss the literature on counterfeiting and barcoding.

2.5.6.1. Counterfeiting

As previously stated, counterfeit products are a fast-growing problem in the healthcare supply chain (Dixit et al., 2019). According to Jarrett, Yang, and Pagliusi (2020), this issue can further be identified in the vaccines supply chain. It is stated that vaccines that do not meet standards, are expired, defective or counterfeit have been identified to be an issue to the health of people around the world. Counterfeit vaccines put people at risk of infection, who think they have been immunized against a disease. Further, they can harm the manufacturer´s reputation and trust in them.

Jarrett, Yang, and Pagliusi (2020) stated that there have been numerous instances recorded in the last decade, which involved counterfeit vaccines, especially in Africa and Asia. 80% of counterfeit products that have been seized by customs, originated from Asia. In the past Indonesia has seen issues with counterfeit vaccines from unregistered manufacturers, affecting products Bio Farma supplies. It is further stated that other vaccine treatments have been seized in the past. However not all instances that appeared globally have been recorded, adding further health concerns to their recipients. The distribution of counterfeit products brings high profits, and the internet makes the process of selling and trading easier. It is the task of national authorities to monitor employees, manufacturers, and distributors to prevent counterfeit vaccines or pharmaceutical products to be manufactured and distributed. However, fragmented and complex supply chains make it easy to bypass national authorities.

Due to the current Covid-19 pandemic, it is stated that it will be likely that counterfeit vaccines will enter the market. Counterfeit medical products for Covid-19 have already been seized, and the sale of a counterfeit Covid-19 vaccine has already been reported in South America (Jarrett, Yang, & Pagliusi, 2020).

Dixit et al. (2019) stated that in order to reduce or eliminate counterfeit vaccines on the market, tracking and visibility of vaccines in their supply chain is necessary. Jarrett, Yang, and Pagliusi (2020) added that regulations have already been issued, stating that traceability and barcoding is required and needs to be implemented, in order to prevent counterfeit vaccines to be received by patients. Vaccines should be tracked from the manufacturing site to the patient receiving it, by including the Global Trade Item Number (GTIN), which stores information on the manufacturer, expiration date, and lot number. Additionally, it is stated that traceability does not only have the advantage of identifying counterfeit vaccines, but it also further gives information on demand, stocks, consumption, and forecasting. According to Jarrett, Yang, and Pagliusi (2020) traceability has been identified as a priority in the vaccines supply chain of

developing countries by over 40 manufacturers, this priority has further been highlighted due to Covid-19.

Sodhi and Tang (2021) stated that technologies in industry 4.0, such as internet of things, sensors, robotics, and blockchains are becoming easier to access and afford, and could result in significant advantages for the traceability efforts, however current tests on the implementation of such technologies have not been fully successful yet.

Jarrett, Yang, and Pagliusi (2020) explained that this process requires the collaboration of the pharmaceutical industry, regulatory authorities on both national and international level, and hardware and software suppliers. Hardware suppliers are needed to modify and improve packaging processes by supplying sensors and printing systems, whereas software suppliers need to develop track and trace systems through applications.

The researchers (Jarrett, Yang, & Pagliusi, 2020) elaborated that at Bio Farma, approximately 20 employees were involved in the development of traceability systems, who further trained other employees on systems, technical aspects, and regulations. However, training of staff that is not part of the manufacturing process has been tested but not yet fully implemented. It is essential that all relevant stakeholders, including healthcare workers are educated on the use of tack and trace systems, in order to ensure its successful implementation.

Jarrett, Yang, and Pagliusi (2020) further highlighted that the integration of digital health systems can result in a positive impact in immunizations, which is further underlined by GAVIs research on blockchain technologies. Additionally, making it possible to use softwares on mobile phones, would enable tracking throughout the whole tracking process of vaccines, including health care workers. Digital health systems and technologies that can be used for barcoding and packaging are a necessity for the success of traceability. It is mentioned that more than 120 countries are currently developing and implementing such systems. Therefore, the demand of vaccine manufacturers to adopt traceability measures will grow and will be accepted to increase their credibility.

2.5.6.2. Barcoding

Barcoding is a tool that includes a numbered code in the form of a rectangle, which can be read by laser or photographic technology. It is printed on the packaging through a small printer and is essential to improve traceability (Jarrett, Yang, and Pagliusi, 2020). They add that labeling of packaging through 2D barcodes is seen to become a requirement in the future. According to Pagliusi et al. (2018) barcodes on secondary packaging is already preferred and recommended

by the WHO, and as stated by Jarrett, Yang, and Pagliusi (2020) is already required in Indonesia and will be required to be in place by UNICEF, by the end of 2021.

The development and implementation of barcodes on primary packaging, has been prioritized by many organizations, such as WHO, VIPS, and UNICEF, as it can track a single vaccine to its end user, further improving traceability and access to information on consumption. It is stated that primary packaging, such as vaccine vials or ampoules, is seen as a technical challenge, due to its size, that will be faced over several years, however most manufacturers do not see it as a challenge that will be overcome quicker. Appropriate sizes of barcodes of vials have already successfully been developed (Jarrett, Yang, & Pagliusi, 2020).

As previously mentioned, temperature sensitive vaccines are a risk to health when stored improperly. Barcoding can further be used to control temperature, such as innovations by Temptime. Such innovations do not only contribute to improvements of the safety of a vaccine, but they can also further reduce costs and waste (Pagliusi et al., 2018). Jarrett, Yang, and Pagliusi (2020) further state that such assurance of proper transport and storage, and therefore efficiency and safety, could also have positive impacts on marketing of a vaccine.

Vaccines can be packaged in different ways, depending on the manufacturer, such as plastic vials, multiple single-doses, glass cartridges, or further modified through blow-fill-seal technologies and ampule design (Jarrett, Yang, & Pagliusi, 2020; Pagliusi et al., 2018). Adapting the vaccine packaging line, including design and testing of software can be costly for manufacturers, however it is necessary, to meet requirements and standards (Jarrett, Yang, & Pagliusi, 2020).

As identified by Jarrett, Yang, and Pagliusi (2020) there are various challenges with the implementation of traceability. These include regulatory requirements and specific needs from the demand side. Traceability innovations need to meet both, while being compatible with information systems. Compatibility issues have been identified by manufacturers in Indonesia, regarding equipment and softwares. Barcodes on vials could not be read, since they are not steady in the line, therefore further adjustments needed to be made, to ensure that they are sent to the right packaging for further transport.

2.5.7. Challenges of the vaccine supply chain

Rele (2020), and Sodhi and Tang (2021) discussed the impacts of Covid-19 on the vaccine supply chain which existed before the pandemic as well. It has created high pressure on the raw materials that are needed to produce the adjuvants which are helping to enhance the body's

immune response to an antigen. Thus, it jeopardizes other global products quality because of the extent usage of the same resource (Rele, 2020).

Jarrett, Yang, and Pagliusi (2020) said that the quality and efficiency of the vaccine can be compromised by the poor performance of the supply chain and can cause further problems in the future. Yang et al. (2021) elaborated on the challenge to find balance between cost-efficient transportation and reliable vaccine supply. Iyengar et al. (2016), and Lee and Haidari (2017) discussed that insufficient supply chain practices can cause shortages in the point of consumption which could be avoided by ensuring reliable data about the medicine and vaccine supply chain. Another solution would be the redistribution of the vaccines between warehouses or even countries to mitigate the risk of shortage.

Rele (2020) further discussed the lack of pre-clinical data about the antigen-adjuvant design development can lead to challenges in R&D and logistics. Beside these issues, new vaccine developments can place pressure on the vaccine supply chain from the point of manufacturing and insufficient capacity. However, it is still unknown if the manufacturers have the capacity to produce billions of doses in a safe and efficient way for distribution.

The profit allocation can be used to improve the profitability of the entire supply chain, which has an important role in establishing effective cooperation and can reduce the risk for the influenza vaccine manufacturers (Sun et al., 2019) as it is the retailer who gets more profit by the on-time delivery (Dai et al., 2016). Jarrett, Yang, and Pagliusi (2020) discussed that the overall auditing costs could be reduced by the cooperation of the suppliers and manufacturers, however it requires trust to share internal information which is commonly not present between the two parties.

Jarrett, Yang, and Pagliusi (2020) stated that as the demand for vaccines are increasing, consequently the risk of wastage of these medical products needs to be reduced by, for instance, offering recycled packaging. Jarrett, Yang, and Pagliusi (2020), and Lee and Haidari (2017) further elaborated on the packaging of the vaccines which can have an impact on the supply chain in a negative way such as higher costs and a positive way whereas less storage is needed during the cold transportation of the vaccines which can reduce the carbon footprint of the operation. Lloyd et al. (2015) discussed that the need for temperature sensitive vaccines is also increasing globally, which means that the related carbon footprint of transportation is growing as well, especially in countries where there are problems regarding the unreliable and delayed

shipment. Thus, the Net Zero Energy program was introduced in Tunesia to create energy efficient transportation for the vaccines.

2.5.8. Cold Vaccine Supply Chain

According to Anderson et al. (2014), Jarrett, Yang, and Pagliusi (2020), and Yang et al. (2021) cold chain can be described as a supply chain that incorporates temperature requirements between +2 °C and +8 °C. Chakravarthy et al. (2019) is referred to the vaccine supply chain as the "virus chain" transported through the cold chain. Chakravarthy et al. (2019), Kartoglu and Milstien (2014), and Preiss et al. (2016) stated that it must ensure that the specific requirements are fulfilled to preserve the safety of the vaccines as explained by Anderson et al. (2014), and Guignard et al. (2019) that these different temperatures and volumes are critical to maintain for a sufficient supply throughout the chain. Anderson et al. (2014), Kartoglu and Milstien (2014), and Singh et al. (2020) discussed that there are stages and equipment that need to be considered in the cold chain such as, the cold storage, transportation, distribution, vehicles, and cold containers. All these steps must be performed in a secure, temperature-controlled environment. Derwand (2014) highlighted the fact that the cold chain has a vital role in reaching the target coverage rates in immunization. Consequently, the more issues are existing in the chain the less is the immunization rate. However, Kartoglu and Milstien (2014) stated that the overall efficiency of the cold chain is equal to the less efficient stage within the chain. Dixit et al. (2019) highlighted that the cold chain management has a vital role in ensuring the right quality of the vaccines through reducing the arising issues. Iwu et al. (2019b), and Kartoglu and Milstien (2014) said that the cold chain can be under pressure while introducing new vaccines.

As claimed by Derwand (2014) solving VSC issues could contribute to reducing the number of children who are lacking important vaccines. Reducing the costs and increasing the immunization rate can be done by improved distribution network and cold chain systems. Furthermore, Changalucha et al. (2019) added that vaccine accessibility can be enhanced by the efficient use of the cold chain. Moreover, the better the coverage of the cold chain system the better the storage infrastructure. Kartoglu and Milstien (2014) evaluated that the vaccine distribution would be less challenging without the cold chain requirements.

2.5.8.1. Challenges of the cold vaccine supply chain

Derwand (2014) argued that challenges can arise from the specific conditions associated with cold vaccine transportation as not every health facility has capacity to provide these

requirements especially in rural areas. Kartoglu and Milstien (2014) stated that it was reported by the WHO's Effective Vaccine Management program that temperature monitoring issues are arising in any stage of the chain. Chen et al. (2014), and Lemmens et al. (2016) elaborated on the issue in developing countries as the cold chain conditions are remaining a major challenge, however Kartoglu and Milstien (2014) said that developed countries are facing these issues too, especially regarding temperature tracking. Additionally Lam et al. (2015) stated that during humanitarian conflicts the road infrastructure can provide challenges for vaccination. Furthermore, the disruption of the cold chain can create barriers to overcome, such as the danger that the medical staff are exposed to. Also, communication problems, lack of information sharing about the stock level (Anderson et al., 2014), uneducated staff (Kartoglu & Milstien, 2014) and poor equipment can raise relevant issues.

Anderson et al. (2014) described the issues associated with the cold chain equipment. It is mentioned that fuel and electricity shortages and poor maintenance are causing inappropriate temperature changes in the cold storage. Furthermore, reparation of these equipment could be difficult which can lead to reduced storage capacity. Thus, Preiss et al. (2016) elaborated on the challenges generated from the maintenance requirements that puts pressure on the distribution and storage. Chen et al. (2014) further added that beside the cold chain conditions, the heat sensitive vaccines are requiring a certain level of technology to be able to perform the transportation and the maintenance.

Covid-19 pandemics have raised interest regarding the cold chain capacity, as before the temperature requirement of the vaccines were not considered as the largest challenge because small batches were processed (Crommelin et al., 2021).

2.5.8.1.1. Temperature tracking

As claimed by Singh et al. (2020) it is highly relevant to monitor the temperature of the heat sensitive vaccines throughout the whole supply chain which requires trust from all the parties in the chain to share the acquired information. Anderson et al. (2014), Chen et al. (2014), Derwand (2014), Hanson et al. (2017), Kartoglu and Milstien (2014), Preiss et al. (2016), Rele (2020), and Romano et al. (2020) discussed the challenges associated with unprofessional temperature monitoring such as lack of knowledge by the healthcare professionals, which results in reduced vaccine efficiency. Anderson et al. (2014), Derwand (2014), Hanson et al. (2017), Kartoglu and Milstien (2014), and Preiss et al. (2016) further elaborated on the freezing

of the vaccines in the cold chain can also be counted as inappropriate temperature. Issues associated with freezing exist in developing and developed countries, and about 15% to 55% of the vaccines are exposed to freezing during transportation (Derwand, 2014; Kartoglu & Milstien, 2014).

According to Jarrett, Yang, and Pagliusi (2020) manufacturers are tracking the temperature of the vaccines upon requests but mostly on international shipments. For instance, it was argued by Kartoglu and Milstien (2014) that WHO is having different requirements regarding the temperature monitoring depending on the nature of the transportation between the nodes, such as international transport, vaccine stores and service level. Jarrett, Yang, and Pagliusi (2020) stated that it is agreed that these tools and methods can improve the security of the vaccines in the supply chain as well as the temperature indicator explained by Romano et al. (2020) that helps to reduce the risks for the consumer.

2.6. Identified Risks from the Literature Review

As a result of the literature review, the major risks have been identified below, however a detailed list of risks can be found in the Appendix §1.

Major risks

- **Complexity of supply chain** *(Lemmens et al., 2016; Singh et al., 2016)*
- **Insufficient cold chain & processes/ temperature/ characteristics** *(Anderson et al., 2014; Dellepiane & Wood, 2015; Derwand, 2014; Dixit et al., 2019; Guignard et al., 2019; Hanson et al., 2017; Kartoglu and Milstien, 2014*; *Romano et al., 2020)*
- **Corruption /counterfeit** *(Dixit et al., 2019; Fernando et al., 2020; Jarrett, Yang, & Pagliusi, 2020; Pagliusi et al., 2018; Singh et al., 2016; Singh et al., 2020; Yadav, 2015)*
- **No collaboration/ trust** *(Jarrett, Yang, & Pagliusi, 2020; Singh et al., 2016)*
- **Insufficient infrastructure** *(Dixit et al., 2019; Lam et al., 2015; Singh et al., 2016)*
- **Outsourcing** *(Dixit et al., 2019; Fernando et al., 2020; Lloyd, Mccarney, Ouhichi, Lydon, & Zaffran, 2015; Pagliusi et al., 2018; Singh et al., 2016)*
- **Environmental concerns** (waste management/recycling/ reverse logistics) *(Dixit et al., 2019; Iyengar et al., 2016; Jarrett, Yang, & Pagliusi, 2020; Pagliusi et al., 2018; Singh et al., 2016; Sodhi & Tang, 2021)*
- **Regulations/ requirements** *(Derwand, 2014; Dixit et al., 2019; Preiss et al.,2016; Pagliusi et al., 2018; Romano et al., 2020; Singh et al., 2016; Yadav, 2015)*
- **Lack of & maintenance of equipment** *(Anderson et al., 2014; Dixit et al., 2019; Preiss et al., 2016)*
- **High volume distribution /frequency of deliveries** *(Hovav & Herbon, 2017; Yadav, 2015; Yang et al., 2021)*
- **Storage** (*Anderson et al., 2014; Chakravarthy et al., 2019; Chen et al., 2014; Dellepiane & Wood, 2015; Jarrett, Yang, & Pagliusi, 2020; Lee & Haidari, 2017; Preiss et al.,2016; Rele, 2020)*
- **Stock management/ forecasting** *(Anderson et al., 2014; Chick, Hasija, & Nasiry, 2017; Dellepiane & Wood, 2015; Dixit et al., 2019; Gurvich & Hussain, 2020; Iyengar et al., 2016; Islam et al.,2020; Iwu et al., 2019b; Jarrett, Yang, & Pagliusi, 2020; Lee & Haidari, 2017; Preiss et al.,2016; Rele, 2020; Singh et al., 2016; Thompson et al., 2016)*

- **Immunization coverage** *(Derwand, 2014; Iwu et al., 2019b; Jarrett, Yang, & Pagliusi, 2020 Lee & Haidari, 2017; Thompson et al., 2016, Yang et al.; 2021)*
- **Capacity of manufacturing** *(Iyengar et al., 2016; Rele, 2020)*
- **Production time** *(Preiss et al., 2016; Thompson et al., 2016)*
- **Product quality** *(Iyengar et al., 2016; Jarrett, Yang, & Pagliusi, 2020; Pagliusi et al., 2018; Singh et al., 2020; Yadav, 2015)*
- **Consumer behavior** *(Dixit et al., 2019; Fernando et al., 2020; Lloyd, Mccarney, Ouhichi, Lydon, & Zaffran, 2015; Pagliusi et al., 2018; Singh et al., 2016)*
- **Short product life cycle** *(Dixit et al., 2019; Fernando et al., 2020; Pagliusi et al., 2018; Singh et al., 2016)*
- **Financing** *(Chen et al.,2014; Dixit et al., 2019; Fernando et al., 2020; Pagliusi et al., 2018; Singh et al., 2016; Sodhi & Tang, 2021; Yadav, 2015)*
- **R&D process & lack of pre-clinical data** *(Guignard et al.,2019; Hovav & Herbon, 2017; Preiss et al.,2016; Rele, 2020; Singh et al., 2016; Thompson et al., 2016)*
- **Prioritizing products** *(Pagliusi et al., 2018; Singh et al., 2016)*
- **Changing demand** *(Iyengar et al., 2016; Pagliusi et al., 2018; Singh et al., 2016; Sodhi & Tang, 2021; Thompson et al., 2016)*
- **Vaccine prices/ competition** *(Lemmens et al., 2016; Singh et al., 2016)*
- **Incompetent & unexperienced staff** *(Dixit et al., 2019; Hovav & Herbon, 2017; Jarrett, Yang, & Pagliusi, 2020; Kartoglu & Milstien, 2014; Pagliusi et al., 2018; Yadav, 2015)*
- **Barcoding** *(Jarrett, Yang, & Pagliusi, 2020)*
- **IT related issues** *(Anderson et al., 2014; Dixit et al., 2019; Fernando et al., 2020; Iwu et al., 2019b; Iyengar et al., 2016; Jarrett, Wilmansjah et al., 2020; Lloyd, Mccarney, Ouhichi, Lydon, & Zaffran, 2015; Pagliusi et al., 2018; Singh et al., 2016; Yadav, 2015)*

3. Methodology

In this section the methods used to answer the research questions will be discussed. This includes the research approach, data collection method and how the collected data was analyzed.

3.1. Research Approach

According to Collis and Hussey (2014), research can be conducted through a qualitative or quantitative approach. Qualitative data is collected in nominal form such as words, whereas quantitative data is collected in numerical form, in the form of numbers.

For the purpose of this research a quantitative approach is used in the form of the Analytical Hierarchy Process, however some qualitative data in the form of text is also included, as interviewees could comment on their answers. Though this data was not analyzed and will merely be used to get a deeper understanding of the Covid-19 vaccine supply chain.

3.2. Data Collection

In order to fulfil the two research objectives, both primary data and secondary data have been used. According to Collis and Hussey (2014), primary data refers to data that has been generated from own research in the form of interviews, surveys, as well as focus groups, whereas secondary data is collected from existing research, including publications, internal records, or databases.

3.2.1. Research Objective 1

For Research Objective 1, *investigate and set up a list of the risks present in the vaccine supply chain*, it was chosen to use secondary sources from existing publications. This has been done in form of a systematic literature review with Prisma using Scopus.com, which publishes peer-reviewed articles and therefore ensures high reliability of the used publications.

The researchers chose to search for publications from 2013 to 2021, due to the MERS-CoV outbreak in April 2012 and therefore ensuring, that the literature includes relevant information for the topic of Covid-19, as it is a derived strain from the MERS-CoV virus (Hewings-Martin, 2020). In total three searches were conducted, which are presented in table 2, including keywords, number of articles found, as well as number of articles chosen from the search. Further searches with different keywords were conducted, however due to the high number of duplications of already found articles, the first three searches were perceived as sufficient and

relevant for further analysis. Additionally, the time constraint of accomplishing a relevant literature review further supported to limit the searches to three.

As it can be seen on Table 2, a total of 115 articles have been found with the applied keywords, however, after investigation of the publications, 67 articles were eliminated, due to their irrelevance to the topic, as well as accessibility to them. Therefore, the systematic literature review is based on 48 peer-reviewed research articles, however additional articles were acquired to complement the systematic literature review, to further clarify, elaborate on information with definitions and up-to-date data.

Search order	**Keywords (title-abstract-keywords)**	Total number of articles	Number of chosen articles
1.	Risk AND vaccine AND supply AND chain	79 (9**)	**31**
2.	Strategic AND issues AND in AND pharmaceutical AND supply AND chains AND review	5	**4**
3.	strategic* OR pharm* AND vaccine AND supply AND chain*, AND challenge* OR issue* OR risk*	31 (3**,6***)	**13**
Total:		**115**	**48**
Search explanation AND: Both words must be present in the search results OR: One of the words has to be present in the search results *: The word has to be present in the search results, but it can in any form		Article explanation **: number of articles lacking accessibility ***: number of duplicates from previous searches	

Table 2: Presentation of the conducted searches.

The systematic literature review resulted in a list of risks in the vaccine supply chain, which serves as a base for the second research objective to rank them according to their complexity. In order to have a manageable list of risks, the 107 risks as shown in Appendix §1 were summarized and reduced to a total of 26 risks and sorted into the different processes of the vaccine supply chain.

Covid vaccine is the closest to flu vaccine, however the flu is seasonal, thus the manufacturing and supply chain process are different from Covid, which is given to patients continuously since it has been introduced. Therefore, all vaccines addressed in the literature have been considered to benchmark the risks in the vaccine supply chain.

3.2.2. Research Objective 2

For the ranking process with AHP, which will be discussed in the Data Analysis section, primary sources were used in the form of interviews and one survey. Due to the sole purpose of the literature review being the source of the list of risks, the results of the AHP were not discussed against the literature of research objective 1. Instead, it was decided to compare and discuss the answers and comments of each expert with each other and add additional information from previous news reports.

3.2.2.1. Panel of experts

The sampling frame is defined as a population record from which a sample can be drawn, if the population is small, the whole population can be used as a sample (Collis and Hussey, 2014). For the purpose of this research, it was decided to choose Läkemedelsindustriföreningen (The Swedish Association of the Pharmaceutical Industry), short LIF, as a population, as this was considered to be the source with the most possible participants for the research. Trying to get a sufficient number of responses, the 85 members of the association, that had their email-addresses published on the member section, were contacted by email, furthermore the Director-General and the Press officer of LIF were contacted, forwarding our inquiry to an expert on vaccines and supply chain issues, with whom one of the interviews was conducted.

The email (Appendix §2) included an introduction of the researchers, the research, as well as further information on the process and timeframe of the research. It was decided to give participants the option of participating in an online-interview as well as filling out a survey, due to time constraints the possible participants might face, caused by Covid-19 and the connected workload.

As seen in table 3, out of the 88 contacts that were contacted, 20 personal replies were received. Three emails could not be delivered, 16 respondents stated that they could not participate in the research due to high workload, not knowing who to forward the email to, due to a large network, and lack of experience with Covid-19 vaccines. A large number of automatic replies

were received; however, these were not counted into the replies. The limited number of responses could be caused by the high workload pharmaceutical companies are facing at the moment, as well as many emails being sent to the customer service email address stated on the website.

Research Objective 2	Number of Contacts	Number of Replies	Number of rejections	Number of interviews/surveys	Number of No answers
LIF-members	85	20	17	3	69
LIF	3	2	0	1	1
Total	88	22	17	4	70

Table 3: Details on Contacts for Research

A total of five members were willing to participate in the research of which three agreed to schedule an interview, and two who requested a survey via email. However, one of the possible survey participants informed us that they were not able to answer the survey due to lack of experience with the Covid-19 vaccine. The information on the participants, including their title, company, date, place, time, length of the interview, as well as the method used, can be seen in table 4 below. For data protection reasons, each of the experts were assigned to be called expert 1, expert 2, expert 3 and expert 4; however, these terms are not in connection with the order in which the interviews and survey were conducted.

Name	Title/Area	Company	Date	Place	Time	Length	Method
Ewa Lindqvist	Senior Manager, Clinical Delivery	x	29.3.21	Zoom	10:15	36 min	Interview
Hedda Magnusson	Clinical trials/ research	ASCRO	31.3.21	Zoom	14:30	44 min	Interview
Bengt Mattson	Policy Manager/ Expert on Vaccine and Supply Chain related issues	LIF	8.4.21	Teams	13:00	73 min	Interview
Fredrik Westerståhl	Head of Supply Nordics	Takeda pharmaceuticals	13.4.21	E-mail	x	x	Survey

Table 4: Information on Research Participants and Research

3.3. Data Collection

The following sections entails the process of preparing and conducting the research.

3.3.1. Preparation for Data Collection

As a first step of the interview preparations, a word document was created including instructions, explanations of risks, comparison matrices of the risks, as well as sections for comments after each matrix. This word document was sent out to people that agreed to participate in the survey and was used as a base for the conducted interviews. The document can be seen in Appendix §3.

3.3.2. Conducting Interviews

Interviews are a research method, which allows the researchers to collect data from their participants by asking questions to find out what opinion the participant has towards subjects and what they think about them (Collis & Hussey, 2014). For the purpose of this research, it has been decided to conduct the interviews as semi-structured survey based. Semi-structured interviews include a predetermined set of questions with the opportunity to follow up on any given answer (Collis & Hussey, 2014). Even though the process of these types of interviews are time consuming, require intensive labor and deep knowledge of the subject, their value of supplying reasoning behind answers, and receiving more information outweighs those disadvantages (Adams, 2015). Interview based on a survey, gives the interviewee the possibility to receive answers to a set of questions, while being able to follow up on responses (Sincero, 2012).

3.3.3. Interview process

The interview started with an introduction to the research, followed by an explanation of how the interview will be conducted and structured. The interviewee was asked if they prefer to stay anonymous, which information can be included, as well as if there were any questions. It was further explained that the interviewee should answer the questions to their best knowledge, and that questions or topics, which the interviewee was not familiar with, could be skipped.

It was decided to use closed comparison questions at first, which require a comparison from a predetermined list of options (Collis & Hussey, 2014) in order to get relevant data for the data

analysis process. Throughout the interview the interviewee was given the option and was encouraged to elaborate and comment on a given answer. This has been done in order to get the necessary data for further data analysis while getting a deeper understanding of the discussed issues in the Covid-19 vaccine supply chain. Both researchers were participating in the interview, one giving the introduction of the interview and taking notes, while the other asked questions. However, follow-up questions were asked by both interviewers.

3.4. Data Analysis Method

As the second research objective aims to set up a ranking from the identified risks through the literature review the AHP decision making system was chosen to set up the list. The investigated specific risks were chosen according to their relevance and occurrence in the conducted literature review.

According to Saaty (1977), the AHP is a system that relies on the idea of pairwise comparison through a matrix that compares the importance of the different alternatives to each other. It is used to help the decision-making processes by identifying the most important/relevant alternative through several attributes by measuring weights. Although these alternatives would be then compared according to several criteria, this paper used only one part of the AHP system and combined it with the Group Decision Making process, the so called AHP-GDM. As it was described by Ssebuggwawo, Hoppenbrouwers and Proper (2009), the group decision making can be looked at as a group as one individual or can assess individual opinions about the same topic. It can be considered as aggregating individual priorities (AIP) where the respondents are acting within their own value system independently; and the aggregating individual judgements (AIJ), whereas the respondents are acting as a group. Therefore, the AIP method is used as all the respondents were acting separately with the same weights due to their similar extent of knowledge regarding the vaccine supply chain. According to Oguztimur (2021), on one hand AHP has the ability to be used in any kind of problems where decisions have to be made, which provides great flexibility and simplicity for researchers. Furthermore, it leads the research to find the best alternative while measuring the consistency of the given judgements which can come from different perspectives; thus, it produces reliable data. On the other hand, it relies on a massive number of calculations which can require a lot of effort and can be time consuming.

The research participants all have an extent knowledge about the vaccine supply chain processes; however, they can have a different perspective about each of the stages in the supply chain due to their different roles and positions. Therefore, they are counted as equal participants in the research without labelling and weighing their knowledge against each other. Furthermore, some of the experts wished to stay anonymous regarding their answers, thus, the research does not identify the identity of expert 1, expert 2, expert 3 and expert 4.

The AHP process had to be complemented by the group decision making objective as the matrices are comparing the risks to one another but there are no criteria given. Furthermore, as it can be seen on Table 5 the identified risks were grouped into seven categories from which six matrices were created because one of the categories do not include any sub risks to be able to conduct the research. Thus, one more matrix was designed which compares the identified seven categories for the final ranking of the different processes in the Covid-19 vaccine supply chain as well as the risks they entail. This decision was made due to the extent number of questions that would have needed to be asked in the case of one matrix that compares all the risks. The matrices were presented in a word document that used a drop-down rating system. In the matrices, the respondents could use a scale from 1 to 9, where 1 indicated equally challenging conditions and 2 meant that one alternative has importance over the other and 9 represented extreme importance over the investigated alternatives (Saaty, 1977; Teknomo, 2006).

Matrices	**Risks(R) in the matrices**
General Vaccine Supply Chain (VSC)	R1: Complexity; R2: Incompetent and unexperienced staff; R3: Lack of collaboration and trust; R4: Outsourcing issues; R5: Environmental concerns; R6: Prioritizing Products.
R&D	R1: Process & lack of pre-clinical data; R2: Financing; R3: Product quality issues; R4: Short product life cycle
Distribution	R1: Insufficient cold chain processes R2: Insufficient infrastructure R3: Lack of maintenance of equipment R4: High volume distribution
Economy	R1: Corruption/Counterfeit; R2: Changing Demand; R3: Vaccine prices/competition; R4: Regulations and requirements;

	R5: Immunization coverage; R6: Consumer behavior.
Manufacturing	R1: Barcoding R2: Capacity R3: Production time
Stock Management	R1: Storage R2: Forecasting issues
All risks	R1: General VSC R2: R&D R3: Manufacturing R4: Distribution R5: Economy R6: Stock Management R7: IT

Table 5: Matrices and risks used in the AHP process.

By using the group decision making process, all the matrices in each category were combined which resulted in one matrix in each category to contribute to the successful ranking of the risks. To calculate the Group Decision Making system combining the different matrices within the categories was necessary and the geometric mean calculation was used which has the ability to produce the reciprocal numbers in the matrices which is important in reaching acceptable consistency (Ossadnik, Schinke, and Kaspar, 2015). To identify the ranking, after the group decision making calculation, a normalized table had to be generated which means that each of the cells was divided by the sum of the column they were placed at. Once the normalized table was done, the priority vectors were calculated by calculating the sum of each row and dividing it by the number of the risks presented in the matrices (Teknomo, 2006). The priority vectors are determining the risks placed in the order whereas the smaller number is the least challenging and the highest priority vector is the most challenging in the matrix (Saaty, 1977).

To identify the reliability of the AHP process, usually a Consistency Ratio (CR) is counted (Saaty, 1977). The consistency ratio can be accepted until 0.1 (Saaty, 1977; Teknomo, 2006), however if more than 4 alternatives are compared in the matrices the ratio can be tolerated up to 0.2 (Hummel, Bridges, and Ijzerman, 2014). In this research all the respondents acquired consistency individually as well as in the combined matrices beside one, which resulted in a negative number that can be due to problems or errors in Excel's automatic calculation (Teknomo, 2006). However, as all the individual matrices are consistent, the negative ratio was accepted.

The reliability of the AHP research is also improved by the possibility to discard risks from the matrices if the expert does not have relevant knowledge about the subject. It was done by Expert 3 who decided not to compare the R&D process in the “All risks" matrix as well as by Expert 4 who chose not to answer the “R&D” matrix. Thus, all the answers were provided by confident and relevant knowledge/experience regarding the subjects by all the experts.

3.5. Evaluation of quality of research design

Reliability of the study means that the research is replicable by other researchers while producing the same results (Collis & Hussey, 2014). In this study the systematic literature review can be considered as high reliability as the keywords are given and it relies on these given articles. However, the outcome of the systematic literature review does not have a high replicability as the major risks were chosen by the researchers own judgement based on the literature review. The AHP process improves the reliability of the study as the research participants are presented even though they cannot be identified throughout the process. The study can be repeated with the same panel of experts and with the same matrices that are assessing the same risks therefore, it can be considered as high reliability. However, the results may be influenced if it is taken outside of the pandemic setting or at various stages throughout the pandemic. Therefore, the study can be considered as it has high reliability.

Validity is indicating if the research and/or survey is investigating what it was intended to. To have high validity, it is important to avoid poor samples and procedure errors (Collis & Hussey, 2014). In this research the healthcare professionals are having wide knowledge and experience about the vaccine supply chain operations as well as the research has begun with an introduction of the AHP process to improve the understanding of the measurements used in the survey. Furthermore, the research was assessed via face validity from a researcher at Chalmers University. Thus, the research obtains high validity.

4. Results and Discussion

In this section the results from the AHP-GDM research will be presented. It is divided into each matrix, for which the final results of each expert alongside the normalized matrices, as well as the combined final result will be presented. Furthermore, the additional opinions of the experts regarding certain matrices and risks will be discussed alongside the results which were supported with relevant news and articles. The initial survey answers, consistency matrices and the group decision calculation can be found in the Appendix §4. It is important to analyze and present the results of each expert in order to understand the foundation of the group decision results. The answers were given in accordance with the Covid-19 pandemic and vaccination. The priority vectors are representing percentages and add up to 100 percent in each of the matrices. The higher the percentage the higher the issue's rank in the order. Furthermore, the CR was accepted below 0.1 and was tolerated below 0.2 values (Saaty, 1977).

4.1. General Vaccine supply Chain

The matrix of the General Vaccine Supply was dealing with the issues concerned with the incompetent and inexperienced staff, complexity of the supply chain, collaboration and trust, outsourcing, prioritizing products and environmental concerns. First, the individual expert matrices are analyzed and followed by the Group Decision Making results.

4.1.1. Expert 1

As Table 6 shows, expert 1 has set up a ranking where the incompetent and unexperencied staff is the most challenging issue with a priority vector of 0.217 which is followed by the complexity (0.187 priority vector) throughout the chain. The third most challenging issues according to expert 1 is the lack of collaboration and trust between the partners and organizations with a priority vector of 0.187. It is followed by the outsourcing issues (0.167) and prioritizing products (0.159) and the least concerning in the vaccine supply chain during the pandemic is the environmental concerns with a priority vector of 0.088. The consistency ratio is below 0.1, thus the judgements are considered to be consistent.

Expert 1	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**Sum**	**Priority vector**
R1: Complexity	0,275	0,045	0,308	0,143	0,133	0,218	1,122	**0,187**
R2: Incompetent & unexperienced staff	0,039	0,318	0,308	0,286	0,133	0,218	1,302	**0,217**

R3: Lack of collaboration & trust	0,137	0,159	0,154	0,286	0,133	0,218	1,087	**0,181**
R4: Outsourcing Issues	0,275	0,159	0,077	0,143	0,133	0,218	1,005	**0,167**
R5: Environmental concerns	0,137	0,159	0,077	0,071	0,067	0,018	0,530	**0,088**
R6: Prioritizing products	0,137	0,159	0,077	0,071	0,400	0,109	0,954	**0,159**
Consistency Ratio								**0,066**

Table 6: General Vaccine Supply Chain Normalized Table-Expert 1

4.1.2. Expert 2

Expert 2 ranked the risks differently from expert 1. As Table 7 clearly shows the most challenging issue is the incompetent and unexperienced staff with a priority vector of 0.302 which is a quite relevant vector. It is followed by the lack of collaboration and trust (0.262) and outsourcing issues with a priority vector of 0.252. The fourth most challenging risk is the environment concerns (0.092) and the fifth is the prioritizing products (0.055). Finally, the last in the order is the complexity with a 0.036 vector. As it is clearly noticeable on the vectors the first three risks received the majority of the weight of the vectors. Lastly, the consistency ratio equals with 0.095, thus the result is consistent.

Expert 2	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**Sum**	**Priority vector**
R1: Complexity	0,043	0,042	0,039	0,032	0,031	0,029	0,215	**0,036**
R2: Incompetent & unexperienced staff	0,261	0,250	0,586	0,095	0,277	0,343	1,812	**0,302**
R3: Lack of collaboration & trust	0,217	0,083	0,195	0,571	0,277	0,229	1,573	**0,262**
R4: Outsourcing Issues	0,261	0,500	0,065	0,190	0,277	0,229	1,522	**0,254**
R5: Environmental concerns	0,130	0,083	0,065	0,063	0,092	0,114	0,549	**0,092**
R6: Prioritizing products	0,087	0,042	0,049	0,048	0,046	0,057	0,328	**0,055**
Consistency Ratio								**0,095**

Table 7: General Vaccine Supply Chain Normalized Table-Expert 2

4.1.3. Expert 3

The results show (Table 8) that complexity of the supply chain (0.401 priority vector) has been ranked as the most challenging from the perspective of expert 3. It is followed by the outsourcing issues with a priority vector of 0.288 and the lack of collaboration and trust with a priority vector of 0.207. As the vectors are showing it well the first three risks are having a large influence as they acquired more than 80 percent of the weights in the ranking. The fourth risk is the environmental concerns (0.036) that is closely followed by the prioritizing products (0.034) and incompetent and unexperienced staff (0.034). The consistency ratio is at 0.067 which means that the answers are consistent.

Expert 3	R1	R2	R3	R4	R5	R6	Sum	Priority vector
R1: Complexity	0,402	0,321	0,742	0,297	0,346	0,296	2,405	**0,401**
R2: Incompetent & unexperienced staff	0,045	0,036	0,015	0,033	0,038	0,037	0,204	**0,034**
R3: Lack of collaboration & trust	0,057	0,250	0,106	0,297	0,269	0,259	1,239	**0,207**
R4: Outsourcing Issues	0,402	0,321	0,106	0,297	0,269	0,333	1,729	**0,288**
R5: Environmental concerns	0,045	0,036	0,015	0,042	0,038	0,037	0,213	**0,036**
R6: Prioritizing products	0,050	0,036	0,015	0,033	0,038	0,037	0,210	**0,035**
Consistency Ratio								**0,067**

Table 8: General Vaccine Supply Chain Normalized Table-Expert 3

4.1.4. Expert 4

From expert 4's point of view, as it can be seen on Table 9, the most challenging issue is the complexity of the supply chain with a priority vector of 0.285. It is followed by the outsourcing issues (0.225). The third issue in the ranking is the problems related to prioritizing products (0.194) thereafter comes the lack of collaboration and trust with a slightly lower vector of 0.171. The fifth challenge is the environmental concerns (0.085) and lastly the incompetent and unexperienced staff (0.041). The consistency ratio is 0.083 which describes consistent results.

Expert 4	R1	R2	R3	R4	R5	R6	Sum	Priority Vector
R1: Complexity	0,270	0,217	0,456	0,227	0,346	0,194	1,710	**0,285**

R2: Incompetent & unexperienced staff	0,054	0,043	0,051	0,045	0,019	0,032	0,245	**0,041**
R3: Lack of collaboration & trust	0,090	0,130	0,152	0,227	0,231	0,194	1,024	**0,171**
R4: Outsourcing Issues	0,270	0,217	0,152	0,227	0,288	0,194	1,349	**0,225**
R5: Environmental concerns	0,045	0,130	0,038	0,045	0,058	0,194	0,510	**0,085**
R6: Prioritizing products	0,270	0,261	0,152	0,227	0,058	0,194	1,162	**0,194**
Consistency Ratio								**0,083**

Table 9: General Vaccine Supply Chain Normalized Table-Expert 4

4.1.5. Group Result

Using the Group Decision Making process, the individual matrices have been combined which generated one single ranking of the risks to be analyzed. This means that in the final ranking as shown in figure 1, the most challenging issues are related to outsourcing (0.271) which is followed by the lack of collaboration and trust (0.238). The third risk is the complexity (0.202) in the chain and thereafter comes the incompetent and unexperienced staff (0.111) with relatively lower importance as Figure 1 represents it well. After that comes slightly behind it the prioritizing products (0.099) and environmental concerns (0.078).

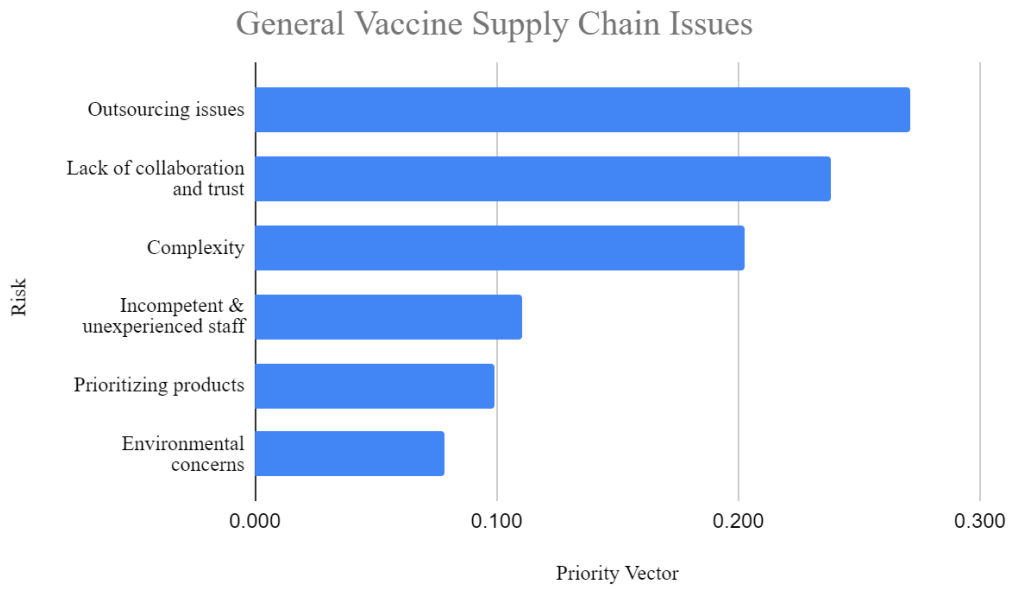

Figure 1: General Vaccine Supply Chain Ranking

4.2. Economy

The "Economy" matrix was focusing on the issues related to Corruption and counterfeiting, Immunization coverage, Consumer behavior, Changing demand, Regulations and Vaccine prices and competition.

4.2.1. Expert 1

Table 10 shows that corruption is the biggest issue by far, with a priority vector of 0.386, this is followed by achieving immunization coverage with 0.190. Changing demand is seen as the third most challenging issue, with a priority vector of 0.093, which is closely followed by the last three risks consumer behavior (0.063), regulations & requirements (0.059), and vaccine prices or competition (0.041) as the least challenging risk.

Expert 1	R1	R2	R3	R4	R5	R6	Sum	Priority vector
R1: Corruption and Counterfeit	0,482	0,545	0,353	0,345	0,590	0,364	2,315	**0,386**
R2: Changing Demand	0,060	0,068	0,176	0,207	0,049	0,091	0,561	**0,093**
R3: Vaccine prices and competition	0,080	0,023	0,059	0,034	0,049	0,091	0,246	**0,041**
R4: Regulations and requirements	0,096	0,023	0,118	0,069	0,049	0,091	0,355	**0,059**
R5: Immunization coverage	0,161	0,273	0,235	0,276	0,197	0,273	1,141	**0,190**
R6: Consumer behavior	0,120	0,068	0,059	0,069	0,066	0,091	0,382	**0,064**
Consistency Ratio								**0,069**

Table 10: Economy Normalized Table-Expert 1

4.2.2. Expert 2

According to expert 2 (see Table 11), changing demand is seen as the most challenging issue, with a priority vector of 0.379, followed by achieving immunization coverage (0.199). The third most challenging risk is consumer behavior (0.104), which is followed by regulations and requirements (0.062), vaccine prices and competition (0.054), and with corruption and counterfeiting being seen as the least challenging risk with a priority vector of 0.035.

Expert 2	R1	R2	R3	R4	R5	R6	Sum	Priority vector

R1: Corruption and Counterfeit	0,048	0,074	0,029	0,019	0,041	0,028	0,211	**0,035**
R2: Changing Demand	0,333	0,519	0,400	0,404	0,619	0,500	2,274	**0,379**
R3: Vaccine prices and competition	0,095	0,074	0,057	0,058	0,041	0,028	0,325	**0,054**
R4: Regulations and requirements	0,143	0,074	0,057	0,058	0,041	0,028	0,373	**0,062**
R5: Immunization coverage	0,238	0,173	0,286	0,288	0,206	0,333	1,191	**0,199**
R6: Consumer behavior	0,143	0,086	0,171	0,173	0,052	0,083	0,625	**0,104**
Consistency Ratio								**0,067**

Table 11: Economy Normalized Table-Expert 2

4.2.3. Expert 3

The results for expert 3 (Table 12) show that corruption and counterfeiting is the most challenging risk with a priority vector of 0.401, which is followed by regulations and requirements (0.255) and changing demand (0.084). Vaccine prices and competition is the fourth most challenging risk (0.034), followed by achieving immunization coverage, as well as consumer behavior, which both resulted in a priority vector of 0.030.

Expert 3	R1	R2	R3	R4	R5	R6	Sum	Priority vector
R1: Corruption and Counterfeit	0,514	0,607	0,391	0,558	0,333	0,333	2,404	**0,401**
R2: Changing Demand	0,057	0,067	0,087	0,070	0,222	0,222	0,504	**0,084**
R3: Vaccine prices and competition	0,057	0,034	0,043	0,031	0,037	0,037	0,202	**0,034**
R4: Regulations and requirements	0,257	0,270	0,391	0,279	0,333	0,333	1,531	**0,255**
R5: Immunization coverage	0,057	0,011	0,043	0,031	0,037	0,037	0,180	**0,030**
R6: Consumer behavior	0,057	0,011	0,043	0,031	0,037	0,037	0,180	**0,030**
Consistency Ratio								**0,061**

Table 12: Economy Normalized Table-Expert 3

4.2.4. Expert 4

The results for expert 4 in Table 13 show that changing demand is seen as the most challenging issue with a priority vector of 0.250, followed by vaccines prices and competition (0.177). Regulations and requirements are seen as the third most challenging risk (0.158), which is followed by achieving immunization coverage (0.113), corruption and counterfeiting (0.106), and consumer behavior being seen as the least challenging risk (0.029).

Expert 4	R1	R2	R3	R4	R5	R6	Sum	Priority vector
R1: Corruption and Counterfeit	0,093	0,069	0,074	0,343	0,057	0,148	0,636	**0,106**
R2: Changing Demand	0,372	0,275	0,223	0,171	0,460	0,259	1,501	**0,250**
R3: Vaccine prices and competition	0,279	0,275	0,223	0,171	0,115	0,259	1,063	**0,177**
R4: Regulations and requirements	0,047	0,275	0,223	0,171	0,230	0,111	0,946	**0,158**
R5: Immunization coverage	0,186	0,069	0,223	0,086	0,115	0,185	0,679	**0,113**
R6: Consumer behavior	0,023	0,039	0,032	0,057	0,023	0,037	0,175	**0,029**
Consistency Ratio								**0,105**

Table 13: Economy Normalized Table-Expert 4

4.2.5. Group Result

Regarding the combined results of the matrices from all four experts, as shown in figure 2, it can be seen that changing demand is the most challenging risk with a priority vector of 0.260), followed by counterfeiting and corruption as the second most challenging risk (0.231) in the Covid-19 vaccine supply chain. The third most challenging risk is achieving immunization coverage (0.175), closely followed by regulations and requirements (0.160). The least challenging risks according to the four experts is vaccine prices and competition (0.097) and consumer behavior with a priority vector of 0.076).

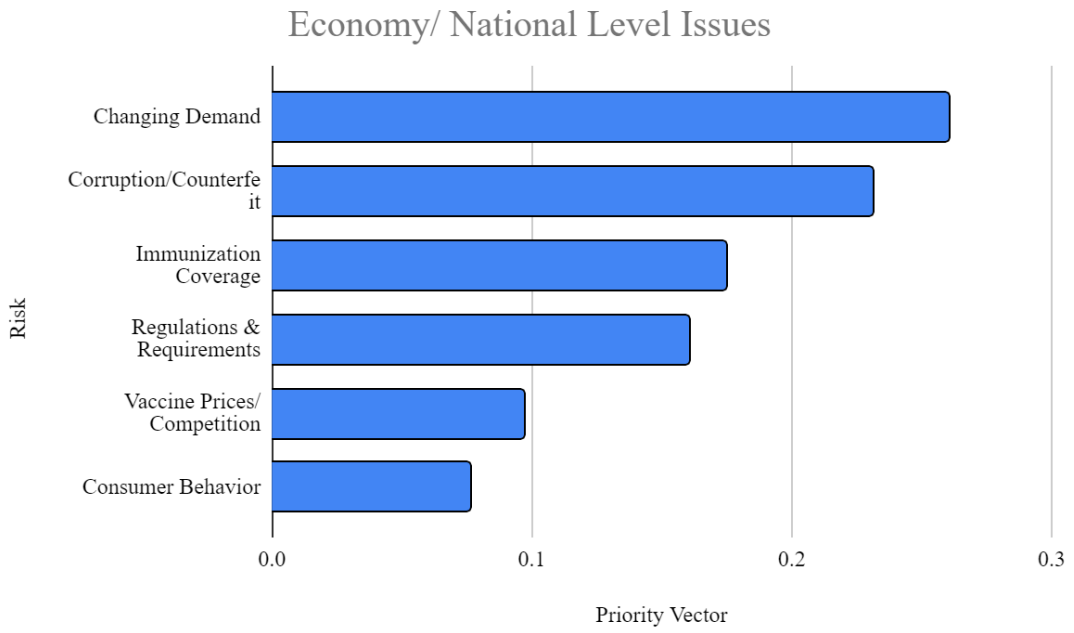

Figure 2: Economy Ranking

4.3. R&D

R&D matrix is investigating the risks related to Lack of preclinical data, Financing, Product quality issues and Short product life cycle. This section contains three individual matrices and one group results.

4.3.1. Expert 1

The results for expert 1 (see Table 14) show that financing is seen as the most challenging risk in research and development with a priority vector of 0.501, followed by product quality issues (0.329). Short product life cycle is the third most challenging risk with a priority vector of 0.085, closely followed by lack of pre-clinical data (0.084).

Expert 1	R1	R2	R3	R4	Sum	Priority vector
R1: Process & lack of pre-clinical data	0,091	0,112	0,057	0,077	0,337	**0,084**
R2: Financing	0,455	0,561	0,683	0,308	2,006	**0,501**
R3: Product quality issues	0,364	0,187	0,228	0,538	1,317	**0,329**
R4: Short product life cycle	0,091	0,140	0,033	0,077	0,341	**0,085**

Consistency Ratio						**0,095**

Table 14: R&D Normalized Table-Expert 1

4.3.2. Expert 2

According to expert 2 the most challenging risks are product quality issues with a priority vector of 0.583. This is followed by lack of pre-clinical data (0.251) and a short product life cycle (0.102). Financing is seen to be the least challenging issue with a priority vector of 0.064 as it can be seen on Table 15.

Expert 2	R1	R2	R3	R4	Sum	Priority vector
R1: Process & lack of pre-clinical data	0,182	0,286	0,157	0,381	1,005	**0,251**
R2: Financing	0,045	0,071	0,090	0,048	0,254	**0,064**
R3: Product quality issues	0,727	0,500	0,628	0,476	2,331	**0,583**
R4: Short product life cycle	0,045	0,143	0,126	0,095	0,409	**0,102**
Consistency Ratio						**0,063**

Table 15: R&D Normalized Table-Expert 2

4.3.3. Expert 3

Table 16 shows that product quality issues are the most concerning (0.588), followed by financing (0.302) and lack of preclinical data (0.058). The least challenging risk according to expert 3 are short product life cycles (0.052).

Expert 3	R1	R2	R3	R4	Sum	Priority vector
R1: Process & lack of pre-clinical data	0,063	0,046	0,071	0,050	0,230	**0,058**
R2: Financing	0,313	0,232	0,214	0,450	1,209	**0,302**
R3: Product quality issues	0,563	0,696	0,643	0,450	2,351	**0,588**
R4: Short product life cycle	0,063	0,026	0,071	0,050	0,210	**0,052**
Consistency Ratio						**0,043**

Table 16: R&D Normalized Table-Expert 3

4.3.4. Expert 4

Did not answer this matrix due to lack of knowledge in research and development.

4.3.5. Group Result

The combined results (figure 3) show that product quality issues are the most challenging risks in the Covid-19 vaccine supply chain (0.551). The second most challenging risks according to the experts is financing (0.243), followed by lack of preclinical data (0.123) and short product life cycles (0.083).

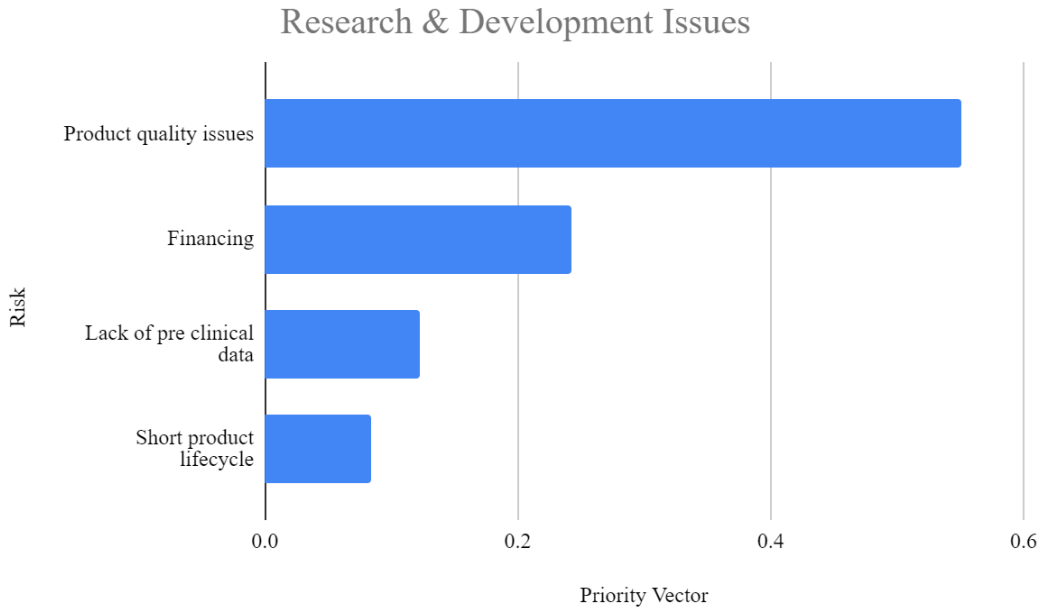

Figure 3: R&D Ranking

4.4. Distribution

The distribution matrix was intended to examine the challenges related to the insufficient cold chain processes, high volume distribution, insufficient infrastructure and the lack of maintenance of equipment.

4.4.1. Expert 1

Expert 1 considered all the risks equally challenging therefore no ranking has been set up.

4.4.2. Expert 2

According to expert 2 the most challenging risks are the ones related to the insufficient cold chain processes equally with the high-volume distribution with priority vectors of 0.329 as seen in Table 17. The third risk is the lack of maintenance of equipment (0.2) and lastly the least challenging is the insufficient infrastructure (0.142). The consistency ratio is below 0.1, thus the judgements are consistent.

Expert 2	R1	R2	R3	R4	Sum	Priority vector
R1: Insufficient cold chain processes	0,333	0,286	0,364	0,333	1,316	**0,329**
R2: Insufficient infrastructure	0,167	0,143	0,091	0,167	0,567	**0,142**
R3: Lack of maintenance of equipment	0,167	0,286	0,182	0,167	0,801	**0,200**
R4: High volume distribution	0,333	0,286	0,364	0,333	1,316	**0,329**
Consistency Ratio						**0,023**

Table 17: Distribution Normalized Table-Expert 2

4.4.3. Expert 3

In the perspective of expert 3 (Table 18), the insufficient cold chain processes are far more challenging than the others with a priority vector of 0.569. It is followed by the insufficient infrastructure (0.248) and high-volume distribution (0.123). Finally, the lack of maintenance of equipment was awarded with a 0.06 priority vector. The consistency ratio is 0.082 which makes the results acceptable.

Expert 3	R1	R2	R3	R4	Sum	Priority vector
R1: Insufficient cold chain processes	0,619	0,723	0,400	0,536	2,277	**0,569**
R2: Insufficient infrastructure	0,155	0,181	0,333	0,321	0,990	**0,248**
R3: Lack of maintenance of equipment	0,103	0,036	0,067	0,036	0,242	**0,060**
R4: High volume distribution	0,124	0,060	0,200	0,107	0,491	**0,123**
Consistency Ratio						**0,082**

Table 18: R&D Normalized Table-Expert 3

4.4.4. Expert 4

As the result shows (Table 19), the most challenging risk according to expert 4 is the high-volume distribution with a large priority vector of 0.65. The second risk is the insufficient cold chain processes with a considerably lower priority vector of 0.154 which is followed closely by the insufficient infrastructure (0.108) related issues. Lastly comes the lack of maintenance of equipment (0.088). The consistency ratio is 0.059 which makes the results consistent.

Expert 4	R1	R2	R3	R4	Sum	Priority vector
R1: Insufficient cold chain processes	0,120	0,111	0,273	0,111	0,615	**0,154**
R2: Insufficient infrastructure	0,120	0,111	0,091	0,111	0,433	**0,108**
R3: Lack of maintenance of equipment	0,040	0,111	0,091	0,111	0,353	**0,088**
R4: High volume distribution	0,720	0,667	0,545	0,667	2,599	**0,650**
Consistency Ratio						**0,059**

Table 19: R&D Normalized Table-Expert 4

4.4.5. Group Result

As the combined matrix (Figure 4) shows, the most challenging risk is related to insufficient cold chain processes (0.331), that is followed closely by the issues concerned with high volume distribution (0.325). The third most challenging issue according to the experts is the insufficient infrastructure (0.201) and lastly the lack of maintenance of equipment with a priority vector of 0.142.

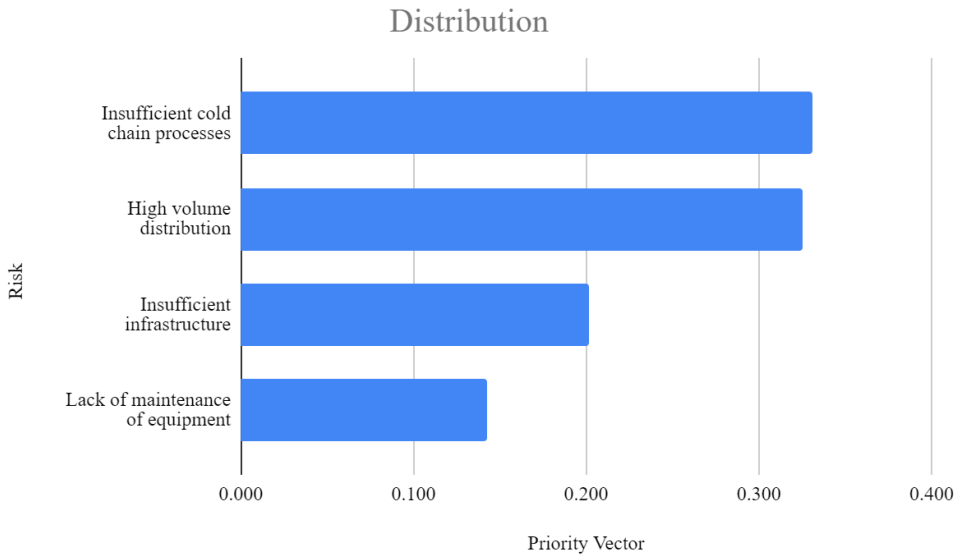

Figure 4: R&D Ranking

4.5. Manufacturing

The matrix of manufacturing was investigating the issues concerned with capacity, production time and barcoding.

4.5.1. Expert 1

As the results show for expert 1 (Table 20), the capacity was rated as the most challenging risk with a priority vector of 0.713. The second risk is the production time with a considerably lower vector of 0.220. The least concerning factor is barcoding (0.067). The consistency ratio is 0.035 which allows the study to accept the results.

Expert 1	R1	R2	R3	Sum	Priority vector
R1: Capacity	0,071	0,082	0,048	0,201	**0,067**
R2: Production Time	0,643	0,735	0,762	2,139	**0,713**
R3: Barcoding	0,286	0,184	0,190	0,660	**0,220**
Consistency Ratio					**0,035**

Table 20: Manufacturing Normalized Table-Expert 1

4.5.2. Expert 2

The most challenging issue from expert 2's point of view is the production time with a large priority vector of 0.564 as it can be seen on Table 21. It is followed by the capacity (0.357) related issues and barcoding with a low priority vector (0.070). The result is considered to be consistent as the CR is below 0.1.

Expert 2	R1	R2	R3	Sum	Priority vector
R1: Capacity	0,077	0,053	0,100	0,230	**0,077**
R2: Production Time	0,462	0,316	0,300	1,077	**0,359**
R3: Barcoding	0,462	0,632	0,600	1,693	**0,564**
Consistency Ratio					**0,051**

Table 21: Manufacturing Normalized Table-Expert 2

4.5.3. Expert 3

The results show that the capacity is the most challenging risk with a large priority vector of 0.764. The second risk in the ranking is the production time with significantly lower vector of 0.166. Finally, the barcoding (0.070) related issues were ranked as the least challenging within these risks as Table 22 shows it.

Expert 3	R1	R2	R3	Sum	Priority vector
R1: Capacity	0,077	0,087	0,045	0,209	**0,070**
R2: Production Time	0,692	0,783	0,818	2,293	**0,764**
R3: Barcoding	0,231	0,130	0,136	0,498	**0,166**
Consistency Ratio					**0,052**

Table 22: Manufacturing Normalized Table-Expert 3

4.5.4. Expert 4

According to expert 4, the most challenging risk is the production time with a 0.584 priority vector. Thereafter comes the capacity (0.354) which is followed by the barcoding (0.062) related issues as it can be seen on Table 23.

Expert 4	R1	R2	R3	Sum	Priority vector
R1: Capacity	0,063	0,045	0,077	0,185	**0,062**
R2: Production Time	0,438	0,318	0,308	1,063	**0,354**
R3: Barcoding	0,500	0,636	0,615	1,752	**0,584**
Consistency Ratio					**0,033**

Table 23: Manufacturing Normalized Table-Expert 4

4.5.5. Group Result

Overall as it can be seen on Figure 5, the capacity (0.565) related issues have been identified as the most challenging followed by the production time with a priority vector of 0.354. Barcoding (0.074) has acquired an extremely low priority vector considering that only three alternatives have been analyzed in this category.

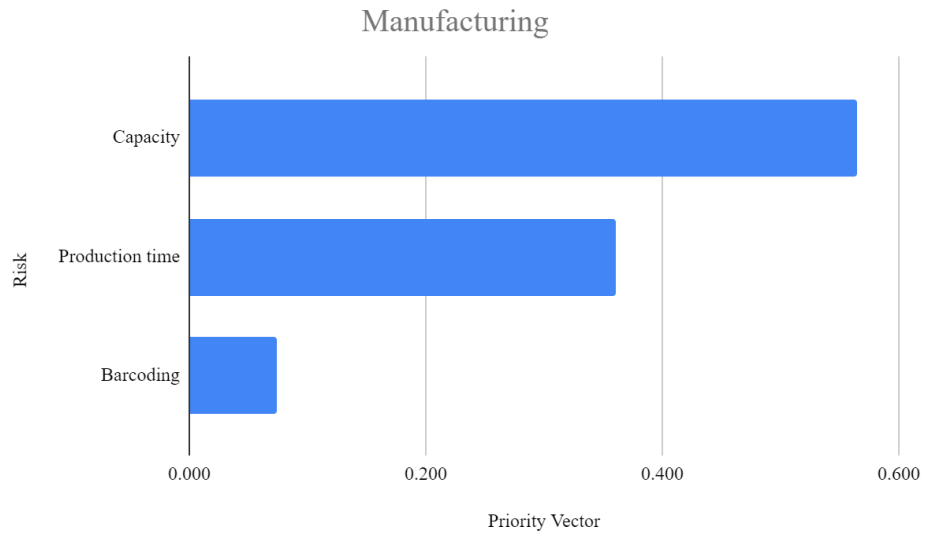

Figure 5: Manufacturing Ranking

4.6. Stock Management

The Stock Management category was analyzing the forecasting and storage related issues. Despite the fact that it compares only two alternatives, the AHP method was used to provide proportional differences between them. The consistency ratio is always 0, as the random consistency index for two alternatives is 0 (Saaty, 1977).

4.6.1. Expert 1

As it can be seen on Table 24, the storage related issues were rated extremely more challenging than the forecasting issues.

Expert 1	R1	R2	Sum	Vector
R1: Storage	0,8	0,8	1,6	**0,8**
R2: Forecasting Issues	0,2	0,2	0,4	**0,2**
Consistency Ratio				**0**

Table 24: Stock Management Normalized Table-Expert 1

4.6.2. Expert 2

Expert 2 found the forecasting issues highly more challenging than the storage related issues, as the Table 25 shows it clearly.

Expert 2	R1	R2	Sum	Vector
R1: Storage	0,2	0,2	0,4	**0,2**
R2: Forecasting Issues	0,8	0,8	1,6	**0,8**
Consistency Ratio				**0**

Table 25: Stock Management Normalized Table-Expert 2

4.6.3. Expert 3

As the results show (Table 26), expert 3 found the issues concerned with storage extremely more challenging than the forecasting issues.

Expert 3	R1	R2	Sum	Vector
R1: Storage	0,9	0,9	1,8	**0,9**
R2: Forecasting Issues	0,1	0,1	0,2	**0,1**
Consistency Ratio				**0**

Table 26: Stock Management Normalized Table-Expert 3

4.6.4. Expert 4

Expert 4 has ranked the forecasting issues as the more challenging and the storage related issues as the less challenging (see Table 27).

Expert 4	R1	R2	Sum	Vector
R1: Storage	0,143	0,143	0,286	**0,143**
R2: Forecasting Issues	0,857	0,857	1,714	**0,857**
Consistency Ratio				**0**

Table 27: Stock Management Normalized Table-Expert 4

4.6.5. Group Result

As it can be seen on Figure 6, the storage (0.524) related issues are the most challenging during the Covid-19 pandemic and the forecasting issues have been rated as less challenging with a priority vector of 0.476.

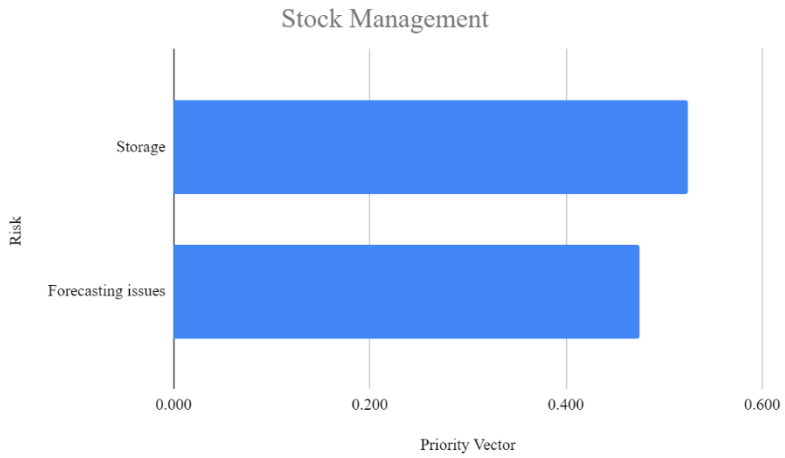

Figure 6: Stock Management Ranking

4.7. All Risks

The "All risks" matrix was used to do a ranking about the investigated categories. Therefore, it includes the General VSC, Economy, Stock Management, Manufacturing, Distribution, R&D as well as IT related issues are considered.

4.7.1. Expert 1

The results for expert 1 show (Table 28) that manufacturing is the most challenging risk in the Covid-19 vaccine supply chain (0.355), followed by economic and national level risks (0.139) and general vaccine supply chain risks (0.136). As the fourth most challenging risk, distributions risks have been chosen (0.116), which are followed by risks in stock management. (0.105). The least challenging risks have been identified as IT risks (0.081) and research and development risks (0.067).

Expert 1	R1	R2	R3	R4	R5	R6	R7	Sum	Priority vector
R1: General VSC	0,115	0,188	0,094	0,254	0,129	0,097	0,077	0,953	**0,136**
R2: R&D	0,038	0,063	0,075	0,085	0,032	0,097	0,077	0,467	**0,067**
R3: Manufacturing	0,462	0,313	0,377	0,423	0,387	0,290	0,231	2,482	**0,355**
R4: Distribution	0,038	0,063	0,075	0,085	0,129	0,194	0,231	0,814	**0,116**
R5: Economy	0,115	0,250	0,126	0,085	0,129	0,194	0,077	0,975	**0,139**
R6: Stock Management	0,115	0,063	0,126	0,042	0,065	0,097	0,231	0,738	**0,105**
R7: IT	0,115	0,063	0,126	0,028	0,129	0,032	0,077	0,570	**0,081**
Consistency Ratio									**0,095**

Table 28: All risks Normalized Table-Expert 1

4.7.2. Expert 2

According to expert 2, manufacturing risks are the most challenging (0.368), which is followed by research and development risks (0.211). The third most challenging risks are within the general vaccine supply chain (0.120), followed by risks in distribution (0.102) and within the economy and national level (0.092). As the least challenging risks, stock management risks (0.068) and IT risks (0.036) have been the result as it can be seen on Table 29.

Expert 2	R1	R2	R3	R4	R5	R6	R7	Sum	Priority vector

R1: General VSC	0,094	0,073	0,081	0,164	0,194	0,116	0,120	0,841	**0,120**
R2: R&D	0,281	0,218	0,203	0,247	0,194	0,174	0,160	1,476	**0,211**
R3: Manufacturing	0,469	0,436	0,405	0,411	0,323	0,290	0,240	2,574	**0,368**
R4: Distribution	0,047	0,073	0,081	0,082	0,194	0,116	0,120	0,712	**0,102**
R5: Economy	0,031	0,073	0,081	0,027	0,065	0,232	0,160	0,669	**0,096**
R6: Stock Management	0,047	0,073	0,081	0,041	0,016	0,058	0,160	0,476	**0,068**
R7: IT	0,031	0,055	0,068	0,027	0,016	0,014	0,040	0,251	**0,036**
Consistency Ratio									**0,104**

Table 29: All risks Normalized Table-Expert 2

4.7.3. Expert 3

From expert 3´s perspective (see Table 30), manufacturing risks are the most challenging (0.525), which is followed by risks within distribution (0.148), IT risks (0.140) and stock management (0.086). The least challenging risks were identified within the general vaccine supply chain (0.074) and economic and national level risks (0.027).

Expert 3	R1	R2	R3	R4	R5	R6	R7	Sum	Priority vector
R1: General VSC	0,070	x	0,116	0,034	0,161	0,034	0,031	0,446	**0,074**
R2: R&D	x	x	x	x	x	x	x	x	x
R3: Manufacturing	0,352	x	0,581	0,712	0,290	0,476	0,736	3,147	**0,525**
R4: Distribution	0,211	x	0,083	0,102	0,194	0,204	0,092	0,886	**0,148**
R5: Economy	0,014	x	0,065	0,017	0,032	0,014	0,018	0,160	**0,027**
R6: Stock Management	0,141	x	0,083	0,034	0,161	0,068	0,031	0,518	**0,086**
R7: IT	0,211	x	0,073	0,102	0,161	0,204	0,092	0,843	**0,140**
Consistency Ratio									**0,103**

Table 30: All risks Normalized Table-Expert 3

4.7.4. Expert 4

The results for expert 4 show that risks within research and development are the most challenging (0.325), followed by economic and national level risks (0.166) and manufacturing

risks (0.121). The fourth most challenging risk was identified as risks in the general vaccine supply chain (0.092) which has been followed by distribution risks (0.081). Stock management (0.071) and IT risks (0.020) were identified as the least challenging risks by expert 4 (Table 31).

Expert 4	R1	R2	R3	R4	R5	R6	R7	Sum	Priority vector
R1: General VSC	0,098	0,100	0,088	0,071	0,132	0,050	0,104	0,643	**0,092**
R2: R&D	0,490	0,501	0,616	0,424	0,529	0,398	0,188	3,146	**0,449**
R3: Manufacturing	0,098	0,072	0,088	0,071	0,132	0,199	0,188	0,847	**0,121**
R4: Distribution	0,098	0,084	0,088	0,071	0,033	0,050	0,146	0,569	**0,081**
R5: Economy	0,098	0,125	0,088	0,283	0,132	0,248	0,188	1,162	**0,166**
R6: Stock Management	0,098	0,063	0,022	0,071	0,026	0,050	0,167	0,496	**0,071**
R7: IT	0,020	0,056	0,010	0,010	0,015	0,006	0,021	0,137	**0,020**
Consistency Ratio									**0,096**

Table 31: All risks Normalized Table-Expert 4

4.7.5. Group Result

Regarding the combined results as seen in Figure 7, manufacturing was identified as the most challenging risk within the Covid-19 vaccine supply chain (0.325), followed by risks within research and development (0.213). The third most challenging risk has been identified as general vaccine supply chain risks (0.115), closely followed by distribution risks (0.114). Economic and national risks (0.098) have been seen as the fifth most challenging risk which is followed by risks in stock management (0.082) and IT (0.054).

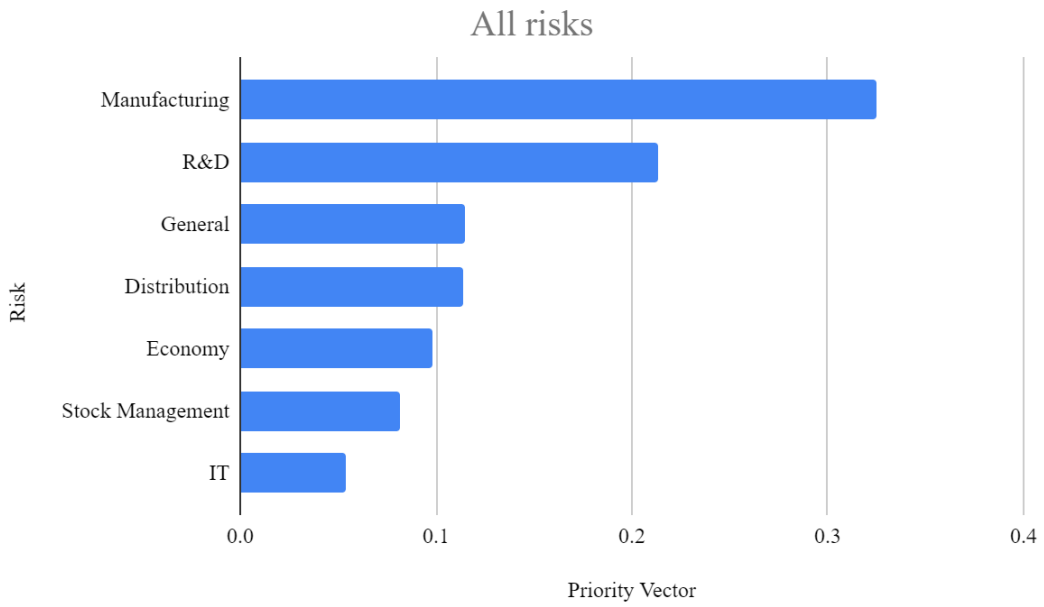

Figure 7: All risks Ranking

5. Ranking of the risks and discussion

From the results in Chapter 4 the rank list of risks has been created and will be discussed in this chapter.

1. Manufacturing	1.Capacity
	2. Production Time
	3. Barcoding
2. R&D	1. Product Quality Issues
	2. Financing
	3. Lack of Pre-Clinical data
	4. Short Product Lifecycle
3. General Vaccine Supply Chain	1. Outsourcing Issues
	2. Lack of trust/collaboration
	3. Complexity
	4. Incompetent and unexperienced staff
	5. Prioritizing products
	6. Environmental concerns
4. Distribution	1. Insufficient cold chain processes
	2. High Volume distribution
	3. Insufficient infrastructure
	4. Lack of maintenance of equipment
5. Economy	1. Changing Demand
	2. Counterfeiting/Corruption
	3. Immunization coverage
	4. Regulations
	5. Vaccine prices/Competition
	6. Consumer behavior
6. Stock Management	1. Storage
	2. Forecasting issues
7. Information Technology	

5.1. Manufacturing

As List 1 shows, the most challenging category during the Covid-19 pandemic according to the four experts is the risks related to manufacturing. It is discussed that the capacity is the largest risk on which expert 3 commented that the companies are currently looking for production sites to further extend the capacity to provide sufficient supply for reaching the goal of the immunization coverage as it was also confirmed by King (2021). Furthermore, BioPlan Associates (2020) elaborated on the importance of the efficient control of capacity to mitigate the challenges faced by it. It is followed by the production time and the barcoding related issues. expert 3 further elaborated on the barcoding as it is not considered as a major issue which is also proved by the results in List 1. Furthermore, expert 2 added that the availability of the components can be further considered as a major concern which was also stated by BioPlan Associates (2020).

5.2. R&D

According to the results of the four experts, risks related to R&D are the second most challenging risks within the Covid-19 vaccine supply chain.

Regarding the product quality issues, expert 1 states that quality is of major importance, for successful vaccine development, expert 3 further adds, that vaccines which are more efficient or have easier storage characteristics, could be chosen over other vaccines and therefore shorten their life-cycle on the market. Moscicki (2021) further discussed that the Covid-19 vaccines have to go through the same clinical development as all the other medicines and the priority is the secureness of people's lives therefore, product quality and the issues with it have an important role to play.

When it comes to the risk of lacking pre-clinical data, expert 1 states that pre-clinical data is quite strong at basic research level, and that trials for this are necessary to understand the effect of the vaccine which was also discussed by Forman et al. (2021). However even though pre-clinical data exists, the vaccine might turn out to be ineffective or have too many side effects to be available to the public. Expert 2 adds to that, that clinical data is an important part of R&D before getting a vaccine on the market which was also confirmed by Forman et al. (2021) and further used for marketing purposes. However, expert 3 states that the lack of pre-clinical data would not mean that there will not be any product to develop and therefore does not see it

as a risk of the vaccine supply chain. They further elaborate that from their point of view, R&D is not considered a part of the vaccine supply chain, however praises R&D during the current pandemic as a masterpiece, since never in the history of vaccine development, R&D has been done in such a fast manner.

The third most challenging risk according to the four experts is financing, which as expert 1 states, is the biggest challenge in R&D, however expert 3 contradicts this statement by stating that during this pandemic, countries have and are very willing to supply finances, as it is such an important matter. This statement was further confirmed by Bisson (2020).

5.3. General Vaccine Supply Chain

The third most challenging category is the General Vaccine Supply Chain and the risks associated with it. The highest rated risk is the outsourcing issues which according to expert 3 can further contribute to the level of complexity throughout the chain. It was further added by NC State University (2021) that outsourcing could lead to for instance issues related to security, shortages in the supply chain and miscommunication that can contribute to the complexity. Furthermore, according to expert 3 and NC State University (2021) outsourcing can have a negative effect on the collaboration and trust within the supply chain. Regarding the lack of trust and collaboration, on which expert 1 commented that because of the extent number of stakeholders it is difficult to have control over the chain. However, expert 3 explained that during the current pandemic, the collaboration can be considered efficient, but to build trust between the actors takes considerably more time. The lack of collaboration is followed by the complexity which can be interrelated with outsourcing according to expert 3.

About the incompetent and unexperienced staff, it was mentioned by expert 1 that this issue can be easily solved by providing training to the employees, therefore it is judged to be a controllable challenge. CDC (2021) further elaborated on the importance of education of employees to ensure the process is done correctly with any type of Covid-19 vaccine. In contrast, expert 3 has no experience with incompetent and unexperienced staff, because of the high standards and supervision in the field. The least challenging issues are related to the prioritization of the products and the environmental concerns. Expert 3 stated that the Covid-19 vaccine is prioritized constantly, and a lot of manufacturers adapted their operations to the Covid-19 vaccines, thus it is not a challenge. Furthermore, both expert 1 and expert 3 elaborated on the unimportance of the environmental concerns during the pandemics because of the need

for fast and efficient deliveries. Breen and Schiffling (2021), and Sveriges Radio (2021) was discussing the waste generated by wrong temperature conditions during transportation as well as can depend on the size of the vials which can further put a strain on the environmental concerns.

5.4. Distribution

The results of the four experts show that distribution risks are the fourth most challenging in the Covid-19 vaccine supply chain. Here, expert 1 states that all risks are the same amount of challenging, since regulations actively control all individual risks within this topic. However, these regulations are in place, since all the risks included in distribution are considered to be high risks.

Expert 2 states that the cold chain is highly connected to the infrastructure, which is supported by expert 3, who states that the cold chain is integrated in the infrastructure, and that it is therefore important to know if the infrastructure is developed well enough to handle the cold chain of the Covid-19 supply chain. They further add that the cases of Moderna and Pfizer have shown that the cold chain is a major issue when it comes to their vaccines.Expert 2 further adds to that, that infrastructure and maintenance of equipment are not a major issue in Sweden, since they are well developed and regulated.

There have been news reports, where Covid-19 vaccines have been transported at the wrong temperature and were given to patients (Reuters, 2021), or had to be discarded on multiple occasions (Andersson, 2021; Chen, 2021; Filby, 2021).

5.5. Economy & National

Through the results it could be identified that economic and national level risks are the firth most challenging in the Covid-19 vaccine supply chain.

Expert 2 states that changing demand and the insufficient availability of Covid-19 vaccines are a major issue in Sweden, on the other hand, expert 3 states changing demand is not an issue at the moment since the vaccines are highly demanded. However, if the vaccine will turn out to be giving annually, this could result in issues for the vaccine supply chain. Expert 1 further comments on this, that currently there are very few cases in which a person can choose what type of vaccine they would like to get. According to Ellyatt (2021) however, the news of blot

clots related issues with the AstraZeneca vaccine, resulted in lower demand for the vaccine. Further it is shown by Sohl Stjernberg (2021), and The Local (2021b), that people turn away from vaccination facilities as soon as it is found out that the AstraZeneca vaccine will be given to them, resulting in the need to discard the vaccines.

Even though expert 2 states that corruption is not a major issue in Sweden, it was ranked in second place by the four experts. Forman et al. (2021) elaborated on the fact that many transport providers introduced enhanced security check in means of drivers and employees to mitigate the number of counterfeited products. UNODC (n.d.) further adds, that regulations and controls are in place at major risk points for corruption, in order to prevent it from taking place.

Immunization coverage is the third most challenging risk according expert 2, this is due to the lack of vaccines available in Sweden. This is supported by The Local (2021a), as Sweden had to change vaccination goals on multiple occasions, as delivery goals of the vaccine have not been met. Expert 3 contradicts this by stating that it is not an issue for the supply chain, but rather the biggest challenge for healthcare providers. It will, however, contribute to demand in the future.

When it comes to regulation being a risk to the vaccine supply chain, expert one states that they rather help than being a risk, however from the view of expert 3 comments that they could be an issue, but not for the supply chain, as in the case of AstraZeneca, where new side effects were discovered, the leaflets had to be changed, which does not concern the supply chain.

Regarding vaccine prices, expert 3 states that there are major price differences between the different Covid-19 vaccines, however this is not an issue since the demand is high. Furthermore, since the situation regarding the Covid-vaccines is different from other vaccine developments, competition does not have a big role. Cohen (2021) states that while vaccine prices are being kept low during the pandemic, due to agreements under unusual circumstances, not considering market forces, various manufacturers have already announced to increase prices once the pandemic is over and vaccinations are given as an annual booster shot.

The least challenging issue according to the four experts is changing consumer behavior, where expert 1 states that consumers rarely have the choice on which vaccine to choose, therefore it is not seen as a big risk. Expert 3 supports this by adding that even if there is changing consumer behavior, it would not result in issues, as the demand for them would still be high. However, the case of AstraZeneca (The Local, 2021b), as previously mentioned, has shown that the

change in preference of vaccines has resulted in lower demand for the AstraZeneca vaccine. This however seems to depend on the country, as Canada's demand of the AstraZeneca vaccine has grown, especially from people who are included in the recommended age group for this type of vaccine (CBC, 2021).

5.6. Stock Management

Regarding the Stock management category, the storage related issues were ranked as the more challenging risks which was confirmed by Mainwaring-Burton (2020) that the different temperatures of the vaccine types are putting further strains on storage than the forecasting issues. The answers were made by the experts from a different perspective, whereas expert 2 saw forecasting as an issue because of the different demand in each of the regions Sweden, while expert 3 said that the forecasting is not an issue as the demand is continuous at the moment.

5.7. Information Technology

The last category in the ranking is the IT related issues, which is not considered to be a major issue in Sweden which was also confirmed by expert 2. This could be supported by the fact that at this point no information can be found on IT issues regarding the Covid-19 vaccine, besides administration issues, where people not belonging to the risks group were able to receive the vaccine, caused by link sharing (SVT, 2021).

6. Conclusion

This research aimed to identify the risks in the vaccine supply chain and identify how they are prioritized within the Covid-19 vaccine supply chain. Through utilization of two different methods these aims have been met by the researchers.

Based on a thorough systematic literature review, a list of risks that could affect the Covid-19 supply chain was created to answer research question 1. The list consists of the risks involved within each stage of the vaccine supply chain from R&D, manufacturing through distribution until the point of administration of the Covid-19 vaccine through a healthcare professional. The extent list of risk identified from the literature review indicates the complexity of the vaccine supply chains. However, for the purpose of the research this list needed to be converted into a shorter summarized list. This highly complex area concerned with the healthcare and vaccine supply chain generates challenges and difficulties that must be addressed as people's lives depend on the availability of vaccines. Therefore, vaccine supply chain personnel must be aware of the most challenging risks and in order to actively use their resources and knowledge to mitigate or eliminate them from their processes. Therefore, through the analytical hierarchy process the categorized and selected risks were ranked according to the interviews with experts in the field. This resulted in a ranking of the risks along the Covid-19 vaccine supply chain according to their priority as well as in a deeper understanding of how these risks are perceived from the perspective of professionals that have shared their experience and knowledge of them. The outcome showed that risks within manufacturing are the most challenging, followed by the R&D, general vaccine supply chain, distribution, economy, stock management and information technology.

Thus, this provides a deeper insight into risks that are usually experienced under normal conditions and shows how they are prioritized during extreme conditions, which are set by the global Covid-19 pandemic. Furthermore, the discussion revealed how the different experts perceive the risks from their experience in the field and gave further insight into reasoning behind their choices, therefore resulting in a ground for discussion regarding the topic.

The result of this research aimed to understand what causes issues along the vaccine supply chain, the ranked risks could be used to mitigate the risks in future pandemic through targeted risk management. It has been stated by Yadav (2015), and Jaberdioost et al. (2013), that the identification of risks is a crucial part in the process of supply chain risk management, however

this gap has not been addressed yet in the healthcare and vaccine supply chain. Furthermore, as the Covid-19 pandemic is a newly emerged topic, risks within the supply chain during Covid-19 have been partly researched, the vaccine supply chain however has not been studied at the time of this thesis being written. However due to its large impact on the success of global immunization against the virus, it is crucial that this topic receives attention. The risks identified in this research and their ranking therefore contribute to the research on this topic, as they can contribute by being a starting point for vaccine supply chain risk management, from which strategies could be generated in order to address them. Knowing the risks and their possible impact on the supply chain as well as how they are prioritized by experts within the industry can be seen as a basis to continue with further research on this topic. In conclusion this research could eventually decrease uncertainties and vulnerable processes and areas in the Covid-19 vaccine supply chain and therefore contribute to an efficient and cost-effective vaccine supply chain. The benefits cannot only be taken advantage of by companies and professionals in the industry as also confirmed through a meeting with a researcher at Chalmers University, but as a consequence further contribute to a smoother process that could as a result partly benefit human health around the world.

6.1. Limitation and Future Recommendations

Through the systematic literature review, the risks were expected to be ranked in a different way, however the AHP process gave an in-depth view on how professionals perceive and experience those risks in their daily work. Since the experts cannot be identified from their answers, and therefore not knowing which area they are experienced with, future replications of this research can produce different outcomes. Through this process we were able to combine the perceptions of the different experts into one final result. These results can give an insight into the situation regarding the Covid-19 vaccine supply chain in Sweden, however, due to the fact, that a small number of experts shared their knowledge and perception of the risks, it is seen as uncertain if the outcome of this study can be generalized on the current situation in Sweden and further on other countries. Limitations of the research could entail that one search engine was used in the process of the systematic literature review with PRISMA; thus, the researchers might have missed relevant articles that could have resulted in a different outcome or a more thorough literature review. In order to achieve research objective 1, articles concerning any part of the world have been used, which could influence the outcome of the list of risks. Furthermore, the literature review consists of scientific articles from 2013 until

February 2021, therefore information that was published previously or after that time frame were not considered as a base of the research. However, newspaper articles and up-to-date numbers up until the 8th of March, were added, which complemented the systematic literature review if it was perceived as necessary by the researchers. Therefore, the research questions might have already been answered by other studies on this topic, which were written while this thesis has been written. Another limitation that could influence the outcome could be connected to the researchers´ bias while selecting the risks to include in the survey. This step was seen as necessary in order to prevent the interviews from being too long and was based on personal judgements generated from the literature review.

However, this thesis gives an insight into the current situation and provides future research possibilities to result in a more generalizable outcome. It is suggested by the researchers to conduct the research with a larger number of professionals from various areas of the Covid-19 vaccine supply chain. Furthermore, it is suggested, that the literature is continuously updated, and its outcome is adapted to up-to-date events, in order to identify risks that have been recognized after this thesis was written. As this paper was written in the early stages of the Covid-19 vaccine supply chain, further risks and challenges could be identified and researched throughout the different processes. Since the topic of risks within the Covid-19 vaccine supply chain has not been thoroughly researched at this point, it gives other researchers the opportunity to further develop a deep understanding of the risks and challenges within it. As viruses of the Covid strain have been identified and researched on in the past, it could be expected that further variants of the strain could emerge in the future. In the case that this would happen, this research could further be developed and adapted onto challenges and issues during the processes of the vaccine supply chain for new variants. However, this process is not limited to the research on covid strains and could further be used as a guide and source for awareness of different risks and challenges that could be experienced throughout the supply chain for vaccines of other viruses and possibly different medications.

References

Adams, W. (2015). Conducting Semi-Structured Interviews. Handbook Of Practical Program Evaluation, 492-505. doi: 10.1002/9781119171386.ch19

Aiello, R. (2021). Canada to keep feeling impacts of COVID-19 vaccine delivery issues: Fortin. Retrieved on 4th of March, 2021, from: https://www.ctvnews.ca/health/coronavirus/canada-to-keep-feeling-impacts-of-covid-19-vaccine-delivery-issues-fortin-1.5295698

Allen, M., & Mirsaeidi, M. (2020). Health and Economy in COVID-19 Era: A Plan for Reconstituting Long-Term Economic Security. Frontiers in Public Health, 8, 235.

Anderson, R., Perrier, T., Pervaiz, F., Sisouveth, N., Kumar, B., Phongphila, S., Rahman, A., Dhiman, R., Newland, S. (2014). Supporting immunization programs with improved vaccine cold chain information systems. IEEE Global Humanitarian Technology Conference (GHTC 2014), 215-222.

Andersson, J. (2021). Regioner stoppar Modernas vaccin – har transporterats för kallt (Regions stop Moderna vaccine - have been transported too cold). Retrieved on 5th of May, 2021, from: https://lakartidningen.se/aktuellt/nyheter/2021/01/regioner-stoppar-modernas-vaccin-har-transporterats-for-kallt/

Arthur, R. (2021). Inside the Pfizer/BioNTech Covid-19 vaccine trial: ´We knew the world was watching and waiting for results´. Retrieved on 4th of March, 2021, from: https://www.biopharma-reporter.com/Article/2021/03/03/Inside-the-Pfizer-BioNTech-COVID-19-vaccine-trial-Insights-on-speed-agility-and-digital-development

Ayati, N., Saiyarsarai, P. & Nikfar, S. (2020). Short and long term impacts of COVID-19 on the pharmaceutical sector. DARU J Pharm Sci 28, 799–805 https://doi.org/10.1007/s40199-020-00358-5

BBC News. (2021). Coronavirus: Vaccine supply fears grow amid EU export threat. Retrieved on 4th of March, 2021, from: https://www.bbc.com/news/world-europe-55805903

BBC. (2018). Sweden country profile. Retrieved 22nd of April, 2021, from: https://www.bbc.com/news/world-europe-17955808#:~:text=Sweden's%20position%20as%20one%20of,70%20years%20up%20to%202006.

Behnam, M., Chelala, M., Gambell, T. & Galliart, M.T. (2020). Medtech´s Call to Action: Meeting the Demand Surge Caused by COVID-19. Retrieved on 4th of January, 2021, from: https://www.mckinsey.com/industries/pharmaceuticals-and-medical-products/our-insights/medtechs-call-to-action-meeting-the-demand-surge-caused-by-covid-19

BioPlan Associates. (2020). 17th Annual Report Biopharmaceutical Manufacturing Capacity and Production. Retrieved 30th of April, 2021, from: https://www.pharmtech.com/view/supply-chain-challenges-creating-hurdles-to-covid-19-vaccine-production

Bisson, R. (2020). Covid-19 R&D: the global funding picture. Retrieved 2nd of May, 2021, from: https://www.researchprofessionalnews.com/rr-funding-insight-2020-6-covid-19-r-d-the-global-funding-picture/

Breen, L. and Schiffling, S. (2021). COVID vaccine: some waste is normal – but here's how it is being kept to a minimum. Retrieved 2nd of May, 2021, from: https://theconversation.com/covid-vaccine-some-waste-is-normal-but-heres-how-it-is-being-kept-to-a-minimum-152772

CBC. (2021). Demand 'through the roof' for AstraZeneca COVID-19 vaccine after age limit drops, pharmacist says. Retrieved 2nd of May, 2021, from: https://www.cbc.ca/news/canada/toronto/astrazeneca-oxford-covid-19-vaccine-demand-high-40-somethings-pharmacist-1.5997098

CDC. (2021). Training and Education. Retrieved 3rd of May, 2021 from: https://www.cdc.gov/vaccines/covid-19/training-education/index.html

Chakravarthy, C., Priya, B., & Premalatha, K. (2019). A Problems Faced by Freight Forwarders of Cold Chain Supply Logistics on Safety of Vaccines with Special Reference To Yashimarine Logistics. International Journal Of Recent Technology And Engineering, 8(2S8), 308-310. doi: 10.35940/ijrte.b1376.0882s819

Changalucha, J., Steenson, R., Grieve, E., Cleaveland, S., Lembo, T., Lushasi, K., Mchau, G., Mtema, Z., Sambo, M., Nanai, A., Govella, N., Dilip, A., Sikana, L., Ventura, F. & Hampson, K. (2019). The need to improve access to rabies post-exposure vaccines: Lessons from Tanzania. Vaccine, 37(S1), A45-A53.

Chen, S. (2021). Report: CVS and Walgreens have wasted over 128,000 COVID doses. Retrieved on 5th of May, 2021, from: https://www.axios.com/covid-vaccine-cvs-walgreens-waste-f045a004-7b0e-46eb-843b-0cdceba0323a.html

Chen, S., Norman, B., Rajgopal, J., Assi, T., Lee, B., & Brown, S. (2014). A planning model for the WHO-EPI vaccine distribution network in developing countries. IIE Transactions, 46(8), 853-865.

Chick, S., Hasija, S., & Nasiry, J. (2017). Information Elicitation and Influenza Vaccine Production. Operations Research, 65(1), 75–96. https://doi.org/10.1287/opre.2016.1552

Cohen, J. (2021). Profiting From Success: The Future Of Covid-19 Vaccine Pricing. Retrieved on 3rd of May, 2021, from: https://www.forbes.com/sites/joshuacohen/2021/04/02/profiting-from-success-the-future-of-covid-19-vaccine-pricing/?sh=52e6494e1bf5

Collis, J. and Hussey, R. (2014). Business research: A practical guide for undergraduate and postgraduate students. New York: PALGRAVE

Crommelin, D., Anchordoquy, T. J., Volkin, D. B., Jiskoot, W., & Mastrobattista, E. (2021). Addressing the Cold Reality of mRNA Vaccine Stability. Journal of pharmaceutical sciences, 110(3), 997–1001. https://doi.org/10.1016/j.xphs.2020.12.006

Dai, T., Cho, Soo - Haeng, & Zhang, Fuqiang. (2016). Manufacturing & Service Operations Management, Manufacturing & service operations management.

Dellepiane, N., & Wood, D. (2015). Twenty-five years of the WHO vaccines prequalification programme (1987–2012): Lessons learned and future perspectives. Vaccine, 33(1), 52-61.

Derwand, R. (2014). Annual World Vaccine Congress 2014: A re-evaluation of the value proposition for increasing vaccine thermostability. Human Vaccines & Immunotherapeutics, 10(10), 3087-3089.

Dessouky, M., Ordóñez, F., Shen, Z., & Jia, H. (2017). Regional Transportation and Supply Chain Modeling for Large-Scale Emergencies.

Dixit, A., Routroy, S., & Dubey, S. (2019). A systematic literature review of healthcare supply chain and implications of future research. International Journal of Pharmaceutical and Healthcare Marketing, 13(4), 405-435.

Ellyatt, H. (2021). Public demand for AstraZeneca vaccine falls in Britain after blood clot scares. Retrieved on May 4th, 2021, from: https://www.cnbc.com/2021/04/27/public-demand-for-astrazeneca-vaccine-falls-after-blood-clot-scares.html

Fernando, E., Meyliana, M., Hendric Spits Warnars, H., & Abdurachman, E. (2020). Key strategic issues pharmaceutical industry of SCM: A systematic literature review. Bulletin Of Electrical Engineering And Informatics, 9(2), 808-817.

Filby, M. (2021). More than 10,000 COVID vaccines thrown out or damaged in Ohio since rollout started. Retrieved on 5th of May, 2021, from: https://eu.dispatch.com/story/news/2021/05/04/ohio-department-health-more-than-10-000-covid-vaccines-thrown-out-or-damaged/4931821001/

Forman, R., Shah, S., Jeurissen, P., Jit, M., & Mossialos, E. (2021). COVID-19 vaccine challenges: What have we learned so far and what remains to be done?. Health policy (Amsterdam, Netherlands), 125(5), 553–567. Advance online publication. https://doi.org/10.1016/j.healthpol.2021.03.013

Godin, M. (2020). Sweden´s Relaxed Approach to the Coronavirus Could Already Be Backfiring. Retrieved on 4th of January 2021, from: https://time.com/5817412/sweden-coronavirus/

Guignard, A., Praet, N., Jusot, V., Bakker, M., & Baril, L. (2019). Introducing new vaccines in low- and middle-income countries: Challenges and approaches. Expert Review of Vaccines, 18(2), 119-131.

Guillermet, E., Dicko, H., Mai, L., N'Diaye, M., Hane, F., Ba, S.O., Gomis, K., Tho, N.T.T., Lien, N.T.P., Than, P.D., Tran Van Dinh, T.V., Jaillard, P., Gessner, B.D., Colombini, A. (2015). Acceptability and Feasibility of Delivering Pentavalent Vaccines in a Compact, Prefilled, Autodisable Device in Vietnam and Senegal. PLoS ONE, 10(7), E0132292.

Gurvich, V., & Hussain, A. (2020). In and Beyond COVID-19: US Academic Pharmaceutical Science and Engineering Community Must Engage to Meet Critical National Needs. AAPS PharmSciTech, 21(5), 153.

Habayeb, S. (2020). Epidemics and Pandemics: Coronavirus Disease in the United States, Lessons Learned and Way Forward. World Medical & Health Policy, 12(3), 218-222.

Haghani, M., Bliemer, M., Goerlandt, F., & Li, J. (2020). The scientific literature on Coronaviruses, COVID-19 and its associated safety-related research dimensions: A scientometric analysis and scoping review. Safety Science, 129, 104806.

Hanson, C., George, A., Sawadogo, A., & Schreiber, B. (2017). Is freezing in the vaccine cold chain an ongoing issue? A literature review. Vaccine, 35(17), 2127-2133.

Hewings-Martin, Y. (2020). How do SARS and MERS compare with COVID-19? Retrieved on March 4th, 2021, from: https://www.medicalnewstoday.com/articles/how-do-sars-and-mers-compare-with-covid-19

Honda-Okubo, Y., Rajapaksha, H., Sajkov, D., Gordon, D., Cox, M., & Petrovsky, N. (2017). Panblok-H1 advax H1N1/2009pdm vaccine: Insights into rapid development of a delta inulin adjuvanted recombinant pandemic influenza vaccine. Human Vaccines & Immunotherapeutics, 13(6), 1261-1271.

Hovav, S., & Herbon, A. (2017). Prioritizing high-risk sub-groups in a multi-manufacturer vaccine distribution program. The International Journal of Logistics Management, 28(2), 311-331.

Hummel, J.M., Bridges, J.F.P. & IJzerman, M.J. (2014). Group Decision Making with the Analytic Hierarchy Process in Benefit-Risk Assessment: A Tutorial. Patient 7, 129–140. https://doi.org/10.1007/s40271-014-0050-7

Islam, M., Chowdhury, F., Qadri, F., Sur, D., & Ganguly, N. (2020). Trials of the killed oral cholera vaccine (Shanchol) in India and Bangladesh: Lessons learned and way forward. Vaccine, 38(S1), A127-A131.

Iwu, C., Jaca, A., Abdullahi, L., Ngcobo, N., & Wiysonge, C. (2019b). A scoping review of interventions for vaccine stock management in primary health-care facilities. Human Vaccines & Immunotherapeutics, 15(11), 2666-2672.

Iwu, C., Jaca, A., Abdullahi, L., Ngcobo, N., & Wiysonge, C. (2019a). Protocol for a systematic review of the effects of interventions for vaccine stock management. Systematic Reviews, 8(1), 14.

Iyengar, S., Hedman, L., Forte, G., & Hill, S. (2016). Medicine shortages: A commentary on causes and mitigation strategies. BMC Medicine, 14(1), 124.

Jaberidoost, M., Nikfar, S., Abdollahiasl, A., & Dinarvand, R. (2013). Pharmaceutical supply chain risks: A systematic review. Daru : Journal of Faculty of Pharmacy, Tehran University of Medical Sciences, 21(1), 69

Jarrett, S., Wilmansyah, T., Bramanti, Y., Alitamsar, H., Alamsyah, D., Krishnamurthy, K., Lingjiang, Y. & Pagliusi, S. (2020). The role of manufacturers in the implementation of global traceability standards in the supply chain to combat vaccine counterfeiting and enhance safety monitoring. Vaccine, 38(52), 8318-8325.

Jarrett, S., Yang, L., & Pagliusi, S. (2020). Roadmap for strengthening the vaccine supply chain in emerging countries: Manufacturers' perspectives. Vaccine: X, 5, 100068.

Juranek, S. & Zoutman, F. (2020). The Effect of Non-Pharmaceutical Interventions on the Demand for Health Care and Mortality: Evidence on COVID-19 in Scandinavia. Retrieved on 4th of January, 2021 from: http://dx.doi.org/10.2139/ssrn.3577213

Kartoglu, U., & Milstien, J. (2014). Tools and approaches to ensure quality of vaccines throughout the cold chain. Expert Review of Vaccines, 13(7), 843-854.

Kennedy, R. (2020). Covid vaccine: Pfizer delays deliveries due to temperature control issues. Retrieved on 4th of March, 2021, from: https://www.euronews.com/2020/12/28/pfizer-delays-covid-19-vaccine-deliveries-due-to-temperature-control-issues

King, A. (2021). Why manufacturing Covid vaccines at scale is hard. Retrieved 30th of April, 2021, from: https://www.chemistryworld.com/news/why-manufacturing-covid-vaccines-at-scale-is-hard/4013429.article

Lam, E., Mccarthy, A., & Brennan, M. (2015). Vaccine-preventable diseases in humanitarian emergencies among refugee and internally-displaced populations. Human Vaccines & Immunotherapeutics, 11(11), 2627-2636.

Lee, B., & Haidari, L. (2017). The importance of vaccine supply chains to everyone in the vaccine world. Vaccine, 35(35), 4475-4479.

Lemmens, S., Decouttere, C., Vandaele, N., & Bernuzzi, M. (2016). A review of integrated supply chain network design models: Key issues for vaccine supply chains. Chemical Engineering Research & Design, 109, 366-384.

Lloyd, J., Mccarney, S., Ouhichi, R., Lydon, P., & Zaffran, M. (2015). Optimizing energy for a ‘green’ vaccine supply chain. Vaccine, 33(7), 908-913.

Mahase, E. (2020). Covid-19: Logistical problems frustrate GPs ready to deliver vaccine in England. Retrieved on 4th of March, 2021, from: https://www.bmj.com/content/371/bmj.m4849

Mainwaring-Burton, R. (2020). The challenges of keeping a Covid-19 vaccine cold. Retrieved 2nd of May, 2020, from: https://www.epmmagazine.com/news/the-challenges-of-keeping-a-covid-19-vaccine-cold/

Medscape. (2020). What is the global incidence of influenza? Retrieved on 21st of February, 2021, from: https://www.medscape.com/answers/219557-3459/what-is-the-global-incidence-of-influenza

Meredith, S. (2021). Last-mile delivery problems hampering pace of Covid vaccine rollout, distributors say. Retrieved on 4th of March, 2021, from: https://www.cnbc.com/2021/01/26/last-mile-delivery-problems-hampering-pace-of-covid-vaccine-rollout-distributors-say.html

Mikulic, M. (2020). R&D spending share of top pharmaceutical companies 2019 and 2026. Retrieved on February 25th, 2021, from: https://www.statista.com/statistics/309471/randd-

spending-share-of-top-pharmaceutical-companies/#:~:text=In%202019%2C%20the%20pharmaceutical%20industry,drugs%20were%20in%20the%202020

Miller, F.A., Young, S.B., Dobrow, M. & Shojania, K.G. (2020). Vulnerability of the Medical Product Supply Chain: The Wake-up Call of COVID-19. Retrieved on 4th of January, 2021, from: https://qualitysafety.bmj.com/content/qhc/early/2020/11/02/bmjqs-2020-012133.full.pdf

Miller, J. (2020). Production and delivery challenges set up turbulent Year of the Vaccine. Retrieved on 4th of March, 2021, from: https://www.reuters.com/article/us-health-coronavirus-vaccines-idUSKBN28X0PO

Moscicki, R. M.D. (2021). Patient safety is at the heart of COVID-19 vaccine R&D.Retrieved 2nd of May, 2021, from: https://catalyst.phrma.org/patient-safety-is-at-the-heart-of-covid-19-vaccine-rd

Mukherjee, S. (2021). COVID vaccine distribution gets off to a shaky start. Retrieved on 4th of March, 2021, from: https://fortune.com/2021/01/07/covid-vaccine-distribution-gets-off-to-a-shaky-start/

Oguztimur, S. (2021). WHY FUZZY ANALYTIC HIERARCHY PROCESS APPROACH FOR TRANSPORT PROBLEMS?.

Ossadnik, W., Schinke, S. & Kaspar, R. (2015). Group Aggregation Techniques for Analytic Hierarchy Process and Analytic Network Process: A Comparative Analysis. Group Decision and Negotiation. 25. 10.1007/s10726-015-9448-4.

Pagliusi, S., Dennehy, K., & Dcvmn Agm Organizing Committee. (2018). Vaccines, inspiring innovation in health. Vaccine, 36(48), 7430-7437.

Pavithra, J., Kavitha, P., & Venkatraman, S. (2019). A Novel Work on Problems Faced by Freight Forwarders with Reference to Yashimarine Logistics. International Journal Of Recent Technology And Engineering, 8(2S8), 303-307. doi: 10.35940/ijrte.b1375.0882s819

Preiss, S., Garçon, N., Cunningham, A., Strugnell, R., & Friedland, L. (2016). Vaccine provision: Delivering sustained & widespread use. Vaccine, 34(52), 6665-6671.

ProMed. (2019). Undiagnosed pneumonia – China (HU). Retrieved on 4th of January 2021, from: https://promedmail.org/promed-post/?id=6864153%20#COVID19

Rayasam, G., & Mande, S. (2020). Role of S&T organisations in mitigation of Covid-19: CSIR as a case study. Indian Chemical Engineer (Calcutta, India : 1997), 62(4), 333-342.

Regeringen. (2020). Internationella Erfarenheter av COVID-19 i Äldreboenden (International Experiences of Covid-19 in Elderly Homes). Retrieved on 4th of January, 2021, from: https://www.regeringen.se/4af363/contentassets/a8e708fff5e84279bf11adbd0f78fcc1/internationella-erfarenheter-av-covid-19-i-aldreboenden_webb.pdf

Rele, S. (2020). COVID-19 vaccine development during pandemic: Gap analysis, opportunities, and impact on future emerging infectious disease development strategies. Human Vaccines & Immunotherapeutics, Ahead-of-print(Ahead-of-print), 1-6.

Reuters. (2021). Sweden gives 1,000 people COVID-19 shots kept at too low temperature. Retrieved on 3rd of May, 2021, from: https://www.reuters.com/article/us-health-coronavirus-vaccine-sweden-idUSKBN29R1QL

Romano, L., Portone, A., Coltelli, M., Patti, F., Saija, R, Iatì, M., Gallone, G., Lazzeri, A., Danti, S., Maragò, O., Camposeo, A., Pisignano, D. & Persano, L. (2020). Intelligent non-colorimetric indicators for the perishable supply chain by non-wovens with photo-programmed thermal response. Nature Communications, 11(1), 5991.

Roser, M., Ritchie, H., Ortiz-Ospina, E. & Hasell, J. (2020). Coronavirus Pandemic (COVID-19). Retrieved on 4th of January, 2021, from: https://ourworldindata.org/policy-responses-covid

Saaty, T. (1977). A scaling method for priorities in hierarchical structures. Journal of Mathematical Psychology, 15(3), 234-281.

Sincero, S.M.(2012). Personal Interview Survey. Retrieved 5th of May, 2021, from: https://explorable.com/personal-interview-survey

Singh, R., Dwivedi, A., & Srivastava, G. (2020). Internet of Things Based Blockchain for Temperature Monitoring and Counterfeit Pharmaceutical Prevention. Sensors (Basel, Switzerland), 20(14), Sensors (Basel, Switzerland), 16 July 2020, Vol.20(14).

Singh, R., Kumar, R., & Kumar, P. (2016). Strategic issues in pharmaceutical supply chains: A review. International Journal of Pharmaceutical and Healthcare Marketing, 10(3), 234-257.

Sodhi, M., & Tang, C. (2021). Supply Chain Management for Extreme Conditions: Research Opportunities. Journal of Supply Chain Management, 57(1), 7-16.

Sohl Stjernberg, M. (2021). Kaoset när patienter ratar Astra Zeneca (The chaos when patients refuse AstraZeneca). Retrieved on 2nd of May, 2021, from: https://www.expressen.se/nyheter/kaoset-nar-patienter-ratar-astra-zeneca/

Ssebuggwawo, D., Hoppenbrouwers, S. & Proper, H. (2009). Group Decision Making in Collaborative Modeling: Aggregating Individual Preferences with AHP. Journal of Physics-condensed Matter - J PHYS-CONDENS MATTER.

Statista. (2020). Impact of the Coronavirus Pandemic on the Global Economy – Statistics & Facts. Retrieved on 4th of January, 2021, from: https://www.statista.com/topics/6139/covid-19-impact-on-the-global-economy/

Sun, Y., Chen, X., & Luo, Y. (2019). Profit Allocation Method in Influenza Vaccine Supply Chain by Risk Compensation. 2019 IEEE 6th International Conference on Industrial Engineering and Applications (ICIEA), 511-515.

Sveriges Radio. (2021). Vaccine waste due to incorrect storage. Retrieved on May 3rd, 2021, from: https://sverigesradio.se/artikel/vaccine-waste-due-to-incorrect-storage

SverigesRadio. (2020). First Case of Corona Virus in Sweden Confirmed. Retrieved on 4th of January, 2021, from: https://sverigesradio.se/artikel/7398979

SVT. (2021). Länkar för vaccinering spreds – fel personer fick vaccin (Links for vaccinations spread - wrong people received vaccine). Retrieved 4th of May, 2021, from: https://www.svt.se/nyheter/lokalt/vast/lankar-for-vaccinering-sprids-fel-personer-far-vaccin

Teknomo, K. (2006). Analytic Hierarchy Process (AHP) Tutorial. https://people.revoledu.com/kardi/tutorial/AHP/

The Guardian. (2021). Covid: Oxford/AstraZeneca vaccine delivery to EU to be cut by 60%. Retrieved on 4th of March, 2021, from: https://www.theguardian.com/world/2021/jan/22/covid-oxfordastrazeneca-vaccine-delivery-to-eu-to-be-cut-by-60

The Local. (2021a). Sweden no longer expects to offer Covid-19 vaccine to all adults in first half of 2021. Retrieved on 4th of May, 2021, from https://www.thelocal.se/20210329/sweden-postpones-vaccination-target-2020/

The Local. (2021b). Swedish regions discard Astra Zeneca vaccines after patients refuse it. Retrieved on 5th of May, 2021, from: https://www.thelocal.se/20210419/refusal-astra-zeneca-vaccine-in-sweden/

Thompson, K., & Duintjer Tebbens, R. (2016). Framework for Optimal Global Vaccine Stockpile Design for Vaccine-Preventable Diseases: Application to Measles and Cholera Vaccines as Contrasting Examples. Risk Analysis, 36(7), 1487-1509.

Thompson, K., & Kalkowska, D. (2021). Potential Future Use, Costs, and Value of Poliovirus Vaccines. Risk Analysis, 41(2), 349-363.

United Nations. (n.d.). Goal 3: Ensure healthy lives and promote well-being for all at all ages. Retrieved on 1st of March 2021 from https://www.un.org/sustainabledevelopment/health/

UNODC. (n.d.). COVID-19 VACCINES AND CORRUPTION RISKS: PREVENTING CORRUPTION IN THE MANUFACTURE, ALLOCATION AND DISTRIBUTION OF VACCINES. Retrieved on 6th of May, 2021, from: https://www.unodc.org/documents/corruption/COVID-19/Policy_paper_on_COVID-19_vaccines_and_corruption_risks.pdf

Wambura, G., Mwatondo, A., Muturi, M., Nasimiyu, C., Wentworth, D., Hampson, K., Bichanga, P., Tabu, C., Juma, S., Ngere, I. & Thumbi, S. (2019). Rabies vaccine and immunoglobulin supply and logistics: Challenges and opportunities for rabies elimination in Kenya. Vaccine, 37(S1), A28-A34.

Wechsler, J. (2021). COVID-19 Vaccine Makers Overcome Challenges to Ramp Up Production. Retrieved on 4th of March, 2021, from: https://www.pharmtech.com/view/covid-19-vaccine-makers-overcome-challenges-to-ramp-up-production

WHO. (2020). Coronavirus disease (COVID-19): Similarities and differences with influenza. Retrieved on 28th of February, 2021, from: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/question-and-answers-hub/q-a-detail/coronavirus-disease-covid-19-similarities-and-differences-with-influenza

WHO. (2021a). Coronavirus. Retrieved on 4th of January, 2021, from: https://www.who.int/health-topics/coronavirus#tab=tab_1

WHO. (2021b). Draft landscape and tracker of COVID-19 candidate vaccines. Retrieved 25th of February, 2021, from: https://www.who.int/publications/m/item/draft-landscape-of-covid-19-candidate-vaccines

WHO. (2021c). Influenza: are we ready? Retrieved from 24th of February, 2021, from https://www.who.int/news-room/spotlight/influenza-are-we-ready

WHO. (2021d). Sweden. Retrieved on 8th of March, 2021, from: https://www.who.int/countries/swe/

WHO. (2021e). What we do. Retrieved on 2nd of March, 2021, from: https://www.who.int/about/what-we-do

Worldometer. (2021). COVID-19 Coronavirus Pandemic. Retrieved on 8th of March, 2021, from: https://www.worldometers.info/coronavirus/

WSP. (2020). Impact of COVID-19 on Global Supply Chain. Retrieved on 4th of January, 2021, from: https://www.wsp.com/en-SE/insights/impact-of-covid-19-on-global-supply-chains

Wuest, T., Kusiak, A., Dai, T. & Tayur, S.R. (2020) Impact of COVID-19 on Manufacturing and Supply Networks — The Case for AI-Inspired Digital Transformation doi.org/10.2139/ssrn.3593540

Yadav P. (2015). Health Product Supply Chains in Developing Countries: Diagnosis of the Root Causes of Underperformance and an Agenda for Reform. Health systems and reform, 1(2), 142–154. https://doi.org/10.4161/23288604.2014.968005

Yang, Y., Bidkhori, H., & Rajgopal, J. (2021). Optimizing vaccine distribution networks in low and middle-income countries. Omega (Oxford), 99, Omega (Oxford), March 2021, Vol.99.

Zayed, M. (2020). Sweden´s Loose COVID-19 Containment Approach and the Resulting Mobility Restrictions. Retrieved on 4th of January, 2021, from: https://airshare.air-inc.com/swedens-loose-covid-19-containment-approach-and-the-resulting-mobility-restrictions

Appendix

§1 Detailed risks in categories.

General

- Complexity of the supply chain *(Lemmens et al., 2016)*
- Inefficient cold chain *(Dixit et al., 2019; Romano et al., 2020)*
- Inefficient processes *(Dixit et al., 2019; Pagliusi et al., 2018; Singh et al., 2016)*
- Lack of performance measures *(Dixit et al., 2019; Pagliusi et al., 2018; Singh et al., 2016)*
- Corruption *(Yadav, 2015)*
- Fragmented supply chain *(Singh et al., 2016)*
- Insufficient collaboration *(Singh et al., 2016)*
- Variety of stakeholders *(Singh et al., 2016)*
- Insufficient infrastructure *(Dixit et al., 2019; Lam et al., 2015; Singh et al., 2016)*
- Insufficient connectivity *(Dixit et al., 2019; Singh et al., 2016)*
- New partnerships of organization in telecommunications, knowledge, health *(Pagliusi et al., 2018)*
- Integration of supply chain *(Lemmens et al., 2016; Singh et al., 2016; Yadav, 2015)*
- Outsourcing: risk of losing flexibility and control *(Dixit et al., 2019; Fernando et al., 2020; Lloyd, Mccarney, Ouhichi, Lydon, & Zaffran, 2015; Pagliusi et al., 2018; Singh et al., 2016)*
- Lack of trust *(Jarrett, Yang, and Pagliusi, 2020)*

Transportation

- Political factors (carbon footprint) *(Iyengar et al., 2016; Sodhi & Tang, 2021)*
- Country specific requirements regarding labeling *(Preiss et al.,2016; Romano et al., 2020)*
- Administrative barriers in international supply chain logistics *(Derwand, 2014)*
- Inappropriate temperature during transportation *(Romano et al., 2020)*
- Lack of equipment *(Dixit et al., 2019)*
- Temperature tracking *(Kartoglu and Milstien, 2014*)

- Freezing during transportation - reduced vaccine efficiency (*Dellepiane and Wood, 2015; Preiss et al.,2016; Anderson et al., 2014; Derwand, 2014; Hanson et al., 2017; Kartoglu and Milstien; 2014)*

Distribution /delivery

- High volume distribution *(Yadav, 2015)*
- Conflict of interest (DC and clinics) *(Hovav and Herbon, 2017)*
- High distribution costs *(Yadav, 2015; Yang et al., 2021)*
- Cold storage conditions *(Derwand , 2014; Guignard et al., 2019; Kartoglu and Milstien, 2014)*
- Vaccine characteristics regarding storage and transportation *(Chakravarthy et al., 2019)*
- New vaccine introductions *(Guignard et al., 2019; Iwu et al., 2019b; Kartoglu and Milstien (2014)*
- Network, connectivity, infrastructure *(Dixit et al., 2019; Singh et al., 2016; Lam et al.; 2015)*
- Lack of financial & human resources *(Yadav, 2015; Chen et al.,2014)*
- Limited governance *(Yadav, 2015)*
- Corruption *(Yadav, 2015)*
- High frequency is costly *(Yadav, 2015; Hovav and Herbon, 2017)*
- Low frequency of deliveries *(Yadav, 2015)*
- Effective/safe transportation *(Singh et al., 2020; Yadav, 2015)*
- Insufficient planning *(Yadav, 2015)*
- Insufficient maintenance & use of vehicles *(Anderson et al. , 2014; Preiss et al., 2016)*
- Increased number of wholesalers *(Yadav, 2015)*

Storage

- Specific conditions/ temperatures (*Dellepiane and Wood, 2015; Preiss et al.,2016; Anderson et al., 2014; Chen et al., 2014; Rele, 2020; Jarrett, Yang and Pagliusi, 2020; Lee and Haidari, 2017)*
- Lack of equipment *(Dixit et al., 2019)*

Stock Management

- Supply shortages *(Anderson et al., 2014; Iyengar et al., 2016; Islam et al.,2020;). Iwu et al., 2019b; Jarrett, Yang and Pagliusi, 2020; Thompson et al., 2016)*
- WHO stockpile (certain amount of vaccines reserved for countries) *(Islam et al., 2020)*
- Insufficient supply (*Dellepiane and Wood, 2015; Preiss et al.,2016; Iyengar et al., 2016; Lee and Haidari, 2017)*
- Stockpile (storage costs) *(Jarrett, Yang and Pagliusi, 2020)*

Government/ Organizations

- Regulations *(Yadav, 2015)*
- Uncoordinated global guidance *(Pagliusi et al., 2018)*
- Unreliable geopolitical conditions *(Sodhi & Tang, 2021; Iyengar et al., 2016)*
- Governmental bodies *(Singh et al., 2016)*
- Introduction of new policies/ regulations *(Dixit et al., 2019)*

IT

- Lack of centralized data *(Dixit et al., 2019; Singh et al., 2016)*
- Advancement of technologies *(Dixit et al., 2019; Fernando et al., 2020; Lloyd, Mccarney, Ouhichi, Lydon, & Zaffran, 2015; Pagliusi et al., 2018; Singh et al., 2016)*
- Insufficiency of capturing and sharing information *(Anderson et al., 2014; Yadav, 2015)*
- Lack of information systems *(Dixit et al., 2019)*
- Implementation of new information technology *(Jarrett, Wilmansjah et al., 2020)*
- Digital infrastructure *(Jarrett, Yang and Pagliusi, 2020)*
- Outdated systems *(Singh et al., 2016)*
- Data inconsistency *(Dixit et al., 2019; Singh et al., 2016)*
- Poor quality of data *(Dixit et al., 2019; Singh et al., 2016)*
- Untransparent operations *(Iwu et al., 2019b; Iyengar et al., 2016)*

Immunization

- Global coverage takes long time *(Derwand, 2014; Iwu et al., 2019b; Thompson et al., 2016, Yang et al.; 2021)*

- Untargeted strategies could cause disruption in other vaccine programs *(Lee and Haidari, 2017)*
- Vaccine stockouts *(Iwu et al., 2019b; Jarrett, Yang, and Pagliusi, 2020; Thompson et al., 2016)*
- More issues in the chain less immunization rate *(Derwand, 2014)*

Manufacturing

- Constrained plant capacity *(Iyengar et al., 2016; Rele, 2020)*
- Raw material shortage *(Iyengar et al., 2016;Crommelin et al., 2021)*
- Composition of the vaccine *(Dai, Cho and Zhang, 2016; Sun et al., 2019)*
- Prequalification process (uncertainty) *(Dellepiane and Wood, 2015)*
- Long production time *(Thompson et al., 2016)*
- Complexity *(Lemmens et al., 2016; Preiss et al., 2016)*
- Poor product quality, defects *(Iyengar et al., 2016; Pagliusi et al., 2018; Yadav, 2015)*
- Inventory *(Pagliusi et al., 2018; Singh et al., 2016)*
- Overproduction *(Pagliusi et al., 2018; Singh et al., 2016)*
- Production yield *(Pagliusi et al., 2018)*
- Unsuitable processing *(Pagliusi et al., 2018; Singh et al., 2016)*
- Waste management *(Dixit et al., 2019; Singh et al., 2016)*
- Inventory management *(Dixit et al., 2019; Singh et al., 2016)*
- Waiting *(Pagliusi et al., 2018; Singh et al., 2016)*
- Poor forecasting *(Dixit et al., 2019; Rele, 2020; Singh et al., 2016; Chick, Hasija & Nasiry, 2017)*
- Environmental concerns *(Dixit et al., 2019; Jarrett, Yang and Pagliusi, 2020; Singh et al., 2016;)*
- Recycling products *(Singh et al., 2016)*
- Reverse logistics *(Pagliusi et al., 2018; Singh et al., 2016)*
- Increased consumer awareness *(Fernando et al., 2020; Singh et al., 2016)*
- Change in customer behavior/ preferences *(Singh et al., 2016)*
- Competitors *(Singh et al., 2016)*
- Poor service levels *(Singh et al., 2016)*
- Stockouts /shortages *(Gurvich & Hussain, 2020)*
- Bottlenecks *(Rele, 2020; Yadav, 2015)*

- Missing storage systems *(Dixit et al., 2019)*
- Degrading ingredients *(Singh et al., 2016)*
- Missing implementation of lean manufacturing *(Singh et al., 2016)*

Finance

- Allocation of resources *(Pagliusi et al., 2018; Chen et al., 2014)*
- Insufficient funding *(Dixit et al., 2019; Pagliusi et al., 2018; Fernando et al., 2020; Singh et al., 2016)*
- Budget limitations *(Dixit et al., 2019)*
- Deficient profits *(Dixit et al., 2019; Dai et al., 2016; Sun et al., 2019)*
- Unreliable financial stability *(Sodhi & Tang, 2021)*

R&D

- Complicated process *(Hovav and Herbon, 2017; Rele, 2020)*
- Extreme conditions (pandemics) *(Jarrett, Yang and Pagliusi, 2020)*
- Development of new products *(Rele, 2020)*
- Long process *(Singh et al., 2016; Preiss et al.,2016; Guignard et al.,2019; Thompson et al., 2016)*
- Technological advances *(Pagliusi et al., 2018)*
- Increasing costs *(Pagliusi et al., 2018; Chick, Hasija and Nasiry, 2017)*
- Decreased product life cycle *(Pagliusi et al., 2018)*
- Success rate *(Pagliusi et al., 2018)*
- Market uncertainty *(Pagliusi et al., 2018)*
- Estimating production process *(Pagliusi et al., 2018)*
- Generic drugs *(Singh et al., 2016)*
- Diminishing patent life *(Singh et al., 2016)*
- Resource allocation for new products *(Yadav, 2015)*
- Capacity planning *(Singh et al., 2016)*
- Lack of pre-clinical data *(Rele, 2020)*
- Failures during testing, trails and commercializing product *(Pagliusi et al., 2018; Singh et al., 2016)*
- Prioritizing products *(Pagliusi et al., 2018; Singh et al., 2016)*
- Changing market requirements *(Pagliusi et al., 2018; Singh et al., 2016)*

- Limited resources *(Singh et al., 2016)*

Economy

- Immediate change/uncertain in demand *(Iyengar et al., 2016; Sodhi & Tang, 2021; Thompson et al., 2016)*
- Globalization *(Dixit et al., 2019; Fernando et al., 2020; Lloyd, Mccarney, Ouhichi, Lydon, & Zaffran, 2015; Pagliusi et al., 2018; Singh et al., 2016)*

Society

- Changing trends *(Dixit et al., 2019; Fernando et al., 2020; Lloyd, Mccarney, Ouhichi, Lydon, & Zaffran, 2015; Pagliusi et al., 2018; Singh et al., 2016)*

Pharmaceutical products/ vaccines

- Scarcity of affordable products *(Singh et al., 2016; Dixit et al., 2019)*
- Counterfeit products *(Dixit et al., 2019; Fernando et al., 2020; Pagliusi et al., 2018; Singh et al., 2016; Jarrett, Yang and Pagliusi, 2020)*
- Expansion of products *(Dixit et al., 2019; Fernando et al., 2020; Lloyd, Mccarney, Ouhichi, Lydon, & Zaffran, 2015; Pagliusi et al., 2018; Singh et al., 2016)*
- Short/ decreased product life cycles *(Dixit et al., 2019; Fernando et al., 2020; Lloyd, Mccarney, Ouhichi, Lydon, & Zaffran, 2015; Pagliusi et al., 2018; Singh et al., 2016)*
- Vaccine prices influenced by competition *(Lemmens et al., 2016)*
- Stealing and selling products *(Dixit et al., 2019; Fernando et al., 2020; Pagliusi et al. 2018; Singh et al., 2016)*
- Wide variety of products *(Singh et al., 2016)*
- Forcing unsimilar products in the same supply chain *(Yadav, 2015)*
- Dynamic nature *(Pagliusi et al., 2018)*
- Financial risks because of the perishable products *(Jarrett, Yang and Pagliusi, 2020)*
- Increased wastage with increased demand *(Jarrett, Yang and Pagliusi, 2020)*
- Not up to global standards *(Pagliusi et al., 2018; Singh et al., 2016)*
- Illegal, hazardous pharmaceuticals (due to incorrect/ ineffective ingredients) *(Singh et al., 2020)*
- Expired products *(Jarrett, Yang and Pagliusi, 2020)*
- Defective products *(Jarrett, Yang and Pagliusi, 2020)*

- Not finding counterfeit products *(Singh et al., 2020; Jarrett, Yang and Pagliusi, 2020)*
- Unregistered manufacturers *(Jarrett, Yang and Pagliusi, 2020)*

Workforce/ Employees

- Unskilled staff *(Dixit et al., 2019; Pagliusi et al., 2018; Yadav, 2015; Hovav & Herbon, 2017; Kartoglu and Milstien, 2014)*
- Deficiency of skilled staff (especially IT and leadership) *(Yadav, 2015)*
- Limited flexibility when hiring staff *(Yadav, 2015)*
- Inability to remove incompetent staff *(Yadav, 2015)*
- Uncertain conditions of the transport workers *(Haghani et al., 2020; Sodhi & Tang, 2021)*
- Lack of experience *(Jarrett, Yang and Pagliusi, 2020)*
- Not taking responsibility *(Yadav, 2015)*

Traceability

- Implementing track and trace technologies *(Jarrett, Yang and Pagliusi, 2020)*
- Training staff *(Jarrett, Yang and Pagliusi, 2020)*
- Changes in requirements for barcoding *(Jarrett, Yang and Pagliusi, 2020)*
- Technical challenges for barcoding (small vials/ ampoules) *(Jarrett, Yang and Pagliusi, 2020)*
- Need to be compatible with various systems and meet specific needs from demand side *(Jarrett, Yang and Pagliusi, 2020)*
- Design and testing of software expensive *(Jarrett, Yang and Pagliusi, 2020)*
- Equipment *(Jarrett, Yang and Pagliusi, 2020)*

§2 - Emails sent to potential research participants

Subject: Master's thesis research on risks in the Covid-19 Vaccine Supply Chain

Dear _____,

We are Julia Galus and Viktoria Barany, Master's students at the University of Gothenburg. Currently, we are writing our master's thesis about the risks within the Covid-19 Vaccine Supply Chain. Therefore, we are looking for professionals in this field who are willing to participate in our research. Since this is a fairly new topic, we would greatly appreciate your cooperation.

The research is based on an already identified list of risks, generated by our conducted literature review, which we would like to rank according to your input. The semi-structured online interview will take a maximum of 45 minutes, which will be conducted from now on, until the 16th of April. All answers will be kept anonymously throughout the entire research process and the data from the interviews will only be used for this research.

We understand that the current situation might restrict your availability and are therefore prepared to send a questionnaire instead, if necessary.

We would appreciate it if you could forward this email to potential candidates.

We wish you a pleasant day!

Yours sincerely,

Julia and Viktoria

gusbaranvi@student.gu.se

gusgaluju@student.gu.se

§ 3 - Survey

SURVEY ON THE RISKS IN THE COVID-19 VACCINE SUPPLY CHAIN

Please return this survey to us until the 16th of April 2021 to gusbaranvi@student.gu.se or gusgaluju@student.gu.se!

If you have any question regarding the survey, please do not hesitate to contact us.

Thank you for your cooperation!

Julia Galus and Viktoria Barany

General Information

Again, we would like to thank you for participating in our research! Please carefully read the instructions in the beginning of the document.

You will stay anonymous through the entire research process and will be referenced as e.g., Expert 1, Expert 2, etc.

The results of this research will only be used for the purpose of our thesis, however, our thesis will be available as a printed version in the University´s library, as well as online.

Instructions

We appreciate every input so please feel free to use the comment section (further opinion on choices, reasonings etc.) after each matrix. In case you do not have any experience or opinion on any of the matrixes, you can leave it blank.

		Horizontal			
		Risk 1	Risk 2	Risk 3	Risk 4
Vertical	Risk 1			-5	
	Risk 2			1	8
	Risk 3				
	Risk 4				

Orange columns = drop down menus

Black and Gray columns = require no answer

In the orange columns you are required to choose a value, determining which risk is more challenging or riskier.

Values -9 until -2 → **horizontal risk** is more challenging/risky

Value 1→ both risks are equally challenging/risky

Values → until 9: **vertical risk** is more challenging/risky

Example from table above:

-5 → Risk 3 is 5 more challenging/riskier than Risk 1

1 → Risk 3 is equally challenging/riskier as Risk 2

8 → Risk 2 is 8 more challenging/riskier than Risk 4

General Vaccine Supply Chain

Complexity of supply chain (the characteristics and requirements it has/requires)

Incompetent & unexperienced staff

No collaboration/ trust (between different shareholders and companies)

Outsourcing (issues that occur, losing control)

Environmental concerns (waste management/recycling/ reverse logistics)

Prioritizing products (which product to focus on first in the different processes)

	Horizontal						
Vertical	***General Vaccine Supply Chain***	Complexity	Incompetent and unexperienced staff	Lack of collaboration and trust	Outsourcing issues	Environmental concerns	Prioritizing products
	Complexity		**Choose a value.**	**Choose a value.**	**Choose a value.**	**Choose a value.**	**Choose a value.**
	Incompetent & unexperienced staff			**Choose a value.**	**Choose a value.**	**Choose a value.**	**Choose a value.**
	Lack of collaboration and trust				**Choose a value.**	**Choose a value.**	**Choose a value.**
	Outsourcing issues					**Choose a value.**	**Choose a value.**
	Environmental concerns						**Choose a value.**
	Prioritizing products						

Comments:

Economy/ National Level Issues

Corruption /counterfeit (black market, counterfeit vaccines, stolen vaccines)

Changing demand (ex. Suddenly people do not want the vaccine)

Vaccine prices/ competition (countries choose from different products at different prices)

regulations/ requirements (from the government and WHO)

Immunization coverage (getting everyone vaccinated)

Consumer behavior (change in preferences)

Horizontal

Vertical	***Economy National Level***	Corruption/ Counterfeit	Changing demand	Vaccine prices/ Competition	Regulations and requirements	Immunization coverage	Consumer behavior
	Corruption/ Counterfeit		**Choose a value.**	**Choose a value.**	**Choose a value.**	**Choose a value.**	**Choose a value.**
	Changing demand			**Choose a value.**	**Choose a value.**	**Choose a value.**	**Choose a value.**
	Vaccine prices/ Competition				**Choose a value.**	**Choose a value.**	**Choose a value.**
	Regulations and requirements					**Choose a value.**	**Choose a value.**
	Immunization coverage						**Choose a value.**
	Consumer behavior						

Comments:

Research and Development

R&D process & lack of pre-clinical data

Financing (from the government and other organizations)

Product quality (ensuring high quality and avoiding defects)

Short product life cycle (short life on the market)

	Horizontal				
Vertical	***R&D***	Process & lack of pre-clinical data	Financing	Product quality Issues	Short product lifecycle
	Process & lack of pre-clinical data		**Choose a value.**	**Choose a value.**	**Choose a value.**
	Financing			**Choose a value.**	**Choose a value.**
	Product quality issues				**Choose a value.**
	Short Product life cycle				

Comments:

Distribution

Insufficient cold chain processes (temperature, characteristics, ensuring effect of vaccine)
Insufficient infrastructure (roads, production sites, warehouses, storage facilities, etc.)
Lack of maintenance of equipment (distribution vehicles)
High volume distribution /frequency of deliveries

		Horizontal			
Vertical	***Distribution***	Insufficient cold chain processes	Insufficient infrastructure	Lack of maintenance of equipment	High volume distribution
	Insufficient cold chain processes		**Choose a value.**	**Choose a value.**	**Choose a value.**
	Insufficient infrastructure			**Choose a value.**	**Choose a value.**
	Lack of maintenance of equipment				**Choose a value.**
	High volume distribution				

Comments:

Manufacturing

Barcoding (putting barcoding on vials and outer packaging)
Capacity of manufacturing
production time

	Horizontal			
Vertical	***Manufacturing***	Barcoding	Capacity	Production time
	Barcoding		**Choose a value.**	**Choose a value.**
	Capacity			**Choose a value.**
	Production time			

Comments:

Stock management

Storage (capacity, cold storage)
Stock management/ forecasting (stockouts, false forecasting)

Horizontal

Vertical	***Stock management***	Storage	Forecasting issues
	Storage		**Choose a value.**
	Forecasting issues		

Comments:

All risks
General VSC
R&D
Manufacturing
Distribution
Economy
Stock Management
IT (Quality of data/ information systems (compatibility/access)

	Horizontal							
Vertical	***All risks***	General VSC	R&D	Manufacturing	Distribution	Economy	Stock Management	IT
	General VSC		**Choose a value.**	**Choose a value.**	**Choose a value.**	**Choose a value.**	**Choose a value.**	**Choose a value.**
	R&D			**Choose a value.**	**Choose a value.**	**Choose a value.**	**Choose a value.**	**Choose a value.**
	Manufacturing				**Choose a value.**	**Choose a value.**	**Choose a value.**	**Choose a value.**
	Distribution					**Choose a value.**	**Choose a value.**	**Choose a value.**
	Economy						**Choose a value.**	**Choose a value.**
	Stock Management							**Choose a value.**
	IT							

Comments:

§ 4 - Answers

The following shows the raw data and analyzed data that is not included in the Results section.

It is structured by expert and risks and includes the raw data and and consistency tables for each expert. In the end, raw data, normalized, and consistency tables are shown for the group matrices.

Formulas used:

Normalized table

$$normalized\ cell = \frac{raw\ result\ cell}{sum\ of\ raw\ result\ column\ of\ risk}$$

$$priority\ vector = \frac{sum\ of\ normalized\ matrix\ row}{no.\ of\ risks}$$

Consistency table

$$consistency\ cell = raw\ data\ cell\ \times priority\ vector$$

λmax

$$= \frac{sum\ of\ consistency\ cells\ row}{priority\ vector}$$

then average of all risks sum

$$consistency\ index = \frac{(\lambda\,\max - no.\ of\ risks)}{(no.\ of\ risks - 1)}$$

$$consistency\ ratio = \frac{consistency\ index}{value\ from\ table\ below}$$

N	3	4	5	6	7	8
RI	0,52	0,89	1,11	1,25	1,35	1,4
CR value*	<0,05	<0,08	<0,10	<0,10	<0,10	<0,10

https://www.semanticscholar.org/paper/Deviation-Handling-Model-in-Highly-Regulated-(Study-Senjaya-Daryanto/e86fc71d080d6c6b3ddf75e3a6a28e7ebd3a77ff

4.1 Expert 1

General Vaccine Supply Chain

General VSC-Expert 1	R1	R2	R3	R4	R5	R6
R1: Complexity	1,00	0,14	2,00	1,00	2,00	2,00
R2: Incompetent & unexperienced staff	0,14	1,00	2,00	2,00	2,00	2,00
R3: Lack of collaboration & trust	0,50	0,50	1,00	2,00	2,00	2,00
R4: Outsourcing Issues	1,00	0,50	0,50	1,00	2,00	2,00
R5: Environmental concerns	0,50	0,50	0,50	0,50	1,00	0,17
R6: Prioritizing products	0,50	0,50	0,50	0,50	6,00	1,00
Sum	3,64	3,14	6,50	7,00	15,00	9,17

Staff is easy to address with training, however it is a high risk, controllable
Biggest problem is the lack of collaboration, because there are many stakeholders involved and it is difficult to control them.
They are not really addressing the environmental concerns.

Consistency-Expert 1	R1	R2	R3	R4	R5	R6	Sum	-
R1: Complexity	0,19	0,03	0,36	0,17	0,18	0,32	1,24	6,64
R2: Incompetent & unexperienced staff	0,03	0,22	0,36	0,33	0,18	0,32	1,44	6,61
R3: Lack of collaboration & trust	0,09	0,11	0,18	0,33	0,18	0,32	1,21	6,69
R4: Outsourcing Issues	0,19	0,11	0,09	0,17	0,18	0,32	1,05	6,26
R5: Environmental concerns	0,09	0,11	0,09	0,08	0,09	0,03	0,49	5,56
R6: Prioritizing products	0,09	0,11	0,09	0,08	0,53	0,16	1,06	6,70
Consistency index	0,08						λmax	6,41
Consistency ratio	0,07							

Economy/ National Level Issues

Economy-Expert 1	R1	R2	R3	R4	R5	R6
R1: Corruption/Counterfeit	1,00	8,00	6,00	5,00	3,00	4,00
R2: Changing Demand	0,13	1,00	3,00	3,00	0,25	1,00
R3: Vaccine prices/competition	0,17	0,33	1,00	0,50	0,25	1,00
R4: Regulations and requirements	0,20	0,33	2,00	1,00	0,25	1,00
R5: Immunization coverage	0,33	4,00	4,00	4,00	1,00	3,00
R6: Consumer behavior	0,25	1,00	1,00	1,00	0,33	1,00
Sum	2,08	14,67	17,00	14,50	5,08	11,00

there are very few cases where you have a choice or preference regarding the vaccine type.
Regulations are actually helping the process and are not seen as a risk.

Consistency-Expert 1	R1	R2	R3	R4	R5	R6	Sum	-
R1:Corruption/Counterfeit	0,39	0,75	0,25	0,30	0,57	0,25	2,50	6,48
R2: Changing Demand	0,05	0,09	0,12	0,18	0,05	0,06	0,55	5,92
R3: Vaccine prices/competition	0,06	0,03	0,04	0,03	0,05	0,06	0,28	6,77
R4: Regulations and requirements	0,08	0,03	0,08	0,06	0,05	0,06	0,36	6,10
R5: Immunization coverage	0,13	0,37	0,16	0,24	0,19	0,19	1,28	6,75
R6: Consumer behavior	0,10	0,09	0,04	0,06	0,06	0,06	0,42	6,55
consistency index	0,09						λmax	6,43
consistency ratio	0,07							

Research and Development

R&D-Expert 1	R1	R2	R3	R4
R1: Process & lack of pre-clinical data	1,00	0,20	0,25	1,00
R2: Financing	5,00	1,00	3,00	4,00
R3: Product quality issues	4,00	0,33	1,00	7,00
R4: Short product life cycle	1,00	0,25	0,14	1,00
Sum	11,00	1,78	4,39	13,00

clinical data is quite robust at basic level research, getting financed is the biggest challenge quality is really important, the trials are necessary to understand what effect the vaccine has, even though you have the preclinical data it might turn out as ineffective and it might have too many side effects to get on the market.

Consistency-Expert 1	R1	R2	R3	R4	Sum	-
R1: Process & lack of pre-clinical data	0,08	0,10	0,08	0,09	0,35	4,18
R2: Financing	0,42	0,50	0,99	0,34	2,25	4,49
R3: Product quality issues	0,34	0,17	0,33	0,60	1,43	4,34
R4: Short product life cycle	0,08	0,13	0,05	0,09	0,34	4,01
Consistency index	0,09				λmax	4,26
Consistency ratio	0,09					

Distribution

Distribution-Expert 1	R1	R2	R3	R4
R1: Insufficient cold chain processes	1,00	1,00	1,00	1,00
R2: Insufficient infrastructure	1,00	1,00	1,00	1,00
R3: Lack of maintenance of equipment	1,00	1,00	1,00	1,00
R4: High volume distribution	1,00	1,00	1,00	1,00
Sum	4,00	4,00	4,00	4,00

All of them are the same. All highly regulated, therefore relatively low risks. Individually controllable due to the regulations on the processes, but the regulations because they are high risks.

Manufacturing

Manufacturing-Expert 1	R1	R2	R3
R1: Capacity	1,00	0,11	0,25
R2: Production Time	9,00	1,00	4,00
R3: Barcoding	4,00	0,25	1,00
Sum	14,00	1,36	5,25

Consistency-Expert 1	R1	R2	R3	Sum	-
R1: Capacity	0,07	0,08	0,05	0,20	3,01
R2: Production Time	0,60	0,71	0,88	2,20	3,08
R3: Barcoding	0,27	0,18	0,22	0,67	3,03
Consistency index	0,02			λmax	3,04
Consistency ratio	0,04				

Stock management

Stock Management-Expert 4	R1	R2
R1: Storage	1,00	0,17
R2: Forecasting Issues	6,00	1,00
Sum	7,00	1,17

All risks

All Risks Expert 1	R1	R2	R3	R4	R5	R6	R7
R1: General VSC	1,00	3,00	0,25	3,00	1,00	1,00	1,00
R2: R&D	0,33	1,00	0,20	1,00	0,25	1,00	1,00
R3: Manufacturing	4,00	5,00	1,00	5,00	3,00	3,00	3,00
R4: Distribution	0,33	1,00	0,20	1,00	1,00	2,00	3,00
R5: Economy	1,00	4,00	0,33	1,00	1,00	2,00	1,00
R6: Stock Management	1,00	1,00	0,33	0,50	0,50	1,00	3,00
R7: IT	1,00	1,00	0,33	0,33	1,00	0,33	1,00
Sum	8,67	16,00	2,65	11,83	7,75	10,33	13,00

Consistency-Expert 1	R1	R2	R3	R4	R5	R6	R7	sum	-
R1: General VSC	0,14	0,20	0,09	0,35	0,14	0,11	0,08	1,10	8,08
R2: R&D	0,05	0,07	0,07	0,12	0,03	0,11	0,08	0,52	7,81
R3: Manufacturing	0,54	0,33	0,35	0,58	0,42	0,32	0,24	2,79	7,88
R4: Distribution	0,05	0,07	0,07	0,12	0,14	0,21	0,24	0,89	7,68
R5: Economy	0,14	0,27	0,12	0,12	0,14	0,21	0,08	1,07	7,67
R6: Stock Management	0,14	0,07	0,12	0,06	0,07	0,11	0,24	0,80	7,58
R7: IT	0,14	0,07	0,12	0,04	0,14	0,04	0,08	0,62	7,56
consistency index	0,13							λmax	7,75
consistency ratio	0,09								

4.2 Expert 2

General Vaccine Supply Chain

General VSC - Expert 2	R1	R2	R3	R4	R5	R6
R1: Complexity	1,00	0,17	0,20	0,17	0,33	0,50
R2: Incompetent & unexperienced staff	6,00	1,00	3,00	0,50	3,00	6,00
R3: Lack of collaboration & trust	5,00	0,33	1,00	3,00	3,00	4,00
R4: Outsourcing Issues	6,00	2,00	0,33	1,00	3,00	4,00
R5: Environmental concerns	3,00	0,33	0,33	0,33	1,00	2,00
R6: Prioritizing products	2,00	0,17	0,25	0,25	0,50	1,00
Sum	23,00	4,00	5,12	5,25	10,83	17,50

Availability of components and products are high risks as well as stockouts.

Consistency-Expert 2	R1	R2	R3	R4	R5	R6	Sum	-
R1: Complexity	0,04	0,05	0,05	0,04	0,03	0,03	0,24	6,65
R2: Incompetent & unexperienced staff	0,22	0,30	0,79	0,13	0,27	0,33	2,03	6,73
R3: Lack of collaboration & trust	0,18	0,10	0,26	0,76	0,27	0,22	1,80	6,85
R4: Outsourcing Issues	0,22	0,60	0,09	0,25	0,27	0,22	1,65	6,52
R5: Environmental concerns	0,11	0,10	0,09	0,08	0,09	0,11	0,58	6,35
R6: Prioritizing products	0,07	0,05	0,07	0,06	0,05	0,05	0,35	6,42
Consistency index	0,12						λmax	6,59
Consistency ratio	0,10							

Economy/ National Level Issues

Economy-Expert 2	R1	R2	R3	R4	R5	R6
R1:Corruption/Counterfeit	1,00	0,14	0,50	0,33	0,20	0,33
R2: Changing Demand	7,00	1,00	7,00	7,00	3,00	6,00
R3: Vaccine prices/competition	2,00	0,14	1,00	1,00	0,20	0,33
R4: Regulations and requirements	3,00	0,14	1,00	1,00	0,20	0,33
R5: Immunization coverage	5,00	0,33	5,00	5,00	1,00	4,00
R6: Consumer behavior	3,00	0,17	3,00	3,00	0,25	1,00
Sum	21,00	1,93	17,50	17,33	4,85	12,00

Changing demand and availability of the vaccines are major issues. In Sweden the problem is the lack of vaccines to reach immunization coverage goals.
Corruption is not a big issue in Sweden.

Consistency-Expert 2	R1	R2	R3	R4	R5	R6	Sum	-
R1:Corruption/Counterfeit	0,04	0,05	0,03	0,02	0,04	0,03	0,21	6,02
R2: Changing Demand	0,25	0,38	0,38	0,44	0,60	0,63	2,66	7,02
R3: Vaccine prices/competition	0,07	0,05	0,05	0,06	0,04	0,03	0,32	5,81
R4: Regulations and requirements	0,11	0,05	0,05	0,06	0,04	0,03	0,35	5,64
R5: Immunization coverage	0,18	0,13	0,27	0,31	0,20	0,42	1,50	7,55
R6: Consumer behavior	0,11	0,06	0,16	0,19	0,05	0,10	0,67	6,44
consistency index	0,08						λmax	6,41
consistency ratio	0,07							

Research and Development

R&D-Expert 2	R1	R2	R3	R4
R1: Process & lack of pre-clinical data	1,00	4,00	0,25	4,00
R2: Financing	0,25	1,00	0,14	0,50
R3: Product quality issues	4,00	7,00	1,00	5,00
R4: Short product life cycle	0,25	2,00	0,20	1,00
Sum	5,50	14,00	1,59	10,50

Clinical data is needed before selling on the market and therefore a crucial part of the R&D process. It is also needed for marketing purposes.

Consistency-Expert 2	R1	R2	R3	R4	Sum	-
R1: Process & lack of pre-clinical data	0,25	0,25	0,15	0,41	1,06	4,22
R2: Financing	0,06	0,06	0,08	0,05	0,26	4,10
R3: Product quality issues	1,01	0,44	0,58	0,51	2,54	4,37
R4: Short product life cycle	0,06	0,13	0,12	0,10	0,41	4,00
Consistency index	0,06				λmax	4,17
Consistency ratio	0,06					

Distribution

Distribution-Expert 2	R1	R2	R3	R4
R1: Insufficient cold chain processes	1,00	2,00	2,00	1,00
R2: Insufficient infrastructure	0,50	1,00	0,50	0,50
R3: Lack of maintenance of equipment	0,50	2,00	1,00	0,50
R4: High volume distribution	1,00	2,00	2,00	1,00
Sum	3,00	7,00	5,50	3,00

Infrastructure and equipment are not a big issue in Sweden.
Cold chain and infrastructure are closely connected to each other.

Consistency-Expert 2	R1	R2	R3	R4	Sum	-
R1: Insufficient cold chain processes	0,33	0,28	0,40	0,33	1,34	4,08
R2: Insufficient infrastructure	0,16	0,14	0,10	0,16	0,57	4,03
R3: Lack of maintenance of equipment	0,16	0,28	0,20	0,16	0,81	4,06
R4: High volume distribution	0,33	0,28	0,40	0,33	1,34	4,08
					λmax	4,06
Consistency index		0,02				
Consistency ratio		0,02				

Manufacturing

Manufacturing-Expert 2	R1	R2	R3
R1: Capacity	1,00	0,17	0,17
R2: Production Time	6,00	1,00	0,50
R3: Barcoding	6,00	2,00	1,00
Sum	13,00	3,17	1,67

Availability of components is a major issue for manufacturing.

Consistency-Expert 2	R1	R2	R3	Sum	-
R1: Capacity	0,08	0,06	0,09	0,23	3,01
R2: Production Time	0,46	0,36	0,28	1,10	3,06
R3: Barcoding	0,46	0,72	0,56	1,74	3,09
Consistency index	0,03			λmax	3,05
Consistency ratio	0,05				

Stock management

Stock Management-Expert 2	R1	R2
R1: Storage	1,00	0,25
R2: Forecasting Issues	4,00	1,00
Sum	5,00	1,25

Forecasting is an issue because you can not control the regions as a whole.

All risks

All Risks Expert 2	R1	R2	R3	R4	R5	R6	R7
R1: General VSC	1,00	0,33	0,20	2,00	3,00	2,00	3,00
R2: R&D	3,00	1,00	0,50	3,00	3,00	3,00	4,00
R3: Manufacturing	5,00	2,00	1,00	5,00	5,00	5,00	6,00
R4: Distribution	0,50	0,33	0,20	1,00	3,00	2,00	3,00
R5: Economy	0,33	0,33	0,20	0,33	1,00	4,00	4,00
R6: Stock Management	0,50	0,33	0,20	0,50	0,25	1,00	4,00
R7: IT	0,33	0,25	0,17	0,33	0,25	0,25	1,00
Sum	10,67	4,58	2,47	12,17	15,50	17,25	25,00

IT is not seen as a big issue in Sweden.

Consistency-Expert 2	R1	R2	R3	R4	R5	R6	R7	sum	-
R1: General VSC	0,12	0,07	0,07	0,20	0,29	0,14	0,11	1,00	8,30
R2: R&D	0,36	0,21	0,18	0,31	0,29	0,20	0,14	1,69	8,04
R3: Manufacturing	0,60	0,42	0,37	0,51	0,48	0,34	0,22	2,93	7,98
R4: Distribution	0,06	0,07	0,07	0,10	0,29	0,14	0,11	0,84	8,22
R5: Economy	0,04	0,07	0,07	0,03	0,10	0,27	0,14	0,73	7,63
R6: Stock Management	0,06	0,07	0,07	0,05	0,02	0,07	0,14	0,49	7,21
R7: IT	0,04	0,05	0,06	0,03	0,02	0,02	0,04	0,26	7,37
consistency index	0,14							λmax	7,82
consistency ratio	0,10								

4.3 Expert 3

General Vaccine Supply Chain

General VSC - Expert 3	R1	R2	R3	R4	R5	R6
R1: Complexity	1,00	9,00	7,00	1,00	9,00	8,00
R2: Incompetent & unexperienced staff	0,11	1,00	0,14	0,11	1,00	1,00
R3: Lack of collaboration & trust	0,14	7,00	1,00	1,00	7,00	7,00
R4: Outsourcing Issues	1,00	9,00	1,00	1,00	7,00	9,00
R5: Environmental concerns	0,11	1,00	0,14	0,14	1,00	1,00
R6: Prioritizing products	0,13	1,00	0,14	0,11	1,00	1,00
Sum	2,49	28,00	9,43	3,37	26,00	27,00

doesn’t have any experience with incompetent staff since the supervision is quite high. There is a good collaboration during corona times, but trust is built overtime. It is hard to say if there is trust between competitors. There might be a connection between lack of trust and outsourcing since the more you outsource the less collaboration and trust you have.
Complexity is due to outsourcing, and outsourcing leads to more complexity.
During covid-19 there are no environmental concerns.
Prioritizing products is not an issue since covid vaccines are the priority. However, a lot of

operations are adapted and are transitioning for covid operations.

During covid prioritization and environmental concerns are not taken into account.

Consistency-Expert 3	R1	R2	R3	R4	R5	R6	Sum	-
R1: Complexity	0,40	0,31	1,45	0,29	0,32	0,28	3,04	7,58
R2: Incompetent & unexperienced staff	0,04	0,03	0,03	0,03	0,04	0,03	0,21	6,19
R3: Lack of collaboration & trust	0,06	0,24	0,21	0,29	0,25	0,24	1,28	6,21
R4: Outsourcing Issues	0,40	0,31	0,21	0,29	0,25	0,31	1,76	6,13
R5: Environmental concerns	0,04	0,03	0,03	0,04	0,04	0,03	0,22	6,18
R6: Prioritizing products	0,05	0,03	0,03	0,03	0,04	0,03	0,22	6,19
Consistency index	0,08						λmax	6,41
Consistency ratio	0,07							

Economy/ National Level Issues

Economy- Expert 3	R1	R2	R3	R4	R5	R6
R1:Corruption/Counterfeit	1,00	9,00	9,00	2,00	9,00	9,00
R2: Changing Demand	0,11	1,00	2,00	0,25	6,00	6,00
R3: Vaccine prices/competition	0,11	0,50	1,00	0,11	1,00	1,00
R4: Regulations and requirements	0,50	4,00	9,00	1,00	9,00	9,00
R5: Immunization coverage	0,11	0,17	1,00	0,11	1,00	1,00
R6: Consumer behavior	0,11	0,17	1,00	0,11	1,00	1,00
Sum	1,94	14,83	23,00	3,58	27,00	27,00

Demand is unlimited during covid so it is not issue, but it could turn into an issue of it would turn into an annual vaccine.

There are huge price issues between the different types of vaccines, but it is not an issue because everyone wants to have it. Since it is a completely different situation with covid-19, competition does not have a huge role to play.

Shifting regulations and requirements could be an issue, for instance Astrazenecas vaccines because of the side effects the product leaflets might need to be changed, but it is not an issue for the supply chain.

Immunization coverage is not an issue for the supply chain since it is calculated with very high numbers and orders on vaccines are over 100% of the population in Europe, but it is a major issue for health care providers. Immunization coverage will decide the demand in the long run.

Changing consumer could be an issue but there is a lot of demand.

Consumer behaviour leads to immunization coverage which is normally the biggest challenge to achieve.

Consistency-Expert 3	R1	R2	R3	R4	R5	R6	Sum	-
R1:Corruption/Counterfeit	0,40	0,76	0,30	0,51	0,27	0,27	2,51	6,26
R2: Changing Demand	0,04	0,08	0,07	0,06	0,18	0,18	0,62	7,38
R3: Vaccine prices/competition	0,04	0,04	0,03	0,03	0,03	0,03	0,21	6,18
R4: Regulations and requirements	0,20	0,34	0,30	0,26	0,27	0,27	1,63	6,41
R5: Immunization coverage	0,04	0,01	0,03	0,03	0,03	0,03	0,18	6,02
R6: Consumer behavior	0,04	0,01	0,03	0,03	0,03	0,03	0,18	6,02
consistency index	0,08						λmax	6,38
consistency ratio	0,06							

Research and Development

R&D-Expert 3	R1	R2	R3	R4
R1: Process & lack of pre-clinical data	1,00	0,20	0,11	1,00
R2: Financing	5,00	1,00	0,33	9,00
R3: Product quality issues	9,00	3,00	1,00	9,00
R4: Short product life cycle	1,00	0,11	0,11	1,00
Sum	16,00	4,31	1,56	20,00

If there are vaccinations with higher efficiency or easier storage characteristics, then there could be a shorter lifecycle for other vaccines.
Without clinical data there would be no product, so it is not an issue for the supply chain. does not consider R&D as part of the supply chain.

Consistency-Expert 3	R1	R2	R3	R4	Sum	-
R1: Process & lack of pre-clinical data	0,06	0,06	0,07	0,05	0,24	4,09
R2: Financing	0,29	0,30	0,20	0,47	1,26	4,16
R3: Product quality issues	0,52	0,91	0,59	0,47	2,48	4,23
R4: Short product life cycle	0,06	0,03	0,07	0,05	0,21	3,98
Consistency index	0,039				λmax	4,12
Consistency ratio	0,043					

Distribution

Distribution-Expert 3	R1	R2	R3	R4
R1: Insufficient cold chain processes	1,00	4,00	6,00	5,00
R2: Insufficient infrastructure	0,25	1,00	5,00	3,00
R3: Lack of maintenance of equipment	0,17	0,20	1,00	0,33
R4: High volume distribution	0,20	0,33	3,00	1,00
Sum	1,62	5,53	15,00	9,33

With Pfizer and Moderna, it has been seen that the cold chain is a big problem.

The cold chain is an integrated part of the infrastructure; therefore it needs to be known that the cold chain can be managed by the infrastructure.

Consistency-Expert 3	R1	R2	R3	R4	Sum	-
R1: Insufficient cold chain processes	0,57	0,99	0,36	0,61	2,54	4,45
R2: Insufficient infrastructure	0,14	0,25	0,30	0,37	1,06	4,28
R3: Lack of maintenance of equipment	0,09	0,05	0,06	0,04	0,25	4,07
R4: High volume distribution	0,11	0,08	0,18	0,12	0,50	4,08
					λmax	4,22
Consistency index		0,07				
Consistency ratio		0,08				

Manufacturing

Manufacturing-Expert 3	R1	R2	R3
R1: Capacity	1,00	0,11	0,33
R2: Production Time	9	1,00	6,00
R3: Barcoding	3,00	0,17	1,00
Sum	13,00	1,28	7,33

Capacity is the biggest issue, since companies/manufacturers are looking for capacity all over the world by having manufacturing sites at different locations to fulfill the demand. The biggest issue in producing the covid vaccines has been to find capacity it holds back the entire campaign to reach coverage.

Barcoding is very straight forward so it is not considered as a major issue.

Consistency-Expert 3	R1	R2	R3	Sum	-
R1: Capacity	0,07	0,08	0,06	0,21	3,01
R2: Production Time	0,63	0,76	1,00	2,39	3,12
R3: Barcoding	0,21	0,13	0,17	0,50	3,03
Consistency index	0,027			λmax	3,05
Consistency ratio	0,052				

Stock management

Stock Management-Expert 3	R1	R2
R1: Storage	1,00	9,00
R2: Forecasting Issues	0,11	1,00
Sum	1,11	10,00

Forecasting is not an issue at the moment because of the high demand, however it might be in the future.

All risks

All Risks Expert 3	R1	R2	R3	R4	R5	R6	R7
R1: General VSC	1,00	x	0,20	0,33	5,00	0,50	0,33
R2: R&D	x	x	x	x	x	x	x
R3: Manufacturing	5,00	x	1,00	7,00	9,00	7,00	8,00
R4: Distribution	3,00	x	0,14	1,00	6,00	3,00	1,00
R5: Economy	0,20	x	0,11	0,17	1,00	0,20	0,20
R6: Stock Management	2,00	x	0,14	0,33	5,00	1,00	0,33
R7: IT	3,00	x	0,13	1,00	5,00	3,00	1,00
Sum	14,20	x	1,72	9,83	31,00	14,70	10,87

doesn't consider R&D as part of the supply chain. However, R&D has been shown to be a masterpiece and never in the history of developing a vaccine has been done so fast. Regarding the economy, countries are willing to supply money for financing.

Consistency-Expert 3	R1	R2	R3	R4	R5	R6	R7	sum	-
R1: General VSC	0,07	x	0,10	0,05	0,13	0,04	0,05	0,45	6,07
R2: R&D	x	x	x		x	x	x	x	x
R3: Manufacturing	0,37	x	0,52	1,03	0,24	0,60	1,12	3,90	7,43
R4: Distribution	0,22	x	0,07	0,15	0,16	0,26	0,14	1,00	6,81
R5: Economy	0,01	x	0,06	0,02	0,03	0,02	0,03	0,17	6,37
R6: Stock Management	0,15	x	0,07	0,05	0,13	0,09	0,05	0,54	6,25
R7: IT	0,22	x	0,07	0,15	0,13	0,26	0,14	0,97	6,90
consistency index	0,13							λmax	6,64
consistency ratio	0,10								

4.4 Expert 4

General Vaccine Supply Chain

General VSC - Expert 4	R1	R2	R3	R4	R5	R6
R1: Complexity	1,00	5,00	3,00	1,00	6,00	1,00
R2: Incompetent & unexperienced staff	0,20	1,00	0,33	0,20	0,33	0,17
R3: Lack of collaboration & trust	0,33	3,00	1,00	1,00	4,00	1,00
R4: Outsourcing Issues	1,00	5,00	1,00	1,00	5,00	1,00
R5: Environmental concerns	0,17	3,00	0,25	0,20	1,00	1,00
R6: Prioritizing products	1,00	6,00	1,00	1,00	1,00	1,00
Sum	3,70	23,00	6,58	4,40	17,33	5,17

Consistency Expert 4	R1	R2	R3	R4	R5	R6	Sum	-
R1: Complexity	0,29	0,20	0,51	0,22	0,51	0,19	1,93	6,77
R2: Incompetent & unexperienced staff	0,06	0,04	0,06	0,04	0,03	0,03	0,26	6,37
R3: Lack of collaboration & trust	0,10	0,12	0,17	0,22	0,34	0,19	1,15	6,72
R4: Outsourcing Issues	0,29	0,20	0,17	0,22	0,43	0,19	1,50	6,69
R5: Environmental concerns	0,05	0,12	0,04	0,04	0,09	0,19	0,54	6,31
R6: Prioritizing products	0,29	0,25	0,17	0,22	0,09	0,19	1,20	6,22
Consistency index	0,10						λmax	6,51
Consistency ratio	0,08							

Economy/ National Level Issues

Economy-Expert 4	R1	R2	R3	R4	R5	R6
R1:Corruption/Counterfeit	1,00	0,25	0,33	2,00	0,50	4,00
R2: Changing Demand	4,00	1,00	1,00	1,00	4,00	7,00
R3: Vaccine prices/competition	3,00	1,00	1,00	1,00	1,00	7,00
R4: Regulations and requirements	0,50	1,00	1,00	1,00	2,00	3,00
R5: Immunization coverage	2,00	0,25	1,00	0,50	1,00	5,00
R6: Consumer behavior	0,25	0,14	0,14	0,33	0,20	1,00
Sum	10,75	3,64	4,48	5,83	8,70	27,00

Consistency-Expert 4	R1	R2	R3	R4	R5	R6	Sum	-
R1:Corruption/Counterfeit	0,11	0,06	0,06	0,32	0,06	0,12	0,72	6,75
R2: Changing Demand	0,42	0,25	0,18	0,16	0,45	0,20	1,67	6,66
R3: Vaccine prices/competition	0,32	0,25	0,18	0,16	0,11	0,20	1,22	6,88
R4: Regulations and requirements	0,05	0,25	0,18	0,16	0,23	0,09	0,95	6,04
R5: Immunization coverage	0,21	0,06	0,18	0,08	0,11	0,15	0,79	6,98
R6: Consumer behavior	0,03	0,04	0,03	0,05	0,02	0,03	0,19	6,60
consistency index	0,13						λmax	6,65
consistency ratio	0,10							

Research and Development

No answer.

Distribution

Distribution-Expert 4	R1	R2	R3	R4
R1: Insufficient cold chain processes	1,00	1,00	3,00	0,17
R2: Insufficient infrastructure	1,00	1,00	1,00	0,17
R3: Lack of maintenance of equipment	0,33	1,00	1,00	0,17
R4: High volume distribution	6,00	6,00	6,00	1,00
Sum	8,33	9,00	11,00	1,50

Consistency-Expert 4	R1	R2	R3	R4	Sum	-
R1: Insufficient cold chain processes	0,15	0,11	0,26	0,11	0,64	4,13
R2: Insufficient infrastructure	0,15	0,11	0,09	0,11	0,46	4,24
R3: Lack of maintenance of equipment	0,05	0,11	0,09	0,11	0,36	4,03
R4: High volume distribution	0,92	0,65	0,53	0,65	2,75	4,24
					λmax	4,16
Consistency index		0,05				
Consistency ratio		0,06				

Manufacturing

Manufacturing-Expert 4	R1	R2	R3
R1: Capacity	1,00	0,14	0,13
R2: Production Time	7,00	1,00	0,50
R3: Barcoding	8,00	2,00	1,00
Sum	16,00	3,14	1,63

Consistency-Expert 4	R1	R2	R3	Sum	-
R1: Capacity	0,06	0,05	0,07	0,19	3,01
R2: Production Time	0,43	0,35	0,29	1,08	3,04
R3: Barcoding	0,49	0,71	0,58	1,79	3,06
Consistency index	0,018			λmax	3,04
Consistency ratio	0,033				

Stock management

Stock Management-Expert 4	R1	R2
R1: Storage	1,00	0,17
R2: Forecasting Issues	6,00	1,00
Sum	7,00	1,17

All risks

All Risks Expert 4	R1	R2	R3	R4	R5	R6	R7
R1: General VSC	1,00	0,20	1,00	1,00	1,00	1,00	5,00
R2: R&D	5,00	1,00	7,00	6,00	4,00	8,00	9,00
R3: Manufacturing	1,00	0,14	1,00	1,00	1,00	4,00	9,00
R4: Distribution	1,00	0,17	1,00	1,00	0,25	1,00	7,00
R5: Economy	1,00	0,25	1,00	4,00	1,00	5,00	9,00
R6: Stock Management	1,00	0,13	0,25	1,00	0,20	1,00	8,00
R7: IT	0,20	0,11	0,11	0,14	0,11	0,13	1,00
Sum	10,20	2,00	11,36	14,14	7,56	20,13	48,00

Consistency-Expert 4	R1	R2	R3	R4	R5	R6	R7	sum	-
R1: General VSC	0,09	0,09	0,12	0,08	0,17	0,07	0,10	0,72	7,82
R2: R&D	0,46	0,45	0,85	0,49	0,66	0,57	0,18	3,65	8,12
R3: Manufacturing	0,09	0,06	0,12	0,08	0,17	0,28	0,18	0,98	8,13
R4: Distribution	0,09	0,07	0,12	0,08	0,04	0,07	0,14	0,62	7,61
R5: Economy	0,09	0,11	0,12	0,33	0,17	0,35	0,18	1,35	8,11
R6: Stock Management	0,09	0,06	0,03	0,08	0,03	0,07	0,16	0,52	7,34
R7: IT	0,02	0,05	0,01	0,01	0,02	0,01	0,02	0,14	7,17
consistency index	0,13							λmax	7,76
consistency ratio	0,10								

Group Decision Results, Normalized Tables and Consistency

General VSC

Group	R1	R2	R3	R4	R5	R6
R1: Complexity	1,00	1,02	1,70	0,64	2,45	1,68
R2: Incompetent & unexperienced staff	0,37	1,00	0,73	0,39	1,19	1,19
R3: Lack of collaboration & trust	0,59	1,37	1,00	1,57	3,60	2,74
R4: Outsourcing Issues	1,57	2,59	0,64	1,00	3,81	2,91
R5: Environmental concerns	0,41	0,84	0,28	0,26	1,00	0,76
R6: Prioritizing products	0,59	0,84	0,37	0,34	1,32	1,00
Sum	4,53	7,66	4,72	4,20	13,36	10,28

Normalized matrix	R1	R2	R3	R4	R5	R6	Sum	Priority vectors
R1: Complexity	0,22	0,13	0,36	0,15	0,18	0,16	1,21	0,20
R2: Incompetent & unexperienced staff	0,08	0,13	0,16	0,09	0,09	0,12	0,66	0,11
R3: Lack of collaboration & trust	0,13	0,18	0,21	0,37	0,27	0,27	1,43	0,24
R4: Outsourcing Issues	0,35	0,34	0,14	0,24	0,28	0,28	1,63	0,27
R5: Environmental concerns	0,09	0,11	0,06	0,06	0,07	0,07	0,47	0,08
R6: Prioritizing products	0,13	0,11	0,08	0,08	0,10	0,10	0,60	0,10

Consistency Total	R1	R2	R3	R4	R5	R6	Sum	-
R1: Complexity	0,20	0,11	0,41	0,17	0,19	0,17	1,25	6,19
R2: Incompetent & unexperienced staff	0,08	0,11	0,17	0,10	0,09	0,12	0,68	6,11
R3: Lack of collaboration & trust	0,12	0,15	0,24	0,42	0,28	0,27	1,49	6,24
R4: Outsourcing Issues	0,32	0,29	0,15	0,27	0,30	0,29	1,61	5,96
R5: Environmental concerns	0,08	0,09	0,07	0,07	0,08	0,08	0,47	5,96
R6: Prioritizing products	0,12	0,09	0,09	0,09	0,10	0,10	0,60	6,00
Consistency index	0,02						λmax	6,08
Consistency ratio	0,01							

Economy

Group	R1	R2	R3	R4	R5	R6
R1: Corruption/Counterfeit	1,00	1,27	1,73	1,61	1,28	2,63
R2: Changing Demand	0,79	1,00	2,55	1,51	2,06	3,98
R3: Vaccine prices/competition	0,58	0,39	1,00	0,49	0,47	1,24
R4: Regulations and requirements	0,62	0,66	2,06	1,00	0,97	1,73
R5: Immunization coverage	0,78	0,49	2,11	1,03	1,00	2,78
R6: Consumer behavior	0,38	0,25	0,81	0,58	0,36	1,00
Sum	4,15	4,06	10,26	6,21	6,15	13,37

Normalized matrix	R1	R2	R3	R4	R5	R6	Sum	Priority Vector
R1: Corruption/Counterfeit	0,24	0,31	0,17	0,26	0,21	0,20	1,39	0,23
R2: Changing Demand	0,19	0,25	0,25	0,24	0,34	0,30	1,56	0,26
R3: Vaccine prices/competition	0,14	0,10	0,10	0,08	0,08	0,09	0,58	0,10
R4: Regulations and requirements	0,15	0,16	0,20	0,16	0,16	0,13	0,96	0,16
R5: Immunization coverage	0,19	0,12	0,21	0,17	0,16	0,21	1,05	0,17
R6: Consumer behavior	0,09	0,06	0,08	0,09	0,06	0,07	0,46	0,08

Consistency Total	R1	R2	R3	R4	R5	R6	Sum	-
R1: Corruption/Counterfeit	0,06	0,08	0,02	0,04	0,04	0,02	0,25	1,07
R2: Changing Demand	0,04	0,06	0,02	0,04	0,06	0,02	0,25	0,97
R3: Vaccine prices/competition	0,03	0,03	0,01	0,01	0,01	0,01	0,10	1,03
R4: Regulations and requirements	0,03	0,04	0,02	0,03	0,03	0,01	0,16	1,00
R5: Immunization coverage	0,04	0,03	0,02	0,03	0,03	0,02	0,17	0,95
R6: Consumer behavior	0,02	0,02	0,01	0,01	0,01	0,01	0,08	0,99
Consistency index	-0,99994					λmax		1,00
Consistency ratio	-0,8064							

Research and Development

Group	R1	R2	R3	R4
R1: Process & lack of pre-clinical data	1,00	0,54	0,19	1,59
R2: Financing	1,84	1,00	0,52	2,62
R3: Product quality issues	5,24	1,91	1,00	6,80
R4: Short product life cycle	0,63	0,38	0,15	1,00
Sum	8,71	3,84	1,86	12,01

R&D-Group-Normalized	R1	R2	R3	R4	Sum	Priority vectors
R1: Process & lack of pre-clinical data	0,11	0,14	0,10	0,13	0,49	0,12
R2: Financing	0,21	0,26	0,28	0,22	0,97	0,24
R3: Product quality issues	0,60	0,50	0,54	0,57	2,20	0,55
R4: Short product life cycle	0,07	0,10	0,08	0,08	0,33	0,08

Consistency Total	R1	R2	R3	R4	Sum	-
R1: Process & lack of pre-clinical data	0,12	0,13	0,11	0,13	0,49	4,01
R2: Financing	0,23	0,24	0,29	0,22	0,98	4,02
R3: Product quality issues	0,64	0,46	0,55	0,57	2,23	4,04
R4: Short product life cycle	0,08	0,09	0,08	0,08	0,33	4,01
Consistency Index	0,01				λmax	4,02
Consistency Ratio	0,01					

Distribution

Group	R1	R2	R3	R4
R1: Insufficient cold chain proces	1,00	1,68	2,45	0,96
R2: Insufficient infrastructure	0,59	1,00	1,26	0,71
R3: Lack of maintenance of equi	0,41	0,80	1,00	0,41
R4: High volume distribution	1,05	1,41	2,45	1,00
Sum	3,05	4,89	7,16	3,07

Normalized matrix	R1	R2	R3	R4	Sum	Priority vectors
R1: Insufficient cold chain proces	0,33	0,34	0,34	0,31	1,33	0,33
R2: Insufficient infrastructure	0,19	0,20	0,18	0,23	0,81	0,20
R3: Lack of maintenance of equi	0,13	0,16	0,14	0,13	0,57	0,14
R4: High volume distribution	0,34	0,29	0,34	0,33	1,30	0,33

Consistency Total	R1	R2	R3	R4	Sum	-
R1: Insufficient cold chain proces	0,33	0,34	0,35	0,31	1,33	4,01
R2: Insufficient infrastructure	0,20	0,20	0,18	0,23	0,81	4,01
R3: Lack of maintenance of equi	0,14	0,16	0,14	0,13	0,57	4,01
R4: High volume distribution	0,35	0,28	0,35	0,33	1,31	4,01
Consistency Index	0,00				λmax	4,01
Consistency ratio	0,00					

Manufacturing

Group	R1	R2	R3
R1: Capacity	1,00	0,13	0,20
R2: Production Time	7,64	1,00	1,57
R3: Barcoding	4,90	0,64	1,00
Sum	13,54	1,77	2,77

Normalized Matrix	R1	R2	R3	Sum	Priority vectors
R1: Capacity	0,07	0,07	0,07	0,22	0,07
R2: Production Time	0,56	0,57	0,57	1,69	0,56
R3: Barcoding	0,36	0,36	0,36	1,08	0,36

Consistency Total	R1	R2	R3	Sum	-
R1: Capacity	0,07	0,07	0,07	0,22	3,00
R2: Production Time	0,56	0,56	0,57	1,69	3,00
R3: Barcoding	0,36	0,36	0,36	1,08	3,00
Consistency index	0,00			λmax	3,00
Consistency ratio	0,00				

Stock Management

Group	R1	R2
R1: Storage	1,00	3,35
R2: Forecasting Issues	2,59	1,00
Sum	3,59	4,35

Normalized matrix	R1	R2	Sum	Priority vector
R1: Storage	0,28	0,77	1,05	0,52
R2: Forecasting Issues	0,72	0,23	0,95	0,48

Consistency Total	R1	R2	Sum	-
R1: Storage	0,52	1,60	2,12	4,04
R2: Forecasting Issues	1,36	0,48	1,83	3,86
Consistency index	1,95		λmax	3,95
Consistency ratio	0			

All risks

Group	R1	R2	R3	R4	R5	R6	R7
R1: General VSC	1,00	0,58	0,32	1,19	1,97	1,00	1,50
R2: R&D	1,71	1,00	0,89	2,62	1,44	2,88	3,30
R3: Manufacturing	3,16	1,13	1,00	3,64	3,41	4,53	6,00
R4: Distribution	0,84	0,38	0,27	1,00	1,46	1,86	2,82
R5: Economy	0,51	0,69	0,29	0,69	1,00	1,68	1,64
R6: Stock Management	1,00	0,35	0,22	0,54	0,59	1,00	2,38
R7: IT	0,67	0,30	0,17	0,35	0,61	0,42	1,00
Sum	8,89	4,44	3,16	10,03	10,48	13,37	18,63

Normalized Matrix	R1	R2	R3	R4	R5	R6	R7	Sum	Priority vector
R1: General VSC	0,11	0,13	0,10	0,12	0,19	0,07	0,08	0,81	0,12
R2: R&D	0,19	0,23	0,28	0,26	0,14	0,22	0,18	1,49	0,21
R3: Manufacturing	0,36	0,25	0,32	0,36	0,33	0,34	0,32	2,27	0,32
R4: Distribution	0,09	0,09	0,09	0,10	0,14	0,14	0,15	0,80	0,11
R5: Economy	0,06	0,16	0,09	0,07	0,10	0,13	0,09	0,68	0,10
R6: Stock Management	0,11	0,08	0,07	0,05	0,06	0,07	0,13	0,57	0,08
R7: IT	0,08	0,07	0,05	0,04	0,06	0,03	0,05	0,38	0,05

Consistency Total	R1	R2	R3	R4	R5	R6	R7	Sum	-
R1: General VSC	0,12	0,12	0,10	0,14	0,19	0,08	0,08	0,83	7,23
R2: R&D	0,20	0,21	0,29	0,30	0,14	0,24	0,18	1,55	7,28
R3: Manufacturing	0,36	0,24	0,32	0,41	0,33	0,37	0,32	2,37	7,29
R4: Distribution	0,10	0,08	0,09	0,11	0,14	0,15	0,15	0,83	7,27
R5: Economy	0,06	0,15	0,10	0,08	0,10	0,14	0,09	0,70	7,19
R6: Stock Management	0,12	0,07	0,07	0,06	0,06	0,08	0,13	0,59	7,20
R7: IT	0,08	0,06	0,05	0,04	0,06	0,03	0,05	0,38	7,16
Consistency index	0,04							**λmax**	7,23
Consistency ratio	0,03								