D3.1 – Gap analysis and recommendations for securing medical supplies for the COVID-19 response

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Executive Summary

The Coronavirus Disease (COVID-19) pandemic has triggered an unprecedented health care crisis worldwide. In addition to the impact on human life, the outbreak is disrupting medical supply chains in countries around the globe. As the spread of the outbreak widens, governments and the private sector started implementing lockdown or social distancing policies to contain the spread of the virus, which has subsequently impacted the global medical supply chains.

The objective of the Health Emergency Response in Interconnected Systems (HERoS) research project is to improve the effectiveness and efficiency of the response to the COVID-19 outbreak. HERoS integrates governance, supply chain management, information and epidemiological modelling in a bottom up manner, to provide new layered insights into the behavioural and social dynamics of the COVID-19 pandemic, that will be translated into policy recommendations. The objective of the current deliverable, D3.1, is to identify the gaps in the medical supply chains caused by COVID-19, and to make recommendations helping to secure medical supplies. Thus, the present deliverable contributes to the effectiveness and efficiency of the response to the COVID-19 outbreak.

By analysing primary data (interviews) and secondary data (reports) of the end-users of HERoS and of other members of medical supply chains, we have identified disruptions and their associated gaps caused by consumer behaviour, capacity limitations and legislation. In particular, gaps in the production, logistics and cargo transport, fulfilment and delivery of medical supplies orders to health professional and patients were identified. In addition, gaps for preventing fraud and competition between suppliers as well as gaps in vetting processes of new partners were noted. Gaps related to quality standards and certificates, as well as imports and exports regulations contributed to delays of delivering life- saving items.

To mitigate disruptions and gaps, it is necessary to reshape medical supply chains and develop one that are more flexible, responsive and agile. This should be a priority for health care professionals, manufacturers, government agencies and logistics providers. Switching from a single sourcing strategy to multiple sourcing, and from a cost efficient to a more flexible supply chain, must be adapted in the health care industry to be able to respond to emergencies such as COVID-19. Pre-positioning of medical supplies, private-public sector collaboration, as well as standardisation of medical supplies, visibility of end-to-end supply chains and forecasting of financial needs are the main practices that must be followed in order to better respond to pandemics such as COVID-19.

Table of content

1 Introduction 1
2 Medical Supply Chains in Times of Pandemics 2
2.1 Medical Supply Chains Flows and Stakeholders 2
2.2 Challenges of Medical Supply Chains 3
2.3 Framework of Analysis 4
2.4 Preparedness versus response 5
3 Methodology 7
3.1 Data Collection 7
3.2 Data Analysis 10
4 Gaps and disruptions in the medical supply chains caused by COVID-19 11
4.1 Operational Level 11
4.1.1 Behavioural disruptions 12
4.1.2 Capacity 13
4.1.3 Legislation 14
4.2 Financial Level 15
4.3 Strategic Level 16
5 Recommendations for securing medical supplies 17
5.1 Inventory pre-positioning 17
5.2 Sourcing and procurement strategies 18
5.3 Standardisation of products and certificates 18
5.4 Cross-sector collaboration and public-private partnerships 19
5.5 Financial forecasting and non-earmarked donations 20
5.6 Agility and visibility of medical supply chains 20
6 Conclusions 23
7 Bibliography 25
Annexes 29
Annex A : Interview Guide for WP3_D3.1 29
Annex B: Consent Form of WP3 30

Table of tables

Table 1: Framework of Analysis 5
Table 2: List of Interviewees 10
Table 3: Medical Supply Chain Gaps and Recommendations 22

Table of figures

Figure 1: Medical Supply Chain Flows and Stakeholders (adapted from Kraiselburd and Yadav, 2013, p. 379) 3
Figure 2 : Research Process 7

List of Acronyms

Abbreviation / acronym	Description
CBK	Centrum Badan Kosmicznych Polskiej Akademii Nauk
COVID-19	Coronavirus Disease
CRI	Associazione della Croce Rossa Italiana
DMP	Data Management Plan
ECDC	European Centre for Disease Prevention and Control
EMA	European Medicines Agency
EU	European Union
FDA	Food and Drug Administration
GDPR	General Data Protection Regulation
HAN	Hanken School of Economics
HERoS	Health Emergency Response in Interconnected Systems
HOPE	Project HOPE – The People to People Health Foundation
NGO	Non-Governmental Organi xation
NHG	Nordic Healthcare Group
OU	The Open University
PCPM	Polish Center for International Aid
SQU	Squadron
TUD	Delft University of Technology
VUA	Stichting VU
OLAF	European Anti-Fraud Office
IFRC	International Federation of Red Cross and Red Crescent Societies

1 Introduction

The Coronavirus Disease (COVID-19) pandemic has emerged as an unprecedented health care crisis worldwide. COVID-19 has impacted on many interconnected systems either directly or indirectly through cascades. First and foremost, any pandemic impacts the life of people who have contracted the disease, but secondly the health care professionals attending to these patients. The spread of the virus and the restrictions on the movements of people and materials globally created uncertainties and variations in demands of goods and medical supplies, causing disruptions in global medical supply chains. The biggest challenge of global supply chains is to provide medical supplies, such as personal protective equipment (PPE), as well as medical equipment for testing and monitoring the disease (WHO, 2020).

Medical supply chains are impacted in many ways, like the closure of production lines, lack of transportation capacity, lack of access to the affected regions, and interruptions of refrigerated 'cold chains' (Comes et al. 2018). The medical systems faced a shortage of essential items (ranging from face masks to gloves, hand sanitizers and PPE) because of a lack of pre-positioned quantities, but also because of irregular purchasing behaviour which includes bullwhipping, panic buying, as well as speculative pricing.

The aim of this report (Health Emergency Response in Interconnected Systems (HERoS) Deliverable 3.1) is to identify medical supply chain gaps and recommendations on how to overcome these gaps for a current response to COVID-19 by analysing primary data (interviews) and secondary data (reports) of the end-users of HERoS and of other members of medical supply chains. By means of these methods, we develop a framework to be used to analyse the supply chain disruptions caused by COVID-19 in three organisational dimensions: operational, financial and strategic, to derive medical supply chain gaps.

The main contributors of the HERoS consortium for this deliverable are the Nordic Health Group (NHG), Polish Center for International Aid (PCPM), Associazione della Croce Rossa Italiana (CRI), Project HOPE (HOPE) as well as the other three working packages of the HERoS project, Free University of Amsterdam (WP1-VUA), Delft University of Technology (WP2-TUD) and NHG, Open University (WP4-OU).

The structure of the document is as follows: Section 2 provides an overview of medical supply chain items, flows and stakeholders as well as the main supply chain challenges associated with a COVID-19 response. Section 2 also includes the framework analysis developed to analyse the empirical data and identify the gaps in medical supply chains. Section 3 describes the methodology followed, and how data were collected and analysed for this deliverable. Section 4 presents empirical results related to the medical supply chain gaps caused by COVID-19. Section 5 presents the recommendations to improve medical supply chain response to COVID-19. Finally, section 6 presents the conclusions and future research.

2 Medical Supply Chains in Times of Pandemics

A supply chain can be defined as the physical and informational resources required to deliver a good or service to the final consumer (Stock and Boyer, 2009). Thus, the overall objective of medical supply chains is to provide the right materials and services, at the right quantity to the right patients in need. This section provides an overview of medical supply chain items, flows and stakeholders as well as the main supply chain challenges associated with a COVID-19 response.

2.1 Medical Supply Chains Flows and Stakeholders

Health care requires five categories of medical products: pharmaceuticals, personal protective equipment (PPE), medical devices, medical supplies, and blood (Mirchandani, 2020). Pharmaceuticals include drugs to fight the disease and vaccines. PPE include gloves, masks and face shields. Medical devices include respiratory ventilators which require specialty manufactured components. Medical supplies consist of testing materials, laboratory and intravenous kits, and surgical centre supplies. Blood has a unique supply chain that it is based on donations (Grant, 2010). Blood has been difficult to collect during the pandemic because of the social distancing measures and lockdowns.

Clearly, many different stakeholders are involved in medical supply chains. There is a complex combination of institutions and organisations that provide regulations, funds, producing, importing, wholesaling and retailing that have to co-ordinate and collaborate to make medical supply chains available to the end-patient (Mirchandani, 2020, Attridge and Preker, 2000). Many of the problems observed in global medical supply chains during normal times are due to the complex interactions between these multiple stakeholders with often conflicting objectives and scope (Kraiselburd and Yadav, 2013). Figure 1 presents the range of actors involved in financing, regulating and physical distribution of medical supply chains globally. The main stakeholders are:

Donors and regulatory stakeholders:

- Funding organisations that provide funds for research and development of medicines as well as testing facilities for COVID-19 or re-configuration of production lines to produce medical equipment needed to fight COVID-19.
- Government policies about lockdowns and social distancing as well as the provide budget for the medical sector.
- International health organisations and agencies such as WHO, the European Centre for Disease Prevention and Control (ECDC), European Medicines Agency (EMA), and the Food and Drug Administration (FDA), play an important role on the risk assessment and the review of inventory of existing medicines in the different countries.
- Ministries of health in different countries that put the regulations in place for the medical sector as well as provide fund for the public health providers.
- There are other financial flows such as those flowing upstream from the end-patient and social insurance schemes to the manufacturer, but we are not including those here.

Supply chain stakeholders:

- Procurement agencies either public or private that they are responsible for the planning and procurement of medical items for hospitals or other health providers.

- Manufacturers that produce medicines, medical equipment, medical supplies and PPEs.
- Transporters that organise the transportation of items to different countries.
- National and regional stores that receive the items and distribute to the hospitals.
- Wholesalers and private importers and logistics providers that link the manufactures with pharmacies and health practitioners.
- Public and private hospitals that provide health care to the patients.
- Pharmacies that sell medicines and other medical items to the general public and patients.
- Health providers individual health professionals like general practitioners and other specialist that are involved in the response to COVID-19 as well as health facility organisations licensed to provide health care diagnosis and treatment.
- NGOs and other international organisations that offer medical and/or logistics services to the populations in need.

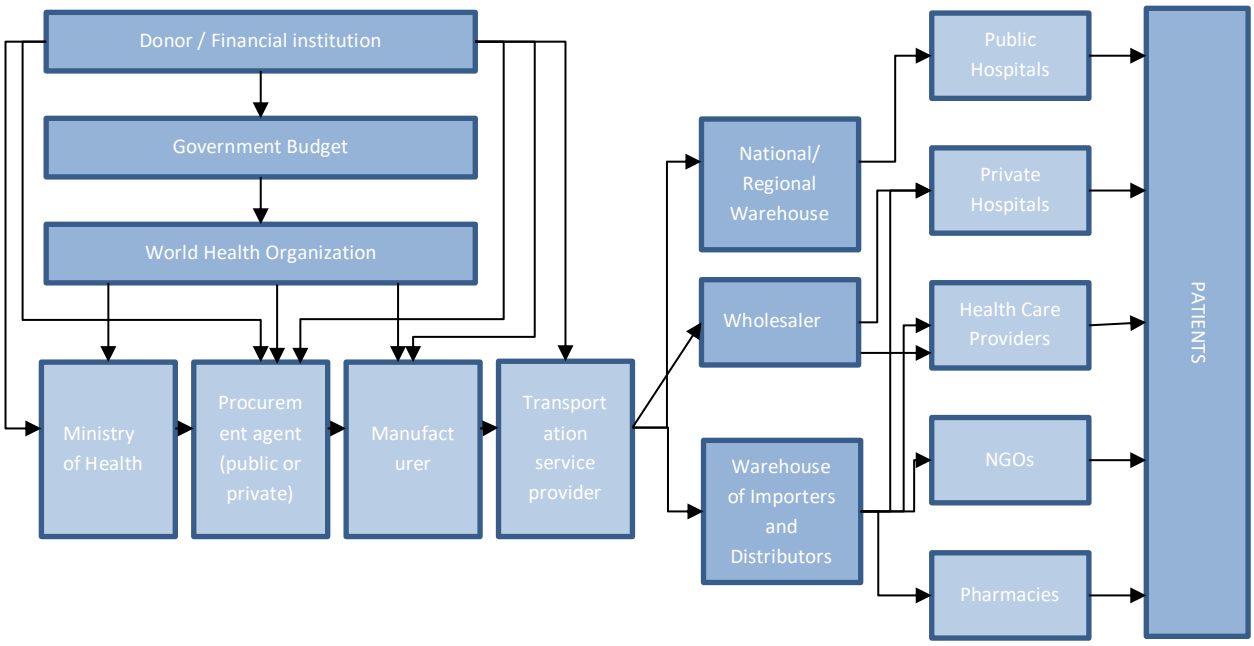

Figure 1: Medical Supply Chain Flows and Stakeholders (adapted from Kraiselburd and Yadav, 2013, p. 379)

2.2 Challenges of Medical Supply Chains

Global medical supply chains are sourced directly and indirectly from China and India and are exposed to risks in supply shortages due to COVID-19. COVID-19 is believed to have started in China in January 2020.To control the spread of COVID-19, China's State Council announced on 27 January that the Chinese Spring Festival holiday would be extended to February 2 across the country. Since late February, China has been gradually resuming manufacturing activities in prioritised industries based on their perceived level of importance. India started the lockdown process in March 2020 and the virus spread in European countries and all over the world by mid-March when it was characterised as a pandemic by the World Health Organisation (WHO). As the number of cases continued to grow, political leaders were encouraging physical or social distancing and by March almost all European countries were in lockdown to slow the rate of transmission and to avoid collapsing of the medical

systems. Unlike other disruption risks, the pandemic outbreak starts small, but scales fast and disperses over many geographic regions (Ivanov, 2020).

Even if the response to the COVID-19 pandemic differs across countries and regions, a majority of countries have imposed quarantines and lockdowns, closed their borders and imposed travel and export bans. Companies, shops and manufacturing plants were closed and in some countries are still closed. The collective effect of these policies, quarantines, bans, and shutdowns have the desired effect of containing the COVID-19 outbreak and avoid collapsing of hospitals. But it has had detrimental effects on the availability of essential medical items on the market, effects on the possibilities of delivering medical aid, as well as secondary effects through cascades in the supply chain.

The drastic rise in demand and panic buying for medical supplies prompted significant price increases and led to production backlogs in fulfilling orders. COVID-19 related misinformation circulation on social media also contributed to spreading panic (Nawrat, 2020). However, the direct impact of misinformation is difficult to measure quantitatively. The most significant challenge is to ensure that critical PPE is sourced and allocated to frontline health workers and other responders in affected countries, especially those most vulnerable to the spread of the coronavirus (WHO, 2020).

2.3 Framework of Analysis

Ensuring global health is obviously a complex challenge that involves many interconnected causes and effects (Kraiselburd and Yadav, 2013). To identify the gaps of medical supply chains a framework was developed to analyse the supply chain disruptions and their impact. Empirical data indicates that COVID-19 has an impact on three levels of organisations and health providers: operational, financial and strategic. Based on these three levels, Table 1 presents a framework of analysis of medical supply chain disruptions and their resultant gaps.

At the ***operational level*** observed disruptions were caused either by:

- Behaviours
  - Bullwhipping
  - Price Speculation
  - Panic buying
  - Fraud
  - Excessive mark-ups
- Capacity / capabilities
- Legislation

At the ***financial level*** it was observed that COVID-19 had an:

- Economic impact on the organisations
- Human resource impact due to losses in jobs and income

At the ***strategic level*** it was observed that COVID-19 influenced the:

- organisations decision because of the government's restrictions and guidelines
- supply chain sourcing strategies

Categories/Dimensions	Gaps
Operational	Behavioural ▪ Bullwhipping ▪ Price Speculation ▪ Panic buying ▪ Fraud ▪ Excessive mark-ups
	Capacity ▪ Workforce ▪ Production capabilities ▪ Shortages
	Legislation ▪ Regulatory Uncertainty ▪ Certifications and standards of products ▪ Quality ▪ Import and Customs ▪ Export bans
Financial	Economic ▪ Sales ▪ Expenses ▪ Donations
	Human Resources
Strategic	Supply Chain Design ▪ Sourcing ▪ Investment
	Risk Management
	Government Involvement

Table 1: Framework of Analysis

2.4 Preparedness versus response

Preparedness pays off. Related disaster relief research has shown a return on investment in a 1:7 ratio between preparedness and response (Stumpf et al., 2017). This results from

- general pricing mechanisms (with a surge in demand but no change in supply) both for items and for their handling including transportation,
- capacity restrictions in manufacturing, warehousing, and transportation, and
- the urgency of the matter once a disaster, or in this case a pandemic, hits.

Overall, there are two broad categories of preparedness: curative preparedness, i.e. activities that focus on smoothing the response, and mitigative preparedness, i.e. activities that focus on the root cause of the disaster, or focusing on the forecasts of the changing nature and needs of specific disasters (Sohn, 2019). Within curative preparedness, the focus is often on preparedness stock, i.e. pre-

positioned inventories in carefully selected warehouse locations. That said, there are also other preparedness activities even here, such as having pre-trained staff on rosters to be deployed, framework contracts with suppliers, and deployable funds (Jahre et al., 2016; Kovács and Tatham, 2009).

But even the very basics of preparedness, that is, to carry safety stock and pre-position it at strategic locations, works well for managing the very beginning of a pandemic. Such stock can include commonly used medical items: drugs as well as personal protective equipment (PPE), but also entire health care units and field hospitals, even the sea-basing of such "floating hospitals" on vessels. The focus is often on difficult-to-get items, items with longer lead times, or with items where local or global capacities would not suffice. As for PPE, knowledge from the 2014 Ebola crisis indicated that neither global stock nor the global manufacturing capacity would suffice for any larger pandemic (Patel et al., 2017).

In the humanitarian health care sector, it has been long acknowledged that preparedness also needs to facilitate response. This comes with a recognition of the high interdependence of medical items. The administration of any future vaccine will require syringes and gloves, the administration of a COVID-19 test not just test swabs but PPE, as well as the laboratory equipment and materials. To speed up the deployment of any urgent such items, humanitarian organisations have for a long time come together to develop (inter-agency health) kits for specific purposes: malaria kits, cholera kits, to entire field hospitals; and also, to standardise across organisations what is in such a kit, to the level of what to expect which box of a kit to contain (Vaillancourt, 2016). Thereby, if one health organisation procures a kit, another gets the funding to mobilise it, but it is used by a third in the field, any one logistician or health care staff would know what to expect where, and how to use it. This is a high level of not just standardisation of items and equipment, but also of processes, enabling the interoperability of health care provision.

Moreover, preparedness is best as a joint, concentrated effort; not just for preparedness kits but overall, ensuring that items and standards work across countries, that quality standards are global, and even through the use of (joint) procurement practices. Pandemic preparedness requires the involvement of numerous stakeholders, including the private sector (manufacturers, wholesalers, logistics service providers), governments and NGOs (Seddighi et al. 2020). Yet the mandates of who needs to prepare for what, who needs to train for which eventuality, and who is to carry which preparedness stock, are not always clear neither within nor across various countries and regions. What is the more, to respond to global disruptions, there is a need for policy and legislation, global product standards and interoperable supply chains, capacity reservations, public-private partnerships and co-ordination mechanisms between different supply chain members.

3 Methodology

A qualitative research method was used to better understand disruptions and gaps that COVID-19 has caused on medical supply chains. The research process comprised three steps. First, the existing literature on supply chain disruptions, medical supply chains risks and emergency response was reviewed, along with existing secondary data related to the topic, to guide development of an interview guide or questionnaire for primary data collection. Second, primary data was collected from and through end users via interviews, to understand and explore in depth the context and advance the knowledge on the topic (Eisenhardt and Graebner, 2007). Interviews are particularly well suited for research that requires an understanding of phenomena or responses to complex systems, like the response to emergencies, because of the depth of focus and the opportunity they offer for clarification and detailed understanding (Ritchie and Lewis, 2003). Third, interview data were coded using NVivo, a qualitative data software that has the ability to organise and sort data (Dean and Sharp, 2006) for content analysis (Krippendorff, 1980). Figure 2 presents the research steps followed for this deliverable.

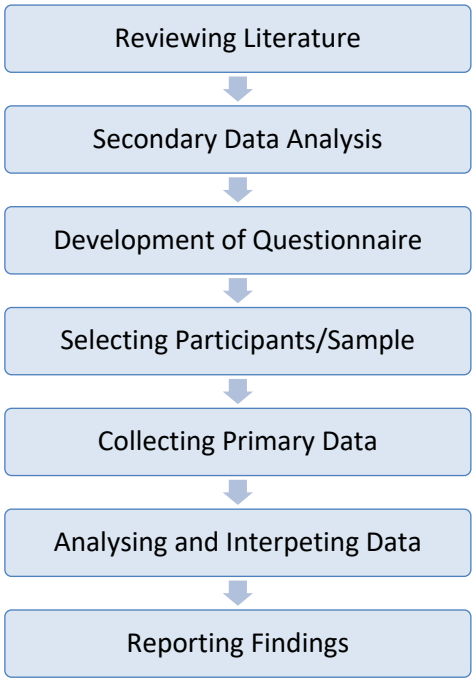

Figure 2: Research Process

3.1 Data Collection

Primary data were collected through semi-structured interviews using the interview guide (see Annex A). HERoS' end-users (PCMP, CRI, HOPE) were interviewed first and then the sample was snowballed from there, asking them to suggest other suitable participants. Researchers also collaborated with the other WPs of the HERoS project in finding participants, and organisations from our network from previous studies were also contacted. In total, 80 organisations contacted yielding 38 interviews (see Table 2). The interviewees included supply chain and medical experts like purchasers, supply chain

manager, doctors and nurses as well as senior management staff from the public and private sector of a range of organisations spanning across different geographical areas including:

- experts from NGOs and health providers
- health professionals (medical doctors and nurses) from hospitals
- pharmaceutical professionals,
- decision makers of ministries of health
- suppliers of medical items and equipment
- producers of PPEs

Due to travel restrictions and social distancing rules, instead of conducting face-to-face interviews, all interviews were carried out online via Microsoft Teams and Zoom. Interviewees were contacted via email to set up the interview calls. Participation in the interview was voluntary and all research participants were given the opportunity to ask questions and receive clear answers before deciding whether to participate. Research participants were reminded of their rights before participation via a consent form which had to be signed before the interview (Annex B). Participants provided the consent form signed either manually or using digital signatures or writing their names. In case that participants could not provide a signed copy of the consent form due to technical constraints (lack of printer or scanner), they could fill-in the form and send it by email using their email as “signature”.

In the beginning of the interview process participants were provided with the information about the processing of their personal data and asked their approval to record the interview. The project was then introduced starting with an introductory question where interviewees were asked to provide information about their role in the organisations and how they have been involved in the COVID-19 response. After that the semi-structured interview guide was followed for the remainder of the interview. Semi-structured interviews allow interviewees to express their attitudes and experiences and bring insights not previously anticipated. The interviews lasted approximately one hour and were recorded.

The interviews were first transcribed automatically using the automate transcription functionality of NVivo which is encrypted both in transit and at rest and only the account owner has access to and control over the data. This process is fully General Data Protection Regulation (GDPR) compliant. Then, a quality check of the transcripts. A process described as respondent validation was adopted whereby interviewees who indicated in the consent form their wish to receive the transcripts were subsequently asked to approve or amend their interview transcript.

The data was collected, stored with security features that include role-based assignments, authentication, authorisation, encryption and other monitoring of IT systems and storage, that comply with best practices and national and European Union (EU) applicable regulatory framework as described to the Data Management Plan (DMP) of the HERoS project. All personal and sensitive data of participants were pseudonymised using codes that include the country, type of organisation and type of role.

Joint interviews were conducted with the HERoS WP1 and WP2 and there was close collaboration to use networks to find organisations to participate in the WPs. In WP1 interviews were conducted together. With the WP2, colleagues from NHG asked their interviewees the questions related to medical supply chains. WP2 sent the transcripts of those interviews for analysis and to include in this report. In some cases, interviewees preferred to provide written answers due to their English language limitations. Language skills of WP3’s team enabled some interviews in a language other than English (e.g. Mandarin). Those interviews were translated by the interviewers.

Pseudonym	Type of Organisation	Country
PL1NGOMED	Medical Provider-NGO	Poland
IT1NGOSC	Medical Provider-NGO	Italy
CH1NGSC	Medical Provider-NGO	China
US1NGOLOG	Medical Provider-NGO	USA
FIN4NGOSC	Medical Provider-NGO	Finland
FIN1GOVLOG	Supply Agency-Governmental	Finland
FIN3GOVLOG	Supply Agency-Governmental	Finland
FIN2PSSC	Pharmaceutical-Private	Finland
HK1PSDIR	Producer of PPEs	Hong Kong
PL2PSDIR	Supplier	Poland
FIN5NGOLOG	Medical Provider-NGO	Finland
FIN8GOVDIR	Ministry of Social Affairs and Health	Finland
FIN9GOVMED	Hospital	Finland
FIN6GOVRES	Ministry of the Interior	Finland
CA2PSDIR	Producer of PPEs	Canada
FIN7GOVSC	Medicines Agency	Finland
FIN10NGOSC	Medical Provider-NGO	Finland
IT3NGOLOG	Medical Provider-NGO	Italy
HK2PSDIR	Producer of PPEs	Hong Kong
CA3NGOLOG	Medical Provider-NGO	Canada
CA4NGOLOG	Medical Provider-NGO	Canada
FIN11PSLOG	Logistics Provider	Finland
FIN12GOVMED	Hospital	Finland
FIN13GOVMED	Hospital	Finland
FIN14GOVMED	Hospital	Finland
FIN15GOVMED	Hospital	Finland
FIN16GOVMED	Hospital	Finland
FIN17GOVMED	Hospital	Finland
FIN18GOVMED	Hospital	Finland
FIN20GOVMED	Hospital	Finland
FIN21GOVMED	Hospital	Finland
IT4GOVMED	Medical Provider-NGO	Italy
IT5GOVMED	Medical Provider-NGO	Italy

IT6GOVMED	Medical Provider-NGO	Italy
SE1GOVMED	Hospital	Sweden
SE2GOVMED	Hospital	Sweden
SE3GOVMED	Hospital	Sweden
SE4GOVMED	Hospital	Sweden

Table 2: List of Interviewees

3.2 Data Analysis

Interview data were put into NVivo, a qualitative data software that has the ability to organise and code data (Dean and Sharp, 2006). An abductive methodological approach used content analysis. Content analysis is a research method for making replicable and valid inferences from data to their context, with the purpose of providing knowledge and new insights (Krippendorff, 1980). The adductive approach is recommended when prior knowledge about a phenomenon is not sufficient and is a theory development process that starts with "observations of specific instances and seeks to establish generalisations about the phenomenon under investigation" (Spens and Kovács, 2006, p.374*).* Data were contextualised with respect to the three dimensions: operational, financial and strategical. The coding paradigm of Corbin and Strauss (2015) was followed which consists of open, axial and selective coding, as it provides a thorough and structured approach for examining the phenomenon of interest.

First, open coding was used on the transcripts of the interviews. Open coding is an interpretive process that helped identify the context and the dimensions of the supply chain disruptions through the emergence of concepts or codes. For this case, the information gathered in the interviews was initially organised into the three dimensions: operational, financial and strategical. Open codes were introduced in NVivo in the form of free nodes used in the early coding when no hierarchical structure was defined. Based on the coding paradigm of Corbin and Strauss, 2015, axial coding was carried out to identify themes and sub-categories. Axial coding is the process of breaking down the core dimensions that we have identified with the open coding. The process allows to make connections between a category and the sub-category, or it can also suggest dropping some subjects from some categories (Corbin and Strauss, 2015).

Finally, selective coding was the final stage in the data analysis where the core categories were choose to discuss results (see Table 1 that presents the coding scheme related to the gaps and the framework of analysis). These core categories corresponded to the concepts of the gaps of medical supply chains occurred by COVID-19 and the measurements that organisations should take to mitigate the supply chains challenges.

4 Gaps and disruptions in the medical supply chains caused by COVID-19

In this section, research results are presented with respect to the disruption and their effects in creating gaps in medical supply chains associated with COVID-19.

Supply chain disruptions come from a "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 MacDonald, 2017). Supply chain risks resulting from a pandemic differ from other disruptions because the pandemic does not threaten only human life, but also the foundation of the global supply network—the free movement of people and goods (Golan et al., 2020, Sheffi, 2015). The COVID-19 pandemic is a disruption of an unprecedented scale testing the resilience of global medical supply chains (Golan et al, 2020). To understand better the disruptions and the gaps that COVID-19 caused on the medical supply chains, a framework was developed to analyse the data. First, disruptions of medical supply chains were identified and from there gaps were derived following a cause-effect relationship. The empirical data shows that COVID-19 has an impact on three levels of organisations and health providers: operational, financial and strategical. Based on these three levels the framework of analysis of medical supply chain disruptions and their effects was developed and presented in section 2 (see Table 1).

4.1 Operational Level

The research participants offer a variety of different products and services to the beneficiaries that cover the majority of medical items used to respond to COVID-19. The following products and services are used by the organisations interviewed:

Products:

- PPE for medical staff
- Respiratory ventilators
- Patients' monitors
- Defibrillators
- Decontamination units
- Triage
- Medicines for COVID-19 like hydroxychloroquine
- COVID-19 testing facilities

Personnel:

- Medical teams (doctors and nurses)

Services:

- Trainings for labour activities
- Infection protection, control and physical distance training for medical staff

- COVID-19 symptoms consultation
- Mental consultation

The empirical data indicate that supply chains of health providers either private, public or non-governmental were disrupted by behaviours, capacity capabilities as well the uncertainty of the legislations. The disruptions were classified into three groups: behavioural, capacity and legislation and from those disruptions derived from the medical supply chain gaps (see Table 3 at the end of Section 5).

4.1.1 Behavioural disruptions

Emergencies are marked by irregular purchasing behaviour, such as bullwhipping, panic buying, speculative pricing as well as fraud. The demand variations through a supply chain is called the bullwhip effect, a phenomenon where supply has difficulties to meet the demand. When the variation in consumer demand increases, demand variation will increase at each subsequent upstream supply echelon, from retailers to wholesalers, to manufacturers and their suppliers (Dooley et al., 2010). The demand shocks -especially for medical items- created by COVID-19 have caused extreme bullwhip effects, resulting in an unpredictable and unstable manufacturing environment where suppliers struggle to predict demand as a result of panicked buyer behaviour. Bullwhipping causes price fluctuations and shortages, (Lee et al., 1997).

All interviewees have experienced price mark ups and shortages especially for PPEs. As indicated by one interviewee: "The *price of the PPEs, it has to be one of the big obstacles. To find a reasonable price in this market has been very difficult*" also "*it was a huge challenge for us and also for our customers because they had to pay a dramatically higher price for standard products".*

Reports also from logistics providers like DHL pointed out that "only the highest paying cargo is likely to move on those remaining flights, a situation described as "pay to play" (DHL Resilience 360, 2020) and the " Trans-Pacific lanes have continued to see increased air freight rates from China to North America, with the highest prices being recorded out of Shanghai" (DHL Resilience 360, 2020).

In addition to speculative pricing, health providers faced also changes in the payment methods and payment ways during COVID-19. Suppliers demanded down payments to deliver medical items. As indicated by one interviewee, "*initially everything that we were finding was 100 percent down payment, 100 percent on payment, which was another reason that we were getting much more careful because, you know, if it doesn't work out, you've got nothing to show for the money that you spend*" and "*I can say we experienced the request of a supplier that asked us to pick up the PPEs directly in a European country and ask us for the payment during the shipment…by transferring the money via online banking "*.

The commercial pressure that COVID-19 put to the organisations also increased the risks of fraud. New suppliers and intermediaries have emerged in the PPE supply chains. Organisations reported that in some cases they were forced to collaborate with new suppliers and other business partners that they were not fully vetted or unable to fully evaluate supplier quality due to time constraints.

"*And then you also had problems in terms of people creating fake businesses, trying to sell products that didn't exist. And so, the normal vetting process that you might go through wasn't really possible. People were creating fake certificates of authenticity. And so, the vetting process, you know, everything was supposed to be moving as quickly as possible, but the requirements to that product created a slowdown. And so that was also a disruption to the system. You're trying to move as quickly as you can.*

And you really couldn't …And then people just, you know, saw a business opportunity or saw that well, put that in scare quotes, a quote unquote, business opportunity and just went into the market knowing that they didn't have this technical expertise to make it, but saw an opportunity to make money. I think there are also factories that retooled in an honest effort to make genuine product. But without the experience of doing it for a long time it didn't necessarily go as well as they would have liked".

As also reported by the World Bank (2020), suppliers and distributors have established new terms and conditions for buyers, including excessive mark-ups, with distributors accused of stockpiling goods to create perceived shortages and selling later at inflated prices and delivery delays, due to practices such as filling orders out of sequence and moving the highest-paying customers to the front of the line.

Supply scams were reported by the European Anti-Fraud Office (OLAF-European Anti-Fraud Office, 2020) which by May 2020 had already identified over 340 companies acting as intermediaries or traders of counterfeit or substandard products linked to the COVID-19 pandemic. As indicated by OLAF, millions of substandard medical products with fake EU conformity certificates have been found in several European countries. Fake products are also often offered for direct sale online to European customers by companies based outside of the EU - for example filtration half-face masks, originating from China with fake certificate marks, which gives confidence to the consumer that they are buying a genuine product (OLAF-European Anti-Fraud Office ,2020).

It is clear consumer behaviour affected the production and distribution of medical items and created gaps in medical supply chains. Shortages of PPE, respiratory ventilators and defibrillators, price speculations were reported by all interviewees. Diagnostic/testing- kits were also scarce (Van Wassenhove and Van Oorschot, 2020). These shortages and fraud practices demonstrate there are gaps in the regulations and in the co-ordination between the different actors involved in the medical supply chains.

4.1.2 Capacity

Due to shutdowns of the production activities in many countries to limit the spread of the virus -and especially in China and India who are the main producers of medical items- many products could not be produced anymore, and orders could not be filled.

When production resumed, the lack of workforce due to governmental policies (lockdowns and quarantine) and the restriction of movements of workers between urban and rural areas to restart the factories was an issue especially in India and China. As pointed out by one interviewee who works in the pharmaceutical sector : "*the biggest issue for them is the lack of manpower, because once in India, when this crisis started, a lot of people who have been working in the factories migrated back to their native places, so which could be for example on the other side of India and now they are having issues of because there are still restrictions, some restrictions internally regarding movement, and of course, the public transport isn't working. So, these they are having a lot of the suppliers are having issues with getting people back".*

Medical staff experienced a lack of PPEs and specific medicines. "*There was a shortage of protective equipment. At some point we did not have enough right away. It was doubtful where they came from and it was quite a big concern…. we had some shortages of medicines like propofol and muscle relaxants. These patients were very difficult and had difficulties breathing. Then you had to use muscle relaxants even when they had not been intubated. And we sometimes do that for quite a short time,*

but now quite long periods are needed, the longest time being a week or eight days with muscles. It is very unusual very large amounts of those drugs as well".

Transportation of medical items was also disrupted. Passenger airlines stopped operations which reduced drastically the air cargo transport. Attempts were made to add some capacity with repatriation flights, military aircraft and passenger planes converted to transporting cargo on a temporary basis (Spanish Red Cross, 2020). In some cases, dedicated flights were used by public organisations to transport PPEs to their countries. As described by one interviewee "*we have used national airlines to bring PPEs from China since the airplanes did not transport passengers anymore*". Customs clearance time increased dramatically which increased the lead times. As highlighted by another interviewee: "*the customs clearance process going into the US became longer than the normal customs clearance process. Instead of two to three days, it was more like four to seven days. And now pretty much any PPE that is being exported from China to the US will be selected for laboratory testing, which is an additional hurdle that you have to clear".*

The high demand for respiratory ventilators and PPEs leads many governments to impose export restrictions in specific products-for example India banded the export of active pharmaceutical ingredients (API), Germany banned the PPEs. To ensure availability of PPEs for health professionals, governments asked national companies from the autocar industry and distillery to switch their production lines and start producing respiratory ventilators, face masks and hand sanitizers. In addition, private companies have been asked to ramp up manufacturing capacity domestically versus overseas during the response, given the border closures and delays in product production and importation.

The high demand for N95 masks led to a shortage of the key raw materials, the nonwoven polypropylene. The shortage of melt-blown fabric is a serious bottleneck in downstream processes for making high-level N95 masks (Asian Development Bank, 2020). The consequences of the production shutdowns and the limitation of transportations lead to the shortages of medical items and long lead times which created gaps in the delivery of medical supplies to the hospitals and beneficiaries.

Experts from hospitals have also reported lack of trained personnel. "*The biggest challenge was the nursing staff, for us to get more intensive care nurses, because the intensive care patients were very sick. It was, in a way, very heavy intensive care. They were not monitored patients. All of them were in ventilators and these where very heavy intensive care things which we needed to do. So, for us to train, rapidly train anaesthesiology nurses, operating room nurses and nurses from different wards for this purpose was the biggest challenge*".

4.1.3 Legislation

Medical supply chains were also affected by the legislation and regulations (or lack of them) during COVID-19. Many governments-imposed import and export bans which disrupted supply chains. Also, several countries lacked regulations with respect to the standards and certificates of the imported items like face masks. As one interviewee explained: "*The main problem was also the certification because we didn't have specific regulation, immediately after the pandemic situation, in Italy. So, we have to check one by one the PPEs and control the validity of the certification*".

The lack of standard certificates for the masks led to the pure quality of PPEs imported to the countries and massive quantities of PPEs rejected. This increased bureaucracy in the economic transactions between countries and the process of customs clearance grew at a time when the speed of the delivery

was very important. One interviewee highlighted that "*they've added declarations between from the importer and the exporter that we understand that these goods meet quality standards and that they will be used in the appropriate way and appropriate health care settings*".

Regulatory uncertainty and different and sometimes contradictory information provided by WHO and other official national and international agencies led to supply chain disruptions. "*I think other issues that tied into the disruption, you know, part of it, I think had to do with messaging from health, public health, like the CDC and the WHO, when the CDC and the WHO put out information about what was appropriate to use. There'd be as you know, that would cause a run on that particular supply. And so that, you know, that messaging certainly created disruptions in the marketplace. And I think that reporting worldwide also ties into it".* In the early phase of the emergency the formal authorities struggled to put adequate co-ordination mechanisms in place that should have provided an estimation of the supply chain needs. In addition, validated information about the disruptions in the supply chain, and about the specific needs at the local level (i.e. by the users) was lacking. This led to situations of uncertainty and missed opportunities in terms of collaboration between organisations in the supply chain.

The legislation or the lack of it, created disruptions in the supply chain, which then created gaps in delivering medical suppliers to patient and medical staffs. Gaps related to the lack of standards, certifications and gaps in the quality of delivered items were also observed.

4.2 Financial Level

During the first phase of the HERoS project the impact of COVID-19 on financial performance of the organisations was also investigated. A more extensive analysis of the financial and economic impact of COVID-19 will be reported in the next deliverables of the WP3 of the HERoS project.

The empirical data indicates that suppliers experienced a decrease in product sales if their products were unrelated to COVID-19, but suppliers experienced an increase in product sales if they are PPE. NGOs that participated in the interviews have experienced an increase of their operations and missions and also on the funding that received from donors. According to one interviewee "*from a financial perspective, we've had a very good response so far to the global appeal, we have also seen different levels of support from private donors or from donations from the general public or membership. During this time, you have an enormous increase of donation. But we also have an enormous increase of needs*". However, NGOs also faced holds on their programs and missions not related to COVID-19 and on funding other than for COVID-19. As indicated by one interviewee "*And now we don't get money for development projects. And there is, of course, the question, should we come back and we will get the money from the donors to re-organise, to do humanitarian actions that have been planned for this year*".

Workforce for health providers did not decrease according to empirical findings. NGOs saw a significant increase of volunteers who registered to support organisations missions during COVID-19. According to two different interviewees "*We have had many new volunteers joining us to our activities on the beneficiary level. So that of course, that's always a positive thing*" and "*we have thousands of temporary volunteers that joined us during this emergency. And we also have the medical personnel that was requested during this emergency. So, we have a great increased amount of personnel in the land in Italy*".

More analytical details about the impact of COVID-19 at the financial level of organisations will be provided in the next deliverables of WP3.

4.3 Strategic Level

From a strategic point of view, a majority of organisations were not prepared for such an extreme crisis. Some of them said they had a risk plan in place which they have activated during COVID-19, but the plans did not cover an event of that scale. "*We have a specific direction for emergency, not maybe for this emergency, this is new for everyone, but we have a specific department for emergency*".

Visibility of the supply chain could help organisations to mitigate the risks occurred by COVID-19. Some organisations leverage their suppliers' network in China to help them to find PPEs and to do the quality check for them before the shipment. As highlighted by one interviewee: "*I recognised that, you know, we've been operating in China for 17 years and we have a network there. We have the ability to leverage our network. And it might be better, easier for us than people who have never done this before*".

Also, NGOs used their branches that operated in China to contact Chinese suppliers to get PPE sent to them in Europe or the US. One end user said that "*We have now been procuring in China for export around the world, and we've been able to do that. We've been able really to achieve both because our organisation has a long history in China. So, we had people on the ground there, and we were fortunate in this unfortunate situation to have a team on the ground there that could help navigate both the import and export of PPEs to try to respond to the crisis*".

Before COVID-19, organisations focused in developing long-term relationships with a single supplier. It appears that during COVID-19 this model did not work properly. The study participants are planning to re-design their supply chain network either by developing multi-source strategies or by geographically diversified procurement and production. Also, governments are asking for more domestic production for emergency items to avoid dependency on other countries.

5 Recommendations for securing medical supplies

In this section, recommendations are put forward to mitigate the supply chain disruptions and gaps caused by COVID-19, based on the empirical data, as well as on the existing literature and taking into account also previous medical emergencies like Ebola. Agility, flexibility and moving beyond efficiency and costs to build resilient supply chains should be considered by the medical supply chain members. some of the best practices that health professionals can follow to better respond to pandemics are presented below and Table 3 summarises the medical supply chains gaps and recommendations to secure medical supplies.

5.1 Inventory pre-positioning

During the last decades, the focus of medical supply chains was on minimising costs by adapting just-in-time approaches and avoiding managing inventories. But pre-positioning of inventories of medical items seems to be a way to respond to pandemics and it is proposed by all our research participants. Pre-positioning of inventories is also a strategy followed by humanitarian organisations to prepare for disaster and epidemics. Recently, a collaborative pre-positioning system was introduced in the humanitarian sector to respond to disaster relief operations within a short time period (within 48 hours) while minimising inventory holding cost. The system is led by an umbrella international organisation, such as United Nations Humanitarian Depot (UNHRD) or a government (e.g., European Community Humanitarian Aid Department (ECHO)). Employing advanced information technology, member humanitarian organisations in the system can borrow (lend) stocks from (to) other member HOs with excess (deficit) stocks (Toyasaki et al., 2017). The system is also expected to contribute to reducing panic buying and/or stock hording.

Our interviewees propose a pan-European pre-positioning system and the movement of needed medical items between countries and organisations: " *I think what it could work is a pan-European network of all organisations .So we know who is having, what amount of PPEs, for example, and having the possibility to move between freely between the organisations*".

Inventory pre-positioning is critical to quickly and efficiently responding to potential emergencies and suggested by the literature as a form of disaster preparation (Altay et al., 2009, Kovács and Spens, 2009, Balcik and Beamon, 2008). However, pre-positioning of medical supplies especially ventilators and medicines requires high investment and holding costs at various locations, due to the high levels of uncertainty of the emergencies. In addition, product expiry especially for the medical items is a major consideration, as there is no inventory turnover between crises (Kunz et al. 2014, Whybark, 2007).

Collaborative pre-positioning to respond to emergencies contributes in minimising costs. It could be managed and co-ordinated by an independent central agency and appears a promising strategy to eliminate gaps in serving beneficiaries.

5.2 Sourcing and procurement strategies

Prior to COVID-19, companies tried to reduce costs by either strategizing in the form of contract manufacturing, lean manufacturing (Cozzolino et al., 2012), offshoring, and outsourcing (Hernandez and Haddud, 2018). These strategies do not prove sustainable when supply gets disrupted by such an unprecedented pandemic (Yang et al., 2018). Companies and governments have learned that they should not rely on a single source and share resources collaboratively to avoid interruptions in supplies (Haque and Islam, 2018). Thus, the supply chain members forced to re-evaluate its sourcing strategies. The transition from a single to a multi-sourcing approach seems inevitable. This is also confirmed by one interviewee: "*…but is also coming very clearly from the pandemic supply chain network discussion is that as much consolidation as possible, but especially for organisations could even join together and kind of do sourcing*". "*We will have to have more suppliers to mitigate the risk of having problems with one. So, this is something that you have now, or you consider to have it in the future*". "*Adopt multi-sourcing and find reputable suppliers to build long-term business relationships*".

Also, discussions at high levels have started to move from the global-for-local approach to a regional-for-local strategy or even a local-for-local strategy. As pointed out by one interviewee from the pharmaceutical sector "*there is a need to diversify geographically to the base of a certain supply. But that is actually not that easy. For example, in Eastern Europe they've had chemical industry before and that would be something that would be useful to a new start of the pharma supply chain. It would give us more flexibility, flexibility from the geographical perspective*". Of course, multiple sourcing requires qualifying suppliers and sites in different countries which comes with a cost (Linton and Vakil, 2020a).

In addition to multi-sourcing strategies, consolidated and joint procurement strategies should be implemented in collaboration between countries (like the European Commission initiative for joint procurement for European countries for diagnostic test, PPEs, respiratory ventilators) and between health providers. Co-ordination and centralisation of procurement was followed by some NGOs to secure the materials. As described by one interviewee: "*consolidate ordering as much as possible and really bringing the whole membership together and trying to make sure that we're trying to utilise consolidated supply chains…", "In the very beginning, when we were trying to get the masks to export them from China, we had all kinds of challenges finding a supplier that was willing to supply us for, you know, relatively small quantities because there were some countries, you know, buying masks out of China in like the millions or tens of millions quantities".* Joint procurement increases the negotiation power of the buyers and increases performance more than purchasing and selling separately, especially under uncertainty (Xianglinga and Ping, 2018).

5.3 Standardisation of products and certificates

One of the main issues that came out of the empirical data is the lack of standard products and their quality certificates to respond to such pandemics especially for the PPE. Each country has its own standards. Thus, in many cases countries and organisations had to reject PPE that did not meet the quality standards of their country. This created delays and organisations had to reorder products to meet the requirements. As pointed out by one interviewee "*people were ordering product that wasn't meeting the specifications of what they needed*".

The development of same standards of PPE and other medical supplies will unify and facilitate the production and delivery of medical suppliers in future pandemics and epidemics. Creation also of a standard list/catalogue of items needed to fight similar diseases will be very helpful for the supply chain and the pre-positioning and collaborative inventory management. What was missing according to an interviewee "*An important thing, it would be the creation of a list of real useful providers of the materials and a list of valid certifications for that kind of material, we can use during emergency. So, we would have been really helped if that was existing before the emergency*". Standardisation of relief items is a topic well discussed in the humanitarian literature and medical supply chains could learn from that. It allows for collaborative inventory transfers between organisations (Schulz and Blecken, 2010).

The development of clear procedures and controls to prevent fraud could contribute to the quality of supplies delivered to beneficiaries.

5.4 Cross-sector collaboration and public-private partnerships

Cross-sector collaboration and fostering collaborative relationships between medical supply and equipment manufacturers and other types of industries, like the auto-industry, could add value to the medical supply chains. These partnerships will share knowledge and best practices in production and logistics (Jüttner and Maklan, 2011). This new business model successfully and domestically produced respiratory ventilators, N95 respirators, face masks and hand sanitizer from companies that did not traditionally belong to so called medical items producers. This collaboration leverages the insights of experienced private sector entities to identify new innovative ways to increase production of medical items.

The support of the governments in this initiative is very important, since they must move fast to change the regulations and approve the switch of the production. Also, non-traditional medical companies need to invest to expand their production capabilities, they also need financial support of governments. In many cases, it was governments that asked from auto industry to be involved in the production of respiratory ventilators. As pointed out by one interviewee who used to produce dies for the car industry and started producing face masks "*So, they were there were several different grants that they put together that were aimed at companies that were doing exactly what we're doing. And the whole idea was that the Canadian government, they would find businesses that were willing to do this and they would support them financially and hopefully through resources*".

Public-Private Partnerships (PPPs) and cross-sector collaboration can play an important role in building supply chain resilience in the disaster and emergencies contexts (Carland et al., 2018, Balcik et al., 2010; Tomasini an Van Wassenhove, 2009; Van Wassenhove, 2006). PPPs are increasingly considered as an innovative tool for bringing services and products to the emergency affected areas. All participants in the study highlighted the need for good relationships and networks between the members of the supply chains to get items at the right place at the right moment: " …*we have the ability to leverage our network*…*we used our existing network to get items out of China*…*we collaborated with the local and national authorities*…"

Establishing pre-agreements with different national/local government agencies and suppliers would facilitate the supply process during the response to a pandemic. Framework agreement is seen as tool

to secure relief items and improve the efficient and effectiveness of the respond. Humanitarian organisations use this practice and often set up framework agreements with suppliers and carriers in advance, which fix rates for all orders during a specified period of time (up to three years) and are renewed at fixed intervals (Gossler et al., 2019, Pazirandeh and Herlin, 2014). Of course, framework agreements do not always secure the delivery of items. As pointed out by one of the interviewees "…*the suppliers have had to just defeat on those framework agreements repeatedly and they haven't been able to meet them*".

PPPs and cross-sector collaboration increase the resilience of medical supply chains against epidemic outbreak. Co-ordination between partners and building of new business models moving from competition to collaboration is essential. For example, pharmaceutical companies that use to compete they are now collaborating to develop the vaccine against COVID-19.

5.5 Financial forecasting and non-earmarked donations

Forecasting not only the future need in items but also the financial needs to respond to such as pandemics could be a helpful tool for governments and organisations. The International Federation of Red Cross and Red Crescent Societies (IFRC) for example uses a Forecast-based Financing (FbF) programme that enables access to humanitarian funding for early action based on meteorological forecast information, combined with risk analysis. Based on that information an allocation of the funding is done in advance. Similar tools could be a solution to forecast the financial needs of the organisations involved to respond to such pandemics. Non-earmarked donations also are recommended for donors to give freedom to the organisations responding to pandemics to use the funds. As mentioned by one interviewees "…*we've had a lot of flexibility and support from our donors to really divert donations towards the COVID-19*".

5.6 Agility and visibility of medical supply chains

Lee (2004, p.105) describes agility as the ability to "respond to short-term changes in demand or supply quickly and handle external disruptions smoothly." The humanitarian literature repeatedly argues that supply chain agility is an essential requirement in humanitarian operations. (Dubey and Gunasekaran, 2016, L'Hermitte et al., 2016, Oloruntoba and Kovács, 2015). Being agile helps organisations quickly and flexibly respond to demand fluctuations, supply disruptions, and changes in suppliers' delivery in different types of humanitarian disasters and varying geographical areas (Falagara Sigala et al., 2020, Dubey and Gunasekaran, 2016). This is especially important for the global medical supply chains.

One way to achieve agility and adapt to changes is by ensuring visibility of the medical supply chain network. The digitalisation ad the use of new technologies can enable autonomous supply chains and help supply chain member to leverage new levels of visibility for demand and supply risks. Visibility of placed orders of PPEs and medical supplies would allow distributors and manufacturers to better identify duplication of orders and forecast the demand to inform manufacture. Fostering a transparent digital relationship with suppliers and producers, health providers can help to check the available inventories and capacity availability across the supply chain network. Enabling real-time visibility of

the supply chain and enhance decision making improve the agility and responsiveness of the medical supply chains.

Dimension	Medical Supply Chain Disruptions	Medical Supply Chain Gaps	Recommendations
Operational	Behavioural ▪ Bullwhipping ▪ Price Speculation ▪ Panic buying ▪ Fraud ▪ Excessive mark-ups	▪ Shortages of PPE, respiratory ventilators, diagnostic/testing kits ▪ Gaps on the regulations of prices ▪ Gaps on preventing fraud ▪ Lack of preparedness to find and minimise suppliers' competitive behaviours ▪ Gaps in vetting processes of business partners	▪ Pre-positioning of medical supplies ▪ Regulations to prevent fraud ▪ Vetting suppliers in advance ▪ Regulate increase of prices
	Capacity ▪ Workforce ▪ Production capabilities	▪ Shortages of raw materials ▪ Gaps in production capabilities ▪ Long lead times ▪ Lack of specialised workforce ▪ Gaps in incentives for industry to ramp up production	▪ Public Private Partnerships and Cross Sector Collaboration ▪ Incentives to ramp up productions ▪ Build pools of trained specialised personnel
	Legislation ▪ Regulatory Uncertainty ▪ Certifications and standards of products ▪ Quality ▪ Reduce any import restrictions and Customs tariffs ▪ Export bans	▪ Gaps in quality of products ▪ Import restrictions ▪ Lack of product certificates ▪ Gaps in free movements of goods ▪ Gap in visibility of supply chain ▪ Gaps in legislation and regulations for imports	▪ Standardisations of product and certificates ▪ Regulations to allow free movements of good in times of emergencies ▪ End to end visibility via digitalisation
Financial	Financial ▪ Sales ▪ Expenses ▪ Donations Human Resources	• Lack of funding rather than COVID-19 donations • Decrease of sales for products not related to COVID-19 response	• Financial forecasting tools • Non-earmarked funding for disaster response

		• Hold on existing programs/missions due to COVID-19	
Strategic	Supply Chain Design ▪ Sourcing ▪ Investment Risk Management	• Lack of preparedness • Gaps in applicability of existing risk plans • Gaps in sourcing strategies	• Develop risks plans for such emergencies • Multi-sourcing strategies and geographically diversified supply chain

Table 3: Medical Supply Chain Gaps and Recommendations

6 Conclusions

COVID-19 outbreak is one of the largest pandemics that has an impact on human life, as well as an impact on medical supply chains around the globe. The deliverable has identified the gaps in medical supply chain and made recommendations on how to secure the medical supplies to respond to pandemics. To this end, a qualitative research approach was followed and 38 health providers and suppliers of medical items in different geographical areas were interviewed.

As the spread of the current outbreak widens, governments and private sector started implementing social distancing measures and even lockdowns to contain the spread of the virus, which in affected medical supply chains across the globe. Medical supply chains are disrupted by consumer behaviour, capacity limitations as well as by legislations or the lack of it. The following gaps were identified:

- Shortages of PPE, respiratory ventilators, diagnostic/testing kits
- Gap on the regulations on prices
- Gap on preventing fraud
- Lack of preparedness to find and minimise suppliers' competitive behaviours
- Gaps in vetting processes of new business partners
- Shortages of raw material
- Long lead times in production and distribution of medical supplies
- Lack of specialised workforce
- Gaps in production
- Gaps in incentives for industry to ramp up production
- Gaps in quality of products
- Imports constraints
- Lack of product certificates
- Gaps in free movements of goods
- Gap in visibility of supply chain
- Gaps in legislation and regulations for imports
- Lack of preparedness
- Gaps in applicability of existing risk plans
- Gaps in sourcing strategies
- Lack of funding rather than COVID-19 donations
- Decrease of sales for products not related to COVID-19 response
- Hold on existing programs/missions due to COVID-19

To mitigate the disruptions occurred by COVID-19 and their associated gaps, medical supply chains need to switch from cost efficiency to flexibility, agility and responsiveness. Pre-positioning of medical supplies could help health providers to cover the gaps. Collaborative pre-positioning seems promising in terms of costs, but there are some areas that need further investigation. For instance, it is not clear who should lead the implementation of such systems, the pharmaceutical sector, hospitals, retailers or governmental agencies? In addition, what are the incentives for stakeholders to join such system? How will these items be allocated between the member organisations or countries in time of emergency?

Additionally, moving from a single sourcing strategy to multi-sourcing strategies could make medical supply chains more agile and flexible since health providers will reduce the reliance on single global sources by including additional local and nearshore suppliers and plants in their supply chain. But of course, switching to new business models is costly and needs investment. Future research should investigate what is the geographical areas that health provides should rely on and what are the optimal sourcing strategies. Centralised and consolidated procurement will also mitigate the disruptions that occur from the decentralised procurement and increase the negotiation power of the buyers.

PPPs and cross-sector collaboration are a means to increase the resilience of medical supply chains against epidemic outbreak. During COVID-19 governments have collaborated with manufactures from different sectors to produce medical supplies. But to secure a second source as a possible countermeasure for supply chain disruptions, the supply chain should be designed via an incentive contract to induce a potential second source's appropriate investment level to the highly customised medical/pharmaceutical products. Thus, further research is needed regarding what kind of incentives should be included in a contract between a government and a potential second source of customised medical items. Also, questions related the ownership of the asset developed of these kinds of partnerships should be further investigated. Governments should develop incentives for industry to ramp up production. This includes easing restrictions on the export and distribution of personal protective equipment and other medical supplies.

Global collaborations on developing quality standards and certificates for medical supplies and especially PPEs could facilitate the production, distribution, customs clearance and use of those items and improve the respond ad service to patients. The use of new technologies to improve the end-to-end visibility, collaboration and agility of global medical supply chains could support health providers to resist in the shocks that pandemics brings. In addition, forecasting tools for the financial needs and the donations could also be a solution to minimise the impact of such pandemics.

Reshaping the medical supply chain and developing a more flexible, responsive and agile medical supply chain must be the first priority for health care organisations, manufacturers, governmental agencies and logistics providers. Lessons learned and good practices from COVID-19 should be used to prepare for the next emergency.

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Annexes

Annex A : Interview Guide for WP3_D3.1

Introductory questions

1. How is your organization involved in a COVID-19 response?
2. What is your role in the organization and how have you personally been involved in the COVID-19 response?

Operational Pillar

3. What kind of services/products/ supply chain services does your organization offer to customers/beneficiaries?
4. Could you please describe your organization's operations/supply chain structure?
5. Could you please describe the main stakeholders in your organization's operations /supply chain?
6. What kind of disruptions/challenges associated with COVID-19 has your organization experienced in its operations /supply chain? Please specify the disruption by product/service that your organization offers.
7. What measures does your organization believe are necessary to mitigate the operational/supply chain challenges that your organization faces?
8. What are the operational/supply performance measures that your organization requests of its suppliers?
9. Have any of your organization's suppliers been unable to meet these measures during COVID-19? If so, what are their reasons why not?
10. Has your organization recognized any opportunities for your operations/supply chain associated with Covid-19? If so, what are they?

Financial Pillar

11. Has your organization experienced any sales increases or decreases since COVID-19? If so, to what extent do you attribute these changes to COVID-19?
12. How did or is your organization forecasting the financial impact of COVID-19 for the next quarter, next year, and next 5-10 years? If so, quantify it, e.g., as a percentage of the organization's annual sales or earnings?
13. Has your organization experienced any increases or decreases in discretionary expenses, e.g., advertising, investment, research and development since COVID-19?
14. Is your organization planning to increase or decrease discretionary expenses for the next quarter, next year, and next 5-10 years?
15. Has your organization experienced any upsizing or downsizing since covid-19? If so, what is the job increase or decrease as a percentage of the organization's workforce?
16. Is your organization planning to upsize or downsize for the next quarter, next year, and next 5-10 years?

Strategic Pillar

17. Does your organization have a risk management plan in place?

18. Is your organization considering a re-design its operations/supply chain during or after COVID-19?
19. What are the main re-design steps your organization is considering (e.g. changing supplier, multiple sourcing, changing country of production/supply)?
20. Is the government involved in any way in your organization's operations or supply chain?
21. If so, what restrictions or guidelines have they developed for your organization and its industry sector?

Annex B: Consent Form of WP3

I volunteer to participate in this research conducted by the HERoS consortium, co-ordinated by the Hanken School of Economics, entitled "Health Emergency Response in Interconnected Systems" (HERoS). HERoS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003606. The HERoS consortium consists of 11 organisations: Hanken School of Economics, TU Delft, VU Amsterdam, The Open University, NHG Finland, CBK, Squadron, PCPM, Arttic, Croce Rossa Italiana, and Project HOPE. The project began in Apr 2020 and will end in March 2023.

The overall objective of HERoS is to improve the effectiveness and efficiency of the response to the COVID-19 outbreak. HERoS creates and provides policies and guidelines for improved crisis governance, with a core focus on responders to public health emergencies, and their needs to make informed decisions. This aim shall be achieved by enabling information-driven self-organisation and co-ordination that considers behaviour, as well as rapid adaptation to dynamically changing situations. To achieve this, HERoS will foster organisational and technical innovation during disasters for responders during critical scenarios from inaccurate, distrusted, and overhyped information. To this end, HERoS will provide them with accurate, validated, enriched, high quality, and actionable knowledge.

1. ☐My participation in this project is voluntary.
2. ☐I understand that I will not be paid for my participation.
3. ☐I understand that I may withdraw my data and myself and discontinue participation at any time without any consequences. I understand that I can only withdraw my data from the research before any findings have been published and/or are included in a deliverable for the study.
4. ☐I understand that I have the right to ask questions and receive understandable answers before making any decision.
5. ☐I understand that I have the right to decline to answer any question or to terminate my involvement at any point during the interview.
6. ☐I have been informed of the following:
    a. the reason for the interview
    b. the purpose for the collection of any personal information, such as contact details
    c. my rights in relation to that personal information
    d. the subject matters to be discussed
7. ☐I have been made aware of any external use of the research.

8. I would ☐ like / ☐ not like to review transcripts of the interview upon completion.
9. I would ☐ like / ☐ not like to receive updates on the progress and findings of the project (Please circle the option you choose).
10. ☐I understand that the interview will last approximately 60 minutes. With my permission, research notes will be taken during the interview, and the interview will be recorded and transcribed.
11. I would ☐ like / ☐ not like to be identified in any reports. If you choose not to be identified, the researcher will not identify you by name in any reports using information obtained from this interview, and your confidentiality as a participant in this study will remain secure. Subsequent uses of records and data will be subject to standard data use policies, which protect the anonymity of individuals.
12. ☐I understand my right to request access to any, and all, personal information that I have voluntarily provided as part of my participation, and that I may ask for that information to be rectified and/or amended if it is inaccurate, or request that all personal information that I have provided be deleted.
13. ☐ I understand that the HERoS consortium intend on retaining pseudonymised versions of research transcripts and questionnaires for a period of up to 12 months following the completion of the project.
14. ☐ I understand that the HERoS consortium will transfer to, and analyse the data in the European Union.
15. I would ☐ like / ☐ not like to be quoted directly.
16. ☐I have read and understood the explanation provided to me. I have had all my questions answered to my satisfaction, and I voluntarily agree to participate in this study.
17. ☐I have been given a copy of this consent form.
18. ☐My HERoS ID/pseudonym number is IT2PSMAC

My signature	Researcher's signature
…….	Falagara Sigala 
Date	Date
…….	14.07.202

Researcher

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Any complaints or queries regarding data protection can also always be sent to the Data Protection Officer, dpo@hanken.fi, as required by the GDPR (Art 39).