POLITECNICO DI TORINO

Master 's Degree in

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Master Thesis

Impact of Covid-19 on the supply chain: The case of personal protective equipment and medical devices

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To the ones who are always
there for me.

Contents

INTRODUCTION

The International Monetary Fund in 2019 predicted a moderate global growth of 3.4 percent for the year 2020. But then, for the third time in three decades, a zoonotic coronavirus has crossed species to infect human population; this virus was first identified in Wuhan, China, in persons that went to a seafood or wet market (Perlman, 2020). Due to fear and uncertainty, global stock markets erased about US$6 trillion in wealth in one week from 24th to 26th of February. As in the events of 2007 and 2008 the initial perception was that Covid-19 would be localized, in this case to China only. It later spread across the world along with the people's travelling (Ozili & Arun, 2020), and everyone understood how interconnected the globe is through the movement of goods and people. Due to the sudden rise in the number of cases and the droplets mode of transmission of the coronavirus, a sudden rise in the demand for personal protective equipment (PPE) and medical devices (MD) to protect the population and the health professionals was observed, leading to a significant shortage of these key goods from the early days of the outbreak (Shrivastava & Prateek Saurabh, 2020).

The global supply chain of the PPE/MD shows its weaknesses in the moment of highest need. The thesis aim is firstly to qualitatively analyze the supply chain of personal protectives equipment / medical devices in order to understand the global supply chain to which they are part, the criticalities that arose during the coronavirus in 2020 and that led to shortages of these key goods in many countries. Then, a quantitative analysis is undertaken through a questionnaire, aimed at Italian, American and Chinese professionals in the PPE / MD sector. The intention of the questionnaire is to understand how daily operations have changed for the responding companies relatively to a period corresponding to the first pandemic wave in Italy, as of March-May 2020, in order to realize how characteristics of the business such as variation in material flows, lead times, relationships with suppliers, production and stock methods and many others have influenced on shortages and bottlenecks in the supply chain.

The questionnaire was sent to importers, exporters, distributors and manufacturers of personal protectives equipment, with the aim of having as an

understanding as complete as possible of the operational difficulties that each of these professionals has encountered due to coronavirus pandemic.

A quantitative study regarding the PPE/MD supply chain has not yet been dealt with in the literature, and specially Italy is lacking in scientific articles relating to the reasons behind the shortages that the country suffered at the outbreak of the epidemiological emergency. Without an understanding of the specificities of the upstream supply chain problem, precautions cannot be taken so that the downstream problems do not occur, in the event of another unforeseen health emergency.

The work carried out is divided into four chapters: the first one deals with the topics of supply chain and supply chain management, in order to frame the argument before discussing the effects of the Covid-19 pandemic on global supply chains. It is then explained the importance of a correct supply of Personal protective equipment and medical devices amid pandemic, and through a literature review the scientific studies published up to date on the criticalities and shortages encountered in the supply chain of these key goods are analyzed. Finally, the research gap is highlighted. The second chapter reports a description of the sample to which the questionnaire was administered, then a description of the methodology followed for the drafting of the questionnaire and the motivation of each of the questions. The third chapter contains the statistical analysis carried out on the answers obtained from the respondent companies. Initially, the answers were analyzed through a descriptive statistic, whose results were integrated with a statistical analysis performed using the Kruskal-Wallis test. The conclusions were then drawn by combining the analyzes of the chapter and the scientific literature published up to date.

The fourth and final chapter illustrates the contribution made by this treaty to the literature concerning the supply chain of PPE / MD during the Covid-19 health emergency, analyzing the limitations of the paper and explaining future steps that research on the topic could take.

The results obtained are able to explain, at least in part, which activities in the supply chain of personal protective equipment have suffered the most disruption and the reasoning behind those, and which traditional methodologies used by the sector have been most harmful and how they have evolved to cope with the sanitary emergency.

1. SUPPLY CHAIN OF PERSONAL PROTECTIVE EQUIPMENT AND MEDICAL DEVICES AMID COVID-19 PANDEMIC

The chapter aim to frame the topic of the thesis, namely the concept of supply chain applied to the market of personal protective equipment and medical devices to combat Covid-19.

The chapter is organized as follows: starting from the historical background and the meaning of concepts such as logistics, supply chain and supply chain management, the intrinsic problems of the concept of global supply chain will be discussed, to then talk about the Covid-19 pandemic and its effect on the most impacted supply chains. Then, the importance of personal protective equipment during a pandemic and the shortages of them that occurred in most of the countries around the world in 2020 will be dealt with in depth. Finally, the research gap the thesis work contributes to close is discussed.

1.1 THE EVOLUTION OF LOGISTICS

The etymology of the word logistics has a Greek origin, from the words "λόγος" (LOGOSH - reason), "λογιστικός" (LOYISTIKOSH - responsible for counting, accountant) [1]. Of the concept of Logistics as we mean it today, there is traces since the end of the 19th century, when it appears for the first time in the book "The Art of War" by Baron Henri, general of the French army at the time of Napoleon; declined in the military field, logistics applies to the process of supplying equipment, weapons and provisions to troops during the war. Until the 1960s, logistics meant the distribution of the finished product, and the only variable studied in the process was therefore the transport of the product, from the warehouse to the final consumer; however, starting from the 1960s, logistics began to take on a role within the company sector. It was in the United States around 1975 that the role of logistics gained visibility and recognition at a global level: once logistics have been applied as a business function, thanks to the reduction of costs, the increase in productivity and the allocative efficiency that it entails, the American model is not slow to make itself known and spread all over the world (Vacar, 2019). Subsequently, the dynamism of an industrial and

economic environment in constant movement has changed the concept and the role of logistics; starting from the 1980s, the term logistics no longer assumes an internal role to each company but integrated: the need for intra-company coordination becomes stronger and stronger, and the foundations for the concept of integrated supply chain are made more solid [2].

1.2 THE INSURGENCE OF THE SUPPLY CHAIN MANAGEMENT

1.2.1 THE CONCEPT OF SUPPLY CHAIN

Central to understanding of Supply Chain Management are *supply chains*, and these have been given numerous definitions that are mainly part of two different schools of thought.

The first one focuses on the fundamental determinants of an efficient supply chain and on the fact that all supply chains start with a raw material and through activities that add value to the product they transform it into a finished product to be delivered to the final consumer. For example, this first category includes the following definitions of supply chain: "a structured manufacturing process wherein raw materials are transformed into finished goods, then delivered to end customers" (Beamon, 1998), and also "a general description of the process integration involving organizations to transform raw materials into finished goods and to transport them to the end-user" (Pienaar, 2009).

The second typology of definitions is more complex, and includes other activities of the supply chain function; these include the definition which describes a supply chain as "the combined and coordinated flows of goods from origin to final destination, also the information flows that are linked with it" (Little, 1999), and also "Supply Chain is the group of manufacturers, suppliers, distributors, retailers and transportation, information and other logistics management service providers that are engaged in providing goods to consumers. A Supply Chain comprises both the external and internal associates for the corporate " (Chow and Heaver, 1999). To date, an exhaustive and up-to-date description of supply chain combining all these concepts is what defines it as:

"a network between a company and its suppliers to produce and distribute a specific product to the final buyer. This network includes various activities, people, entities, information and resources. The supply chain also represents the steps required to bring the product or service from its original state to the customer"
(Assey Mbang, 2012).

1.2.2   KEY PLAYERS IN A GLOBAL SUPPLY CHAIN

"In today's global factory, the production of a single commodity often spans many countries, with each nation performing tasks in which it has a cost advantage" (Gereffi and Korzeniewicz, 1994).

Since the above quote was said, in 1994, various factors have contributed to the establishment and expansion of global supply chains, as the rapid advancement in production technology that enabled various industries to further slice up their production chains, the reduction in information costs, the decline in the trade costs in home and host countries (i.e., because of the improvement in port efficiency and access to information and communication technology facilities).

Today, a large number of goods are produced in global factories, in which products are designed in a country, assembled in another and with parts and components originated in another (Nicita, Ognivtsev, & Shirotori, 2013).

Although every supply chain is different, there are some common key players in most of the global supply chains, and those are as follows [3]:

1- *Manufacturers:* Organization that sources, provides or manufactures ingredients, raw materials, parts, finished products or other goods to downstream supply chain organizations; manufacturers will directly give goods to a logistics or transport provider that will deliver them to the receiving organization.

2- *Intermodal marketing company/logistics service providers/ship-rail/ship-truck/rail-truck:* They handle intermodal containers like shipping containers by load and unload them between ships, trucks and railways or they transport the containers to downstream supply chain organizations.

3- *Terminal/Port/Depot:* They are locations where goods are sent, received, handled, processed or otherwise managed.

4- *Non-Vessel operating common carrier (NVOCC)/ Freight forwarder:* They administer, manage and organize the transfer and transportation of ingredients, raw materials, parts and finished products from one place or organization to another. They do not move goods themselves, but contracts with logistic server provider to move the goods on behalf of their client.

5- *Transportation provider/Ocean/Road/Rail/Air transport:* They move goods from one location or organization to another, by owning or leasing the

transportation infrastructure needed to physically transport the goods. They can be part of an integrated logistics company, or simply contracted by an NVOCC or LSP.

6- *Logistic server provider (LSP)/ Third-party logistics/ Warehouses / Shippers/ Distributors:* They are primarily responsible for ensuring that goods get from one point in the supply chain to another. Different LSPs are involved in several ways at multiple points in any supply chain. An LSP will receive goods from an upstream organization and transport them to a downstream one. They may also be involved in storing and warehousing goods, inventory control, moving containers and goods, packaging, cross docking, freight forwarding and distribution to end customers.

7- *Equipment provider:* They manufacture, own or lease the physical infrastructure and assets needed to transport goods and supply transport infrastructure to logistics companies, transport providers, BCOs, IMCs, NVOCCs.

8- *Supplier/beneficial cargo owner (BCO)/ Importer/ Receiver/ Retailer:* They are importers of goods who take ownership of those goods when they are received, and they use their own logistics functions to take receipt, manage and transport goods.

9- *Warehouse and Distribution center/ Storage/ Distributors:* They store ingredients, raw materials, parts and finished products, and they are responsible for securing goods and storing them in an appropriate environment on behalf of suppliers; they also supply and distribute the goods to downstream organizations then the demand is there.

1.2.3 THE CONCEPT OF SUPPLY CHAIN MANAGEMENT

Even though it was previously implemented by numerous companies, the concept of Supply Chain Management (SCM) was formalized only in the 2000s and to this day it remains as one of the biggest paradigms shifts in modern business management: individual companies, in fact, no longer compete as autonomous entities, but rather as supply chains. In this competitive environment, the success of a business will depend on the management's ability to weave a network of business relationships (Lambert & Cooper, 2000).

The fundamental difference between traditional logistics and supply chain management is the level of analysis: the logistics function of the company in the first case integrates with the logistics functions of other companies, while in the second case the companies are linked with one or more business functions to one or more companies, creating a network. Furthermore, while the focus of SCM is competitive advantage, the main focus of logistics is to satisfy customer needs [4].

In October 1998, the Council of Logistics Management (CLM) announced a modified definition of logistics, and this exposes how logistics management is only a part of the SCM. The definition is as follows: "Logistics is that part of the supply chain process that plans, implements, and controls the efficient, effective flow and storage of goods, services, and related information from the point-of-origin to the point-of -consumption in order to meet customers' requirement ".

The globalization of production and the inclination of producers to supply themselves globally have meant that the focus of market competition is no longer between goods, but between supply chains that deliver goods; competition in the international market is increasingly linked to the speed and quality of delivery of goods to the final consumer, and for this reason an effective management of connection processes is crucial (Trkman, Stemberger, & Jaklic, 2005).

Supply chain management is part of this system, which examines and manages the network of supply chains of a company globally.

Also with regard to the SCM there are different definitions in the literature, such as the following, which refers to the SCM as "The management of a network of relationships within a company and between interdependent organizations and business units made up of material suppliers , purchasing, manufacturing, logistics, marketing and related systems that facilitate the back and forth flow of materials, services, finances and information from the original manufacturer to

the end customer with the benefits of adding value, maximizing profitability through efficiency and achieving customer satisfaction " (Stock & Boyer, 2009) Again, another definition state that "The whole purpose of supply chain and logistics management is to provide customers with the level and quality of service they need and do it at a lower cost for the entire supply chain " (Christopher, 2011). The Global Supply Chain Forum (GSCF) has developed the following definition: "Supply Chain Management is the integration of key business processes from end-user to original suppliers that provides products, services and information that add value to customers and other stakeholders".

1.2.4 SUPPLY CHAIN MANAGEMENT BUSINESS PROCESSES (Adapted from Lambert, Guinipero, & Ridenhower, 1998)

"Successful supply chain management requires a change from managing individual functions to integrating activities into key supply chain processes" The key supply chain processes identified by the members of Global Supply Chain Forum in order to reach an integrated supply chain management are the following: first of all, *customer relationship management* which has the aim of identify the key customer or customer groups that the organization targets as critical to its business mission; with those customers the company has to reach product and service agreements, specify the level of performance and together with them the company has to further identify and eliminate sources of demand variability. The second SC processes is *customer service management,* that is the key point of contact for administering the product/service agreement and provides the customer with real-time information on promised shipping dates and product availability through interfaces with the organizations' production and distribution operations. *Demand management process* is then necessary to balance customer's requirements with the firm's supply capabilities; part of managing demand involves attempting to determine what and then customers will purchase. The fourth SC process is *Customer order fulfillment process,* which requires integration of the firm's manufacturing, distribution and transportation plans; this is especially important with those key supply chain members and carriers, in order to meet customer requirements and reduce total delivered cost to the customer. Another process is the *manufacturing flow management*, in which the advantages of SCM are exploited through manufacturing processes that

enables flexibility to respond to market changes, orders that are processed on a just-in-time basis in minimum lot sizes and production priorities that are driven by required delivery dates. The *procurement process* enables long-term strategic alliances developed with a small group of suppliers, based on their contribution and criticality to the organization, and the win-win relationship between suppliers and company has to be reached. Moreover, the purchasing function develops rapid communication mechanisms such as electronic data interchange (EDI) and Internet linkages to quickly transfer requirements. The *product development and commercialization process* have the aim of integrate customers and suppliers into the product development process and to shorten the product life cycles, so that the right products must be developed and successfully launched in ever shorter timeframes in order to remain competitive. The last process is the *management of returns*, that enables identification of productivity improvement opportunities and breakthrough projects.

1.3 VULNERABILITIES OF THE SUPPLY CHAINS

Today's marketplace is full of uncertainty, instabilities and turbulence; in the last years, and exceptionally in the 2020, these turbulences tended to increase. Together with the chaos that the marketplace creates in the supply chains, the vulnerability of them to disturbance or disruption has increased. Many companies have experienced a change in their supply chain risk profile as a result of changes in their business models, so that organizations need to develop appropriate programs to mitigate and manage that risk (Christopher, 2011); In most sectors in fact, as automobiles, mobile phones, computer or any high-end technology products, the need for a shorter life cycles necessitate frequent introduction of new products in order to survive the industry (Sreedevi & Saranga, 2017). This results in significant uncertainties in the environment, which makes supply chains more complex (Merschmann & Thonemann, 2011).

Some of these risks are external to the supply chain and are called disruption risks, and some of them that are internal to the supply chain and are called operational risks: the first ones arise from interactions between the supply chain and its environment (Cranfield University, 2002), and refer to catastrophic events that are not totally controllable as fire, strikes, machine breakdown, terrorism and natural catastrophes (Lü˙ker, Seifert, & Biçer, 2019). On the other hand, the operational risks within the supply chain are caused by sub-optimal interaction and co-operation between entities along the chain and denotes the risk events that can be predicted and are more controllable such as quality and quantity problem or longer lead time (Chowdhury, Lau, & Pittayachawan, 2019).

For what concerns internal risks, the following issues foster the success in supply chain management: risk awareness among top managers, risk management as an integrated part of the SCM, each individual employee in each given time have risk awareness and understanding of his/her role in the processes and understanding that changes in business strategy change supply chain risk profiles. Also, at a tactical level, activities that could be carried out to handle and prepare for disruption are the risk identification process, risk assessment process, supply chain continuity management and co-ordination processes and processes to ensure learning from experiences (Cranfield University, 2002).

Quite a bit is known about what makes global supply chains so vulnerable, and following there is a framework of the most common risks or threat to a supply chain:

- *Focus on efficiency rather than effectiveness:* in many sectors the are significant opportunities to take out costs by focusing on inventory reduction; to do so, Just-in-time practices are adopted, and this method, exceptionally useful in stable market conditions, may become less viable as volatility of demand increases.[1] The focus on cost efficient supply chains is one of the reasons for supply chain's susceptibility to risks (Wong, Arlbjørn, Hvolby, & Johansen, 2006).

- *The intrinsic threat to globalization of supply chains:* Nowadays, supply chains are extended from one side of the globe to the other through offshore sourcing, manufacturing and assembly. The reason for this tendency is the reduction of costs, even if the result of these cost-based decisions is often higher levels of risk because of extended lead-times, greater buffer stocks potentially higher level of obsolescence.[1] Also, restrictions on the mobility of goods can make greater damages in the case of global sourcing: if limitations on cross-border flows or transportation impedances are in place, the threat to a global supply chain is enormous (Miller, Young, Dobrow, & Shojania, 2020).

- *Restriction on quality and availability in specific markets due to regulatory compliance failures:* This is a risk to availability of certain product in a supply chain, for example for those goods in industries regulated for public of consumer safety, such as medical products, aviation, automotive and telecommunication (Miller, Young, Dobrow, & Shojania, 2020).

- *Focused factories and centralized distribution:* the tendency toward producing in fewer sites is due to the scale economies that can be reached in manufacturing in greater volumes are produces, but as a result production costs are lowered but the product has to travel greater distances, often across many borders. By doing so, flexibility in manufacturing is lost, because those focused factories are designed to produce in very large batches to achieve maximum scale economies. Another tendency is then to centralize distribution, and to have few distribution centers[1]. Having few manufacturers bring the threat that in the case of an event affects a

single firm, such as disruption, there are risks of major disruption to product manufacturing (Miller, Young, Dobrow, & Shojania, 2020).

- *The trend toward outsourcing:* many companies in the past years have decided to outsource activities that were previously conducted within the organization; this idea has many attractions, but bears also several risks, as the failure of one of the links in the chain, and by definition, more complex the supply network the more links there are and hence the greater the risk of failure[1].

- *Reduction of the supplier base:* Another prevailing trend is to reduce dramatically the number of suppliers from whom an organization procure materials, components, services, etc. This bears some risks, as the possible supply chain disruption due to the failure of limited sources[1]; also, the enhancement in the supplier dependence increases the supply chain's susceptibility to risks (Hendricks & Singhal, 2005).

- *Volatility of demand:* market turbulences has increased and a consequent reduction in the predictability of demand has occurred. The demand volatility is due to numerous factors, as the shorter life cycles often driven by technology change, highest level of competitive activity leads to marketing-led disturbances to demand in many consumer markets and an increasing variety within product range. Also, many supply chains have in-built features which contributes to the "chaos" effect[1].

- *Lack of visibility and control procedures:* the visibility refers to the ability of all members of a chain to see from one end of the pipeline to another, and the lack of it forces supply chain members to rely on forecast and to build buffers which only worsen the situation. Supply chain control refers instead to respond to disturbances in appropriate ways; problems arise when disturbances are not recognized in time and when there is a time lag for the remedial action to take effect[1].

- *Scarcity of critical inputs:* if there is scarcity of a resource inputs, there is a higher risk of major disruption due to non-substitutability of resources or if tightly coupled production arrangements are in place, such as companies linked to the one who provide the inputs with just-in-time

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[1] This material is adapted from the Executive Report made by Cranfield University, on behalf of the Department of Transport, Local Government and the Regions (UK): Supply Chain Vulnerability, January 2002.

methodology or short cycle manufacturing contracts (Miller, Young, Dobrow, & Shojania, 2020).

- *Short-termism in sourcing activities:* There is a risk to availability of a product if his supply chains' sourcing activities do not prioritize long-term supply reliability, and instead focus on upfront costs, sole sourcing, poor contract management (Miller, Young, Dobrow, & Shojania, 2020).

Along with the operational and disruption risk, scholars are suggesting exploring a third category of risks, called extraordinary risks, which refers to epidemic or pandemic outbreaks (Paul & Chowdhury, 2020). There are three components of extraordinary risks that make them different from other SC risks: long-term disruption existence and its unpredictable scaling, the simultaneous disruption propagation in the SC, as the ripple effect, and the epidemic outbreak propagation among the population, and the simultaneous disruption in supply, demand and logistic infrastructure. Also, unlike other disruption risks, the epidemic outbreaks start small but scale fast and disperse over many geographic regions (Ivanov D. , 2020).

In the following paragraph the Covid-19 outbreak will be dealt in detail, and as an extraordinary risk, 94% of Fortune 1000 companies have reported seeing coronavirus-driven supply chain disruption [20].

1.4   THE COVID-19 OUTBREAK

In the December of 2019 the first cases of a novel human pneumonia case were reported in Wuhan City, China. Despite significant efforts to contain the spread of the virus, including a travel ban to and from eight cities in Hubei province, because of its contagiousness, COVID-19 has already spread globally. Since then, about half of humanity (c4.5bn people) was under some form of containment, and Covid-19 created the fifth pandemic after the 1918 Spanish Influenza.

SARS-CoV-2 is believed to be a spillover of an animal coronavirus and later adapted the ability of human-to-human transmission (Liu, Kuo, & Shih, 2020).

During the previous pandemics, the economies of developed states were not as interconnected as they are nowadays, and supply chains did not rely on international trade on such a scale (Veselovská , 2020).

The Covid-19 pandemic has been a global shock and the impact of it on the global supply chains has been massive (Ivanov D. , 2020); the baseline forecast envisions a 5.2 percent contraction in global GDP in 2020, the deepest global recession in decades. Over the longer horizon, the consequences of the covid-19 outbreak will bring to lower investment, an erosion of human capital through lost work and schooling, and fragmentation of global trade and supply linkages [5]. Following, Figure 1 show the proportion of economies with an annual contraction in per capita GDP, Data for 2020-21 are forecasts.
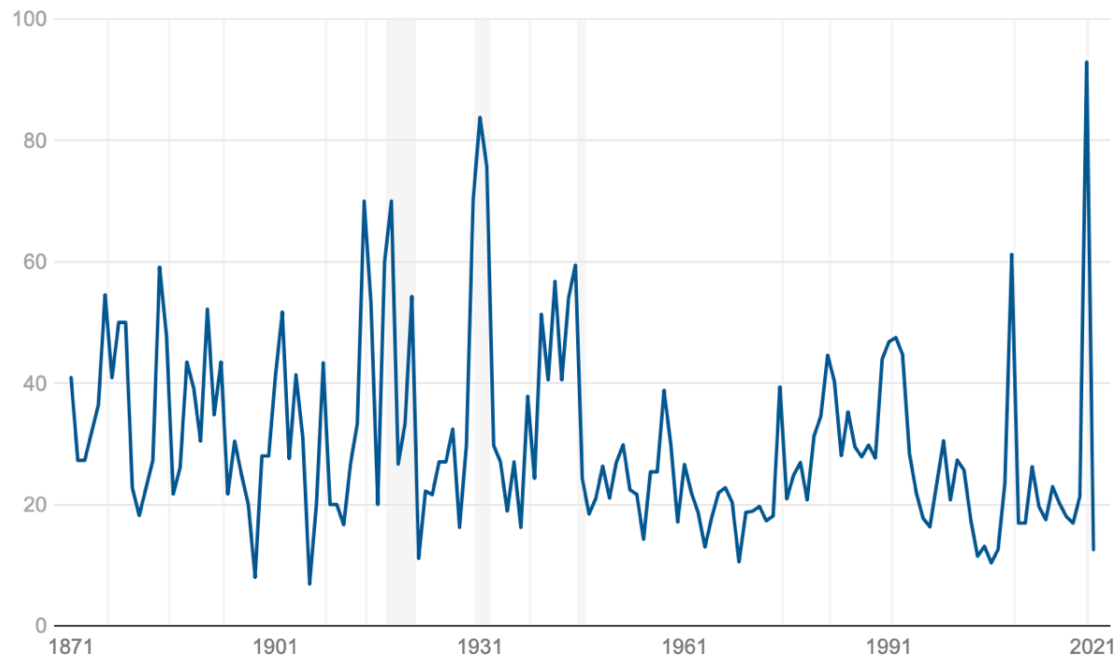
Figure 1 - Share of economies in recession, 1871-2021
(Source: World Bank, 2020)

The full impact of Covid-19 on supply chains is still unknown, however, for certain it will have global economic and financial ramifications that will be felt through global supply chains, from raw material to finished products (Deloitte, 2020).

The Covid-19 pandemic has three essential features that make it different than other recent virus outbreaks: firstly, it is a global phenomenon, and as the Imperial College COVID-19 Response Team stated, "last time the world responded to a global emerging disease epidemic of the scale of the current Covid-19 pandemic with no access to vaccines was the 1918–19 H1N1 influenza pandemic". Secondly, the effects of the pandemic have been both in the economic activity than of public health for most national economies; for this reason, policy impact aimed to address one of these effects typically exacerbate the other, and the estimated economic impacts to range between 2 trillion dollars and 4.1 trillion dollars[2] globally. The third feature that makes the 2020 pandemic unique is that the global economy is so inter-connected through global supply/value chains and international movements of people, capital, goods and services that no country is immune to the health and economic impacts of the virus, unless it is totally isolated from the rest of the world (Strange, 2020).

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[2] Reference: ABD Report NO 130, April 2020.

1.4.1 SUPPLY CHAINS DISRUPTION DURING COVID-19 PANDEMIC

The disruption of a supply chain can be defined as follows:

"combination of an unintended and unexpected triggering event that occurs somewhere in the upstream supply chain (the supply network), the inbound logistics network, or the purchasing (sourcing) environment, and a consequential situation, which presents a serious threat to the normal course of business operations of the focal firm"
(Bode and Mac Donald, 2017).

The definition above can be applied to the case of the Covid-19 event, in fact, according to a survey by the Institute for Supply Management, more than 80% of the companies involved in the survey believed, at the beginning of March, that they would have encountered difficulties, while at the end of the month this percentage has risen to 95% [6].

The pandemic has tested the ingenuity, resilience and flexibility of supply chains globally, as they have sought to maintain essential operations [7]. Also, the Covid-19 emergency has exposed the weaknesses in the global supply chains, once several operations have been impeded or their effectiveness was not possible, for some of the following event (Strange, 2020):

- People involved in the physical distribution of goods (truck drivers, pilots etc.) may be affected by the virus or may not be allowed to cross national borders

- Absenteeism of employees due to fear of being infected, because of quarantines, exposure to Covid-19, travel restrictions, school closures which will impact parents or young families who don't have alternative care options, or because of local containment policies. The local containment policies can also contribute to labor shortages and interruptions along the supply chain (Deloitte, 2020)

- International air or cargo travel has been reduced, due to which the average delivery times of companies globally have doubled: in Asia (by 222% for China, by 217% for Korea and 209% for Japan), in Europe (by 201%) and in the United States (by 200%) (Management, 2020)

- Social distancing and other health checks create delays at borders

- Many firms and governments have experienced shortages of key goods and services, as foreign suppliers have favored local markets or they have forced by their government in doing so, through export bans

- Volatile demand: In many countries, citizens first stocked up on basic necessities for fear of a potential supply problem in the future, and this is called panic buying. In addition to this, remote working, the lower purchasing power of consumers, the trend towards buying in bucks so to reduce the trips to the stores and the prevention and safety measures have caused a sharp drop in the demand for certain products and services (Deloitte, 2020)

- The epicenter of the Covid-19 emergency is in the nerve center of global trade (over 200 of the Fortune Global 500 firms have a presence directly in Wuhan); also, a study by Dun & Bradstreed estimates that 163 of the Fortune 1000 have Tier 1 suppliers (those they do direct business with) in the impact area, and 938 have one or more Tier 2 suppliers (which feed the first tier) in the same impacted area [8].

- Pervasive practice of Just in Time (JIT) supply chain management: about 2/3 of automotive industries are Just-In-Time intensive and also the personal protective equipment (PPE) sector strongly relies on that methodology. [9] As mentioned before, JIT is highly beneficial in stable market conditions, and the coronavirus pandemic highlighted how vulnerable and highly susceptible this concept is in time of crisis.

These factors have created the roots for a 13 to 32 percent reduction in global merchandise trade in 2020, as the World Trade Organization (WTO) stated; following in the Figure 2, is reported a chart showing the World trade merchandise volume.
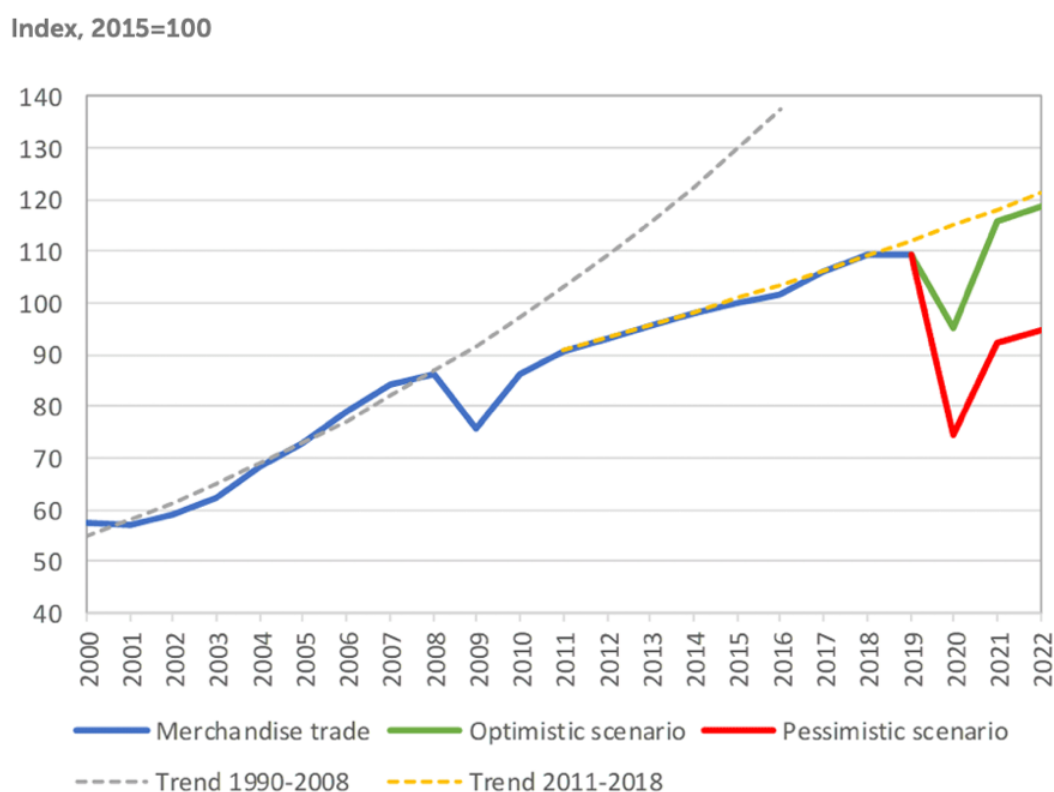
Index, 2015=100

Figure 2 - World Merchandise Trade volume, 2000-2022
(Source: WTO Secretariat, 2020)

1.4.2 PERSONAL PROTECTIVE EQUIPMENT AND MEDICAL DEVICES

PPE acts as a physical barrier that prevents healthcare staff from becoming contaminated with bodily fluids, and they gradually evolved as a mean of protection from pathogens.

PPE became standard practice when recommended in the 1970s, initially by the US Centers for Disease Control and Prevention, then their use was intensified, and universal precautions were introduced for the care of all patients after the human immunodeficiency virus (HIV) spread in the 1980s. Later on, universal precautions became known as standard precautions and are used as standard practice by healthcare staff to protect themselves from viruses such as hepatitis B and C. The emergence of severe acute respiratory syndrome (SARS) in 2003 emphasized the importance of PPE, particularly because 20% of those infected were healthcare workers. Then, the Ebola virus disease outbreak in West Africa in 2015 killed more healthcare staff than any previous Ebola outbreak (Brown, Munro, & Rogers, 2020).

Nowadays, personal protective equipment is defined by EU regulation 425/2016 and its function is to *protect the wearer* from health or safety risks; When used correctly, PPE act as a protection between infectious materials and the skin, mouth, nose or eyes. When used properly and in conjunction with other infection control practices such as hand washing and the use of alcohol-based hand disinfectants, it reduces the spread of infection from one person to another to a minimum.

On the other hand, the regulation governing Medical Devices is Directive 93/42/EEC, and it says that they guarantee the *protection of the patient* and should only be used as indicated by the manufacturer who defines its intended use.

In both cases, CE marking guarantees compliance with specific technical standards in order to protect the patient. There may still be some confusion due to the fact that some products can perform both functions at the same time, and the key point to keep into consideration is whether the main purpose of the device is to protect the wearer or to avoid external contamination [10].

With no licensed vaccine or effective antiviral therapies, the previous outbreaks underlined the role and reliance on PPE such as gloves, aprons, eye protection, masks and gowns that when used correctly function as a physical barrier to the transmission of infectious particles present in bodily fluids. It also protects patients from transmission via the contaminated hands or clothing of healthcare staff (Brown, Munro, & Rogers, 2020).


INTERNATIONAL TRADE IN MEDICAL SUPPLIES' SUPPLY CHAINS

Medical supplies market is a producer-driven value chain, based on business-to-business transactions, and the global trade is led by large vertically integrated multinational companies placed in advanced industrial economies with worldwide production facilities.

Between 2008 and 2018, the global trade in personal protective equipment has more than doubled in value, and the driver was a large surge in demand due to a rapidly aging population in both rich and middle-income countries and increase expenditure in healthcare in the developing world (Gereffi, 2020).

Following, the Figure 3Figure 3 - Global Trade Network of some PPEs, 2018 shows the trade network maps show high geographic and regional concentration in the PPE supply chain, and three clusters emerge: Asia, EU and the US; PRC

(People's Republic of China) appears to be the main producer and exporter many PPE and MD (as masks, gowns, protective suits and goggles) to Asia and the rest of the world. Malaysia followed by Thailand and PRC is the main exporter of surgical gloves in the world (ABD Briefs, 2020).
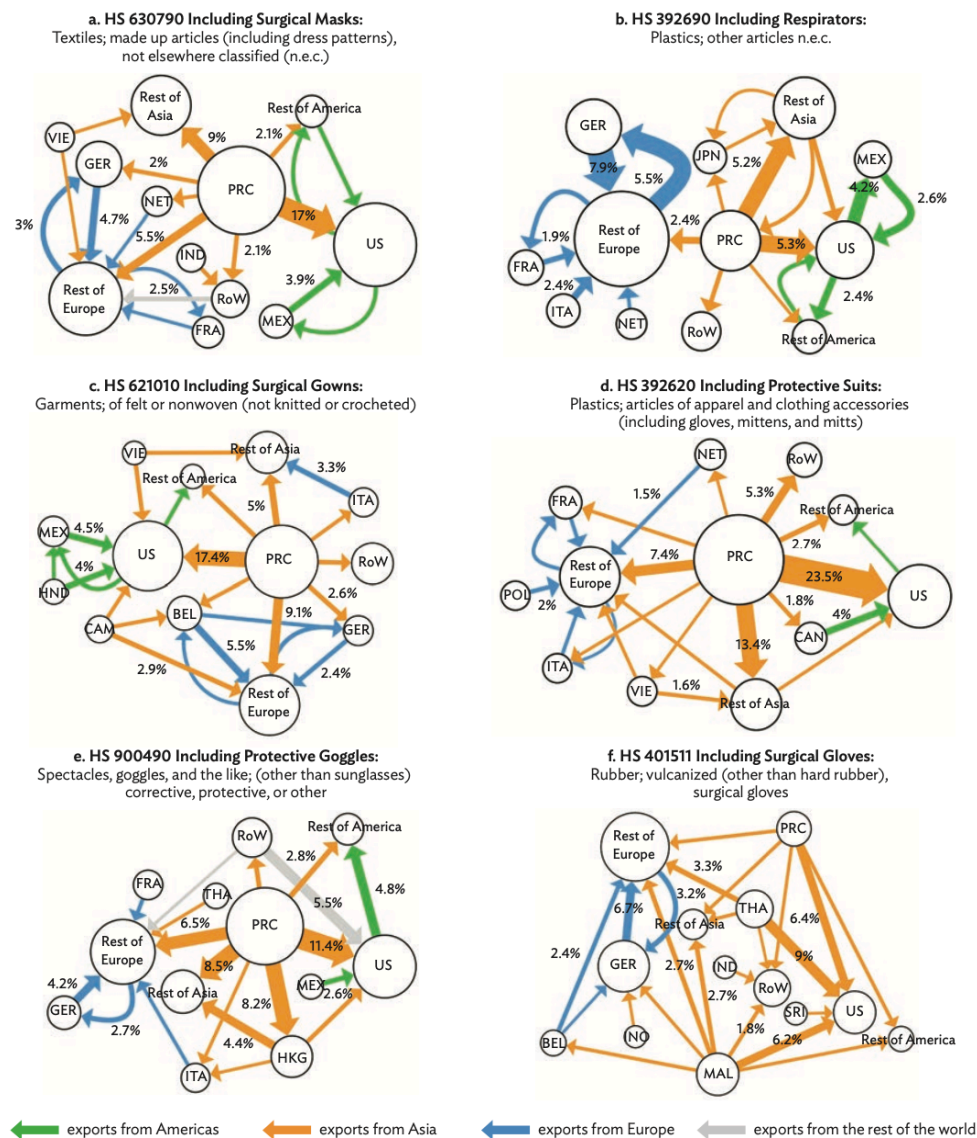
BEL = Belgium; CAM = Cambodia; CAN = Canada; FRA = France; GER = Germany; HKG = Hong Kong, China; HND = Honduras; HS = Harmonized System; IND = India; INO = Indonesia; ITA = Italy; JPN = Japan; MAL = Malaysia; MEX = Mexico; NET = Netherlands; POL = Poland; PPE = personal protective equipment; PRC = People's Republic of China; RoW = rest of the world; SRI = Sri Lanka; THA = Thailand; US = United States; VIE = Viet Nam; n.e.c. = not elsewhere classified.

Figure 3 - Global Trade Network of some PPEs, 2018
(Source: Asian Development Bank Calculations, 2020)

The main form of transmission for a respiratory virus as Covid-19 are the "respiratory droplets", when infected people sneeze or cough (OECD, Beyond Containment: Health systems responses to COVID-19 in the OECD , 2020); when the droplets are emitted, they transfer the virus by three contact methods ((World Health Organization, 2020)): droplets that are inhaled directly are referred to as airborne, droplets that land on an individual's hand or body and are then transferred to the face are contact and droplets that land on a surface and then are transferred are referred to as fomites.

According to estimates by the World Health Organization (WHO), the global healthcare sector will need 89 million masks, 76 million gloves and 1.6 million goggles per month to deliver an appropriately response to the COVID-19 pandemic globally– in order to meet these numbers, the WHO estimated and asked that the healthcare supply industry increase its production of PPE by at least 40%.

Without proper personal protective equipment and medical devices, healthcare workers are more likely to become ill, and a decline in the supply of healthcare due to worker illness combines with intensified demand for care cause the healthcare infrastructure to become unstable; although sick healthcare workers also contribute to viral transmission and increase the demand for care while simultaneously reducing the health system capacity (Cohen & Rodgers, 2020).

The demand of PPE all over the world has surged during the Covid-19 emergency, disrupting the global supply chain of these goods, putting lives at risk and showing how fragile the health supply chain is, for a number of reasons (ABD Briefs, 2020).

Features related to the characteristics of the PPE/MD supply chain and which played a role in the disruption are the following:

- **JIT Business Model: Lower Inventories for everyone in the health supply chain**

In recent decades the expansion of globalization has encouraged the adoption of lean production and Just-in-Time supply chains for personal protective equipment and medical devices encouraging players along the supply chain to

reduce inventories as much as possible in order to lower operating costs and the amount of cash tied up in inventory. This approach is used also from the most vulnerable and important players in the health supply chains hospitals, who choose to adopt the JIT approach to purchase items such as N95 masks as a cost-saving mechanism (Gereffi, 2020); the supply chain manager at Mercy Hospital in Chicago stated that JIT purchasing can really add up, and that the hospital say a 50 percent drop in on-hand inventory in 2014 (with respect to 2015) [11].

- **Scarcity of critical inputs**

The surge in demand for PPE as N95, protective suits and surgical masks has led to a shortage of a key component, nonwoven fabric manufactured with polypropylene. Whereas Polypropylene is one of the most commonly produced plastics in the world and, as a polymer deliver from oil, can be easily supplied, and the manufacture of PP non-woven fabric is also quite widespread, the Polypropylene electret melt-blown non-woven is a specialized fabric, produced by a limited number of companies globally because of the high initial investment required in machinery. For this reason, it has been difficult to increase supply during the crisis and also to find companies that can switch to this production within a reasonable time (it takes about half a year at least to assemble a single machine production line to make melt-blown fabric in normal times[3]) and without massive investment [12]; The low number of producers means that in the case of disruption or decisions of these few companies there is a great risk of disruption of the entire chain following them (Miller, Young, Dobrow, & Shojania, 2020).

- **Geographic concentration of the manufacturers**

As shown before, Asia is producing most of the PPEs used globally, and China used to produce half of the world's masks4; this characteristic of the personal protective equipment supply chain contributed to the disruption of the supply chain principally for three reasons:

1) *Export bans*: Nonetheless PRC was the first country affected by the Covid-19 emergency, and in response to demand, China's government restricted its PPE exports, and purchased a substantial portion of the global supply. These shocks contributed to an enormous disruption to the global supply chain of PPE; Afterwards export bans were imposed

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[3] (ABD Briefs, 2020)
[4] (Sharma, Gupta, & Jha, 2020)

in various economies, as: Bangladesh, Canada, Czech Republic, Egypt, France, Germany, India, Indonesia, Iran, Japan, Jordan, Kazakhstan, Kenya, Malaysia, Pakistan, Poland, the Russian Federation, the Republic of Korea, Taipei, Thailand and Ukraine (ABD Briefs, 2020).

2) *Transport restrictions during emergency*: The Covid-19 related restrictions as roadblocks and quarantine measures gave caused port congestion and delays in cargo loading/unloading, undermining region's maritime supply chain and connectivity. Although the pandemic has reduced the shipping demand and port traffic, shipping continued to play a key role in the global supply chain, transporting essential goods, as personal protective equipment and medical devices, especially from Asia (United Nations ESCAP, 2020).

    A survey conducted by "Shipping and Freight Resource" interviewing more than 300 operators in the logistics and freight transport sector to measure the effect of the coronavirus pandemic on global supply chains, showed that 70% of respondents reported a drop in volumes, 61% were affected by transit delays, 50% by port delays and 40% by capacity problems (Agostino, Caballini, & Della Chiara, 2020).

3) *Unique sourcing*: (Zhu, Chou, & Tsai, 2020) Many companies and governments, relied upon China for what concerns key inputs for the medical industry's supply chain, and during emergency they could not acquire sufficient raw materials for their business, and they have learnt the hard way of heavily relying on China's economy. Many CEO's requested for their supply chain teams to find other sources wholly independent of China, but it still remains the most popular as a manufacturing location due to its huge and expanding domestic market, competent labor, the entrenched supplier ecosystem, as well as the government's continued assistance towards manufacturers and the establishment of dependable infrastructure; Professor Yossi Sheffi from MIT states that "Chinese medical products are difficult to be replaced as they are cheap and of good quality"[13].

    The lack of information and transparency in the medical supply chain resulted in many problems during the emergency, and supply chains closer to home could allow an unprecedented amount of information that can be used towards the allocation, prioritization and distribution

of medical supplies, and also alleviate shortages given that several bottlenecks can be eliminated.

1.5 RESEARCH GAP

The thesis work aim is to study in depth the supply chain of personal protection devices and medical devices before the Covid-19 emergency and the criticalities that companies are suffering during the pandemic and which have led to deficiencies down the supply chain, through a questionnaire.

The impact of the pandemic on the supply chain of both for an essential good, that are those who are absolutely necessary for the population to survive and to remain healthy even amid pandemic, such as medical supplies and food [24], and a non-essential good, that are those who are not essential to a populations' survival and can be stopped or closed down during a pandemic [24], will be analyzed along this paragraph, in order to describe a picture as complete as possible on the consequences on the supply chains of Covid-19.

For what concerns essential goods, together with the in-depth analysis done in the paragraph 1.4.2 regarding the personal protective equipment/medical devices supply chain, the food & beverage sector will be studied along this paragraph, as is key for the population to remain during a pandemic (Singh, Kumar, Panchal, & Manoj Kumar, 2020).

Also, the automotive sector is the most impacted sectors by the pandemic, with a global output that is expected to drop by 13% (Baker McKenzie Report, 2020), that is the one studied in the following paragraphs.

The final aim is to demonstrates how the thesis work fits into the present literature in order to contribute to fill a gap in the research regarding the health sectors' supply chain disruption due to the pandemic. In fact, in the most impacted sectors, such as Food and Beverage and Automotive sector a work similar to that which the thesis aims to do has been already carried out.

1.5.1 FOOD AND BEVERAGES SECTOR

The Covid-19 has impacted the entire food and beverages (F&B) supply chain, from farm field to consumer; even if is not the first global health pandemic to occur, it is taking place in a context marked by unprecedented increases in population size: as such, demand for large volumes of products has put enormous amounts of pressure on the F&B industry [14]. Even if food supply chain has shown remarkable resilience [17], the pandemic has reminded the world how dependent we are on a well-functioning global food value chain and

how vulnerable we are to disruption in this key sector (Elleby, Domínguez, Adenauer, & Genovese, 2020). The literature for the F&B supply chain amid pandemic is extensive, and in the reminder of this paragraph the up-to-date research on the theme is eviscerated.

Since the effects of Covid-19 on the F&B supply chain change upon the specific good and the country, several were the research based on a case study from a particular State.

A case study on the food supply chain in Wuhan during pandemic, done through a quantitative analysis of the data of a survey sent to food suppliers in Wuhan, showed how the social distances and prevention measures of the Covid-19 pandemic had negative impact on food supply chain, and about 83,1% of food suppliers experienced a decrease in revenues (Min, Zhang, & Li, 2020). Moreover, a research conducted on the US Lettuce supply chain shows the reasons of the disruption that happened along the chain and offer recommendations for a more resilient supply chain (Locker, 2020).

India, a country that implemented one of the most stringent lockdowns to contain the virus, has had a food supply chain disruption over the 2020, and the long-distance food supply chains have been hit the hardest during the pandemic, with welfare consequences for urban consumers and farmers (Mahajan & Tomar, 2020); a case study on Uttar Pradesh, an Indian state, identifies and analyzes the different factors that contributed to the severe disruption of the farming chains and the agricultural sector, though a questionnaire (Kumar , et al., 2020). An online questionnaire about the disruption of the supply chain was sent to the stakeholders in the shrimp aquaculture sector in India, in order to understand the impact on the sector (Kumaran, et al., 2020). Also, a research studied the key indicators for monitoring the food supply chain disruption in a developing country like Bangladesh (Amjath-Babu, Krupnik, Thilsted, & McDonald, 2020). Another questionnaire was sent to companies working on the F&B sector in South Africa, in order to understand the impacts that the pandemic had on the daily operations, and the results showed high levels of supply chain disruption, with the 50% of those who previously sourced out of South Africa seeking local sourcing due to supply chain interruptions (Telukdarie, Munsamy, & Mohlala, 2020). A research studied the animal welfare and the livestock supply chain sustainability over the Covid-19 outbreak, finding significant disruptions occurred in livestock, milk and meat supply chains (Hashem, González-Bulnes,

& Rodriguez-Morales, 2020). An analysis on the shocks on demand-side and supply-side of the food supply chain in Canada assessed the mayor sources of disruption in the country (Hobbs, 2020).

A survey was released from the EU Science Hub, which targets companies and businesses (including small enterprises and farmers) active in the production, distribution, processing, wholesale or retail stages of the agri-food supply chain; The aim is to investigate the resilience, constraints and responses of operators to COVID-19, all along the chain; the survey is available in all the 24 EU official languages [19].

The major and widespread bottlenecks and instabilities that the food supply chain had to face globally during the healthcare emergency were also studied in detail by the literature, and they were related to the following areas:

- **Inputs Bottlenecks:**

Labour has been a bottleneck for those rings of the supply chain that depends on seasonal workers and who are labour intensive, as fruits and vegetables, meat processing or packaged-goods companies: limits in the mobility reduced the availability of seasonal workers for planting and harvesting in various countries (OECD, Preliminary Report: Evaluation of the Impact of the Coronavirus (COVID-19) on Fruit and Vegetables Trade, 2020; Stephens, Martin, Van Wijk, & et al., 2020), whereas reduction in workload was due to shortages of workers due to sickness and lockdown measures. This is a particularly felt problem for farmers, in fact, considering as example the US market, only three in ten workers in the US agricultural workforce are borne in or are citizen of the US, while the rest are born in other countries and many are in the US on agricultural visas [15]; these workers due to Covid-19 pandemic may be difficult to find, because of travel restrictions or because they avoid close-quarters activities to reduce their own risk (Felix, Martin, Mehta, & Mueller, 2020).

In confined spaces such as packing plants for fruits and vegetables or meat processing facilities there has been the necessity to reduce operations in order to ensure adequate protections of employees (Aday & Aday, 2020). Also, concerns around pesticides were raised from several countries, as Brazil, because China is their largest supplier of raw materials for the production of pesticides [16].

- **Transportation problems:**

The global transportation for food is highly segmented across bulk, as ships and barges, container, truck and air freight (Schmidhuber & Bing, 2020); due to the

pandemic, governments have made significant restrictions in the transportation of goods, and reports show that using the trucks for food distribution was declined to 60% since the restriction in France ((FAO, 2020); (Bakalis , Valdramidis, Argyropoulos,, & et al., 2020), however, the bigger disruption happened in air freight, as a consequence of the steep decline in passenger air travel, which normally accounts for the majority of air cargo capacity [17].Fruits and vegetables, as other perishable high value products, were more impacted by transport and logistics problems, also because the perishability is affected by quarantine measures and delays in border inspection ((OECD, Preliminary Report: Evaluation of the Impact of the Coronavirus (COVID-19) on Fruit and Vegetables Trade, 2020); (FAO, 2020); (Shahidi, 2020)). These conditions retarded the delivery of food and agricultural inputs, creating problems in providing continuous food supply to markets (ILO, 2020).

- **Demand and consumer behaviors shift**

The healthcare emergency has led to a shift in consumer demand and behavior across the globe for what concerns food purchasing and consume, requiring important changes in the way food supply chains operate [18]; for many, covid-19 preventive measures interrupted the daily routine, resulting in boredom, stress and modifying the eating habits (Muscogiuri, Barrea, Savastano, & et al., 2020) and resulting in an unusual demand shift from food service to retail. Food-service distributors have been significantly affected by the switch to takeout only, and the challenge for them is to rebalance supplies with outgoing orders, managing the overcapacity in their storage facilities and distribution network (Felix, Martin, Mehta, & Mueller, 2020). Also, export restrictions enforced by major exporting countries and the following panic buying from customers caused a significant rise in food price for certain items (EDP, 2020).

Also, in a study on eighteen countries, it was shown that food buying behavior on the consumers changed, as they prefer to consume healthy foods, but at the same time to achieve this without exceeding their budget; also, many consumers are looking for food products to improve their mood during the pandemic (Aday & Aday, 2020). These shifts in consumers demand are exceptionally felt by consumers & packaged-goods companies, who faced increase in demand for certain product types (i.e., long-life foods) and packaging types (i.e., smaller sizes for home consumption); these kinds of companies have still to face the dilemma of how to approach demand peaks and what demand scenario to prepare for

(Felix, Martin, Mehta, & Mueller, 2020). A study analyzed how the global event of the Covid-19 changed the demand for food worldwide, and the amount of that change (OECD, 2020), whereas a study on the behaviors of the Italian population food choices was monitored under the covid-19 quarantine, showing great amount of changes respect to prior the pandemic (CREA (The Council for Agricultural Research and Economics), 2020).

- **Just-in-Time approach**

The food distribution system is built around just-in-time manufacturing and delivery, and the sudden and unexpected spike in demand across key categories created short-run stockouts (Mussell, Bilyea, & Hedley, 2020).

As it can be understood from the paragraph, the literature concerning F&B supply chain disruption due to Covid-19 is wide and varied: there is a part of the literature linked to case studies of a specific country, region or the type of food considered, and another more generic linked to the reasons for the global disruption; following, in Table 1, a summary of the topics covered by the literature mentioned in the current paragraph is presented.

Table 1 - Literature review F&B supply chain amid pandemic summary

Topics covered	Bibliographic references
Impacts on global agricultural markets of the Covid-19 pandemic	(Elleby, Domínguez, Adenauer, & Genovese, 2020); (Min, Zhang, & Li, 2020)
Disruption of the lettuce supply chain amid pandemic	(Locker, 2020)
Indian food and beverages supply chain disruption	(Mahajan & Tomar, 2020)
Case study of the Uttar Pradesh agricultural supply chain disruption amid pandemic	(Kumar , et al., 2020).
Disruption of the shrimp aquaculture supply chain in India amid pandemic (through a questionnaire)	(Kumaran, et al., 2020).
Key indicators of the disruption of the food supply chain in Bangladesh	(Amjath-Babu, Krupnik, Thilsted, & McDonald, 2020)
Impacts of the pandemic on the daily operations of companies in the F&B supply chain in South Africa (through a questionnaire)	(Telukdarie, Munsamy, & Mohlala, 2020)

Livestock supply chain sustainability and disruption amid pandemic	(Hashem, González-Bulnes, & Rodriguez-Morales, 2020)
Canadian supply chain disruption of the F&B supply chain	(Hobbs, 2020)
Bottlenecks in the global F&B supply chain amid pandemic	(OECD, Preliminary Report: Evaluation of the Impact of the Coronavirus (COVID-19) on Fruit and Vegetables Trade, 2020; Stephens, Martin, Van Wijk, & et al., 2020); (Felix, Martin, Mehta, & Mueller, 2020); (Aday & Aday, 2020); (Schmidhuber & Bing, 2020); (FAO, 2020); (Bakalis , Valdramidis, Argyropoulos,, & et al., 2020); (ILO, 2020); (Muscogiuri, Barrea, Savastano, & et al., 2020); (Felix, Martin, Mehta, & Mueller, 2020); (EDP, 2020)
Population food choices amid quarantine (questionnaire to Italian population)	(CREA (The Council for Agricultural Research and Economics), 2020).

1.5.2   AUTOMOTIVE SECTOR

The impact of Covid-19 on the automotive sector has been unprecedented, even if the automotive supply chain was experiencing turbulence and disruption in recent years due to a combination of regulatory, environmental, political, economic and technological factors (KPMG Report, 2020). The industry's annual turnover is equivalent to the world's sixth larger economy, and now is facing a sharp drop in demand and investment, together with a supply chain disruption (International Labour Organization (ILO) Brief, 2020).

The number of non-scientific articles published online about Automotive supply chain disruption amid pandemic is broad, whereas the scientific research papers on the argument are just a few and are discusses below while the major criticalities and bottlenecks that the automotive supply had to face along the 2020 are explained:

- **Production facilities of components shutting down**

Wuhan, the city where the first Covid-19 outbreak occurred, is known as "motor city", as it is home to auto plants as General Motor, Honda Motor, Nissan Motor, the Peugeot Group, Renault and Toyota Motor; moreover, more than the 80%[5] of the world's automotive supply chain is linked to China. Production in Wuhan and in most of China stopped first, followed by the rest of the world, and it is estimated that factory closures in Europe and North America have caused 2.5 million passenger vehicles to be removed from production schedules (International Labour Organization (ILO) Brief, 2020). Also, once the government guidelines allow the reopening of the production lines, site managers will have to follow protocols in place to ensure the right safety precautions, such as social distances between workers, so that the productivity of a line would be compromised.

- **Outsourcing-related problems**

Automotive supply chains stretch across multiple geographies, which will be at different phases of the pandemic and whose governments may have different stances towards opening up economies (KPMG Report, 2020); this, together with the legal and trade restrictions, such as closed borders, increase the shortage of

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[5] (KPMG Report, 2020)

required parts and limited distribution of supplies (Accenture Report, 2020) and creates the room for disruption of the automotive supply chain, which is composed by a sheer number of components, including modules and subassemblies, most of them from China (Ishida, 2020). In fact, as Kristin Dziczek[6] stated "Even a disruption of one part of the supply chain could depress some U.S. auto production. We need all the parts to make a car, we can't do it with 99.9%".

- **Just-in-Time Inventories management**

China is the world's main supplier for intermediate inputs for manufacturing companies, and a decline in output and exports from China is having direct impact on many automotive companies, for whom the limited use of inventories and the heavy reliance on Just-in-time manufacturing is resulting in shortages that are affecting their production capabilities and overall exports (International Labour Organization (ILO) Brief, 2020). In fact, even if the production were to continue, in many cases the just-in-time nature of the auto industry means production would halt as the result of suppliers stopping operations because they were left without the parts to complete their production schedule [21].

- **Suppliers' specific knowledge**

Automotive components are typically sophisticated, intricately engineered, and most of them are manufactured by Chinese suppliers [22], and with these suppliers having to close down or being unable to resume sufficient production capacity, many downstream companies are forced to seek alternative suppliers. However, there have been challenges during the pandemic in seeking suppliers that could meet specifications and quality requirements. As a result, downstream enterprises may find themselves unable to meet contractual commitments or resume sustainable operations (Baker McKenzie Report, 2020).

In addition to the literature presented, a global research survey was sent to 1'181 companies across six sectors (automotive, IT, tech and telecoms, machinery and equipment, chemicals, energy and utilities, and agri-food) about their experiences with disruption and their plans to make their supply chains more resilient [23].

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[6] Vice President at the Center for Automotive Reseach

Following, in Table 2, a summary of the topics covered by the literature mentioned in the current paragraph is presented.

Table 2 - Literature review of the Automotive sector amid pandemic summary

Topics covered	Bibliographic references
Automotive sector' global supply chain impact of Covid-19	(KPMG Report, 2020); (International Labour Organization (ILO) Brief, 2020)
Problems and bottlenecks in the Automotive supply chain amid pandemic	(KPMG Report, 2020); (International Labour Organization (ILO) Brief, 2020); (Accenture Report, 2020); (Ishida, 2020); (Baker McKenzie Report, 2020)

1.5.3 PERSONAL PROTECTIVE EQUIPMENT AND MEDICAL DEVICES SECTOR

The existing literature dealing with the impact of covid-19 on the supply chain of personal protective equipment is relatively broad, as shortages in this market have impacted the healthcare system of many countries, but also narrow in the elements considered by the research. Much of the studies that has been done on the subject analyzes the global PPE supply chain and the threats that became reality with the global pandemic in 2020 because of intrinsic characteristics of the PPE/MD supply chain ((ABD Briefs, 2020); (Woolley, Smith, & Arumugam, 2020); (Miller, Young, Dobrow, & Shojania, 2020); (Gereffi, 2020); (Zhu, Chou, & Tsai, 2020); (United Nations ESCAP, 2020)), and the outcomes are reported in the paragraph 1.4.2. Other works analyze the situation of a particular country, commenting on the government's response to the emergency and seeking solutions where mistakes have been made: the first of these research articles gives insights on the challenges, solutions and recommendations, related to the health supply chain to developing countries like India amid pandemic; the authors state that some solutions for companies that operate or have business relations in China and other impacted countries are: Educate employees on COVID-19 symptoms and prevention, reinforce screening protocols, prepare for increased absenteeism, restrict non-essential travel and promote flexible working arrangements, align information technology (IT) systems and support with evolving work requirements, prepare succession plans for key executive positions and focus on cash flow. On the other hand, for companies that produce,

distribute or source from suppliers in China and other impacted countries, steps may include: Enhance focus on workforce/labour planning, focus on Tier 1 supplier risk, illuminate the extended supply network, understand and activate alternate sources of supply, update inventory policy and planning parameters, enhance inbound materials' visibility, prepare for plant closures, focus on production-scheduling agility, evaluate alternative outbound logistics options and secure capacity and conduct global scenario planning (Sharma, Gupta, & Jha, 2020). A second work analyzes the US government response to the PPE shortages, saying that the four-contributing factor to it are the way that hospitals budget for PPE, domestic demand shocks, federal government failures and disruption to the global supply chain of these goods (Cohen & Rodgers, 2020).

A research based on the US critically analyzed the differences between the Covid-19 pandemic and previous ones, identifying areas for improvement in the coordination between the public and private sectors in order to manage the use of personal protective equipment and its supply (Patel, et al., 2017). An Italian research analyzes the government's management of personal protective equipment / medical devices, and the preparedness plan to avoid disruption that each country has for a pandemic (Ranieri de Maria, 2020). An international questionnaire was sent to workers in the health sector, with the aim of knowing the availability and use of PPE in the treatment of patients with Covid-19 in intensive care; respondents report widespread shortages and reuse of single-use PPE items, while half of the respondents had never had fit-testing of masks (Ramanan, et al., 2020). Another survey it has been sent to surgeon in England, regarding the availability of PPE during their work amid the Covid-19 emergency, and over half of them (57%) have experienced shortages of personal protective equipment during the month of April (Rimmer, 2020). A further multinational survey was sent to evaluate PPE preparedness across intensive care units in six Asia-Pacific countries during the initial phase of the coronavirus disease, finding that most ICUs from the countries considered showed good awareness of the WHO PPE guidelines by either conforming or exceeding the recommendations (Rajamani, et al., 2020).

Another report analyzes how the public health authorities have been trying to contain and mitigate the spread of the coronavirus SARS-CoV-2, investigating the four key measures- operational, financial, and R&D that are needed to provide effective patient care and reduce the pressure on health systems to

manageable levels (OECD, Beyond Containment: Health systems responses to COVID-19 in the OECD , 2020). A report is aimed to improve supply chain performance during a pandemic through the correct exploitation of Sales and Operations Planning (S&OP) practices that Covid-19 forced, especially for those supply chain that have been disrupted during 2020 as the PPE/MD one: the need to use Outside-in processes focused on consumption and the necessity of a better implemented demand planning practices (Cecere & Denman, 2020).

Several articles found solutions to the problems that the Global Healthcare supply chain highlighted during the pandemic, as the need of a "Vision test" and of data transparency among different countries, public-private partnerships to ensure agility in responding to demand shocks and the necessity for the government agencies and businesses to booster the investment in AI and digital transformation (Padula, Dai, Zaman, & Davidson, 2020). Also, another research state that US Congress should require all major PPE manufacturers (for example, those with US market shares > 10%) to undergo stress testing, that would be critical to ensuring that PPE manufacturers can ramp up domestic production capacity within a reasonable period of time (Dai, Bai, & Anderson, PPE Supply Chain Needs Data Transparency and Stress Testing, 2020). An in-depth interview with a UK biomedical SME based in Shanghai, China is aimed to inform future procurements of PPE and to depict the current Covid-19 pandemic and PPE crisis in the UK (Harvey, 2020).

Following, in Table 3, a summary of the topics covered by the literature mentioned in the current paragraph is presented.

Table 3 - Literature review PPE/MD supply chain amid pandemic summary

Topics covered	Bibliographic references
Bottlenecks in the global supply chain of PPE/MD amid pandemic	(ABD Briefs, 2020); (Woolley, Smith, & Arumugam, 2020); (Miller, Young, Dobrow, & Shojania, 2020); (Gereffi, 2020); (Zhu, Chou, & Tsai, 2020); (United Nations ESCAP, 2020)
Analysis of the government response to Covid-19 global supply chain disruption of PPE	India: (Sharma, Gupta, & Jha, 2020) Us: (Cohen & Rodgers, 2020)
Review of the lesson learnt from the previous viruses outbreaks and improvement of the readiness of PPE for future responses	(Patel, et al., 2017)
Characteristics and errors of health management of the COVID-19 pandemic in Italy	(Ranieri de Maria, 2020)
International questionnaire to health workers regarding the availability, training and use of PPE amid pandemic	(Ramanan, et al., 2020)
Survey to surgeons in England regarding the availability of PPE during April 2020	(Rimmer, 2020)
Survey to six Asian countries to assess preparedness in the ICUs treatments	(Rajamani, et al., 2020)
Measures used by the health authorities to contain the spread of the Covid-19	(OECD, Beyond Containment: Health systems responses to COVID-19 in the OECD , 2020)
Sales & Operations Planning practices amid pandemic	(Cecere & Denman, 2020)

Solutions aimed to fix the global supply chain of PPE in case of another emergency	(Padula, Dai, Zaman, & Davidson, 2020); (Dai, Bai, & Anderson, PPE Supply Chain Needs Data Transparency and Stress Testing, 2020); (Harvey, 2020)

Even if the topic is new, several researches have been done regarding the PPE/MD supply chain disruption; however, the specific impacts of the pandemic on the firms and the difficulties faced by individual companies positioned in different echelons of the supply chain of personal protective equipment due to the Covid-19 emergency are still unknown.

The thesis work focuses on a survey whose questions aim to analyze how daily work has changed, the reasons behind the change and the problems that occurred in the part of the supply chain to which a certain company belong to, due to pandemic. The companies to which the questionnaire was administered manufacture, import or distribute personal protective equipment or medical devices to combat the SARS-CoV-2 coronavirus.

The study is meaningful in order to understand the reasons for shortages and delays in the delivery of the goods considered, such as masks, gloves, protective suits and visors, which have caused severe consequences on public health.

The Producers, distributors and importers contacted are from three countries, in order to have a complete view of the national market of Italy, the United States and China. Furthermore, as for Italy there is no existing published literature to date specific for its case on the reasons for the shortages of personal protective equipment due to problems in the supply chain, the thesis work is particularly interesting. Understanding the weakest points in the private sector PPE supply chain is critical to stemming them and making the supply of these essential goods secure in order not to have further shortages in the current health emergency and in the event of a future health emergency.

2 BUILDING THE SURVEY

In the course of the present chapter, it will be described the research performed in order to find players in the reference market and the methodology undertaken in order to write the questions of the survey, so that the answers would give useful information for the purpose of the thesis and could be used to perform statistical analysis.

2.1 SAMPLE DESCRIPTION

The companies investigated for the purpose of the thesis are of two categories: the formers are part of the market of personal protective equipment used to protect the individuals from Covid-19 external pathogens, and the latter are part of the market of medical devices used to protect other people from possible pathogens from the individuals who use them. From the companies of the market of the personal protective equipment's or medical devices must be removed and not considered all those companies that treat other assets outside of those for the battle against the Covid-19, as companies that deal with medical devices such as technical equipment, diagnostic, biomedical, electro-medical, or companies that deal with personal protective equipment such as safety shoes, work gloves or protective helmets. Both companies that were in the personal device market before the health emergency and companies that reconverted during the pandemic were reached.

Companies from Italy, China and US were contacted, as it has been said in paragraph 1.5.3, there is no in the up-to-date literature a case study on Italy to understand the shortages of DPI/ DM occurred during the emergency, and this work thesis aim is also to fill this gap. Then, the United States and China are, for different reasons, two countries that are key in the fight against Covid-19 through personal protective equipment and medical devices.

On one hand, China is the largest producer of raw materials and finished products for the defense against the virus, while the United States is at the same time a productive force but also the country where serious problems have been encountered in the PPE/DM supply chain. In fact, the United States was ranked first as a country prepared for a pandemic according to the WHO, but at the beginning of the crisis due to Covid-19 the federal government's Strategic

National Stockpile included 12 million N95 masks and 30 million surgical masks, about 1% of the 3.5 billion required in the U.S. in the first year of the pandemic [24]. Moreover, in the US, the shortages of personal protective equipment/ medical devices and other critical health care supplies for dealing with the pandemic in the United States still haven't been solved (Nd. Referred to the 17th of September 2020) [25].

For these reasons while importers, distributors and producers from Italy were contacted, for United States and China has been decided to contact only the producers, in order to interrogate them on the criticalities felt from the first link of the supply chain.

For the three countries several Government or Regional databases were used to find the name of the companies in the desired industry:

- *Italy*: Lists of personal protective equipment companies authorized to sell by Inail[7][26], lists of authorized suppliers by ASSOLOMBARDA[8][27], lists of companies authorized to produce DPI during emergency by Istituto Superiore di Sanità [28], list of companies that have received economic incentives to expand their production or to convert to DPI from the decree Curaitalia [29], List of suppliers/producers provided by Confindustria's PGE program[9] [30], list of suppliers of DPI by FNO TSRM e PSTR[10] [31], list of producers of PPE in the Tuscany territory by Fondazione ISI [32], CNA Reggio Emilia list of companies in the PPE/DM market [33], CNA Lombardia list of producers of PPE/DM [34], CNA Pisa list of companies of the territory that provide PPE/DM [35], List of companies who are willing to produce surgical masks by Regione Campania [36], List of PPE companies published by Confcommercio Treviso [37], list of companies of PPE associated with Lapam Federimpresa of Modena and Reggio Emilia [38] and list of suppliers of DPI by University of Pisa [39].

- *United States:* List of West Michigan PPE manufacturers, Manufacturers association for PPE

- *China:* List of authorized manufacturers of PPE/MD released by the Chinese government

2.2   SAMPLE SIZE

In order for the sample to be *representative* of the population, some variables must be identified:

1- *Population*: entire group about which some information is required to be ascertained (Banerjee & Chaudhury, 2010), in the case in question the population consists in companies whose import, export, produce or distribute PPE and/or DM for the protection against Covid-19 within a given country. Those goods are surgical masks, N95 masks, surgical gloves, examination gloves, coveralls/gowns and goggles/face shields.

A precise data is particularly difficult to find, as many companies have reconverted during the Covid-19 emergency to the personal protective equipment market, and also several companies that deal with personal protective equipment or medical devices do not deal with products for defense against the virus COVID-19 and the goods previously mentioned. For these reasons, the number of the population was considered to be the number of medical device companies in a given country, being the only precise data available online, being aware of the large approximation made.

However, statistics show that population size is irrelevant when it is large or unknown and becomes influential only when the work relates to a relatively small group of people [40]; for this reason, the analysis considers an imprecise number for the population, reported in Table 4, as the real number is unknown.

2- *Confidence level*: gives an estimated range of values which is likely to include an unknown population parameter (Easton & McColl, 1997); a standard confidence level was used for the analysis in question, i.e. 95%. That number means that if the study was repeated and the range calculated each time, a researched would expect the true value to lie within these ranges on the 95% of occasions (WW, 1999).

3- *Margin of error*: is an indicator of the precision of an estimate (Freund & Mohr, 2010), and the range in which the true population proportion is estimated to be (WW, 1999); A fairly acceptable margin of error was used for the analysis, i.e., 5%.

The values of the population, confidence level, margin of error and sample size for each of the three populations to which the questionnaire was administered are presented in Table 4, Table 5 and Table 6.

In order to compute the minimum sample size that would be representative of the population, the simplified formula of Equation 1 is used (Yamane, 1967); the term "e" is considered to be 0,05 in the three cases as the confidence interval is 95% and the margin of error is 0,05.

Equation 1 - Rapresentative sample size

$$n = \frac{N}{1 + N(e)^2}$$

Table 4 - Sample size for the Italian population

ITALY

Population (N)	4,022
Confidence Level	95%
Margin of error	10%
Minimum sample size for it to be representative (n)	367
Real sample size (companies to which the questionnaire was administered)	**994**

Table 5 - Sample size for the American population

US

Population (N)	6,500
Confidence Level	95%
Margin of error	10%
Minimum sample size for it to be representative (n)	377
Real sample size (companies to which the questionnaire was administered)	**980**

Table 6 - Sample size for the Chinese population

CHINA

Population (N)	17,236
Confidence Level	95%
Margin of error	10%
Minimum sample size for it to be representative (n)	390
Real sample size (companies to which the questionnaire was administered)	**391**

As it can be noticed, the number of companies contacted (real sample size) is higher than the minimum number of companies to contact for the sample to be representative.

2.3 QUESTIONNAIRE CONSTRUCTION

The questionnaire was sent during a health emergency to key companies in delivering pathogen protection to health professionals and the population, hence it is reasonable to consider the workload that the companies contacted were subject to. Moreover, evidences in the literature show that the length of the survey, especially for the business-oriented studies, has negative influence on email survey response rate (Jobber & Saunders, 1993), and also that the survey length is one of the main reasons for business persons' non-response (Tomaskovic-Devey, Leiter, & Thompson, 1994). For these reasons the length of the survey was optimized in order to give the right amount of information with the smaller number of questions possible.

Two questionnaires were sent, one in Italian sent to Italian companies one in English sent to US and Chinese companies, both with the same questions.

The will is to have, from the answers to the questionnaire, a snapshot of what were business practices and daily operations before the Covid-19 emergency, to what extent they changed during the emergency due to supply chain problems and criticalities and how they were transformed afterwards. The goal of consulting professionals from three different countries is to be able to compare the answers in order to be able to notice similarities and differences among the

countries, and so to have the biggest picture possible of the global supply chain of personal protective equipment and medical devices.

In order to have a picture of the same status for all responding companies, it was decided to identify as the "pre Covid-19" period the one before March 2020, as the "during the lockdown" period the moths March-May 2020, which corresponds to the first wave of the epidemic in Italy, and period "after the lockdown" which corresponds to after May 2020.

2.3.1 SUPPLY CHAIN OPERATIONS REFERENCE (SCOR) MODEL

The structure of the questionnaire was built following the Supply Chain Operations Reference Model (APICS (2017, Supply Chain Operations Reference Model, Version 12.0) management tool, as it helps to explain the processes along the entire supply chain and provides the basis to improve those processes [42]. The model was developed by an independent, non-profit-orientated association called the Supply Chain Council (SCC) in the 1996 (Poluha, 2007), and it has been described as the most promising model for supply chain strategic decision making (Huan, Sheoran, & Wang, 2004). Being a process reference model for supply chain management, spans from the supplier's supplier to the customer's customer (ILIM, Institute of Logistic and Warehousing, 2010), and it results to be very useful for the aim to understand and organize information about a global supply chain as the PPE/MD one. The latest version of the SCOR management tool is the 12.0, launched by the Supply Chain Council in 2017.

SCOR analyzes a company's supply chain operations in different levels, and the whole model is based on six different management processes, that are the following:

- Plan: Entails the demand and supply planning and management [42], and enables the activities associated with developing plans to operate the supply chain. These include determining requirements, gathering information about available resources, balancing requirements and resources to determine planned capabilities and gaps in demand or resources, and identifying actions to correct these gaps [45].
- Source: This step entails sourcing infrastructure and material acquisition; it describes how a company manages inventory, the supplier network, supplier agreements and supplier performance [42].

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- Make: Are the processes that transform goods to a finished state to meet planned or actual demand (ILIM, Institute of Logistic and Warehousing, 2010) and includes production activities, packaging, staging product, releasing, managing production network, equipment and facilities and transportation [42].

- Deliver: Processes that provide finished goods and services to meet planned or actual demand, and it includes order management, transportation management and distribution management (ILIM, Institute of Logistic and Warehousing, 2010).

- Return: Processes associated with returning or receiving returned products for any reasons (ILIM, Institute of Logistic and Warehousing, 2010);it involves the management of business rules, return inventory, assets, transportation and regulatory requirements [42].

- Enable: Added in SCOR version 11 in 2012, describes the activities associated with the management of the supply chain and focuses in supporting the other five process steps; includes business rules management, performance management, data management, resource management, facilities management, contract management, supply chain network management, regulatory compliance management, risk management and supply chain procurement [45].

The processes Source, Make and Deliver of the company, together with those of clients and suppliers, form a "supply chain" planned as a whole by the different actors in the process Plan, as it can be seen in Figure 4.

Additionally, in all the "contact links" Deliver-Source is included the process Return, for the management of returns (ILIM, Institute of Logistic and Warehousing, 2010).For each of these first level processes, the SCOR model proposes a second and a third level of greater detail; however, in order to be properly operational, it would sometimes be necessary to reach a further level of specificity of the processes whose configuration is left to the company (Lovecchio, 2013).
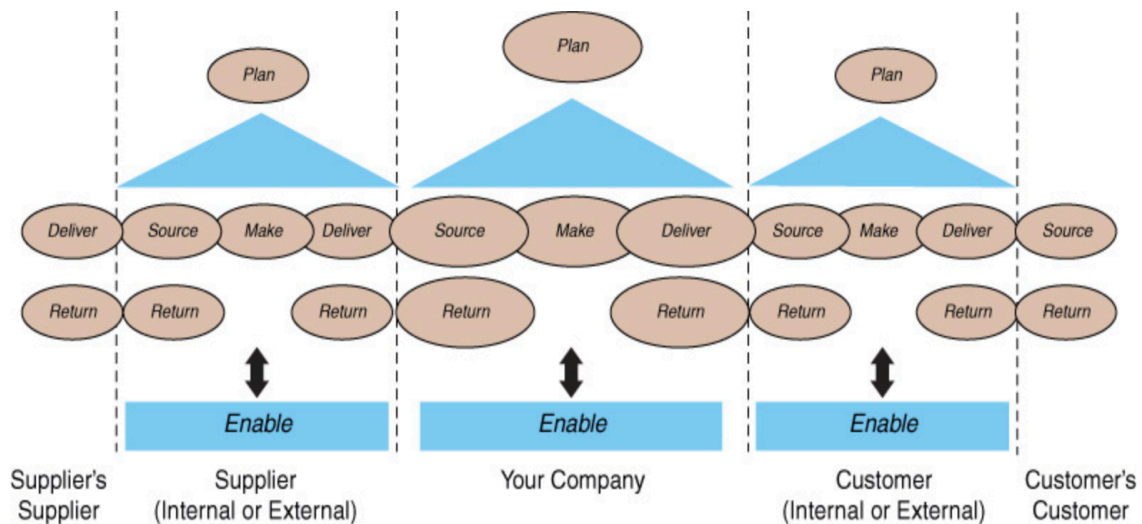
Figure 4 - Perimeter of a company, SCOR method 12.0
(Source: Apics (2017), SCOR, version 12.0)

In defining the topics of the questionnaire, the SCOR method was very useful as a guide for action, in order not to forget some of the processes that make up the supply chain of each company. The following steps are those that have been done in order to formulate the final questionnaire:

STEP 1: Systematic analysis of the literature performed in the main library databases, like Scopus, ResearchGate, Science Direct and Emerald Insight. Firstly, the focus was to understand the supply chain of the personal protective equipment and medical devices, and so the keyword searched were "PPE supply chain", "PPE industry", "PPE players supply chain". Then, the analysis moved to more specific concepts, linked to Covid-19, and the keyword used shifted to "PPE supply chain amid pandemic", "PPE criticalities Covid-19" and so on; to better understand the topic, also non-scientific literature was used, as reports from companies as KPMG, Accenture, Mckinsey and Co, Deloitte and others, since the topic is so new that the scientific literature was not completely developed yet.

STEP 2: Studying the SCOR method in order to insert every possible interesting topic to be included in the questionnaire in the right process.

STEP 3: Composing the following table, by inserting in the most suitable process the findings of the literature done in STEP 1.

Table 7 – SCOR processes topics

Process	Topic	Literature references
Plan	- Demand planning (i.e., assessing the needs in real-time due to the emergency situation) - Prioritization of orders and deliveries	- (Dai, Bai, & Anderson, 2020; Padula, Dai, Zaman, & Davidson, 2020; Cecere & Denman, 2020)
	- Sales and Operation planning response to health emergency	- (Harvey, 2020) - (Cecere & Denman, 2020)
Source	- *Purchase orders* - *Scheduling deliveries: lead time of arrival from suppliers*	- (ADB Briefs, 2020; Harvey, 2020; Gereffi, 2020)
	- *Geographic concentration of suppliers*	- (Harvey, 2020) - (ADB Briefs, 2020; United Nations ESCAP, 2020; Zhu, Chou & Tsai, 2020; Sharma, Gupta & Jha, 2020; Cohen & Rodgers, 2020)
Make	- *Bottlenecks in production (i.e., melt-blown fabrics)* - *Production ramp-up (i.e., requested from governments, to increase the company's revenues, etc.)* - *Lead time of production* - *Production management methods (JIT, MTO, MTS, others)*	- (ADB Report, 2020; Miller, Young, Dobrow, & Shojania, 2020) - (Cohen & Rodgers, 2020) - (Miller, Young, Dobrow, & Shojania, 2020) - (Gereffi, 2020; Dai, Bai, & Anderson, 2020)
Deliver	- *Logistics constraints (i.e., export bans, travel restrictions)* - *Customer orders: Lead time of delivery to customers* - Increase in price for the PPE/MD	- (ADB Briefs, 2020; Agostini, Caballini & Della Chiara, 2020; United Nations ESCAP, 2020) - (Harvey, 2020)

			(Harvey, 2020; Cohen & Rodgers, 2020)
Return	-	Full refund for companies who buys in buffers to stock in case of needs	- (Harvey, 2020)
Enable	-	Sharing of the data among/with critical suppliers	- (OECD, Beyond Containment: Health systems responses to COVID-19 in the OECD , 2020)
	-	Metrics used before and after the health emergency (i.e., The Days Inventory on Hand, that is the monetary value of inventory to time and it is calculated by dividing the stock on hand by the average daily sales [43], burn rate that is the rate at which a new company is spending its venture capital to finance overhead before generating positive cash flow from operations [44]., etc.)	- **Specificata fonte non valida.** - (De Maria, 2020; Sharma, Gupta & Jha, 2020) - (Miller, Young, Dobrow, & Shojania, 2020) - (Gereffi, 2020; De Maria, 2020; Harvey, 2020)
	-	*Risk management: Supply chain disruption plan*	
	-	*Performance management during respect to prior emergency*	
	-	*Inventory management and procurement system (JIT, FIFO, LIFO, EOQ, others)*	

STEP 4: Choice of topics to be included in the questionnaire among those listed in table above. The focus of the survey was decided to be on the process Source, Make, Deliver and Enable, as they are linked to the goal of the thesis: understand the variations in the business of the respondent companies due to supply chain problems.

Not all topics of the chosen processes are addressed in the questionnaire, and the reasons are explained below:

- Deliver: it was decided not to include in the questionnaire questions related to the price increase regarding PPE / MD during the Covid-19 emergency, because information on the price was not particularly important information for the purpose of the study that the thesis work wants to do.

- Enable: it was decided not to include in the survey questions related to sharing data with suppliers and the metrics used before and during the health emergency. As both the topics are very technical, and not all the employees of the companies to which the questionnaire was administered would have been able to answer, as much of the survey were sent through the information email of the companies. More information of this matter is reported in the paragraph 2.3.2.

The topics covered by the questions of the survey are those highlighted in italics in Table 7.

STEP 5: Developing the structure of the questionnaire, dividing into coherent sections the processes selected. The decision to divide the questionnaire into the following sections instead of the SCOR processes was taken so that the questionnaire was easier to understand by any employee of the companies contacted.
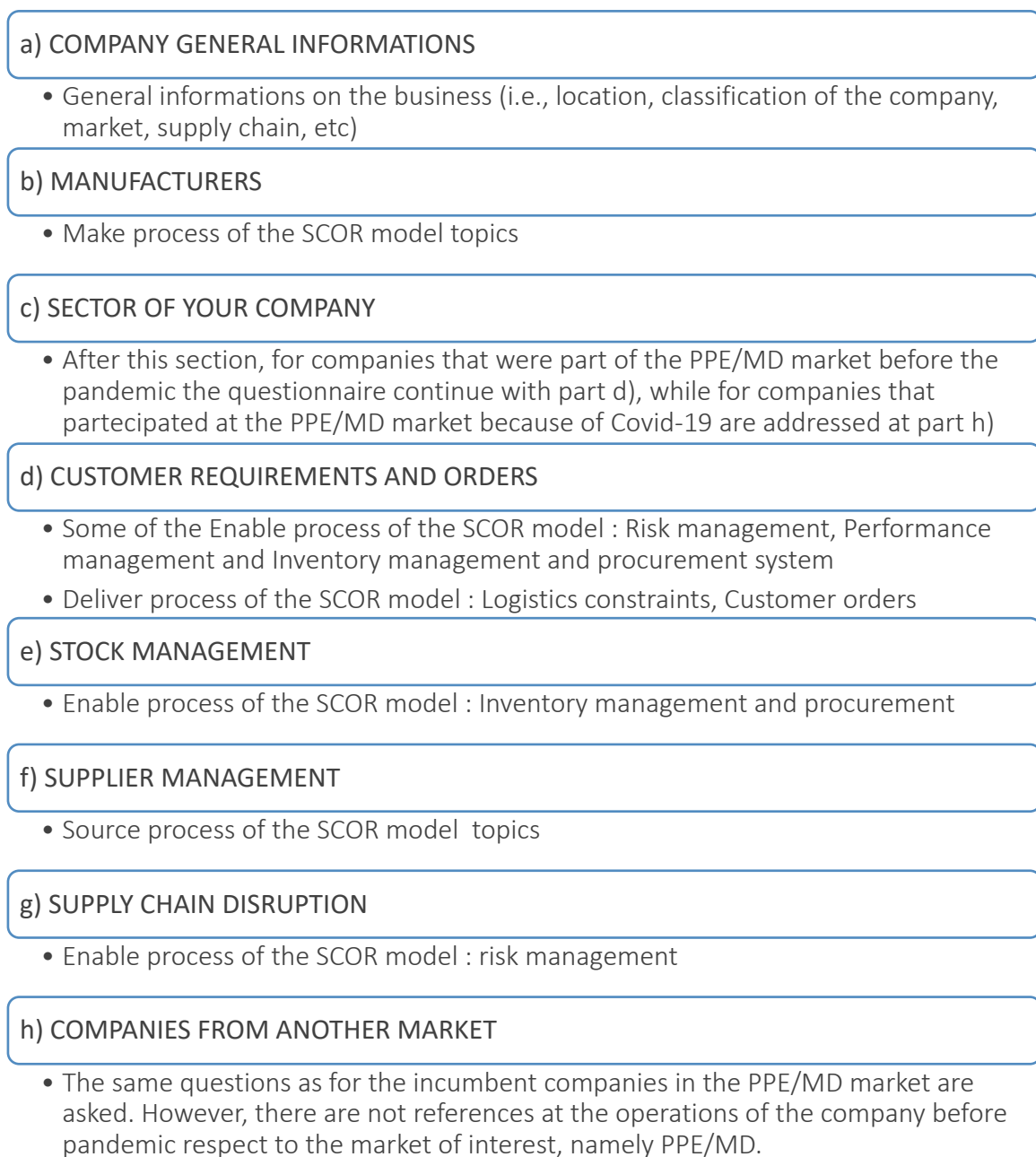
The structure is shown in Figure 5.

a) COMPANY GENERAL INFORMATIONS

- General informations on the business (i.e., location, classification of the company, market, supply chain, etc)

b) MANUFACTURERS

- Make process of the SCOR model topics

c) SECTOR OF YOUR COMPANY

- After this section, for companies that were part of the PPE/MD market before the pandemic the questionnaire continue with part d), while for companies that partecipated at the PPE/MD market because of Covid-19 are addressed at part h)

d) CUSTOMER REQUIREMENTS AND ORDERS

- Some of the Enable process of the SCOR model : Risk management, Performance management and Inventory management and procurement system
- Deliver process of the SCOR model : Logistics constraints, Customer orders

e) STOCK MANAGEMENT

- Enable process of the SCOR model : Inventory management and procurement

f) SUPPLIER MANAGEMENT

- Source process of the SCOR model topics

g) SUPPLY CHAIN DISRUPTION

- Enable process of the SCOR model : risk management

h) COMPANIES FROM ANOTHER MARKET

- The same questions as for the incumbent companies in the PPE/MD market are asked. However, there are not references at the operations of the company before pandemic respect to the market of interest, namely PPE/MD.

Figure 5 - Survey structure

2.3.2 QUESTIONNAIRE ADMINISTRATION

The questionnaire was built using the Google form tool and was administered to companies starting from 25 November 2020.

Many of the e-mails available were of the kind info@companyname, and hence it was not possible to know what the professionalism of the respondent was. For this reason, it has been decided not to go into technical details with any of the

questions in the survey, as this could have discouraged some respondents from completing it, or the answers could have been incorrect.

Each company on the list received three reminders, each 15 days apart, unless a response has already been received from the same company.

2.3.3   QUESTIONNAIRE SECTIONS

Previously in the chapter it has been talked about the sections of the questionnaire and the type of question present in each of them. In this paragraph the questions are reported, together with the motivation of each of them.

COMPANY GENERAL INFORMATIONS

1- Please write the name of your company and in which country it is based:
The name of the respondent company will not be disclosed in the thesis work for privacy reasons, but it is necessary to know it in order to delete them from the database and not to send further reminder to fill the questionnaire to companies who already responded; Knowing the country of origin is then essential in order to position the company in the GSC.

2- What is your company's annual revenue? (year 2019)
  - *Less than 2M€*
  - *From 2M€ to 10M€*
  - *From 10M€ to 50M€*
  - *Over 50M€*
To uniquely identify whether the responding company is a small, medium or large enterprise this question together with a question about the number of employees is necessary [41]. However, since, as mentioned above, it is important to keep a small number of questions, it was decided to keep only one of the two, as it gives us a measure of the company, even if inaccurate.

3- What is your function within the company?

4- Which of the PPEs/MDs your company has treated since the onset of Covid-19? (Multiple answers are allowed)
  - *Surgical masks*
  - *Other types of masks (i.e., N95, KN95, …)*
  - *Viewers*

- *Protective suits*
- *Gloves*
- *Solutions Alcoholic*
- *Other*

In the current literature it is stated that the shortcomings and criticalities that have occurred in the global supply chain of PPE / DM differ according to the PPE / DM considered (Bhaskar, 2020). For this reason, knowing which supply chain the company is part of is necessary in order to put the answers to the questionnaire by each company in the right context/subsystem.

5- *From which countries do your customers come from? (Multiple answers are allowed)*
- *Domestic market*
- *EU and domestic market*
- *USA and home market*
- *Everywhere*

In order to understand each respondent's supply chain, it is necessary to understand from where his customers and suppliers come from. In order to reduce the number of queries only the origin of the customers is asked, however in a subsequent section specific questions are asked about suppliers.

6- *What is the main business activity in the PPE/MD industry?*
- *Importing*
- *Exporting*
- *Distribution*
- *Production*
- *Import and export*
- *Import and distribution*
- *Import and production*
- *Production and export*
- *Production and distribution*
- *Other (without production)*
- *Other (with production)*

This question allows to understand which business the company is engaged in within the personal protective equipment / medical devices market. The companies interviewed are both companies that were in the PPE / MD market before Covid-19 and companies that entered the market due to Covid-19 during 2020; In this question, if the respondent chooses an alternative with also the

characteristic "production", enter the next section, otherwise the respondent is redirected to the subsequent one.

The last two alternatives, "Other (without production)" and "Other (with production)" are for those companies that engage in a more niche business than those listed above.

MANUFACTURERS

This section of the questionnaire aims to deal with the topics of the Make process treated in Table 7.

7- *How much has your company's production capacity increased compared to the pre-Covid19 situation? (regarding PPE/MD market, in %) Please, answer to this question only if your company was in the PPE/MD market prior to the Covid-19 pandemic*

	0	1	2	3	4	5	6	7	8	9	10	
0 %	○	○	○	○	○	○	○	○	○	○	○	100 %

This answer aims to give a measure of the production ramp-up that the respondent company has had.

8- *Production management methods used by your company for what concerns PPE/MD:*

	Yes, before Covid	Not before Covid	Yes, during March-May	Not during March-May	Yes, after May	Not after May
JIT (just in time) - produce only what has already been sold or is expected to be sold soon	☐	☐	☐	☐	☐	☐
MTO (make to order) - manufacturing process in which goods are made only after receiving customer orders	☐	☐	☐	☐	☐	☐
MTS (make to stock) - a make-to-stock manufacturing process is one in which goods are made and stored before customer orders are received	☐	☐	☐	☐	☐	☐
Assemble to order - requires that the basic parts of the product are already manufactured but not yet assembled prior to the order	☐	☐	☐	☐	☐	☐

The answer to the question is composed of several parts and has been constructed so that in a single question the respondent gives us more information, useful for a complete understanding of the company's production management.

The idea is that by answering this question we have a clear idea of how the production management of the individual company has changed due to the advent of Covid-19, while knowing how it was managed before the pandemic.

SECTOR OF YOUR COMPANY

This section serves to differentiate the companies that were in the PPE/MD market before the health emergency and those that entered during 2020. This is because the questions of the former will refer to the change in the daily operations of the before-during-post the emergency, while those of the second will refer to their operations during and after Covid-19.
If the respondent selects the third answer they will be carried over to the last section of the questionnaire, "Companies from another market".

9- *Which sector did your company belong to before the Covid-19 emergency?*
- *PPE*
- *PPE/MD and another sector*
- *Another sector, my company did not deal with PPE before the Covid-19 emergency*

CUSTOMER REQUIREMENTS AND ORDERS

This section of the questionnaire consists of questions related to the Deliver process of the SCOR method and questions related to the concept of performance management of the company of the Enable process of the SCOR method. There are questions relating to the Deliver process about customer orders and logistics constraints; For what concerns the Performance management of the company, the aim is to understand how companies' daily operations have changed during and after the first epidemic wave of Covid-19, compared to the normal course of the business.

10- *The change in the average number of orders received on a weekly basis was, for your company (relative to the PPE market): (Consider as a reference the pre-Covid19 period for the Period March-May and a reference of Period March-May for the After-May consideration)*

	No one (0-15%)	Very limited (15%-30%)	Moderate (30%-45%)	Significant (45%-60%)	Very significant (60%-75%)	Exponential (+75%)	I don't know
Period March-May	○	○	○	○	○	○	○
After May	○	○	○	○	○	○	○

11- *The change in the average number of quantities shipped on a weekly basis was, for your company (relative to the PPE/MD market): (Consider as a reference the pre-Covid19 period for the Period March-May and a reference of Period March-May for the After-May consideration)*

	No one (0-15%)	Very limited (15%-30%)	Moderate (30%-45%)	Significant (45%-60%)	Very significant (60%-75%)	Exponential (+75%)	I don't know
Period March-May	○	○	○	○	○	○	○
After May	○	○	○	○	○	○	○

12- *The change in the average number of lading lines on a weekly basis was, for your company (relative to the PPE/MD market): (Consider as a reference the pre-Covid19 period for the Period March-May and a reference of Period March-May for the After-May consideration)*

	No one (0-15%)	Very limited (15%-30%)	Moderate (30%-45%)	Significant (45%-60%)	Very significant (60%-75%)	Exponential (+75%)	I don't know
Period March-May	○	○	○	○	○	○	○
After May	○	○	○	○	○	○	○

The questions 10,11 and 12 have the function of understanding, through a numerical value, how much the daily work of respondents has changed compared to the normal course of operations before the health emergency; It was decided to use the period before the emergency as a reference and to have a numerical value of the subsequent variations. Even in this case the decision to eliminate the questions on the number of orders, quantities sent and number of bill lines per week before the pandemic is due to the necessity to cut the non-essential questions.

13- *The time elapsed between the receipt of an order and the issuance of the same by your company is, on average (relative to the PPE/MD market):*

	<5 days	Between 5 and 7 days	Between 8 and 10 days	Between 11 and 15 days	>15 days
Before Covid-19	○	○	○	○	○
Period March-May	○	○	○	○	○
After May	○	○	○	○	○

The objective of this question is to understand, from the company side, how much lead time has increased during and after the lockdown compared to the previous period.

This, together with the next question, gives essential information to understand how much the company's efficiency has decreased and for what reasons.

14- *For those for which the lead time increased during and/or after the lockdown respect to prior to it, the phenomenon is mainly due to (relative to the PPE/MD market):*

	Yes, during the period March-May	Not during the period March-may	Yes, after May	Not after May
Production delays by my company due to the difficulty of increasing capacity quickly	☐	☐	☐	☐
Delays due to reduced transport efficiency (air, land, sea)	☐	☐	☐	☐
Reduction of staff to ensure social distancing	☐	☐	☐	☐
Delays by suppliers	☐	☐	☐	☐
Government barriers have increased the lead time	☐	☐	☐	☐
Absenteeism on the part of my company staff for fear of contagion / because they are at risk	☐	☐	☐	☐
Cases of Covid-19 have reduced my company's workforce	☐	☐	☐	☐

Among the possible answers on the left are those that, in the literature up to date, are present as reasons for the disruption of the global supply chain of the PPE / MD and in general for disruption of global supply chains amid pandemic.

The analysis of the answers will give us the measure of how many of the respondents have suffered one or the other difficulty.

STOCK MANAGEMENT

This section deals with another fundamental topic in order to understand the critical issues that occurred in the PPE / MD supply chain: the inventory management and procurement of the Enable process. Through the answers to questions 15 and 16 it will be possible to have information about the management and methodologies used by the companies to treat the stocks before, during and after the first wave of Coronavirus.

15- Inventory management methodologies used by your company (relative to the PPE/MD market):

	Yes, before Covid	Not before Covid	Yes, during March-May	Not during March-May	Yes, after May	Not after May
JIT (just in time) - produce only what has already been sold or is expected to be sold soon	☐	☐	☐	☐	☐	☐
FIFO (first in, first out) - the first item introduced into the warehouse is the first to come out	☐	☐	☐	☐	☐	☐
LIFO (last in, first out) - the last item introduced in the warehouse is the first to come out	☐	☐	☐	☐	☐	☐
EOQ (economic order quantity) - inventory management model that defines the optimal purchase quantity in order to minimize the sum of procurement costs, and warehouse maintenance costs	☐	☐	☐	☐	☐	☐

16- The average weekly stock level (regarding PPE/MD market): (Consider as a reference the pre-Covid19 period for the Period March-May and a reference of Period March-May for the After-May consideration)

	Remained unchanged (0-15%)	Increased in a limited way (15%-30%)	Increased moderately (30%-45%)	Highly increased (45%-60%)	Decreased in a limited way (15%-30%)	Decreased moderately (30%-45%)	Decreased in a heavy way (45%-60%)
During March-May	○	○	○	○	○	○	○
After May	○	○	○	○	○	○	○

SUPPLIERS MANAGEMENT

In this section topics related to the process Source are studied in detail; thanks to the initial questions in the "company general information" section, it is possible to know which are the suppliers of the respondent company and where they come from. For example, if the company's answer in question 6 was "Manufacturers", the company's suppliers will be raw materials or components. Having understood which are the suppliers of the company thanks to the first section, the aim of this section is instead to understand the variations in the work and the difficulties encountered with the company's provider during and after the health emergency.

17- *The change in the average number of supplier orders placed on a weekly basis was, for your company (relative to the PPE/MD market):*
(Consider as a reference the pre-Covid19 period for the Period March-May and a reference of Period March-May for the After-May consideration)

	No one (0-15%)	Very limited (15%-30%)	Moderate (30%-45%)	Significant (45%-60%)	Very significant (60%-75%)	Exponential (+75%)	I don't know
Period March-May	◯	◯	◯	◯	◯	◯	◯
After May	◯	◯	◯	◯	◯	◯	◯

18- *Was the increase in time between issuing an order to suppliers and receiving it by your company due to which of the following causes? (considering the PPE/MD market)*

	Yes, during the period March-May	Not during the period March-May	Yes, after May	Not after May
Production delays due to shortage of upstream raw materials	☐	☐	☐	☐
Export bans from the countries of our suppliers	☐	☐	☐	☐
Fabric shutdowns/Covid infections in suppliers facilities	☐	☐	☐	☐
Restriction in the transportation of your suppliers	☐	☐	☐	☐
Reduction of suppliers' staff to ensure social distancing	☐	☐	☐	☐
The lead time has decreased	☐	☐	☐	☐
The lead time remained unchanged	☐	☐	☐	☐

Among the possible answers on the left are those that, in the literature up to date, are present as reasons for the disruption of the global supply chain of the PPE / MD.

The analysis of the answers will give us the measure of how many of the respondents' suppliers have suffered one or the other difficulty.

19- The number of suppliers your company relies on is (considering the PPE/MD market):

	During the period March-May	After May	It will remain so in the future
Increase only in the number of suppliers	☐	☐	☐
Decrease only in the number of suppliers	☐	☐	☐
Increase only in the geographical areas of suppliers	☐	☐	☐
Decrease only in the geographical areas of suppliers	☐	☐	☐
Invariant in number and in geographical areas	☐	☐	☐

The answer to this question indicates how much the geographic area of origin and the number of suppliers has changed due to the pandemic for the respondent company. This assumes importance in a context in which global supply chains are being redistributed: the response of the individual company tells us how much the part of the supply chain in which the company is will change to avoid future disruptions in case of another health emergency.

SUPPLY CHAIN DIRSUPTION

This section consists of a single question, aimed at figuring out if the company had a contingency plan or not before the pandemic. Depending on the answer, the answers given to the previous questions are considered differently. It would have been interesting to ask those who had or drafted an emergency plan to ask what it is made up of; however, also in this case, the reduction of the number of questions and the time to complete the questionnaire was the priority.

20- Did your company have a plan to manage supply chain disruption for its customers?
- *Yes, before the Covid-19 crisis*
- *No, my company created a plan during the Covid-19 crisis*
- *No, he never had a plan*

- *I don't know*
- *Other*

At this point the questionnaire ends.

COMPANIES FROM ANOTHER MARKET (New entrants in the PPE/MD due to Covid-19)

This section of the questionnaire is aimed at companies that have converted to the PPE / MD market following the health emergency, and so who selected the third option in the question number 9 of the survey.
The questions are the same as those posed to those who were in the market before 2020; it does not refer to the course of operations before March, as it would be deviant to have information about a market other than that of PPE/ MD.

10- What were the reasons that led your company to differentiate itself in the PPE/MD market?

11- What was the sector your company was part of before the Covid-19 emergency?

11- The change in the average number of orders received on a weekly basis was, for your company (relative to the PPE/MD market), compared to the period March-May:

	No one (0-15%)	Very limited (15%-30%)	Moderate (30%-45%)	Significant (45%-60%)	Very significant (60%-75%)	Exponential (+75%)	I don't know
After May	○	○	○	○	○	○	○

12- The variation in the quantities shipped on a weekly basis was, for your company (relative to the PPE/MD market), compared to the period March-May:

	No one (0-15%)	Very limited (15%-30%)	Moderate (30%-45%)	Significant (45%-60%)	Very significant (60%-75%)	Exponential (+75%)	I don't know
After May	○	○	○	○	○	○	○

13- *The average weekly change in the number of lading lines was, for your company (relative to the PPE/MD market), compared to the period March-May:*

	No one (0-15%)	Very limited (15%-30%)	Moderate (30%-45%)	Significant (45%-60%)	Very significant (60%-75%)	Exponential (+75%)	I don't know
After May	○	○	○	○	○	○	○

14- I *The time elapsed between the receipt of an order and the issuance of the same by your company is, on average (relative to the PPE/MD market):*

	<5 days	Between 5 and 7 days	Between 8 and 10 days	Between 11 and 15 days	>15 days
Period March-May	○	○	○	○	○
After May	○	○	○	○	○

15- For those who had a longer lead time respect to the normal course of business, the phenomenon is mainly due to (relative to the PPE/MD market):

	Yes, during the period March-May	Not during the period March-may	Yes, after May	Not after May
Production delays by my company due to the difficulty of increasing capacity quickly	☐	☐	☐	☐
Delays due to reduced transport efficiency (air, land, sea)	☐	☐	☐	☐
Reduction of staff to ensure social distancing	☐	☐	☐	☐
Delays by suppliers	☐	☐	☐	☐
Government barriers have increased the lead time	☐	☐	☐	☐
Absenteeism on the part of my company staff for fear of contagion / because they are at risk	☐	☐	☐	☐
Cases of Covid-19 have reduced my company's workforce	☐	☐	☐	☐

16- Inventory management methodologies used by your company (for what concerns PPE/MD):

	Yes, during March-May	Not during March-May	Yes, after May	Not after May
JIT (just in time)	☐	☐	☐	☐
FIFO (first in, first out)	☐	☐	☐	☐
LIFO (last in, first out)	☐	☐	☐	☐
EOQ (economic order quantity)	☐	☐	☐	☐

17- The variation in the average number of orders to suppliers made on a weekly basis was, for your company (relative to the PPE/MD market), compared to the period   *March-May:*

	No one (0-15%)	Very limited (15%-30%)	Moderate (30%-45%)	Significant (45%-60%)	Very significant (60%-75%)	Exponential (+75%)	I don't know
After May	○	○	○	○	○	○	○

18- Was the increase in time between issuing an order to suppliers and receiving it by your company due to which of the following causes? (considering only the PPE/MD market)

	Yes, during the period March-May	Not during the period March-May	Yes, after May	Not after May
Production delays due to shortage of upstream raw materials	☐	☐	☐	☐
Export bans from the countries of our suppliers	☐	☐	☐	☐
Fabric shutdowns/Covid infections in suppliers facilities	☐	☐	☐	☐
Restriction in the transportation of your suppliers	☐	☐	☐	☐
Reduction of suppliers' staff to ensure social distancing	☐	☐	☐	☐
The lead time has decreased	☐	☐	☐	☐
The lead time remained unchanged	☐	☐	☐	☐

3 STATISTICAL ANALYSIS

In this chapter the data collected from the respondent are studied, the findings are statistically analyzed and interpreted, then conclusions are drawn about the criticalities in the PPE/MD supply chain encountered by companies.

3.1 COLLECTED DATA

The questionnaire was sent to Chinese, US and Italian companies. None of the Chinese and American contacted answered the questionnaire; in most cases, for Chinese and US companies, the e-mails containing the questionnaire were not delivered to the recipient for reasons of preventive blocking by the information system of the companies. Furthermore, for many Chinese companies the language of the questionnaire may have been an additional obstacle in answering.

For what concerns Italian companies instead, the response rate of the survey is of 11% with 99 responses over 900 companies contacted.

These results are not surprising, in fact higher response rates are found to be achieved when respondents were geographically and culturally closer to the research project's originating country and are more internationally oriented and came from countries with a lower level of power distance(Harzing, 2000). Moreover, a study reported typical response rates for international mail surveys to lie between 6% and 16% (Harzing, Response rates in international mail surveys: Results of a 22 country study, 1997). Since then, the situation has not improved, and the double-digit response rates are increasingly difficult to achieve (Harzing, Reiche, & Pudelko, 2012).

3.1.1 DATASET

Once the answers were received, the dataset was built, and irrelevant answers were removed. Of the 99 answers, 5 were not relevant and the corresponding rows were deleted from the database, as the respondents were not part of the market for personal protective equipment or medical devices, but rather the market for alcoholic solutions, plexiglass walls or dispensers for alcoholic solutions.

3.2   DESCRIPTIVE STATISTICS

In this paragraph are reported descriptive statistics, with the aim of understanding the structure and characteristics of the respondents, in order to draw the first conclusions regarding the effects of Covid-19 on operations during and after the Lockdown of the months between March and May, when the first pandemic wave has seriously affected Italy. The sequence of the statistics studied in this paragraph follows the order of the questions of the survey, enlightening only the most interesting results.

As it has been said in paragraph 3.1, the totality of respondents are Italian companies, and among them, the majority are small/medium enterprises, with the 54% that had a profit of less than 2M€ in 2019, as it can be noticed from Figure 6.

Figure 6 – Respondents profit

The Figure 7 shows that the presence of the respondents in the global market of PPE/MD goods is substantial, as the 46% of them has clients also outside the Italian market.
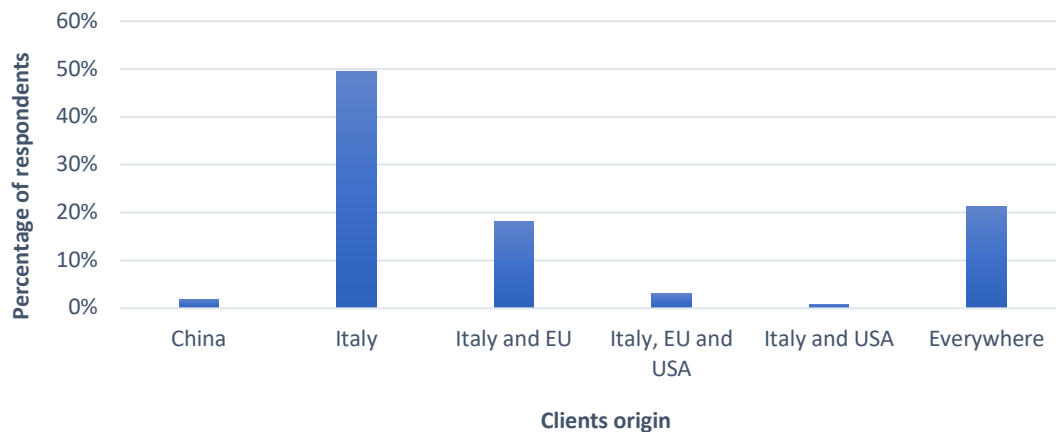
Figure 7 - Respondents client base origin

In particular, Figure 8 shows the outcomes of a comparison analysis between the origin of the customers and the main activity of each respondent, and the result is that there is a strong diversity between the companies. This creates room for a complete understanding of the problems that occurred in the personal protective equipment/medical devices supply chain, allowing to fill, even if partially, the lower level of global awareness due to the response not received from China and USA.
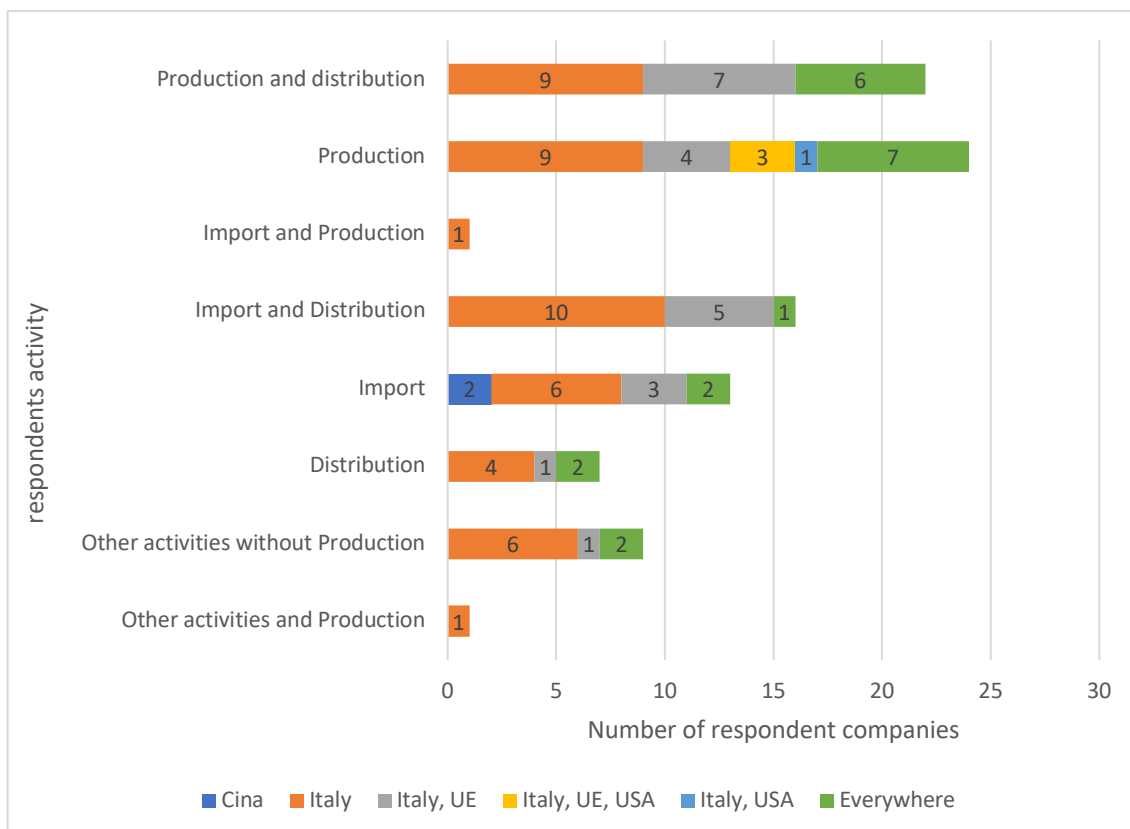
Figure 8 - Respondents Activity vs Clients' origin

The respondent's activity in the analyzed sector is various, as it can be noticed in Figure 9.

The highest percentage of respondents, the 51%, are involved in production, while 32% are involved in imports and 25% in distribution, as Figure 9 reports. The Other category contains the interviewed companies' responses "Other and producers" and "Other not producers" which are the companies who do an industry-specific activity different from importing, exporting, distributing and producing.
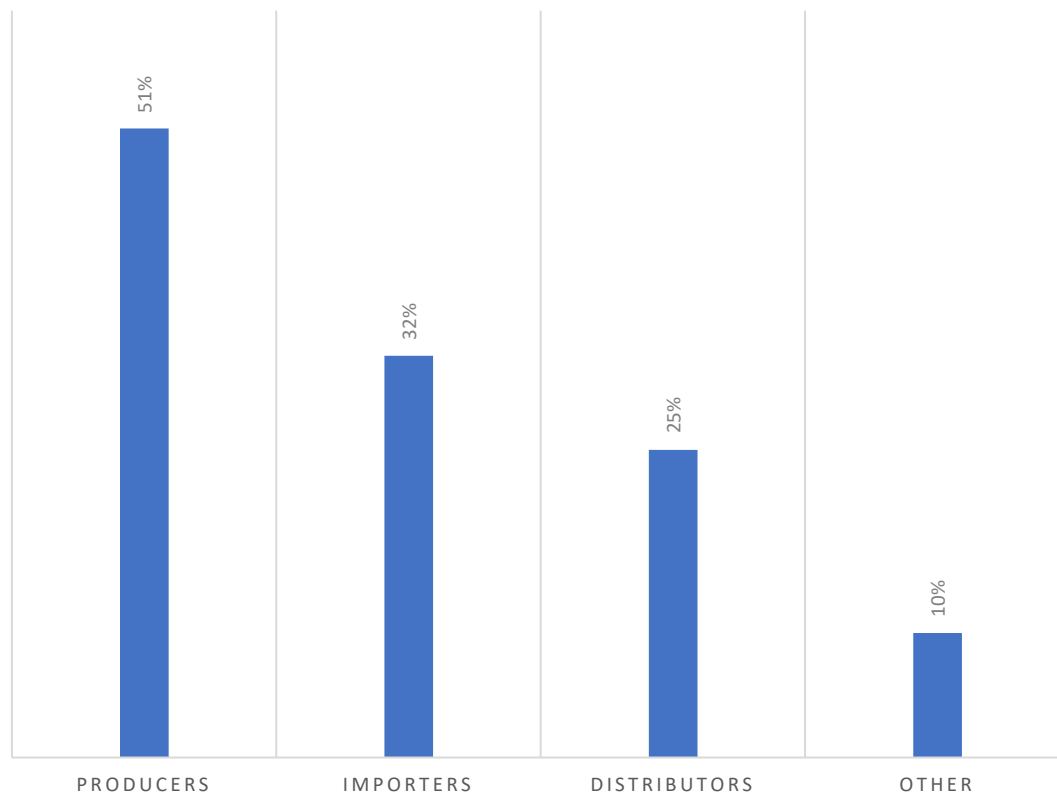
Figure 9 - Respondents activity

Every important PPE/MD for the defense against Coronavirus is represented by the 93 respondent companies. As it can be noticed from Figure 10, the 81% of companies are linked to the supply chain of surgical masks, the 55% of companies to other types of masks, 24% and 23% respectively to gloves and gowns supply chain, 38% to the visors one and only 2% to protective glasses chain.
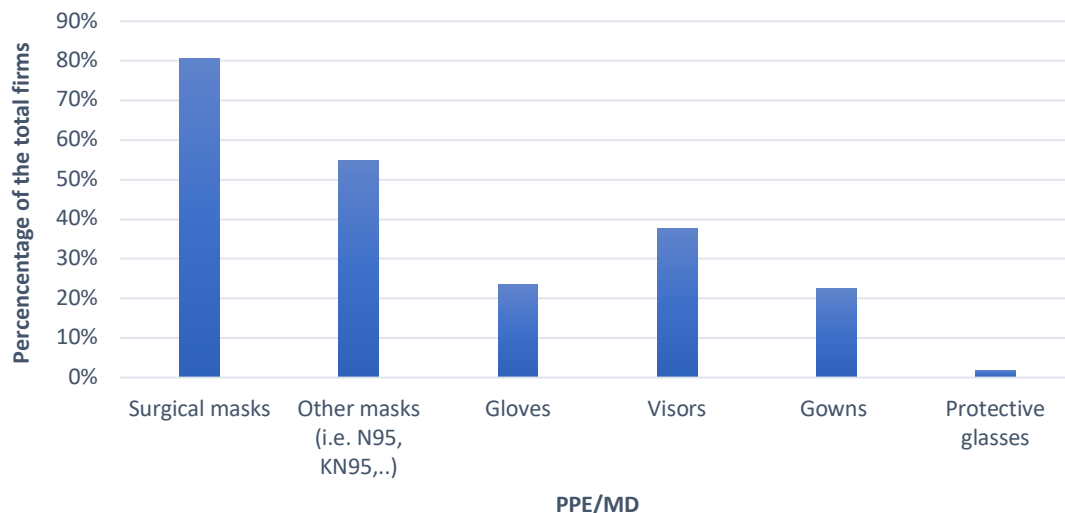
Figure 10 - Respondents PPE/MD good

The reliability of the responses is an important factor to be considered once analyzing the results of a questionnaire sent through e-mails to companies, in fact in this specific case the 69% of respondents were Managers, Senior Executives, Vice Presidents or Directors of the company, as the Figure 11 shows. This means that the response dataset is made up of skilled professionals, and the answers have to be considered reliable.
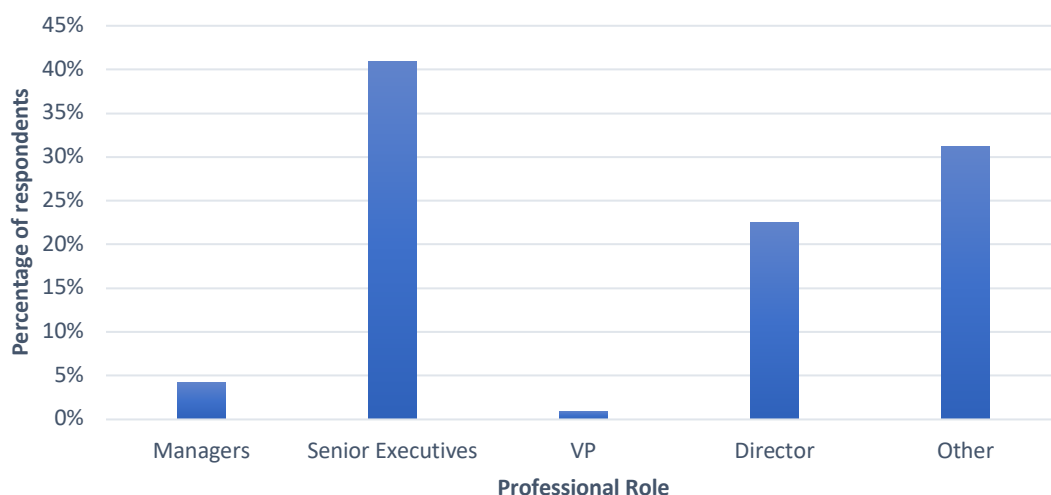
Figure 11 - Respondents professionalism

A further information that emerges from the analysis of the respondents is that in Figure 12, that the 83% of the questionnaires were filled from new entrants in the PPE/MD sector.

This is consistent according to the Italian market of PPE/MD for the protection against viruses prior to the pandemic: while Italy is in twelfth place in the ranking of the major exporters in the medical equipment sector, in the PPE market Italy

is the fourth European supplier for "low technology" medical devices such as PPE for medical use (especially overalls, gowns and protective goggles) imported mainly from China and re-exporting abroad. However, at the dawn of the pandemic, Italy saw its PPE production focus on type-3 PPE, the category that includes PPE intended to protect the individual from lethal or serious and permanent injury. Furthermore, among the products manufactured in Italy before the start of the pandemic, there were no masks [46]. The 51% of the respondents are involved in Manufacturing protection devices against a virus and the 81% of the responding manufacturers produce masks, and therefore this is in line with the 83% of respondents that entered in the PPE / MD market due to the pandemic, as in Figure 12. For the respondents of the survey who entered in the market due to the Sars-Cov19, the reasons for the entrance were for the 71% linked to pandemic necessity both for the public health and to sustain the business, for the 17% linked to the business opportunities to diversification that the pandemic brought, whereas for the 12% linked to the experience in the Chinese market or with the import practices. Furthermore, the most frequent conversion sectors for the PPE market are textiles, plastics, Automotive and fashion [46]: of the respondents, 19% were in the textile sector, 9% in the plastics sector, 3% in the Automotive sector and 43% in the fashion one.
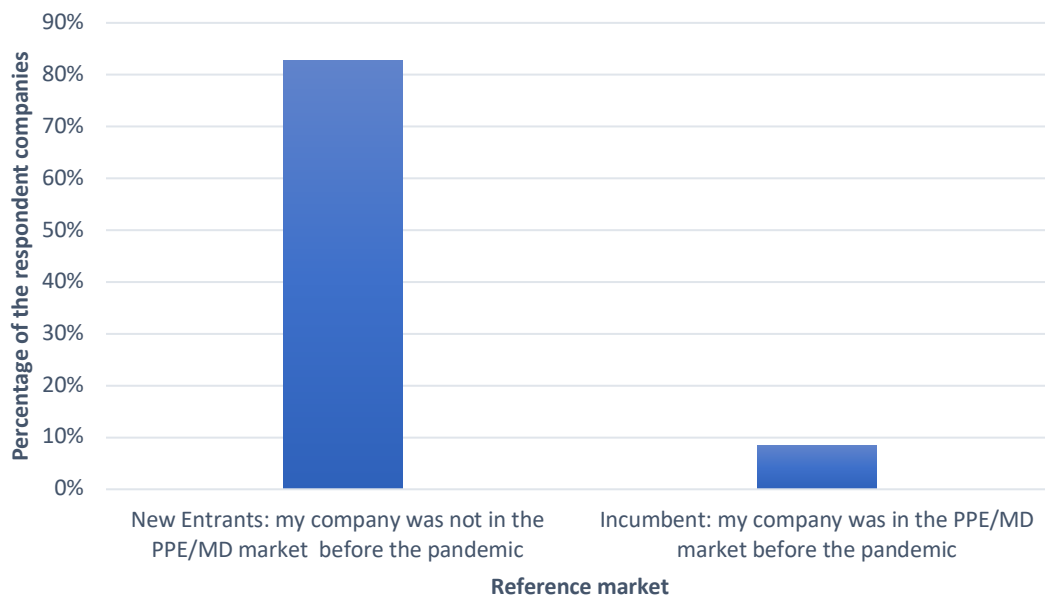
Figure 12 - Reference market of respondents

Respondents who were involved in the production of personal protective equipment and / or medical devices even before Covid-19 have widely observed

a significant increase in production to cope with the increasing demand due to the pandemic: in particular the 73% of the respondents has increased production capacity by more than 60%. Figure 8 shows an analysis carried out on the aggregate results of the new entrants and incumbents' respondents, however, only the responses of the latter with respect to the management of pre-Covid19 production (first column of each production management) were considered. In the literature, the just-in-time method appears to be the most widely used in the medical supply chain of which personal protective equipment and medical devices are part, in order to obtain efficiency and reduce costs to a minimum (Cohen & Rodgers, 2020); this phenomenon is also visible in Figure 8, where it is noted that the respondents who have never used Just-in-Time as a production management method are the lowest percentage of the four studied, that is 10%. On the other hand, JIT is not the most used production management method before the pandemic, but this can be linked to the characteristics of the products managed by the respondent companies before 2020: as previously stated, most of them dealt with PPE for the protection of the worker from accidents at work, and not from the supply chain of purely medical products. An interesting data that can be seen from the analysis of Figure 8 is how the Make to Stock method is the method whose usage is increased the most during the lockdown compared to before the pandemic: this is linked to the need for companies to produce in order to try to stock up in the event of a further increase in demand, or in any case produce as much as possible, at full capacity of the company production system. On the contrary, Make to Order is the method that suffered the greatest contraction from before the pandemic to during the lockdown, as waiting to receive an order to produce would have meant delaying the delivery of a basic necessity during the pandemic, as well as being counterproductive as the entire offer of the PPE / MD company would surely find demand in the short term.

In a separate analysis of the production management methods of new entrants and incumbents, it can be deduced that Just-in-Time is the most used method by both during the lockdown, respectively by the 31% of incumbents and the 29% of new entrants; on the other hand, after the lockdown, the methods used for the highest percentages correspond to the JIT for the incumbents, used by the 33% of them, while the 30% of the new entrants used the make to stock method.
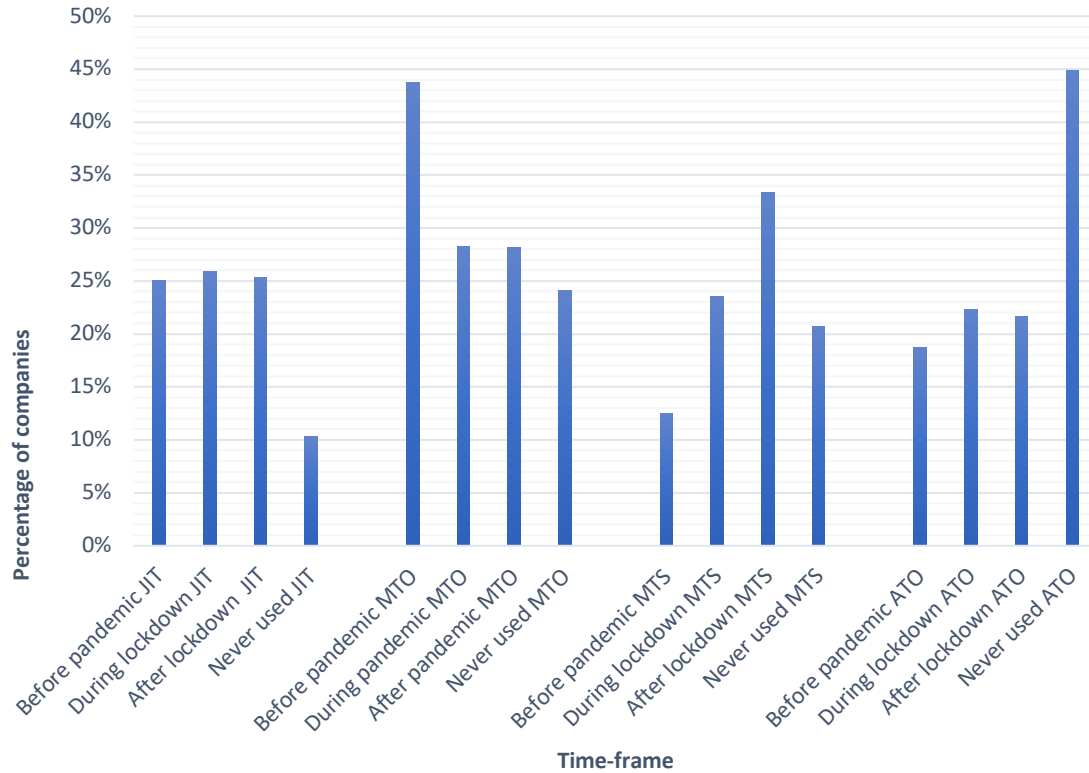
Figure 13 - Production management of respondents

The questionnaire section "Customer requirements and Orders" provides interesting insights for descriptive analysis. In fact, the 75% of the incumbents report that they have had an increase whatsoever in the variation of the orders and the quantities shipped during the lockdown respect the period before march, and 19% of them assert to have had an exponential increment (+75%) in orders and quantities shipped to clients over the same period of time; The leading lines of each order are instead increased for the 73% of incumbents during the lockdown compared to before it.

Furthermore, considering all respondents (incumbents and new entrants), it can be noticed from the answers that more than the 75% of them underwent an increase in orders received, quantities shipped and leading lines after the lockdown compared to the period March-May. For less than the 20% of respondents the period after the lockdown compared to the March-May period the variables of orders received, quantity shipped, and number of leading lines had a variation as small as 0-15%.

The generalized and massive increase in the variables analyzed between the period before the pandemic and the period between March and May is to be associated with an exponential increase in the demand for PPE / MD for

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protection against Covid-19 by the population and health professionals ; the increase in the variables of orders, quantities shipped and leading lines between the period of the lockdown compared to the period after it is most likely not related to the fact that demand was lower during the lockdown, but other factors may have influenced the ability of companies to manage large quantities of equipment.

To support this thesis there are the answers obtained to the question relating to the lead times of the company before, during and after the lockdown in Figure 9. It can be seen an increase in companies that have reduced lead time to less than 5 days during and after the lockdown compared to prior to it; Another interesting data is the percentage of respondents for whom the lead time was more than 15 days before Covid-19: this percentage goes from 25% in the period before March to 18% in the period March-May until it drops down to 5% in the period after May.

The orders lead time trend is shown in Figure 10, from which it can be seen that, for both periods considered, for the majority of the respondents the lead time remained unaltered, despite having, as previously highlighted, increased the outbound flows to customers.
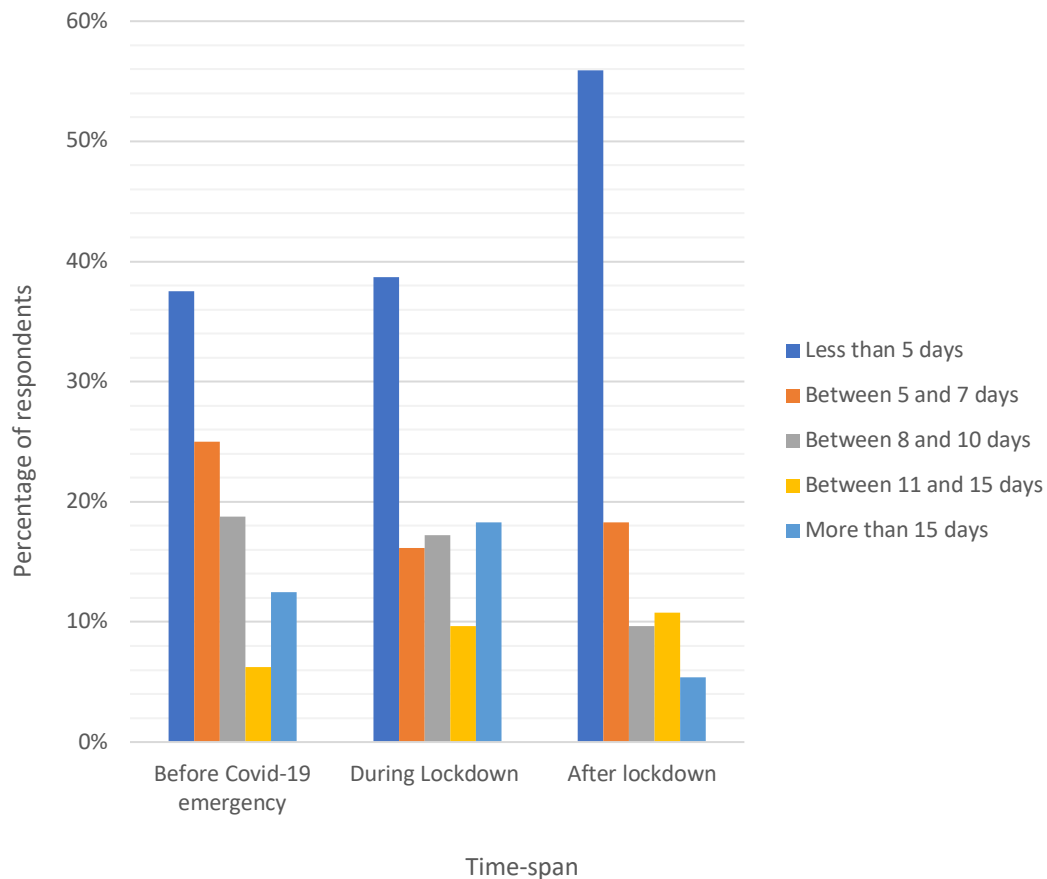
Figure 14 - Respondents lead time
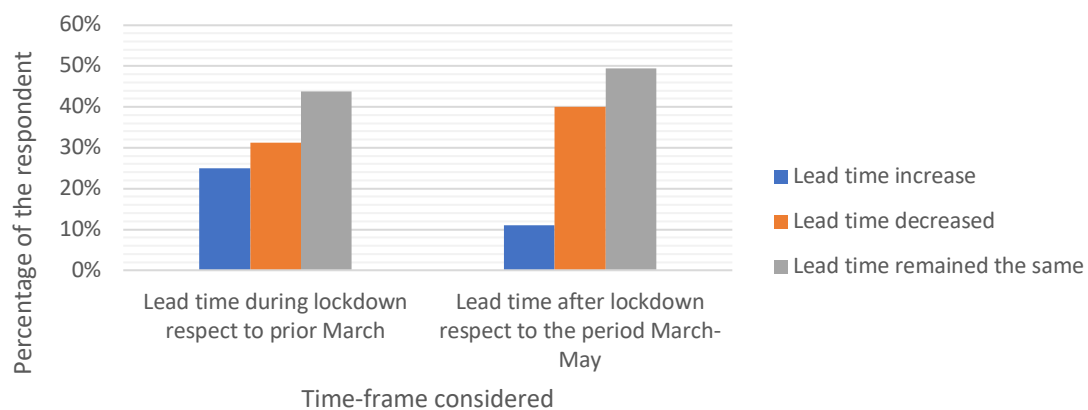
Figure 15 - Lead time variation of respondents

The 25% of respondents reported an increase in lead time during the lockdown compared to before March and 11% a further increase after the lockdown compared to the period of March-May. The analysis of the reasons for this increase dives interesting information regarding the problems that companies in the PPE/MD market had to overcome during the first wave of the pandemic: as can be seen from Figure 11, the 23% of respondents who suffered an increase in

lead time during the lockdown identified as cause the inefficiency of transport (sea, air or road), and the delay suffered by their suppliers. After the lockdown, however, 23% of respondents identified the inefficiency of transport and government barriers, including export bans from third countries or tight controls to certify PPE / MD as the reason for the increase in delivery times.
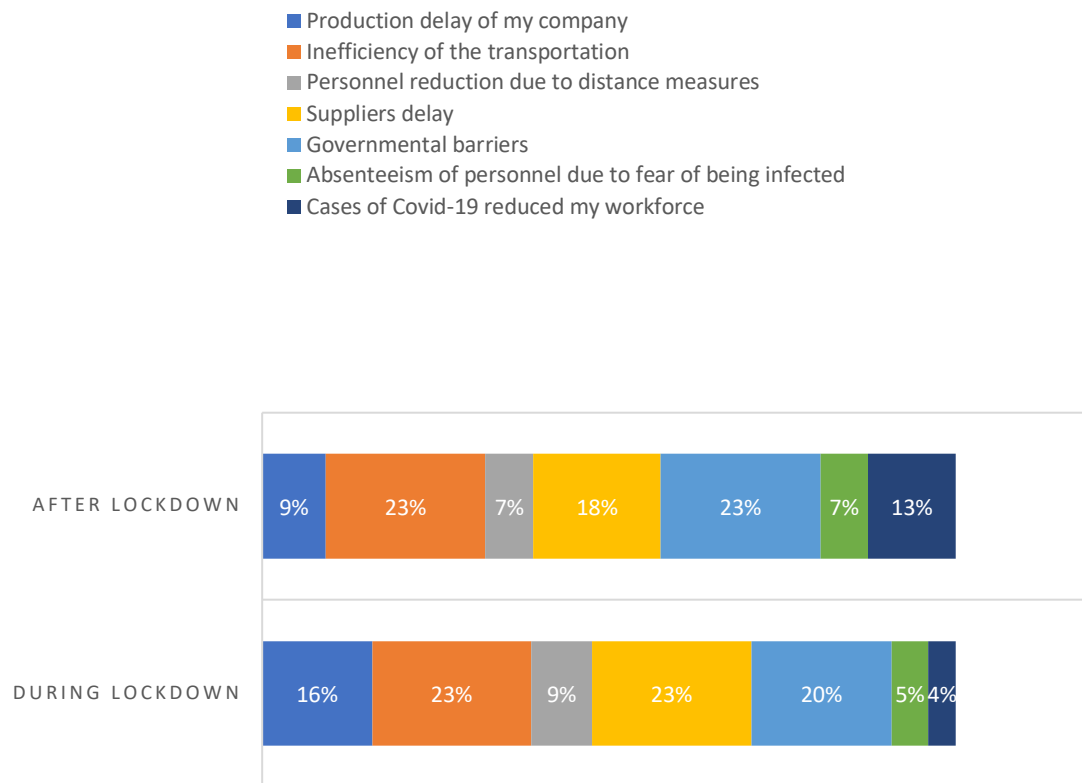
Figure 16 - Reasons for lead time increase

The "Stock management" section of the questionnaire is used for the purpose of descriptive analysis to understand whether changes took places in stock management for the companies to respond to the variations in business operations amid pandemics, and therefore if the practices used responded in positively during and after the lockdown occurred in the period March-May 2020. As can be seen from Figure 12, prior the lockdown, the most used inventory management method was Just-in-Time, in order to minimize inventory costs and optimize working capital. As can be seen, however, the use of Just-in-Time as a method of inventory management undergoes a reduction of 4% during the lockdown compared to before and a further 7% after the lockdown compared to during it. While it is the most efficient inventory management method in times with almost constant demand, reducing inventory to a minimum so as to reduce

costs has resulted in shortages of the studied essential goods, because of the rapid change in demand from the population and health professionals. In delicate times such as those of Covid-19, the use of the Just-in-time method generates too fragile supply chains (Zhu, Chou, & Tsai, 2020).
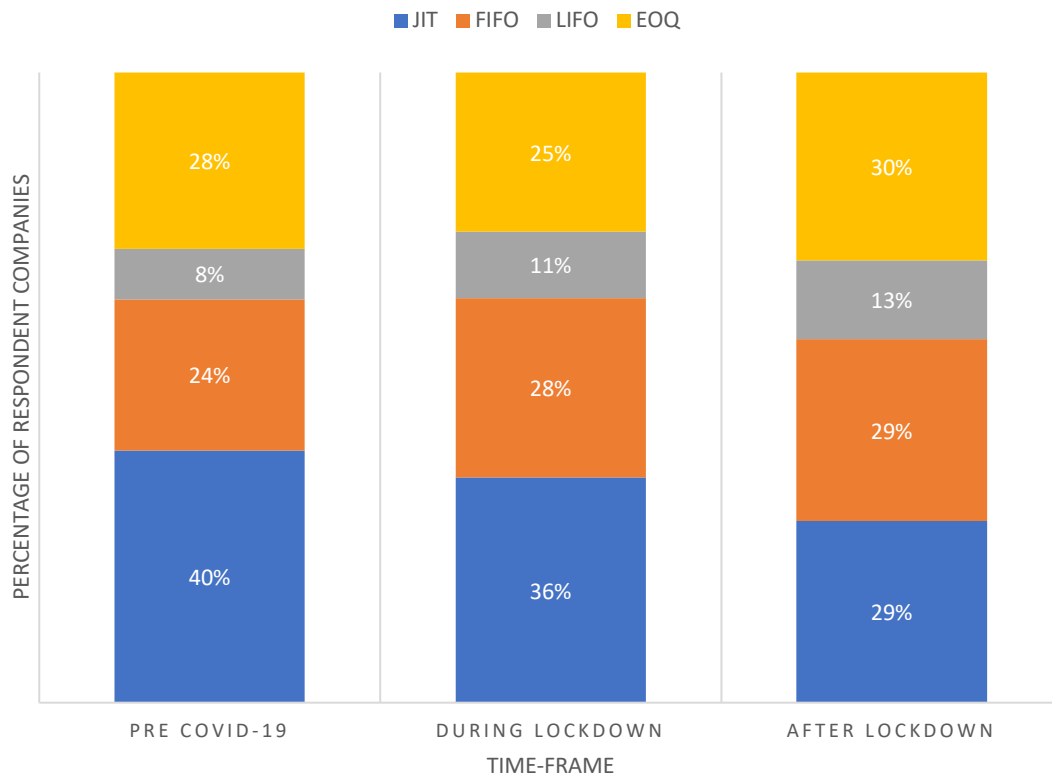
Figure 17 - Stock management of respondents

While the most used method during the lockdown was still the JIT, after the lockdown the most used inventory management method shifted instead to the Economic order quantity. As can be seen from Figure 13, during the lockdown the 44% of respondents found that the level of stocks remained the same and the same percentage of respondents reported that it increased, while for only 13% of them the level of inventory is diminished. This can be traced back to the change in the inventory management method of the respondents themselves, in fact, having reduced the use of Just-in-Time, the level of stocks is, by definition, growing. The same reasoning applies to the level of inventories which, for 55% of companies, increased after the lockdown compared to during the March-May period: this could also be a consequence of the further reduction in the use of Just-in Time and the wider diffusion of the EOQ method.
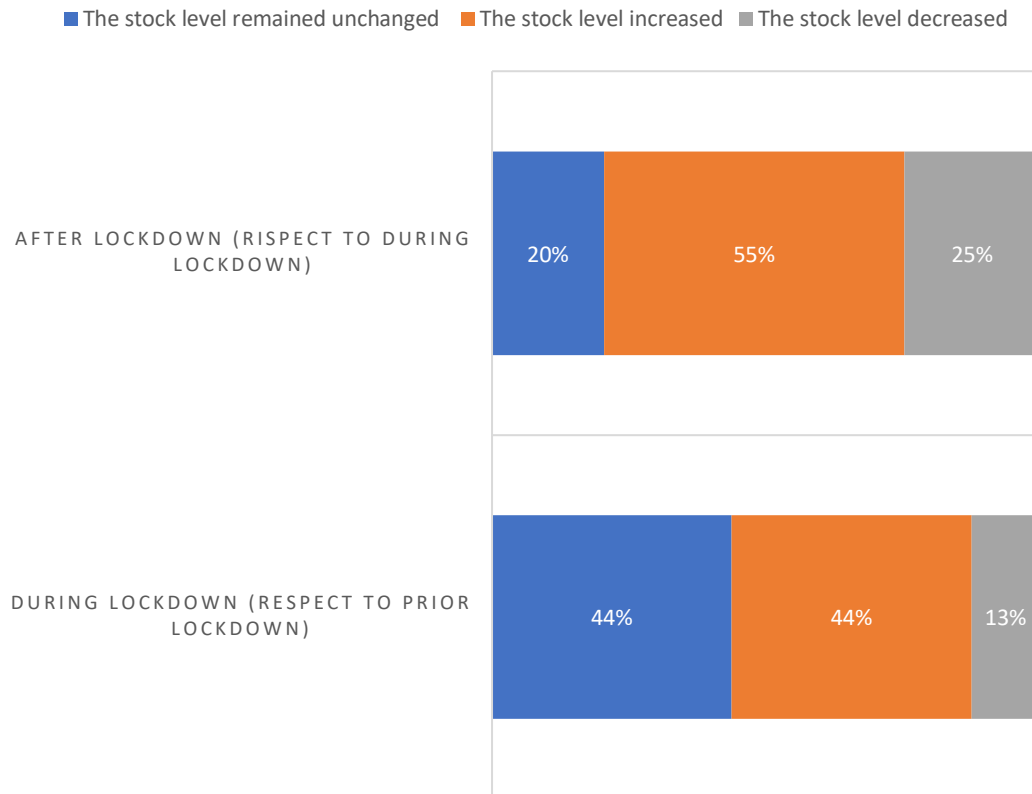
Figure 18 - Average inventory level respondents

The "Suppliers Management" section is analyzed through descriptive statistics in order to understand the relationship between respondents and their suppliers during and after the first lockdown, having the opportunity to analyze how the management of suppliers by respondents is changed; During the lockdown, the 38% of respondents showed a moderate increase (30-45%) in orders placed to their suppliers, while 25% of them showed an increase in orders of more than 45% respect to prior lockdown. After May, however, although the highest percentage of respondents, that is 22%, indicated that the increase in orders made to suppliers was moderate, 43% of them highlighted an increase in orders made to suppliers more 45% compared to the lockdown period. This is linked to a better ability of companies in the PPE / MD market to manage a greater quantity of incoming and outgoing material. As can be seen from Figure 14, in order to cope with an increase in orders during the lockdown, 29% of companies decided to increase the number of suppliers, while after the lockdown the decision taken by 47% of respondents was to increase the number of geographic areas of suppliers. These decisions find fundament in Figure 15, where it can be seen that during the lockdown the most common reason for the lead time of their suppliers

was the closure of the upstream factories: this led them to look for other suppliers, increasing the number of them.

After the lockdown, however, 21% of respondents found an increase in the lead time of suppliers due to transport restrictions (export bans, governmental delays in checking the certifications of the goods, borders restrictions and controls, …) and therefore many of them have decided to look for suppliers in other geographical areas. Due to the lockdown, as can be seen in Figure 14, the 35% of the companies have stated that the greater number of geographical areas of origin of the suppliers will be maintained also in the future: the aim is to reduce the fragility of the supply chain and make it more resistant to changes in demand similar to those that occurred during the pandemic in 2020 [47].
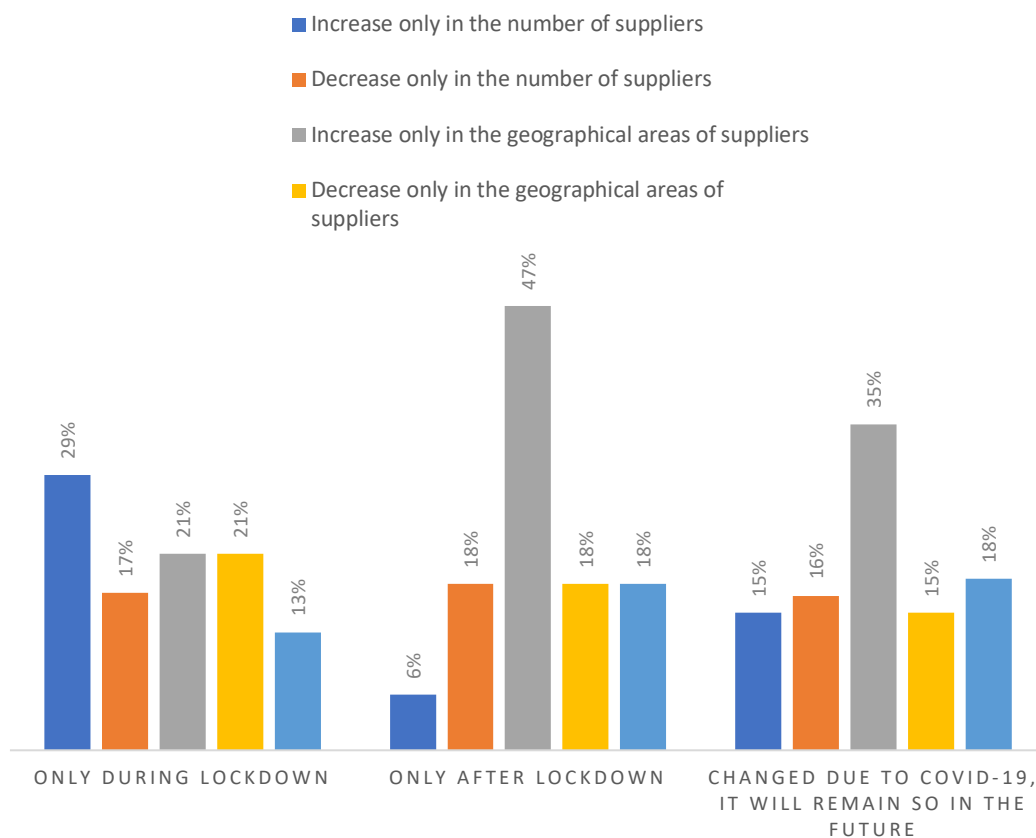
Figure 19 - Suppliers number and geography change due to Covid-19

Legend:
- Production delays due to shortage of upstream raw materials
- Export bans from the countries of our suppliers
- Fabric shutdowns/Covid infections in suppliers facilities
- Restriction in the transportation of your suppliers
- Reduction of suppliers' staff to ensure social distancing
- The lead time has decreased
- The lead time remained unchanged

AFTER LOCKDOWN: 7% | 0% | 21% | 14% | 21% | 36%

DURING LOCKDOWN: 15% | 12% | 18% | 15% | 17% | 9% | 12%

TIME-SPAN

PERCENTAGE OF RESPONDENT COMPANIES

Figure 20 - Lead time of suppliers

The 31% of the respondent companies had a plan before the spread of Covid-19, in order to being able to cope with a possible disruption of the supply chain: this figure is alarming, as the companies deal with a basic necessity, and they should all be prepared for an event such as the pandemic. After 2020, the 81% of responding companies will have a plan to reduce the risk, and this bodes well in the hypothesis of another pandemic.

■ My company prepared a plan during Covid-19 emergency

■ My company never had a plan

■ I don't know

■ Yes, my company had a plan before Covid-19 emergency
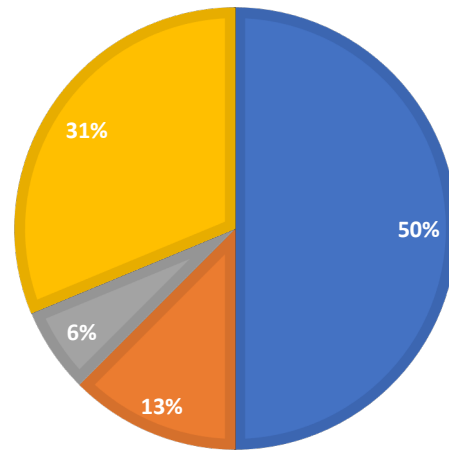
Figure 21 - Disruption plan

Following, in Table 1 is reported a summary of the most important results of the descriptive statistical analysis.

Variables	Results
Respondents in numbers	- 56% of the companies are small enterprises - 51% of them has clients also outside the Italian market - 51% are producers, 32% are importers, 25% are distributors - The most important PPE/MD to combat a pandemic are represented in the responses: masks, gloves, gowns, protective glasses and visors - The 69% of the respondents are high skilled professionals - The 81% of the respondents are new entrants, as they were not in the PPE/MD market prior to Coronavirus outbreak.
Production management	- Prior to pandemic, MTO and JIT were the most used methods - MTO was the method whose usage has been reduced the most during and after the lockdown - MTS was the most used production method after the lockdown
Customer requirements and orders	- Higher increase in orders from clients, quantities shipped, and leading lines combined with decreased lead time after lockdown respect to during it - Those who reported increased lead time during lockdown encountered mostly suppliers delays and transportation inefficiencies - After the lockdown, those who reported longer lead time encountered mostly governmental barriers and transportation inefficiencies
Stock management	- Prior to the pandemic JIT was the most used stock management method, and during and after the lockdown is the method who suffers the highest reduction - After the lockdown the most used method is EOQ, in order to optimize inventory levels and costs
Suppliers Management	- The number of orders to suppliers increased the most after the lockdown respect to during it

Table 8 - Summary of results from descriptive statistics

	- During the lockdown the 29% of companies decided to increase the number of suppliers, as the most widespread reason for suppliers' delays were the shutdown of fabrics; whereas after May the most common decision, taken from the 47% of the respondents, has been to increase the areas from which suppliers came from, as the most widespread reason for suppliers' delay became the restriction of transportation
Disruption plan	- One out of three companies had a disruption mitigation plan prior pandemic, whereas after lockdown eight out of ten companies had it

3.3   QUANTITATIVE ANALYSIS OF THE DATASET

The Kruskal-Wallis test is technique used when the distribution is not normally distributed, and it is able to analyze the variance of a population over certain variables: it inspects whether there the population have identical medians (Arditi, Mangano, & De Marco, 2015). To correctly use the Kruskal-Wallis test, some categorial ordinal variables have to be identified, in order to be able to give them numerical values in a ranked way (Nahm, 2016). The Kruskal-Wallis test is presented in the Equation 1:

Equation 1 - Kruskal-Wallis test

$$K = \frac{(N-1)(\sum_{i=1}^{g} nj(\bar{r}i - \bar{r})^2)}{\sum_{i=1}^{g} \sum_{j=1}^{n}(rij - \bar{r})^2}$$

where:

nj = number of observations in group i;

rij = rank of observation j from group i;

N = total number of observations across all groups.

In Table 9 is reported a summary of the variable identified as interesting to be studied in correlation with the numerical variables identified as categorial. At each variable, more categorial variables has been associated in order to find variances: for each couple variable-categorial variable a Kruskal-Wallis test is performed through Minitab. For each test performed on the couple Variable-Categorial variable, if the test has p-value lower than 0,05 the null hypothesis can be rejected in favor of the alternative hypothesis of at least one difference among the groups under analysis (Arditi, Mangano, & De Marco, 2015). The p-value is a probability that measures the evidence against the null hypothesis. lower probabilities provide stronger evidence against the null hypothesis.

Table 9 - Categorial variables

Variables	Categorial variables
Respondents activity *(Represented in* **Figure 9***)*	- Orders variation during and after lockdown - Quantities shipped variation during and after lockdown - Leading lines variation during and after lockdown - Lead time during and after lockdown - Stock levels during and after lockdown - Variation in suppliers' orders during and after lockdown - Suppliers lead time
Respondents client base origin *(Represented in* **Figure 7***)*	- Orders variation during and after lockdown - Quantities shipped variation during and after lockdown - Leading lines variation during and after lockdown - Lead time during and after lockdown
PPE/MD treated from *respondents* *(Represented in* **Figure 10***)*	- Orders variation during and after lockdown - Quantities shipped variation during and after lockdown - Leading lines variation during and after lockdown - Lead time during and after lockdown - Stock levels during and after lockdown - Variation in suppliers' orders during and after lockdown - Suppliers lead time

Below, the analyzes carried out using the Minitab software are reported, together with a critical analysis of the results, taking into consideration the descriptive analysis of the respondents. The aim of the following study is to understand how the daily operations of the respondent companies are changed amid the first pandemic wave in Italy, in order to track down the criticalities and problems encountered in their supply chains.

The Table 3 report an analysis conducted to understand how the variables of order variation, quantities shipped variation, leading lines variation, lead times, stock levels, variations in orders to suppliers and lead times of suppliers are dependent on the activity of the respondent company.

As can be seen, the variables have undergone a similar behavior for producers, importers and distributors, while the activities of "Other (with production)" and "Other (without producers)" have an average value lower than the other three, bringing the p-value to be less than 5%. If the Kruskal-Wallis test is performed only on the three activities " Producers", "Importers" and "Distributors", the p-value is always greater than 5%, meaning that the null hypothesis cannot be rejected, and the result of the test is that three activities have identical median.

This result should be read in light of the characteristics of the sample of companies that answered the questionnaire, in order to draw solid and compliant conclusions. The "Other (with production)" and "Other (without production)" activities were chosen by companies that do not import, export, distribute and produce; due to the way in which the questionnaire is structured, it is not possible to know what their role was in the PPE / MD market during and after the lockdown; also, only the 8% of the respondents to the questionnaire said they were part of these two types of activities.

On the other hand, producers, importers and distributors have experienced a moderate increase in the variation of orders, quantities shipped and weekly leading lines (30% -45%), even if distributors and importers have values mostly above average while producers mostly inferior; this is due to the fact that the producers who replied to the questionnaire are mostly new entrants, and the time waited for state funds or/and industrial conversion works have delayed the timely industrialization of PPE / MD; among the most significant incentives are those provided for by the #curaItalia Decree starting from April 1, 2020, that consisted in 50 million euros to support Italian companies that were willing to expand or reconvert their business to produce protective equipment against

coronavirus [49]. This is especially true if we consider the sample of responding companies, which are mostly small / medium-sized companies with profits of less than 2M, therefore unable to invest large amounts of money before the incentives arrive. Distributors and importers, instead, could already work at full capacity from the start of the lockdown by importing and distributing protectives equipment, as large number of initial investments are not needed. From Table 3 it can be seen how the lead time has decreased for Producers, Importers and Distributors after the lockdown compared to during it, as was also highlighted in Figure 10. A comparative analysis was then made for the respondents who showed an increase in lead time during or after the lockdown: for the category of importers, the reason that recurs in most cases is the inefficiency of transport during the lockdown and government barriers after the lockdown; for distributors, on the other hand, the most common reason during and after the lockdown was the inefficiency of transport. Long logistics chains such as PPE/MD are more vulnerable and riskier, and dependence on foreign countries for the supply of basic necessities has been a losing strategy in a delicate moment like that of the pandemic (Agostino et al., 2020).

Furthermore, for producers the most recurrent reason for the lead time increase is the suppliers delay, both during and after the lockdown: in paragraph 1.4.2 it was discussed in detail how the scarcity of raw materials and the unique geography of the companies that process the raw materials for the production of PPE / MD created room for disruption in the supply chain of these key goods. Distributors and importers managed to maintain a higher level of stocks than producers in the periods considered, although this may be linked to the greater number of importers and distributors in Italy compared to the number of producers. The respondent's producers, in fact, changed the production management method from JIT (during lockdown) to MTS (after lockdown), moreover changing the management of stocks from JIT (during) to FIFO (after lockdown), therefore trying to increase the stock level.

Table 10 - Kruskal-Wallis test on means of respondents' activity
{n producers= 47; n importers= 30; n distributors= 45; n other (with production) = 1; n other (without producers) = 9}

Variable: Respondents Activity	Mean scores					Kruskal-Wallis p-value (Adjusted for ties)
	Producers	Importers	Distributors	Other (with production)	Other (without producers)	
Orders variation during lockdown	3,00	3,50	4,00	-	3,00	0,57
Orders variation after lockdown	3,00	4,00	4,00	1,00	2,00	**0,05**
Quantities variation shipped during lockdown	3,00	5,00	4,00	-	2,00	0,24
Quantities variation shipped after lockdown	3,00	4,00	4,00	1,00	2,00	**0,02**
Leading lines variation during lockdown	2,00	5,00	3,50	-	2,00	0,08
Leading lines variation after lockdown	3,00	4,00	4,00	1,00	1,00	**0,00**
Lead time during lockdown	2,00	3,00	2,00	3,00	1,00	0,24
Lead time after lockdown	1,00	1,00	1,00	2,00	3,00	0,40
Stock levels during lockdown	2,00	3,50	3,00	-	-	0,45
Stock levels after lockdown	2,00	3,00	3,00	-	2,00	0,80
Variation in suppliers orders during lockdown	3,00	3,50	3,00	-	2,00	0,31
Variation in suppliers orders after lockdown	3,00	3,50	4,00	1,00	1,00	**0,00**
Suppliers lead time	2,00	3,00	3,00	1,00	3,00	**0,01**

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Depending on the areas of origin of the customers, the variables of orders variation, quantities shipped variation and leading lines variation during the lockdown assume different values. In the analysis of Table 4, it must be taken into account that the "EU" response also includes Italy and "Worldwide" includes the EU, China and the USA.

Respondents who have customers in Italy, the EU and the US show lower values of the variables in the first column during the lockdown than respondents with customers in China and around the world.

The values of the variation in orders, quantities shipped, and leading lines are significant (+ 45-60%) both during and after the lockdown for companies that have customers all over the world: if before and during the lockdown, the countries that had the most need for PPEs were the Asian ones (mainly China), later they were also the Europeans, maintaining a variation of the variables considered high.

As for China, the data shared by the government indicate that as of 1 May 2020 the total number of infections were 84,000 [50], whereas in Italy the number of

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13 The variables in the first column whose refer to the period "during lockdown" contain the responses of companies that were already part of the PPE market before the coronavirus (incumbents), as they refer to variations respect to prior coronavirus periods.

infections as of 1 May 2020 corresponds to 204,000 [51]. Since the Chinese population is more than 23 times the Italian population, the need for PPE / MD is much higher; this leads to an increase in orders, quantities shipped and bill lines during the lockdown that is greater for those companies that also have customers in China. Additionally, it can be noted that the quantities shipped and leading lines to Chinese customers have increased exponentially (+ 75%), while the variation in orders moderately (30-45%).

While the epidemiological situation in China was slowing down after May, coronavirus infections were increasing in a worrying way in Europe. In fact, from 15 March to 26 May, due to the trend of infections and the need for PPE / MD to protect the population, the EU has instituted export restrictions [52]; as can be seen from Table 4, the number of orders, quantities shipped and leading lines increased for Italy and Europe (which also includes Italy in the analysis) after the lockdown compared to during the lockdown (March -May), while the behavior of the variables for China is the opposite. The situation in the US is very different: as of May 1, 2020, the confirmed coronavirus cases were 24,000 [53], a very low number compared to the country's population: it can be seen from Table 4 that the three variables of order variation, quantity shipped and leading lines during the March-May period are very small for the US column; even after the lockdown, the increase in the three variables studied is minimal, and this may be linked to the European and Italian export bans and to the domestic market that absorbed the offer of the territory.

The Europe, on the other hand, during the period March-May sees an increase of about 15% in the variables analyzed, and this is consistent with the epidemiological situation of the period, which was under control in most European countries. The inconsistent results obtained with the analyzed period are those of Italy: during the lockdown it is one of the most affected countries in Europe [54], and respondents report a moderate increase (30%) in orders from Italian customers, and an increase of 15-30% in the quantities shipped and leading lines.

An answer to this anomaly can be found through the analysis of the activities of the respondent companies with also Italian clients: 46% of them claimed to also be involved in the production of PPE / MD, while 49% also engaged in distribution activities; The demand that has not turned into supply in the short term, during the first wave of contagions, is a problem that is highly likely to be

associated with these two activities. On the other hand, all the respondents who have customers in China deal with imports: this means that outside the period in which the government has imposed bans, exports outside Italy were efficient and numerous. As previously mentioned, the incentives to reconvert or expand production going towards the needs of the pandemic have reached the end of the lockdown, and this partly justifies the slowdown in the Italian market that can be seen in Table 4. Once the production of protective devices and medical devices has incremented the capacity, after the lockdown, it can be seen that companies with customers also in Italy have had moderate variations (30-45%) compared to the previous period (March -May).

As for the criticality of distribution, however, the Coronavirus Emergency Commissioner Domenico Arcuri, in the press conference of May 12th, 2020, stated that the PPE / MD distribution network has suffered slowdowns due to distributors who have indicated that they have quantities of products which they actually did not have [55].

Table 11 - Kruskal-Wallis test on means of respondents' client origin
{n China = 2; n Italy= 71; n UE= 24; n USA= 4; n Worldwide = 20}

Variable: Respondents client base origin	Mean scores					Kruskal-Wallis p-value (Adjusted for ties)
	Cina	Italy	UE	USA	Worldwide	
Orders variation during lockdown	3	2,5	1,5	1	4	**0,023**
Orders variation after lockdown	2,5	3	3	1	4	0,292
Quantities variation shipped during lockdown	6	2	1,5	1	4	**0,021**
Quantities variation shipped after lockdown	4,5	3	3	1	3	0,215
Leading lines variation during lockdown	6	2	1,5	1	4	**0,046**
Leading lines variation after lockdown	4,5	3	3	1	3	0,376

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This analysis, read together with that linked to the results of the Kruskal-Wallis test in Table 3, brings out an important fact: the orders and quantities shipped to Italian customers are reduced during the lockdown, since most of the respondents are part of two categories which suffered critical issues during the period. Producers have not been able to produce since the beginning of the pandemic, due to the delay in the funds allocated and the time required for

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14 The variables in the first column whose refer to the period "during lockdown" contain the responses of companies that were already part of the PPE market before the coronavirus (incumbents), as they refer to variations respect to prior coronavirus periods.

industrial conversion: this is one of the consequences of the over-reliance on producers in countries such as China or Malaysia (ref. paragraph 1.4.2): the necessity to create new production plants during the emergency, involves delays and contagion due to the shortages of PPE/MD. Moreover, only the 27% of the respondent's incumbent producers had a disruption preparation plan: those plans are especially important for manufacturers of finished drug products in order to be aware of their suppliers' and contractors' responses to personnel shortages in order to work with them to ensure the availability of high quality materials and services that contribute to the manufacture of MNPs; also, manufacturers can benefit from preparing for emergencies as pandemic through prevention and risk mitigation (U.S. Department of Health and Human Services Food and Drug AdministrationCenter for Drug Evaluation and Research (CDER), 2011).

On the other hand, distributors had criticalities due to supply chain problems: the 50% of respondents who distributed PPE/MD during the considered period did not had a disruption preparation plan prior the pandemic, and the 17% of the respondents did not know whether the company had it or not.

Furthermore, the JIT management of production and inventory management along the supply chain by most companies and the reliance on outsourcing for necessary raw materials did not hold up especially in the first pandemic wave. This is a piece of the problem of shortages of key goods in Italy [56] during a pandemic such as personal protective equipment and medical devices.

Through the Kruskal-Wallis test of Table 5, each personal protective equipment and medical devices were analyzed in relation to the variables of: order variation, quantity shipped variation, leading lines variation, company lead time, stock levels, variation of orders to suppliers and leads time of suppliers during and after the lockdown. For none of the variables studied, the personal protectives equipment has a different median, as the p-value is always greater than 5%. It can be noted that the variables of variation orders, quantities shipped, and leading lines have a similar behavior for all the PPE considered, with a moderate (30% -45%) or significant (45% -60%) increase compared to the period. For every one of the devices considered there was a reduction in company lead time after the lockdown compared to during it, as was also highlighted with the descriptive statistic of Figure 10. An interesting fact highlighted by the analysis in Table 5 is that the trend of the personal protective equipment stocks during the lockdown

follows the increase in demand for each of the devices: the greater the demand (Bhaskar, 2020), the lower the stock level; the inventory management method used by the highest number of respondents was the JIT during the lockdown, as can be seen from Figure 12: this method does not allow to react in the most efficient way in the case of a variable demand.

Table 12 – Kruskal-Wallis test on respondents' PPE/MD marketed
{n other types of masks = 50; n gloves = 22; n surgical masks = 74; n gowns = 20; n visors= 33; n eye protection = 2}

Variable: PPE/MD treated from respondents	Mean scores						Kruskal-Wallis p-value (Adjusted for ties)
	Other types of masks (N95; KN95)	Gloves	Surgical masks	Gowns	Visors	Eye protection	
Orders variation during lockdown	3	4	3	4	4	-	0,435
Orders variation after lockdown	4	3,5	4	4	4	4,5	0,844
Quantities variation shipped during lockdown	3	4	3	4	4	-	0,833
Quantities variation shipped after lockdown	3	3,5	3,5	4	4	4,5	0,87
Leading lines variation during lockdown	3	3	3	3,5	3	-	0,866
Leading lines variation after lockdown	3	3	3	3,5	3	5	0,672
Lead time during lockdown	3	3,5	2	2,5	3	5	0,313
Lead time after lockdown	1	2	1	1,5	2	2,5	0,544
Stock levels during lockdown	0	3	1	2	3	-	0,798
Stock levels after lockdown	3	3	2	2	3	-	0,692
Variation in suppliers orders during lockdown	3	3	3	4	3	-	0,416
Variation in suppliers orders after lockdown	3	3	4	4	3	3	0,775
Suppliers lead time	3	4	3	4	3	4,5	0,487

[15]

In Table 6 below there is a summary of the results obtained from the Kruskal-Wallis analysis, also in light of the results of the descriptive analysis:

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[15] The variables in the first column whose refer to the period "during lockdown" contain the responses of companies that were already part of the PPE market before the coronavirus (incumbents), as they refer to variations respect to prior coronavirus periods.

Table 13 – Summary of the results

Results of the analysis	Reasoning behind it
From the results of the survey, producers report a moderate variation in quantity shipped from before to during the lockdown (+ 30-45%), as well as after the lockdown compared to during the period March-May 2020. On the other hand, importers show a very significant increase in quantities shipped during the lockdown (+ 60-75%), while after it significant (+ 45-50%). Distributors, on the other hand, report a significant increase in quantities shipped (+ 45-50%) during the lockdown as well as after it.	The production activity turned out to be the most fragile during the first wave of the epidemiological emergency in Italy. While new entrant producers had to wait for statal funds or spend time to reconvert their company to become an authorized PPE/MD producer, the incumbent producers were not ready for a supply chain disruption, as only the 27% of them had a plan for it prior to the pandemic. This slowed down the massive production of PPE / MD that Italy needed during the first wave of coronavirus outbreak. On the other hand, Importers and Distributors were able to manage both during and after the lockdown highest levels of positive variations in quantities shipped and orders, proving consistent with the great demand for PPE / MD required by the Italian state. This is also due to the intrinsic characteristics of the activities: the distribution and importing activity requires a much lower investment and time (i.e. machinery, personnel and authorizations).
The lead time of respondents had a sharp increase during the lockdown respect to prior to it of after it	The criticalities that increased the lead time of the respondents during the first pandemic wave were linked to the fragility of the PPE supply chain, as its over-reliance on unique sourcing for raw materials and extensive transportation among the players of the global supply chain. The lead time decreased after the lockdown as the export bans from several key countries were relaxed, in states like China coronavirus infections started to drop. For instance, as Chinese demand

and stock were fulfilled, more PPE/MD are left over for export [57].

Stock level of importers and distributors during and after the lockdown is higher than the one of producers	The method used by producers during the lockdown was mainly the JIT, while after the lockdown was mainly the FIFO, therefore the aim of the producers was to increase the stock levels. Even if producers fought to increase their stock levels, distributors and importers maintained a higher level of stocks in the periods considered. The demand for key products towards the small number of Italian PPE / MD producers during the first wave of coronavirus was much higher than their potential supply, and their efforts to increase stock levels were not enough in a time of crisis and disruption of the supply chain. Thus, the inventory level remained more critical in this first wave for producers respect for distributors and importers, who could count on a foreign offer of key goods with fewer resources and time, being able to maintain higher stock levels.
During the lockdown the variables of orders variation, quantities shipped, and leading lines had different medians respect to respondent's client origin	Companies who export to China have high values of the variables analyzed during March-May 2020, as afterwards export limitation banned these types of activities. US clients have low values of the variables during and also after lockdown, as the Coronavirus cases in the country were still low then. EU clients have lower values of the variables during the lockdown, as the first wave in Italy occurred prior to the rest of Europe. On the other hand, criticalities are enlightened in the Italian market: the low values of the variables during the lockdown are incoherent with the high amount of Coronavirus cases in the

country. Most of the respondents are producers and distributors, and the majority of the incumbents in both activities didn't had a disruption plan prior the coronavirus pandemic. On the other hand, the new entrants who produce PP/MD in the earliest day of the coronavirus outbreak, had still to receive economic incentives to reconvert their facilities, and/or had to spend time to reconvert their plant in order to be an authorized producer of PPE/MD.

Quantitative evidence of how the JIT method is harmful during a moment of emergency

The JIT method is the most used by the respondents, and the behavior of the stock level variable show how inefficient it is in rapid demand changing times. In fact, the more the good had a high demand (i.e., surgical and other masks), the lower its inventory levels were during the emergency.

4 CONCLUSIONS

In this last chapter are discussed the benefits brought by the thesis work on the state of the art of the literature, concerning the problems encountered along the supply chain of the personal protective equipment / medical devices once the health emergency has started to spread globally in early March 2020. Subsequently, the limits of the thesis will be analyzed together with the future steps that the research on the topic should deal with, starting from the thesis work.

4.1 BENEFITS OF THE THESIS WORK

The main findings of the research work that bring benefits on the state of the art of the argument are listed below:

1- Production management methods have been modified by companies due to the advent of Coronavirus, which have tried to increase inventories along the supply chain in order to cope with rapidly changing demand.

2- The management of suppliers has seen a transformation compared to before the pandemic: previously the number of raw materials, semi-finished or finished product suppliers for the PPE/MD industry and the geographical area of origin were reduced for most companies, with a view to cost savings (ABD Briefs, 2020). On the other hand, during and after first pandemic wave in Italy, on the optimization of costs along the supply chain, the perspective of risk mitigation won, increasing the geographical areas of origin of the suppliers.

3- The activity that suffered the most disruption and that caused delays and bottlenecks downstream during the first pandemic wave was the productive one, mainly due to the over-reliance on exports from Asian countries, for the intrinsic characteristic of the production methods of PPE/MD, whose require high economic disbursement and authorizations, and a diffuse lack of preparation for a supply chain disruption from the incumbents.

4- The lead time increase that manufacturers, importers and distributors reported during the first Italian lockdown was due to intrinsic characteristics of the global supply chain. The problems related to a long and disperse supply chain were highlighted from the health emergency, first of all through the delay in suppliers, transport problems and barriers governmental.

5- The widespread use of JIT as inventory management has been replaced by methodologies that offer a higher level of security, demonstrating how a high unpredictability of demand and unstable economic situation is not compatible with an extreme cost reduction such as that linked to use of the JIT. In any case, while modifying inventory management, the production activity managed to maintain a lower inventory level than the import and distribution activities. As stated above, the demand for PPE for the few Italian producers in the first pandemic wave was much higher than their supply: the level of stocks was insufficient as whatever was produced, was sold instantly.

6- Depending on the origin of the customers, the respondents demonstrated a consistent behavior of the variables of variation of orders and quantities shipped with respect to the quantities of infections in the periods considered for Europe, China and the USA. The respondents who have Italian customers are for the most part Italian producers, and the reduced variation in orders and quantities shipped resulting from the survey, in a period of crisis as of the first pandemic wave in Italy, demonstrates once again how shortages were mainly due to bottlenecks upstream of the productive part of the supply chain.

7- The use of JIT as a method of production and inventory management along the PPE / MD chain has proved insufficient and harmful in the event of a health emergency. The method proved all the more harmful the more the good was needed in large quantities and quickly, as in the case of surgical masks and FFP2.

The benefits of the thesis work are many: first of all, the analysis of the quantitative study confirmed some of the existing evidence in the literature on the motivations of PPE / MD shortages in various countries around the world ((ABD Briefs, 2020), (Cohen & Rodgers, 2020) (Sharma, Gupta, & Jha, 2020) (Harvey, 2020)). Furthermore, the quantitative study was able to demonstrate cause-and-effect links and relationships in the global supply chain of essential goods such as personal protective equipment during a pandemic. The thesis work is also the first quantitative analysis in the Italian literature of the PPE / MD supply chain amid covid-19: there is not scientific literature on the subject in Italy up to date, and the thesis work confirmed thanks to the quantitative analysis some of the arguments on shortages present in non-scientific articles published in newspapers and found other results still little explored.

Also, evidence that had been highlighted by scientific journals during 2020 for other countries, as USA, was also confirmed for Italy thanks to the thesis work.

4.2   LIMITS OF THE THESIS WORK

The main limitation that the thesis highlighted is the response rate, which is about 11%: the willingness was to analyze the global supply chain of the PPE / MD from different points of view, that is, from the point of view of Chinese, American and Italian companies. The comparative analysis of the three situations would then have fully explained where and why the supply problems arose at a global level: this was not possible as the response rate for Chinese and American companies was 0%.

Moreover, due to time limits, the questionnaire was only administered in November, December 2020 and January 2021. In those months, coronavirus cases in Italy were growing and many of the companies contacted were overwhelmed by work. The response rate from Italian companies could have been higher in the case of administration in an epidemiologically calmer period.

4.3   FUTURE RESEARCH

The importance that the topic of the thesis has on public health requires intensive research activity, so that the criticalities highlighted during the first wave of coronavirus in Italy no longer occur in the case of another unexpected pandemic, or in the one than still is present today. The thesis work studies (for the first time in the Italian literature up to date) in a quantitative way the general causes, at the sectoral level, of deficiencies down the supply chain: shortages that were highlighted at the level of the population in the moment of maximum need. Future research work could start from the causes highlighted in the thesis work and analyze the consequences that each of them actually had on the supply chain and the role that each of them had in the shortages that occurred.

Thanks to this, ad hoc risk mitigation rules can then be drawn up for the pandemic risk on the PPE / MD supply chain.

The thesis also underlines how companies in the PPE / MD sector changed their day-to-day operations during and after the first lockdown in Italy compared to before the health emergency. This aspect can be further investigated by future research, in order to demonstrate how much the practices in use have changed considering a bigger sample, and the consequences that these changes.

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