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Viability and Resilience in the Personal Protective Equipment Supply Chain. The Impacts of Covid-19

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Abstract: The recent Covid-19 pandemic has caused major disruptions in healthcare systems, in particular in the Personal Protective Equipment (PPE) supply chain. The present paper aims at studying the effects of Covid-19 on its main supply chain variables and at investigating how viability and resilience concepts were applied during this period. A Systematic Literature Review helps identify the variables and strategies most commonly considered, forming the basis of a survey then carried out among French and Italian companies operating in the PPE supply chain. The results allow to derive both academic and practical implications.

Keywords: Supply chain management, Personal Protective Equipment, Covid-19 pandemic, Viability, Resilience, Systematic Literature Review, Survey

1. INTRODUCTION

Supply chain (SC) viability and resilience have recently emerged as key issues in operations management under the pressure of different crises. Among them, the spread of Covid-19 has heavily affected SCs worldwide, causing severe disruptions and supply shortages. Companies and organizations producing goods and services had to develop their ability to respond quickly to these operational disruptions through flexible contingency plans, which is known as resilience, and their capacity to strongly redesign their structure and their operations in order to maintain themselves, which can be defined as viability (Ivanov et al., 2023).

In that context, healthcare SCs have been particularly impacted by the Covid-19 pandemic, facing several issues spanning from hospital supplies of critical drugs to personal protective equipment (PPE). Back in 2020 PPE, such as masks and gloves, quickly moved from being products used for safety reasons in particular working environments to be every-day-used items playing a pivotal role in containing the Covid-19 spread. This caused a massive spike in demand for such products with consequences at every SC echelon, from raw materials suppliers and PPE manufacturers to wholesalers and distributors and up to the hospitals and pharmacies where the items are used or sold to consumers. It took few weeks to report a shortage of PPE in many hospitals and health facilities, leaving healthcare workers and the public vulnerable to infection. The pandemic also caused the PPE prices to soar: in April 2020, the prices of masks, gowns, and N95 masks had risen 1500%, 2000%, and 6136% respectively, compared to the pre-Covid-19 levels (Ash et al., 2022).

This paper aims at investigating how the PPE SC adapted to the sudden changes brought about by the Covid-19 pandemic.

More precisely, the following two research questions are addressed: (1) What were the effects of Covid-19 on the main logistics variables in the PPE SC? (2) What were the effects of Covid-19 on the strategies adopted in the PPE SC and its viability and resilience?

The chosen approach relies first on a Systematic Literature Review (SLR) about PPE SC during the Covid-19 pandemic. This helps identify the SC variables and strategies that are most commonly considered in such a context. Next, an international survey of PPE manufacturers, distributors, and wholesalers is carried out in two of the European countries most affected by the pandemic, namely France and Italy, based on a questionnaire built from the SLR results. While most of the available literature focuses on the first pandemic waves in 2020 and early 2021, the present research addresses the PPE SC behavior in the last pandemic phases in 2022 and compares it with the one in the earliest periods, trying to capture the main alterations. It can thus highlight deeper changes affecting the PPE SC, questioning its structure and operations over a longer time period.

The paper is organized as follows: Section 2 details the SLR and its main findings. In Section 3, the survey methodology is described. The results of the survey are presented in Section 4 and discussed in Section 5. Lastly, in Section 6, a conclusion and some perspectives about future works are proposed.

2. LITERATURE REVIEW

2.1 Literature review methodology

In order to analyze the previous research works focusing on the PPE SC during the Covid-19 pandemic, a SLR is performed. This structured methodology is known to be helpful to synthetize research findings in a systematic,

transparent, rigorous, and reproducible way (Snyder, 2019). After defining the topic under study precisely, inclusion and exclusion criteria are introduced and keywords are chosen, based on different keyword levels: "supply chain management", "PPE", and "Covid pandemic" were systematically used, and complemented by combinations of more detailed and specific keywords covering the main supply chain aspects. The complete list of keywords can be found in (Caggia, 2023). Search queries are then issued on databases of peer-reviewed literature to select papers of interest using these criteria. The first list of papers to consider can be completed with additional papers using a snowballing approach (Voicu and Babonea, 2011), leading to the final corpus to analyze. The main findings are then summarized and literature gaps may be identified. Table 1 presents the main characteristics used to search for and select the papers to analyze in the present research work.

Table 1. Characteristics for the literature review

| Inclusion criteria	
Topic	Focus on PPE SC during the Covid-19 pandemic
Language	English
Document types	Journal papers, conference papers
Time interval	2020-2022
Source (database)	Scopus
Snowballing	Backward selection + forward selection

2.2 Description of the paper corpus

Based on the different queries on Scopus, 94 papers are found. After careful reading, 50 of them are selected as relevant for our review. The snowballing approach (forward and backward selections) allows to add 14 more papers, leading to a corpus of 64 papers focusing on the management of the PPE SC during the Covid-19 pandemic. A detailed list of the papers can be found in (Caggia, 2023) and is available from the authors upon request.

28% of the papers were published in 2020, 42% in 2021, and 30% in 2022. They are part of a wide range of journals and conferences covering different scientific fields, from industrial engineering and management science to infection control and epidemiology. The only journal with more than 2 papers is the "International Journal of Production Research" (IJPR) with 4 publications. 69% of the 64 papers used a qualitative methodology, based on, in particular, a systematic review (30%), a case study (27%) or interviews (14%). Sometimes these methodologies have been combined together. With regard to quantitative methods, 14% of the papers develop mathematical models for optimization. In terms of geographical scope, most of the papers are very general and do not focus on a particular area. The only countries that are the subject of a study in more than 2 papers are the US, the UK,

and Canada (with 20, 3, and 3 different papers respectively).

2.3 Main outcomes from the literature review

The studies from the literature highlight different effects of the pandemic on the PPE SC, like a surge in the demand (Abdolazimi et al., 2023), stockpile depletion (Sodhi et al., 2023), and a huge production backlog (Singh et al., 2022). Potential solutions are also suggested and analyzed to mitigate the consequences of the disruptions, to recover from such a crisis, and to increase the adaptability of the system. Among these strategies are the implementation of new replenishment policies (with safety stock) (Li et al., 2023), building additional capacity (Abedrabboh et al., 2021) or the adoption of ICT (Information and Communications Technology) to improve inventory visibility (Livingston et al., 2020).

The analysis of the 64 papers enables us to identify the main SC impacts and strategies debated in the literature. The results are displayed in 2 Pareto diagrams developed based on the number of papers addressing each impact and strategy. An example is shown in Figure 1.
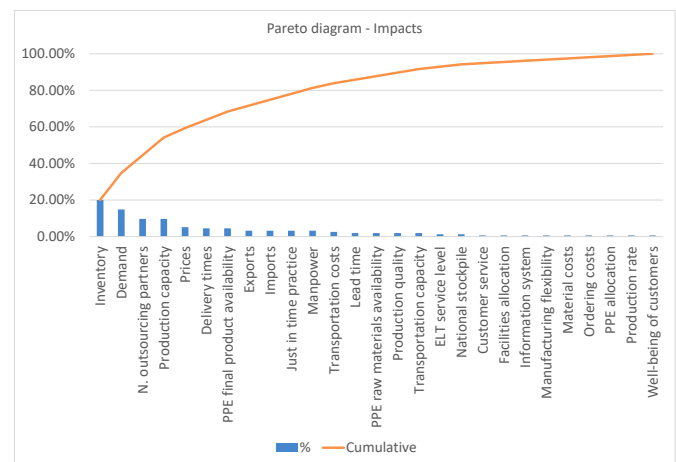
Figure 1: Pareto diagram of the impacts of the Covid-19 pandemic on the PPE supply chain studied in the literature

Although the literature review gives us some insights about the way the PPE SC was impacted by the Covid-19 pandemic and how it tried to adapt to the sudden changes that this crisis triggered, there remain some gaps that need to be filled. The research focuses mainly on the early stages of the pandemic, corresponding to what are sometimes called the "first" and the "second waves" in Europe. Reactions to cope very quickly with such sharp disruptions are mainly captured, whereas the possible evolution and adaptation in the longer term cannot thus be identified and studied. Therefore, there is a need for empirical studies aimed at assessing whether the PPE SC learned some resilience and viability lessons by the management of the Covid-19 pandemic situation. Moreover, very few papers consider the response to the crisis in France and Italy, and none of them compare these two countries, that were among the first and hardest affected by the pandemic in Europe. Additionally, the percentage of confirmed cases that resulted in a death was particularly high in Italy and France. To address these gaps, an international survey to PPE manufacturers, distributors, and wholesalers has been carried out in France and Italy.

3. SURVEY METHODOLOGY

The methodology unfolds through the following three steps.

3.1 Questionnaire design

A closed-ended item questionnaire has been developed, so that it is quick and straightforward for the participants to complete. Such a type of survey also makes it easier to discuss the answers through statistical analysis. The questions are chosen based on the SC impacts and strategies identified in the SLR and classified by the Pareto diagrams. In both the cases, we considered all the Class A items, and also included a few items with a lower percentage that are recognized to be relevant from a SC point of view. This finally leads to a list of 20 questions divided into three groups.

The first group is related to general information about the responding companies, in order to categorize them (according to their country, type of PPE managed, or SC echelon, for example). In the second group, each question considers one of the selected impacts on SC variables and asks about its evolution in 2022, compared to the period 2020-2021: customer demand, stock level, customer delivery time, production capacity, and production rate (for manufacturers only). The third group corresponds to questions about the adoption of the selected SC strategies during the pandemic: Just in Time (JIT) adoption, ICT adoption, Stock visibility, Diversification of sources, and Resilience level.

Except for questions regarding the adoption of JIT practices and ICT solutions, which only admit a yes/no answer, a 5-point Likert scale is systematically used to grade the answers and convert them into numbers: from "much decreased" (1), to "moderately decreased" (2), "unchanged" (3), "moderately increased" (4), and "much increased" (5).

The detailed list of questions can be found in (Caggia, 2023) and is available from the authors upon request.

3.2 Sample selection

Potential respondent companies in Italy and France are selected based on national codes referring to their economic activities and using appropriate databases. For Italian companies, the ATECO codes related to the production, import or wholesale of surgical masks, protective clothing, and equipment for medical care are considered. The search is then performed in the AIDA[1] and the National Healthcare Institute[2] databases. For French companies, the NAF and NACE codes are used for search in databases available from Companiesdata.cloud[3], Silex[4], and Orbis[5].
A final sample of 175 and 145 companies, for Italy and France, respectively, was obtained after removing the duplicates and the firms not concerned.

3.3 Survey administration

The survey is administered through emails, written in Italian or French depending on the company targeted, from January to March 2023. The questionnaire is supported by an online form that makes it very easy to collect and then analyze the data. To avoid the bias introduced by the midpoint of a 5-point Likert scale (Nadler et al., 2015), the respondent from each company that agreed to participate in the survey is contacted either by phone or video call. The survey items and the meaning of the midpoint options are explained during these meetings.

By the end of March 2023, when the survey is closed, the response rates are 14.9% and 13.3% for Italian and French companies, respectively, which are in an acceptable value range for performing the subsequent statistical analysis (Rosano et al., 2022).

First, the questionnaire answers undergo the Cronbach's Alpha test to check the internal consistency. Then, they are analyzed by means of descriptive statistics, which provides a global overview of the respondents and allows to study the effects of the Covid-19 pandemic on both the selected SC variables and the strategies adopted.

4. RESULTS ANALYSIS AND INTERPRETATION

The values of the Cronbach's Alpha coefficient of the survey items range from 0.6 to 0.7, which can be considered acceptable values. Following the discussion of the main results of the questionnaire.

4.1 Respondent profile

The three focus echelons in the PPE SC introduced in Section 2.3 are almost equally represented in the French group of respondents: 35% manufacturers, 41% distributors, and 24% wholesalers. However, manufacturers dominate the Italian group (77%), while distributors and wholesalers together constitute the remaining 23%. As a matter of fact, many companies started producing PPE in Italy following the Covid-19 pandemic onset and, although a significant number of them failed soon, especially the smallest ones, many companies are still active nowadays. Masks and gloves are the main PPE products marketed by the French respondents as they are responsible for at least half of the yearly revenue for 47% of them respectively. On the contrary, masks alone constitute the main product for 73% of the surveyed Italian companies. Finally, almost all the companies answering the questionnaire, regardless of the country, serve their domestic market, with a very small percentage of them mainly operating with foreign European customers. No customers located in the US or in the rest of the world are reported.

4.2 Main supply chain variables

According to the survey outcomes, the customer demand in 2022 is pretty much reduced for most of the investigated companies compared to its levels in 2020 and 2021. However, the associated trend appears to depend on the different timing adopted by the two countries in relaxing the obligation to use masks, which are the product contributing to half of the revenue for approximately 50% or even more of the surveyed

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[1] Aida | Italian Company Data | Bureau van Dijk (bvdinfo.com), https://www.bvdinfo.com/engb/
[2] https://www.iss.it/it/home
[3] https://companiesdata.cloud/ode
[4] https://silex-app.com/a-propos-de-silex/
[5] https://orbis.bvdinfo.com

companies. To be more precise, the PPE customer demand has decreased significantly for 70% of the French companies and for only 58% of the Italian one. In fact, France basically removed the obligation to wear masks between March (buildings open to the public, except healthcare facilities) and May (public transportation) 2022. On the contrary, Italy started to relax it in workplaces, shops, and recreational commercial activities in June 2022. Then, masks were no more mandatory on public transportation means since October 2022 but they were still used in healthcare facilities. It has not to be forget that, as mentioned in Section 4.1, most of the customers of the investigated companies are national ones. As expected, a decrease in the customer demand had an impact on stock levels. Again, the situation is different in the two analyzed countries. On the one hand, 61% of the Italian respondents declared to have reported a stock decrease in 2022, which was quite large for almost 40% of the surveyed companies. On the other hand, French companies in the PPE SC show a more conservative behavior. Only 35% of them reported a stock reduction and a same percentage of respondents declared to have an unchanged stock level compared to 2020 and 2021. In general, the French SC players preferred not to cut down their stocks significantly to prevent any possible material shortages in the event of new Covid-19 pandemic waves in the next future. Additionally, a deeper analysis of the questionnaire answers reveals that French companies with declining stock levels mainly produce and trade gloves, while the 30% of companies reporting an increase in stock are active in the mask market. Although no longer mandatory, masks were still frequently used by many people in a variety of situations throughout the 2022. The customer demand decrease, together with stock levels that in several cases are still higher than the market needs in 2022, generate a positive effect on customer delivery time. In fact, very few investigated SC actors, both in French and Italy, faced an increase in the value of such a quantity, while for most of them it stayed unchanged compared to the previous years or even decreased. The overview of the behavior of the main SC variables is completed by investigating the production capacity and the actual production rate of PPE manufacturers. Coherently with the discussed results about the demand and the stock levels, most of the producers in both French and Italy either decreased or kept unchanged their production capacity in 2022. It is interesting to point out that almost 40% of the investigated organizations in each country preferred not to vary a lot the maximum volume of goods they could provide in a given time frame. This can be attributed to a still unclear general perception the pandemic was definitely over at that time. However, the actual production rate decreased in 2022, in order to keep up with the market dynamics. French manufacturers seemed to more quickly adapt their production rates to it than Italian ones. Anyway, in both the countries there is the willingness to reserve a portion of the available production capacity to accommodate possible demand surges.

4.3 Supply chain strategies

According to literature, advanced ICT solutions, such as for instance RFID technology, Light Fidelity technology, and Warehouse Management Systems, are able to increase the degree of coordination among SC partners. This is highly beneficial to improve SC viability in the case of unexpected disruptions (Ivanov, 2022). The questionnaire respondents were asked to state if they adopted any of these solutions following the Covid-19 pandemic. The answers obtained are quite consistent between the two countries: 88% of French respondents and 62% of Italian ones affirmed they did not implement any similar new solutions during the pandemic years. Such an outcome should not be interpreted as a general reluctance to adopt ICT tools assisting SC operations. Rather, the exceptional nature of the Covid-19 situation and the uncertainty about its potential recurrence in a near future led companies to be less prone to invest in often expensive technological solutions. They preferred to wait and see how the market and SC conditions would stabilize before making impactful infrastructure changes.

Many French companies already adopted inventory visibility to address the SC vulnerabilities revealed by Covid-19 in the early pandemic phases. In fact, 53% of them did not increase neither decrease its application level in 2022. However, 35% of the PPE traders were late adopters and increased their inventory visibility only in 2022. Similarly, 48% of the Italian companies resorted to SC visibility only in the last pandemic phases. 40% of the Italian respondents even declared to have decreased their SC visibility: this is probably due to the fact that customer demand was reducing two years after the pandemic onset.

Contrary to the expectations and literature evidences (Micheli et al., 2021), the number of companies in the PPE SC adopting the JIT strategy has increased both in France and Italy. However, if the percentage of the Italian respondents implementing JIT grows from 54% before Covid-19 to 73% in 2022, the corresponding percentages in France are lower, 29% and 47% respectively. Such a result should be explained in the light of the different inventory policies observed in the survey (Section 4.2). In particular, Italian companies revealed to be more prone to limit the quantity of products in stock than French companies and they significantly decreased their inventory levels as soon as the crucial phases of the pandemic were over.

About diversification of sources, another key strategy to recover from SC disruptions, nearly half of French and Italian companies continue to rely on multiple suppliers as they did in the first pandemic phases. Additionally, some companies, more in Italy than in France, have recently significantly increased their supplier diversification. They are probably the organizations that have suffered the most from the PPE SC disruptions and have been slow to recover. It is also worth noting that 40% of the Italian companies are decreasing their diversification level, although in a moderate way, while only 6% of French companies are considering a reduction in the number of their suppliers.

Finally, Figure 2 depicts how the company resilience level has changed in 2022. Most of the French and Italian companies believe they are moderately decreasing or keeping unchanged their resilience level. However, a part from some Italian companies, the lessons learned from Covid-19 do not seem to foster a further increase in resilience compared to the levels PPE companies have already achieved during the first

pandemic periods in order to survive in the market. Here the surveyed companies seem quite optimistic and do not perceive an improvement in resilience as so crucial for their success in the next future.
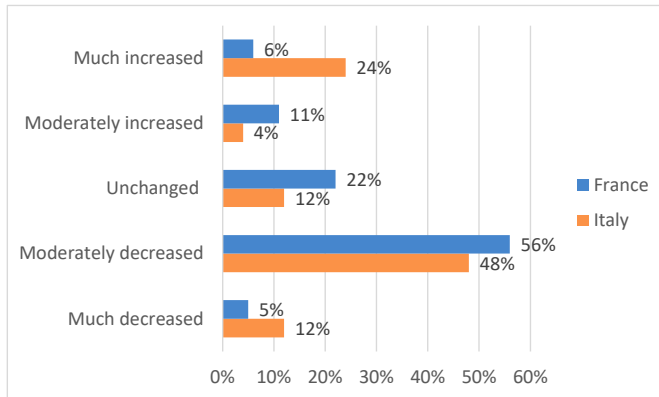

Figure 2. Changes in resilience for French and Italian companies (% respondents)

5. DISCUSSION

The PPE SCs in both France and Italy had to accommodate several changes as a result of the Covid-19 pandemic but also experienced new challenges due to its decline. Indeed, during the pandemic, companies had to adjust their operations to the new circumstances, in an effort to meet the escalating customer demand. Two years after the onset, the epidemiological situation was largely brought under control. As a result, the demand for PPE was decreasing, although certain products, like masks, were still used in many situations. Consequently, companies were cutting down their stock levels, albeit in quite a prudent way so that to be ready in case of new strong pandemic waves. A similar approach was adopted by manufacturers. Production rates were diminished coherently with the latest market trends but production capacities were not significantly reduced. This is a strategy supporting viability and resilience. The production capacity, in terms of machines and other equipment, cannot be drastically changed in the short run. If on the one hand it might be the reason for a limited variation of production capacity in 2022 compared to 2020 and 2021, on the other hand such an awareness drives companies not to embark on reduction paths of production capacity to avoid being caught unprepared by future SC disruptions.

The French and Italian companies participating to the survey demonstrate to have improved their viability through a stable application of strategies related to stock visibility and supplier diversification. In fact, they seem to be already consolidated approaches most of the investigated companies do not intend to abandon. An improved inventory visibility leads to an optimized inventory management, better demand planning and, ultimately, a timely decision-making, which is crucial in anticipating and responding to fluctuations in demand or unexpected SC disruptions (Dai et al., 2020). Additionally, supplier diversification enhances the ability to mitigate risks, which in turn provides more flexibility in order to prevent SC delays. Also, diversifying suppliers can lead to better

negotiation power and cost-effectiveness (Abdolazimi et al., 2023).

However, the experience companies in the PPE industry should have gained during the pandemic years in terms of improving their viability and resilience is not so evident when addressing other SC strategies. For example, the investigated organizations still seem to be reluctant towards the adoption of ICT solutions supporting both material and information flows. The positive effects of ICT on the ability to survive in the PPE industry during the pandemic period were proved (Hu, 2022). Thus, now that the uncertain period due to the Covid-19 pandemic is over, PPE companies should consider increasing their ICT level to make their SC more responsive. The surveyed companies were increasing the level of JIT adoption, although the key role of this strategy in determining disruptions in the PPE SC in the early Covid-19 periods. This is a counterintuitive result that might be consistent with the stock reductions in 2022 but should be monitored carefully. In fact, an extensive use of JIT could compromise the positive effects of other strategies that promote viability and resilience, such as supplier diversification and stock visibility.

To summarize, the surveyed companies in both France and Italy are navigating a balance between retaining strategies implemented during the Covid-19 period and returning to pre-pandemic approaches. This balance is reflected in their overall resilience level, which remained relatively stable in 2022 without significant declines or increases. Therefore, companies should focus on further improving the resilience level. The post-Covid era demands a strategic focus on SC resilience. Companies that prioritize resilience are better positioned to cope with uncertainties, seize opportunities for growth, and establish a competitive advantage in an ever-evolving business landscape (Corominas, 2022). Ultimately, by investing in resilience, organizations can ensure sustained success to their SCs in the face of dynamic challenges.

6. CONCLUSIONS AND PERSPECTIVES

The present research investigates viability and resilience in the PPE SC during the last Covid-19 pandemic phases by focusing on specific strategies.

From an academic perspective, further studies might expand the achieved results from both a geographical and a time point of view. The reaction of the PPE SC to the pandemic could be investigated in other countries, not only in Europe but also in Asia, where many PPE manufacturers serving markets worldwide are located. The impacts of an international SC on its behavior might be deepened. Then, it might be interesting to carry out an empirical analysis of what happened after 2022. Did the PPE SC improve its resilience level learning from the pandemic events? Are there any new challenges (e.g., wars, critical international political and economic scenarios) threatening it? Moreover, this paper might set a methodology, combining the SLR with the survey approach, to explore how unexpected events affect viability and resilience in other SCs. PPE SC managers might find the outcomes of the present research interesting as they provide insights into what happened within their industry, beyond the borders of their own companies and across two different countries. Such a

knowledge could serve as a foundation for shaping future strategies aimed at enhancing resilience, particularly in anticipation of potential disruptions stemming from factors such as unstable geopolitical situations: political conflicts in Asia, where mask manufacturing is concentrated, can result in trade restrictions and tariffs, disrupting the flow of masks for an extended period, potentially lasting months to years. Other examples could arise from major natural disasters impacting production or logistics strategic facilities for several months.

However, the present work suffers from some limitations. The outcomes of the survey have been analyzed by qualitative descriptive statistics only. Additionally, the economic impacts of resilience strategies available to the PPE SC have not been explored.

Thus, future research will extend the time frame of the study to include data from 2023 to provide a more comprehensive view of the evolution of the PPE supply chain in the post-pandemic era. Additionally, the economic efforts and resources required by the strategies adopted to achieve viability and resilience will be analyzed. This will help to identify what strategies are suitable and affordable, so that they can be applied in preparation of possible new disruptions in the medium-long run. Finally, quantitative statistics tools will be also adopted.

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