RESEARCH LUXEMBOURG

LUXINNOVATION
TRUSTED PARTNER FOR BUSINESS

INCERT
Because it's always a matter of security

LUXEMBOURG CENTRE FOR LOGISTICS AND SUPPLY CHAIN MANAGEMENT (LCL)

LUXEMBOURG INSTITUTE OF SCIENCE AND TECHNOLOGY

Supply Chain and Logistics in Luxembourg: An overview, the effects of the pandemic, and an outlook into the future

A report compiled by

Work Package 13 Supply Chains and Logistics

Research Luxembourg COVID-19 Task Force*

May 8, 2020

*Further information on the task force can be found at `https://researchluxembourg.lu/covid-19-taskforce/`; Principal authors are Benny Mantin, Joachim Arts, Francesco Ferrero.

Executive Summary

Flows of goods and services are at the core of how economic prosperity is created. During the COVID-19 pandemic, these flows have been dramatically impacted and altered, while necessitating new ones. The current crisis exhibits features that makes it an unprecedented setting:

- **Disruption is global**. While initially it was limited to China, it quickly spread elsewhere and now encompasses the entire globe.
- **Both supply and demand are affected**. This bears consequences for the resumption plans (a double Bullwhip effect[1]).
- **Both internal and external flows are restricted**. Due to the restrictions imposed, companies face challenges to conduct their transformation processes, while transportation and logistics systems are also severely impacted.

Work Package 13 Supply Chains and logistics, henceforth WP13, operates along two pillars: assessing the impact on the different providers in the logistics sector and analysing supply chains that support various sectors of the economy in Luxembourg. This report provides a broad view of supply chains at large and appraises the potential need for enhancing resilience following the current pandemic with an emphasis on the Luxembrougish perspective.

WP13 has carried out a **"logistics networks disruption" survey**. Key observations form the survey include:

- **Most participants experience a sectorial shift in demand** with a strong decrease in services for the automotive and steel industry as well as fashion and retail, and an increase in demand for e-commerce, healthcare and pharmaceuticals.
- The **impact on operations** is manifested through lower number of shipments, lower utilization of vehicles and higher operating costs.
- **Market uncertainty** is on the top of participants' minds.
- Larger firms (with 50+ employees) are 2.5 times more likely than smaller firms to have prepared a **business resumption plan**.

Additional messages were communicated by respondents. These were aggregated into several themes:

- **Staffing.** The reduced workforce is a challenge. Respondents are struggling to deal with higher volumes with less people, worried about hiring and training in a fast-changing environment and hope for continuation of arrangements such as "short-time" provisions and taxation of frontaliers.

[1] See, e.g., `https://sloanreview.mit.edu/article/the-bullwhip-effect-in-supply-chains/`.

- **Liquidity.** Keeping the money fluid and afloat is a challenge.
- **Coordination & consolidation.** A need was voiced for a more coordinated approach in all kinds of logistics for sensitive goods. A wish was made for reduced dependence from providers based in other continents.
- **Luxembourg's competitive advantage.** Luxembourg can become the logistical EU hub for the distribution of vaccines and/or other treatments for COVID-19 when they will hopefully be available.

WP13 also carried out a **supply chain analysis** that identifies several key features of supply chains: degree of globalization, opacity, length of supply chains, narrowness of supply chains, slack, degree of complexity and degree of volatility. These features suggest the following outlook for companies:

- **Globalization:** Companies can gain more control on their supply chains by reshoring pertinent activities.
- **Opacity:** In order to manage and mitigate risk, it is important to gain more visibility into upstream activities in the supply chain.
- **Length of supply chains:** Control can be increased by shortening supply chains.
- **Narrowness of supply chains:** Companies can search for alternative/additional suppliers as well as markets to sell their products.
- **Slack:** Find a new balance between lean operations and safety buffers in inventory.
- **Complexity:** Simplification of products leads to simpler and shorter supply chains.

Additional needs that emerge are:

- **Automation** and **digitization**. The current pandemic may speed up the investment and commitment to embrace various technologies ranging from 3D printing and additive manufacturing, through robots and autonomous vehicles, to artificial intelligence/machine learning/deep learning and internet of things (IoT).
- **Coordination** and **synchronization** of supply chains. The exit will cause a double bullwhip effect (first going upstream and then downstream). The double bullwhip can easily take 6-9 months before supply chains stabilize. Coordinated supply chains can reach stability sooner in 3-6 months.

There are also several **long term policy recommendations**:

- **Development of a national control tower:** Such a control tower will allow stake holders to assess and monitor the status of the logistics networks and essential supply chains. It is a necessary, though not sufficient, condition to make transportation networks and supply chains more resilient. LIST, LCL (within the University of Luxembourg) and INCERT received a grant by the FNR COVID-19 Call for the ACTING NoW project aimed at deploying a prototype of such a control tower.

- **Emergency national stockpiles of strategically important goods:** Strategic stockpiles enable a country to absorb the shocks posed by future major disruptions. The current crisis can inform where strategic stockpiles can buffer future disruption events.

- **Assess resilience:** This encapsulates both the resilience of locally prominent industries as well as the resilience of transportation networks. This ensures stake holders become aware of risk to which they are susceptible and become educated about measures they can take to make their supply chains/networks/operations more resilient for future crises.

- **Resilience workshops for industry:** Resilience will be a priority for many companies. The aftermath of the current pandemic is a good time to exchange best practices and learn from experts in supply chain resilience to prepare for the next disruption. The government can be an important facilitator for this transition through workshops.

WP13 is conducting closer analysis of certain supply chains. Specifically: healthcare, food and automotive. While the mapping of food and automotive supply chains is still ongoing, the mapping of the **healthcare industry** raises the attention to several risks exposures. Below are recommendations to minimize exposure.

- **Strategic Stockpile of healthcare products.** This echoes the earlier, general, long-term recommendation. Such a stockpile will protect against a possible second wave and ensure availability of supplies in case the pandemic persists.

- **Consider establishing a monitoring system.** Such a dashboard could provide early indicators of potential disruptions both in terms of manufacturing capacity and logistical infrastructure to deliver these goods.

- **Strategic production.** In the context of the pandemic, it may be wise to establish and support local production of Personal Protective Equipment (PPE). In the longer run, it is prudent to study general healthcare needs and how to facilitate production and availability closer to home.

1 About Work Package 13 Supply Chains and Logistics

The COVID-19 Task Force has been set up in order to offer the health system and the Government the combined expertise available within the Luxembourg public research sector (LIH, LISER, LIST, LNS, Luxinnovation, University and FNR, under the coordination of the Ministry of Higher Education and Research).

The mission of the task force is to:

- Coordinate the provision of support from the national research community to healthcare providers and the government in order to contain the current COVID-19 pandemic.
- Help identify and centralise a variety of priority activities, leveraging on the cross-sectoral expertise in biology, medicine, mathematics, computer science, epidemiology, economics and social science.
- Be the point of contact between the national research ecosystem, the clinical community and the authorities to foster common projects.

There are 13 work packages in this task force. WP13 is dedicated to logistics and supply chains. This work package operates along two pillars:[2]

- Assessment of the impact on the different logistics providers in Luxembourg. In the course of this, input from an online survey will feed data to a dashboard that will provide information on the changing logistics environment.
- Analysis of supply chains that support various sectors of the economy in Luxembourg. A report will feature various supply chain considerations and will be a valuable input for the exit strategy (WP00). An online survey is envisioned as well.

[2]Originally, WP13 was also engaged with a third pillar—supporting WP04 in the planning process of large scale testing in Luxemrboug. However, this task is on hold at the moment.

Figure 1: Members of WP13

2 Introduction

Flows of goods and services are at the core of how economic prosperity is created. In recent decades, supply chains have become increasingly globalized, complex and intertwined. To improve efficiency and gain greater return to scale, firms along the supply chains specialize in ever-finer parts of the entire process. This leads to two major outcomes.

First, it is not uncommon for supply chains to have 6 tiers or more. Consider for example, the apparel industry. For one garment, the process embeds multiple steps, such as fiber production, spinning of the fiber, weaving, dyeing, cutting, sewing, and finishing of the garment. Keeping in mind that other parts of the garment (buttons, zippers) are often produced by other suppliers and that distribution and logistics engage even more players in this complex network of goods delivery to customers. In other industries, such as automotive, electronics, and aerospace, the products are far more complex resulting in even longer supply chains.

Second, firms—who now have developed expertise in very specialized parts of the production process—play a role in simultaneously providing components to numerous companies that ultimately interact with end consumers. That is, if in the past one could have envisioned a supply chain being a pyramid where the base of the pyramid corresponds to all raw material suppliers and the top of the pyramid is the consumer, now supply chains are so intertwined that one can only imagine a large lattice, or a fisherman net where, on one side you have many suppliers, on the other side you have the consumers, and in-between you have exponentially many chains of interactions between them.

Given this complexity, firms lose visibility into their own supply chains. Global shocks illustrate this very well. Take the 2011 flood in Thailand. Although it has attracted only limited attention in the global media, it had long lasting supply chain effects. The magnitude of the effects has reduced the global supply of hard drives by about 30% well into 2012 and caused companies like Honda to cut production around the world due to component shortages.[3] It was only then, that some companies realized that many of their components were sourced, one way or another, from Thailand.

The COVID-19 pandemic started with an outbreak in Wuhan, China, in December 2019. With Wuhan, being a key manufacturing and transportation hub, coupled with the help of the Chinese new year migration, the virus spread to other provinces by early-mid January. Later in January, when the cordon sanitaire was imposed on Wuhan, it became the largest quarantine in human history. With production halting and flows of goods severely restricted, the effect echoed and sent shock waves throughout supply chains. Soon after, major facilities closed down in China due to lack of components, and later on facilities elsewhere around the globe were impacted by the shortage of supplies. On 11 March, when a pandemic was declared, the global supply effects faced demand side challenges.

[3]See, e.g., `https://www.ft.com/content/f0f9a234-fb33-11e0-8756-00144feab49a`.

The current crisis exhibits features that make it an unprecedented setting:

- **Disruption is global**. While initially it was limited to China, it quickly spread elsewhere and now encompasses the entire globe.
- **Both supply and demand are affected**. This bears consequences for the resumption plans (a double Bullwhip effect).
- **Both internal and external flows are restricted**. Due to the restrictions imposed, companies face challenges to conduct their transformation processes, while transportation and logistics systems are also severely impacted.

Figure 2: Impact timeline

This document is structured as follows. Section 3 discusses the logistics sector in Luxembourg. Section 4 discusses how supply chain network complexity arises, what can be done to manage that complexity and discusses the network complexity of several industries that are important to Luxembourg. These and other industries are then assessed in Section 5 after which some reflections are offered about the implications of this assessment along different stages of supply chains. Resilience and risk management in supply chains is then discussed in Section 6. Finally, conclusions and recommendations are given in Section 7.

3 The logistics sector in Luxembourg

3.1 Overview of the sector

Luxembourg benefits from an exceptional geographical advantage—located in the heart of Europe—coupled with proximity to other densely populated areas in Europe—80% of the European Union GDP can be serviced from Luxembourg in one day. This provides the country a phenomenal opportunity to play a key role in the European logistics sector. Accordingly, the country has established the logistics sector as a core pillar in the diversification plan. This led to an ongoing investment in logistical infrastructure and supporting services.

Luxembourg's logistics sector is now highly ranked globally (in 2016 it was ranked second in the World Bank's Logistics Performance Index). It prides itself on three core advantages: connectivity, efficiency, and quality.[4] In terms of connectivity, it features, among others, air links to all continents, an extended gateway to major European ports, and an advanced ICT environment. In terms of efficiency, Luxembourg has state-of-the-art multi-modal transport infrastructures, a fast and efficient airport, easy and fast import/export procedures, as well as optimized customs and VAT procedures. Lastly, quality encapsulates the stable business environment and business-friendly administrations the companies enjoy in Luxembourg, the presence of qualified and certified logistics players, a positive fiscal environment, access to highly skilled and multilingual workforce, as well as logistics-dedicated training. Importantly, this sector is greatly supported by the creation—through a three way agreement between the Government, the University and the MIT—of the Luxembourg Centre for logistics and Supply Chain Management (LCL), which provides a portfolio of education, research and outreach activities.

Among others, Luxembourg has also implemented a multi-product specialization strategy within its logistics sector by focusing on certain types of products requiring specific handling and/or storage solutions:[5]

1. Industrial products, primarily high-value goods ranging from steel, glass and plastic to aerospace and aeronautic goods.

2. Automotive industry in becoming first and second tier supplier to manufacturing and assembly lines of automotive plants located in Germany, France and Belgium as well as the Netherlands and the UK.

3. High-tech and electronics, ranging from semi-conductors to consumer electronics.

4. Pharmaceuticals and healthcare products: this industry requires and follows strict considerations in terms of quality assurance, legislative framework, transport and handling. To that end, LuxairCARGO's dedicated Pharma & Healthcare Centre, which is certified to the highest standards, supports this sector.

[4]Source: `https://logistics.public.lu/en/why-luxembourg/key-strengths.html`
[5]Source: `https://logistics.public.lu/en/why-luxembourg/key-sectors.html`

5. Live animals and perishable products (such as food and plants): These two domains are supported by dedicated facilities by local logistics providers, which include, for example, temperature controlled rooms, for the former, and noise and light-controlled stalls for the latter.

6. High valuables such as fine wines, artwork and collectibles which require dedicated storage and conservation solutions.

7. Products distributed via e-commerce.

Logistical networks can be long and complex involving different players. This is often an intricate network involving various providers and governmental agencies as flows of goods generally require proper documentation, identification and physical checks along the way, along with other certificates and permits. The chain of providers include, but is not limited to, carriers (road, rail, air, maritime), warehouse providers, freight forwarders, consulting and managing services, contract logistics (generally referred to as 3PL), integrated logistics (also known as 4PL), express courier services, as well as handling agents.

Figure 3 provides an overview of some of the players in the logistics sector in Luxembourg. As is evident, the sector entertains a large number of players in this domain with many companies who are active internationally.

Figure 3: A non-exhaustive overview of key players in the logistics sector (Source: Ministry of the Economy (Directorate Logistics 2020))

3.2 Immediate impacts of the COVID-19 on the logistics sector

The logistics sector has experienced some dramatic impacts during the early days of the pandemic. We outline some of the key observations by transportation mode based on publicly available knowledge and discussion with stake holders from the industry. (Note: operational status relates to mid-late April.)

1. Rail: operations are fully functional.

2. Air: The Cargocenter has experienced an increase in volumes of goods. As Joe Schroeder, Head of Communications at LuxairGroup indicated "a lot of masks, breathing apparatus, technical, sanitary and medical equipment, and food" have been handled at the Cargocenter premises. This is due to the fact that belly capacity in commercial flights is not available any more, changing demand patterns and the urgency of those needs. However, despite the increase in volumes, the Cargocenter is facing a challenge with internal resources: absenteeism is close to 40% (out of a workforce of about 1,300) due to, e.g., sick leave, leave for family reasons, and temporary workers who cannot travel. A pool of 200 temporary workers supported the operations (from CFL Multimodal, Luxport, and the army, among others).[6]

3. Inland Waterways: currently idle. This ports normally deliver metal, scrap, food, and components for wind turbines and windmills.

4. Road: generally operational, with congestion mainly at borders. A dashboard was created to visualize such issues (`https://covid-19.sixfold.com/`). This issue was limited in scsope as it was quickly resolved by the European Comission's Green Lanes initiative[7].

Choice of transportation mode is a complex trade-off faced by companies. It is often based on key characteristics such as speed (how long does it take to the shipment to arrive?), frequency (how often is a service operated?), location flexibility (where is the service located?), and the price of each transportation mode. These considerations, and their respective strengths, are illustrated in Table 1.

In times of crisis, the choice between modes can alter substantially. Airfreight, despite the higher cost, becomes a preferred mode as many supply chains managers seek to expedite deliveries, to ensure shifting of inventories away from infected and congested areas, and to avoid slow moving modes (namely shipping). Evidently, as Figure 4 reveals, China outbound airfreight movements have doubled and even tripled for some of the destinations as compared to last year. This rise in demand has triggered a surge in airfreight rates (see Figure 5).

[6]Source: `http://www.lessentiel.lu/fr/luxembourg/story/du-volume-mais-moins-de-bras-au-cargocenter-18061676`

[7]For details see `https://ec.europa.eu/commission/presscorner/detail/en/IP_20_510`.

Table 1: Transportation modes and key features

Mode	Speed	Frequency	Location flexibility	Cost
Rail	Fast	Average	Low	Average
Water	Very slow	Average	Low	Very low
Truck	Average	High	Very extensive	High
Pipeline	Slow	High	Very limited	Low
Air	Very fast	Average	Average	Very high

However, as carriers convert their passenger aircraft or simply use the belly-hold capacity,[8] additional capacity fills the market and price pressure is presently easing.

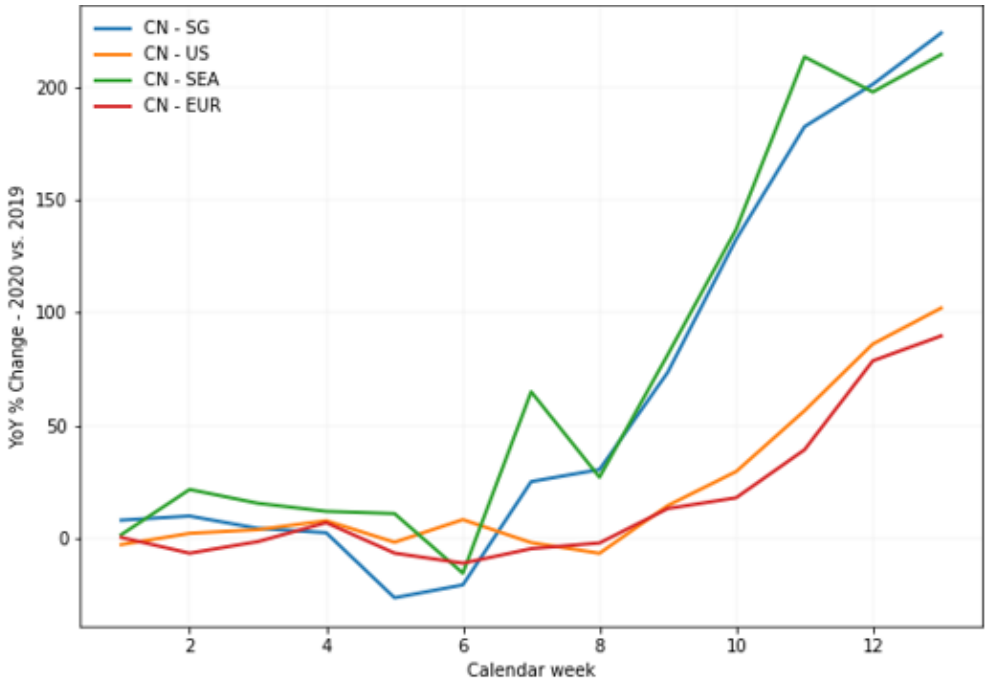

Figure 4: Airfreight movements: year over year change in movements between China and other four destinations (Source: TheLoadStar based on TAC Index data[10])

[8]See, e.g., `https://www.aircargonews.net/airlines/american-airlines-increases-cargo-only-pax-flights-to-combat-capacity-crunch/` which reports on airlines increasing freight capacity between Europe and the US or `https://centreforaviation.com/analysis/reports/covid-19-air-cargo-suddenly-attractive-for-us-airlines-520444?utm_source=capa&utm_medium=email&utm_campaign=Aviation%20Analyst%3A%2009-Apr-2020` which reports on the general increased attractiveness of air cargo to airlines.

[10]See `https://theloadstar.com/air-cargo-rates-may-be-levelling-out-amid-fears-of-a-drop-in-demand/`; the TAC Index (`https://www.tacindex.com/`) provides indices on major trade lanes based on actual transaction data submitted by entities active in the relevant markets.

[11]`https://www.aircargonews.net/data/airfreight-rates-continue-to-increase/`

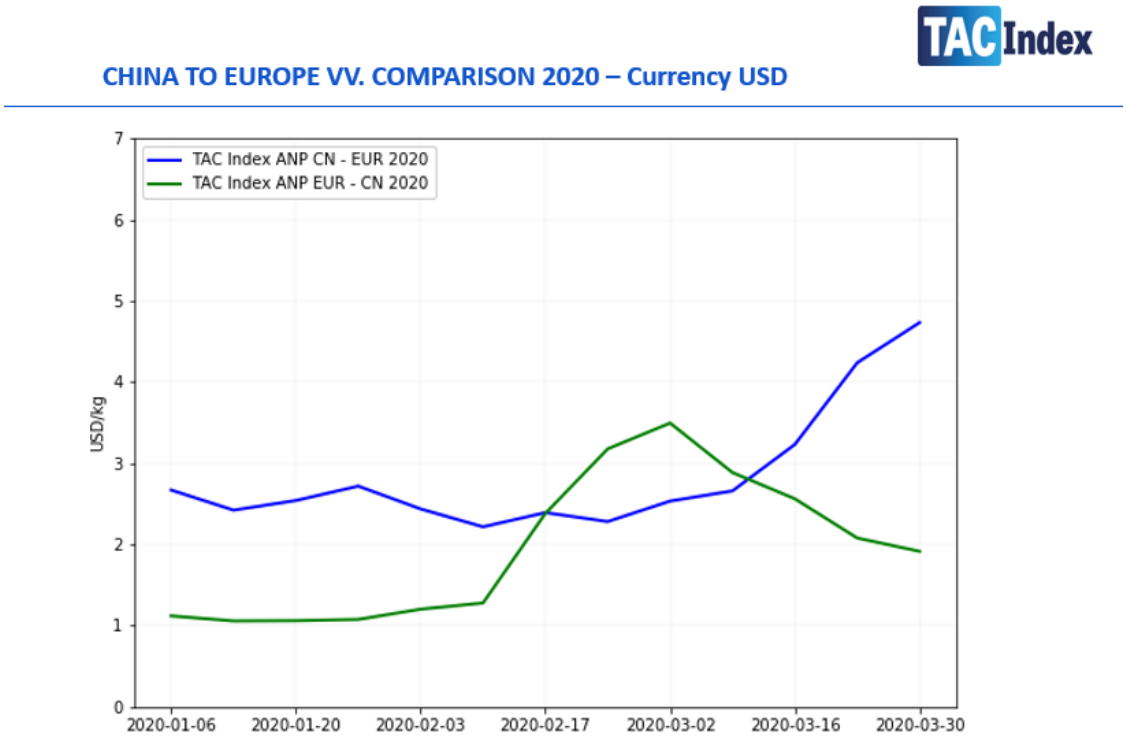

Figure 5: Airfreight rates (Source: Aircargo news[11])

3.3 "Logistics Networks Disruption" Survey

WP13 has developed a survey to gain deeper insights into the impacts of COVID-19 and the evolving effects on flows during the crisis. The survey is hosted on INCERT's secure platform and was circulated to diverse stake holders in the logistics domain on Wednesday, 15 April, 2020.

Sixty-three (63) Luxembourg-based companies from the logistics sector or providing immediately related services to the logistics sector such as specific IT solutions, received an invitation to participate in an online questionnaire. Thirty-five (35) of them took the time to answer it in spite of the complexity of running their operations at the moment. With a response rate of more than 55%, it is clear the industry is eager to voice their needs and concerns. The profile of respondents ranges in size of companies from 2 to 4,000 employees, with a median of 27. The collected data has not been weighted statistically according to the profile of the respondents. The questionnaire was designed by the WP13 members and pre-tested with some of the most significant Logistic providers in Luxembourg. The self-administered survey has been conducted during week 16 of this year (April 13 to 19, 2020). This report summarizes the input provided by the respondents and therefore reflects the assessment by the companies of the situation in that week. Questions asked in the survey related among others to the impact of the COVID-19 crisis on the operations, service level and workforce of the surveyed companies, the main challenges as well as to their way to

respond to the present crisis.

3.3.1 Key observations

Most survey participants experience a sectorial shift in demand, i.e. the relative weight of client sectors in terms of sales has changed due to the COVID-19 pandemic. There is a strong decrease in services for the automotive and steel industry as well as fashion and retail, and an increase in demand for e-commerce, healthcare and pharmaceuticals. Almost all effects are heterogeneously distributed across respondents with some participants reporting an increase while some other ones noticing a decrease. This is illustrated in Figure 6.

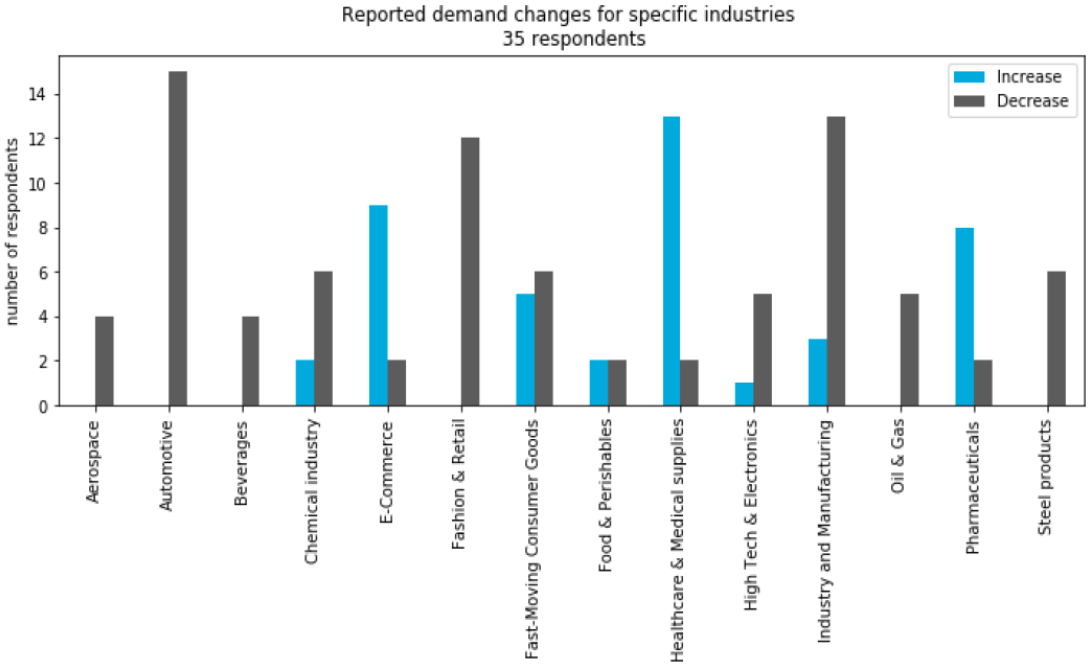

Figure 6: Demand changes by sector

As indicated by Figure 7, about 35% of participants experience severe impacts on their operations, 43% report no or limited negative impact, and 22% experience increased activity.

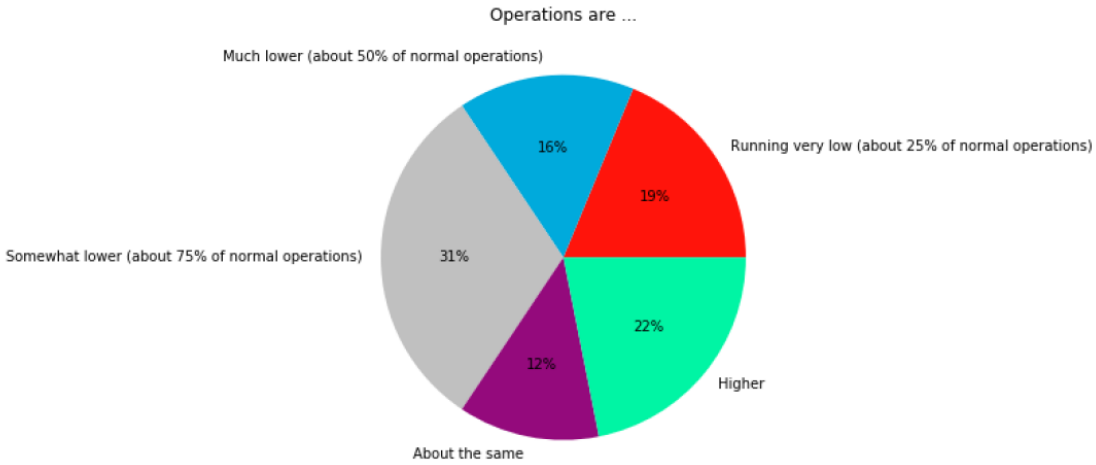

Figure 7: Level of operations at the different respondents

In concrete terms, the impact on the operations can be observed through a lower number of shipments, a lower fill-rate of vehicles and higher operating costs. The full effects are outlined in Figure 8.

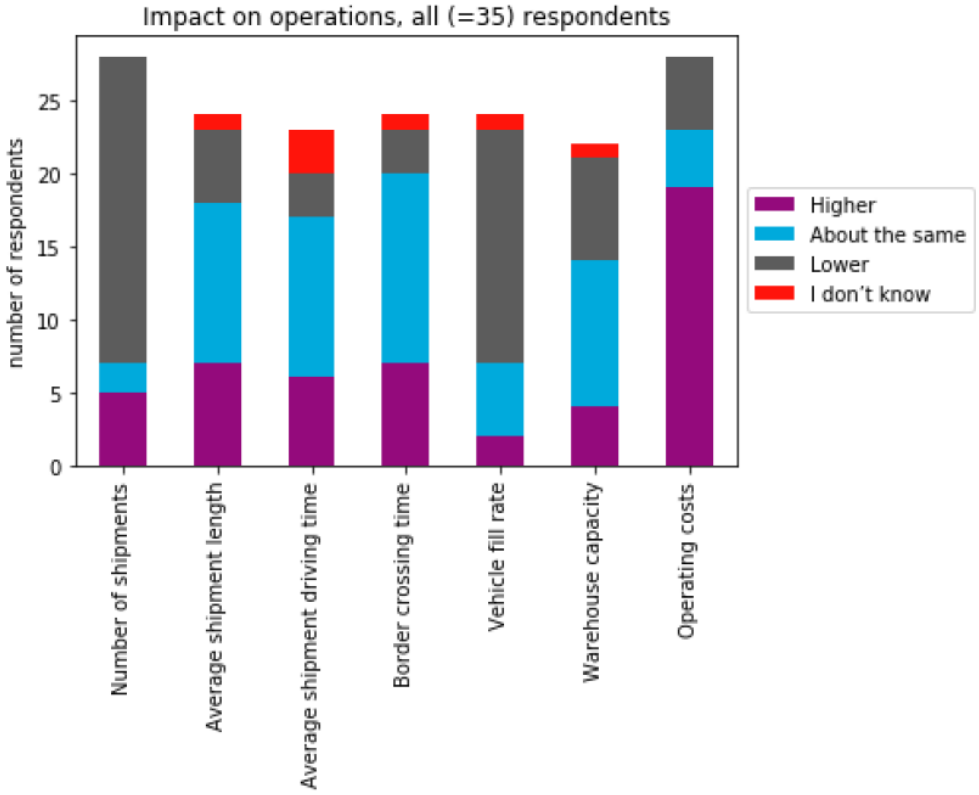

Figure 8: Impact on operations at the different respondents

Figure 9 provides an overview of the different challenges faced by respondents. The market uncertainty (sudden increases or falls in demand, increased volatility) is on the top of participants' minds. Regulatory impacts (such as paperwork, border controls, job regulation) do not seem to be a key concern. More operationally, decrease in revenues and cash flow seems to be a key challenge, in particular for the small organisations and the fast-growing ones such as the startups.

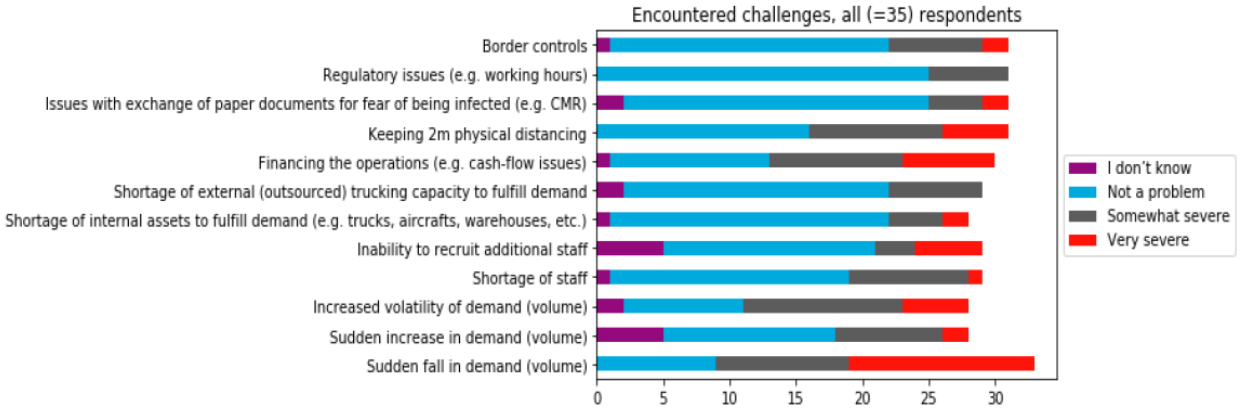

Figure 9: Challenges encountered by the different respondents

Figure 10 summarizes the impacts on the workforce. For instance, 73% of the workforce is on average available for running the operations of the companies at regular workload.

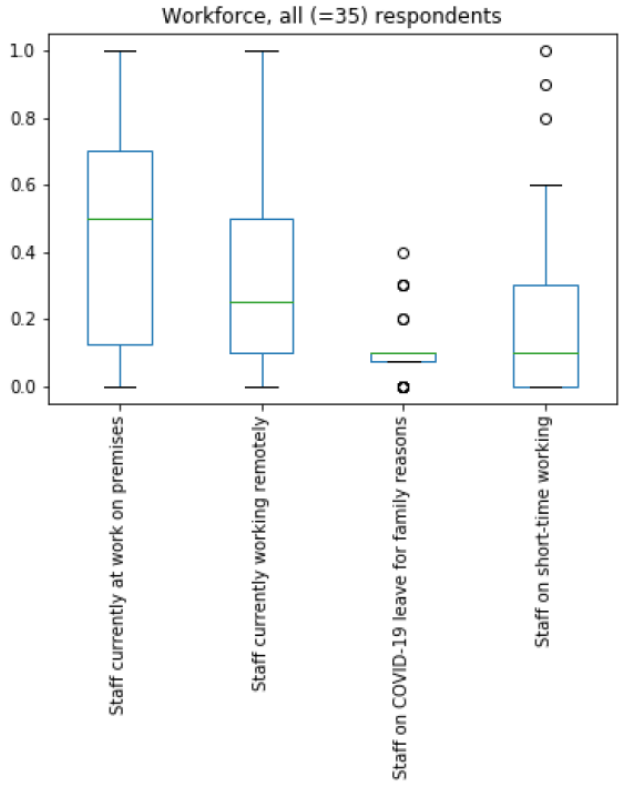

Figure 10: Effects on workforce

Larger firms (with 50 employees or more) are 2.5 more likely than smaller firms to implement a business resumption plan.

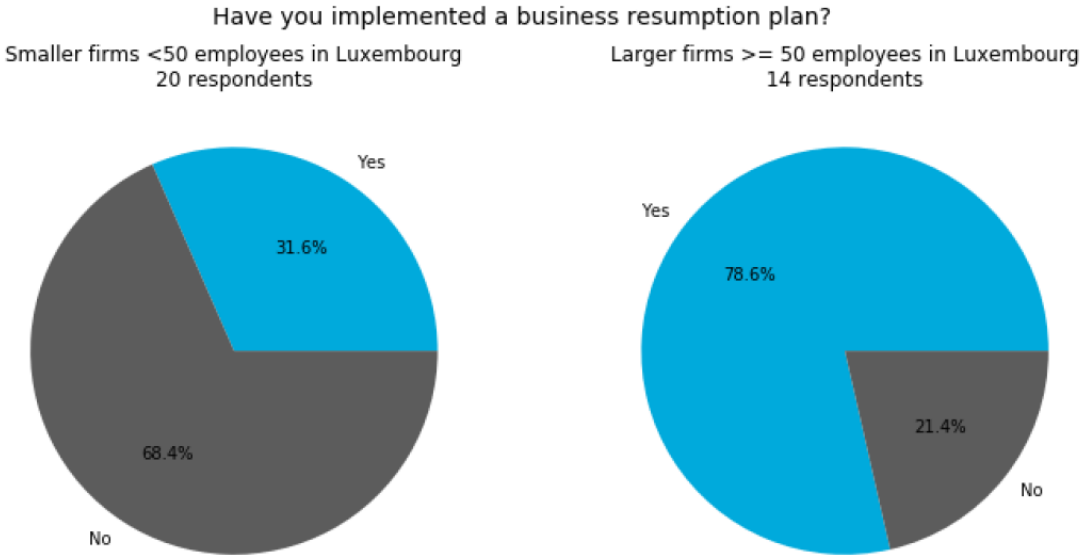

Figure 11: Business Resumption Plans

Lastly, as noted in Figure 12, almost half of the organisations with more than 50 employees have been engaged in supply chain risk analysis to prepare for disruptions, while more than three quarters of organisations with less employees have not.

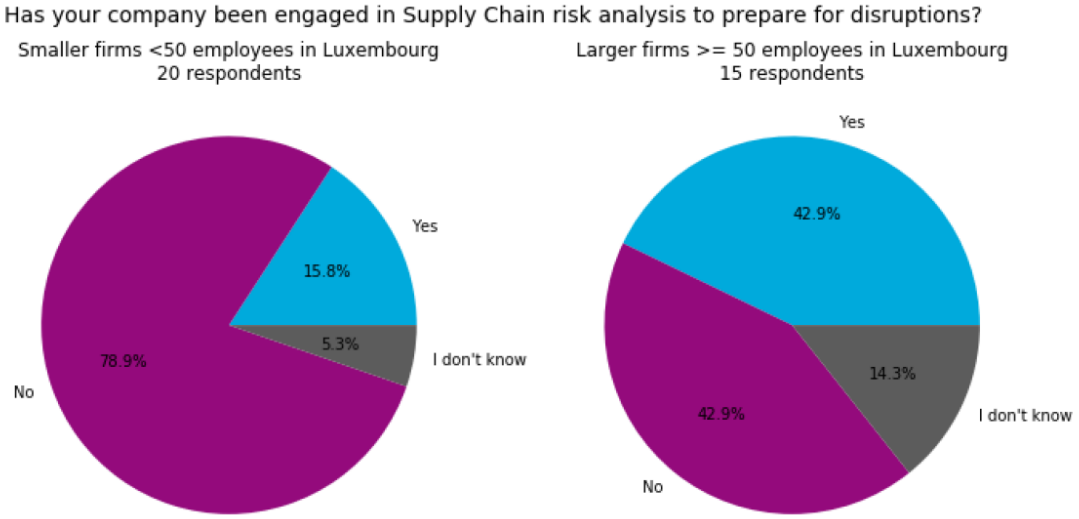

Figure 12: Engagement of respondents in Supply Chain risk analysis

3.3.2 Additional feedback from respondents

Several respondents used open-ended questions to highlight urgent needs and to deliver specific messages to the authorities. Some expressed the wish that this survey and the work of WP13 are used as a channel for bilateral communication between them and the different teams working on crisis management within the Grand-Duchy. In order to support this request we have grouped their feedback into five clusters.

Issues with staff

Some participants are struggling to get higher amounts of orders prepared and shipped with less people. They also look with concern at an uncertain future. Hiring and training staff requires six months or more and it is extremely difficult to understand how much staff will be needed in the near future and what skills will be key. There will probably be a need to retrain part of the current workforce so that they can adapt to changing business requirements. Last but not least, some respondents would like to be reassured about the continuation of current exceptional arrangements such as "short-time" provisions or agreements with the bordering countries about the taxation of the many cross-border commuters (*frontaliers*) currently teleworking from home.

Issues with liquidity and finances

"Keeping the money fluid and afloat" is seen as a challenge. Customers deciding to postpone payments without an agreement are just one of the issues provoking shortage of liquidity. The situation seems to be particularly critical for startups that might face tough choices such as leaving products half-baked despite large investments having already been put into them, or firing recently acquired talents risking not being considered trustworthy and stable employers in the future. Some companies lament that they do not fit well in any of the standard categories identified by the state aid measures, which suggests that an ad- hoc approach might be necessary for them.

Issues with Personal Protective Equipment (PPE)

Getting enough PPE for their workers is still a struggle for some of the respondents. This should be mitigated by the Government initiative to allocate free-of-charge a kit of five masks per employee to companies with the help of the Chamber of Commerce and by the recent launch of the EPI-Covid19 platform (`https://www.epi-covid19.lu/`), an initiative of Luxinnovation in collaboration with the wedo.lu team of the Fédération des Artisans, with the support of its partners and under the aegis of the government. Its purpose is to connect the national supply and demand of personal protective equipment (PPE) in the context of the health crisis related to Covid-19.

Issues with borders

One of the respondents reports that it is still difficult for people and goods to move across borders, and that the adoption of a single and standardised cross-border document for the whole of Europe would help significantly in the present circumstances. A recent decision by the European Council[12] goes in this direction but the road to actual implementation is still long and potentially bumpy.

Wish for a consolidated approach at national or EU-wide level

Some respondents suggested to devise a more coordinated approach in all kinds of logistics for sensitive goods, collecting the priority needs from hospitals, airport, food and beverage providers and organising public requests for quotations in order to avoid the delays or the rise of transport rates that are currently common. We note that this mandate is in part covered by the Cellule Logistique COVID-19 inside the Ministry of Health. One suggests to plan for Luxembourg to become the European hub for the distribution of the vaccines or other treatments for COVID-19 when they will hopefully be available. Independence of European countries from providers of key stuff based in other continents is also seen as a priority.

[12]See https://www.consilium.europa.eu/fr/press/press-releases/2020/04/07/digitalisation-of-freight-transport-information-council-adopts-new-rules/

4 Supply chain network complexity

The design and complexity of a supply chain network scales with the complexity of of the product that is delivered at the end of that supply chain (Inman and Blumenfeld 2014). Accordingly, supply chains for relatively simple products such as dairy are shorter and more localized than supply chains for a complex product such as a car. Since the complexity of products varies by industry, so does the complexity of the supply chain networks, as well as their susceptibility to different risks. One easy way to measure product complexity (as a proxy for supply chain complexity) are the number of different parts included in the product. Figure 13 shows how the risk that a plant within a supply chain is disrupted increases with product complexity.

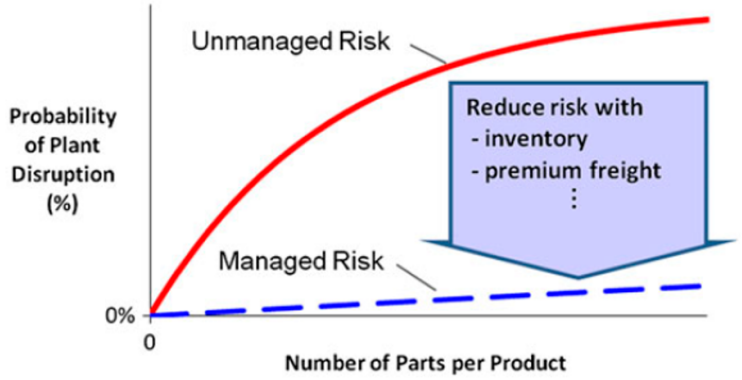

Figure 13: Supply chain risk as function of product complexity (Source: Inman and Blumenfeld (2014))

There are two ways to manage risk in supply chains. The first is to find ways to reduce the probability that a risk materializes, also known as prevention. The other way is to prepare the supply chain to absorb the risk, also known as mitigation; see Figure 14. Most ways to hedge risk are some combination of both.

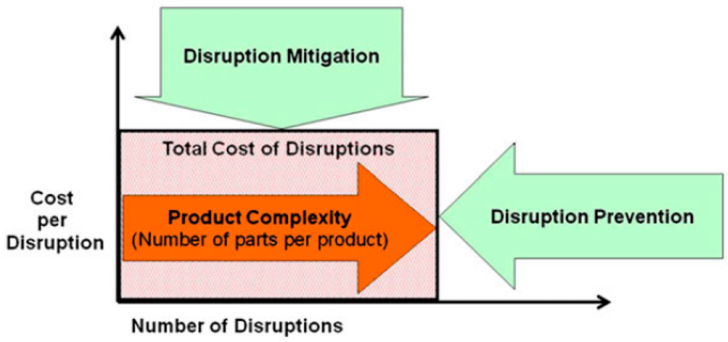

Figure 14: Risk management by frequency reduction and mitigation (Source: Inman and Blumenfeld (2014))

Traditionally supply risks are hedged by inventory or ways to get supplies quickly e.g. through a premium freight carrier. A premium freight carrier only works when a supplier is still operational. Inventory hedges only work for the limited period of time before inventory is depleted. If the disruption period is short then inventory can avoid problems altogether and if the disruption lasts longer, then at least the effects of the disruption can be mitigated by rationing the inventory. This is a key point in the case of COVID-19, which exhibits a systematic world-wide shock.

Multiple sourcing is an efficient strategy to mitigate sourcing risk provided that the risk of supply disruptions of each supplier are relatively independent. A well-known example of where this went wrong are the floods in Thailand 2011. A critical component for hard drives was manufactured only by several sources in Thailand. When the flood hit Thailand, it also hit each source of this critical component. Despite the practice of multiple sourcing, the industry was hit hard by this disruption and production output remained below usual levels for about two years[13].

The coming sections discuss several industries that are important to Luxembourg. Particular attention is paid to their supply chain complexities and measures that are available to prevent and mitigate supply chain risks.

4.1 Healthcare

4.1.1 Overview

For the purposes of supply chain analysis the healthcare industry can be divided into companies that deliver care to patients and companies that provide supplies needed for the safe delivery of such care. In the latter group we distinguish the delivery of pharmaceuticals, medical technology (including MRI-scanners and protective gear), and Laboratories that deliver amongst others test results. The healthcare delivery itself includes hospitals and other clinics.

The limited supply of certain consumable goods (such as masks) offers an opportunity for unscrupulous players. This is not unique to the healthcare industry, but the tight market and the rise of substandard and fake parts intensifies the volatility of the market. Examples include the the recall of 600,000 defective Chinese-sourced N95 masks in the Netherlands and substandard Chinese testing kits in Spain (Sheffi 2020).

[13]See `https://www.ft.com/content/f0f9a234-fb33-11e0-8756-00144feab49a` and `https://en.wikipedia.org/wiki/2011_Thailand_floods`

Due to the crisis there is global shortage of consumables that protect against infectious decease such as masks. Some countries have indicated that they are setting up their own production capacity for such items in an effort to become less dependent on the global market which is overheated right now[14]. At the same time, the supply chain of pharmaceuticals is mostly secure for the time being despite shut down production in India and China due to inventory reserves for 6-12 months[15].

4.1.2 Mapping of the sector

To better understand the situation at hand, we took the initiative to map this sector. An overview of key stake holders active in Luxembourg is provided in Figure 15. This is not intended to be an exhaustive list, but rather an indication of the scope of this sector.

Figure 15: List of main actors active in Luxembourg within the healthcare supply chain (Source: Ministry of the Economy, INCERT, Fedil)

Importantly, taking a supply chain perspective, we then outlined the relationships between those stake holders to identify key challenges. Specifically, in Figure 16 we consider product flows and, given the current pandemic, we categorize flows into safe flows (indicated in green as no disruptions foreseen), flows with potential weaknesses (indicated in orange), flows with risk (indicated in red) with disruption imminent.

[14]See e.g. `https://nos.nl/artikel/2330007-inkoop-en-productie-mondkapjes-in-nederland-had-sneller-gekund.html` for the Netherlands and `https://www.france24.com/en/20200331-france-s-macron-visits-coronavirus-mask-factory-as-health-workers-complain-of-acute-shortage` for France

[15]`https://www.europeanpharmaceuticalreview.com/article/116145/covid-19-update-coronavirus-and-the-pharmaceutical-supply-chain/`

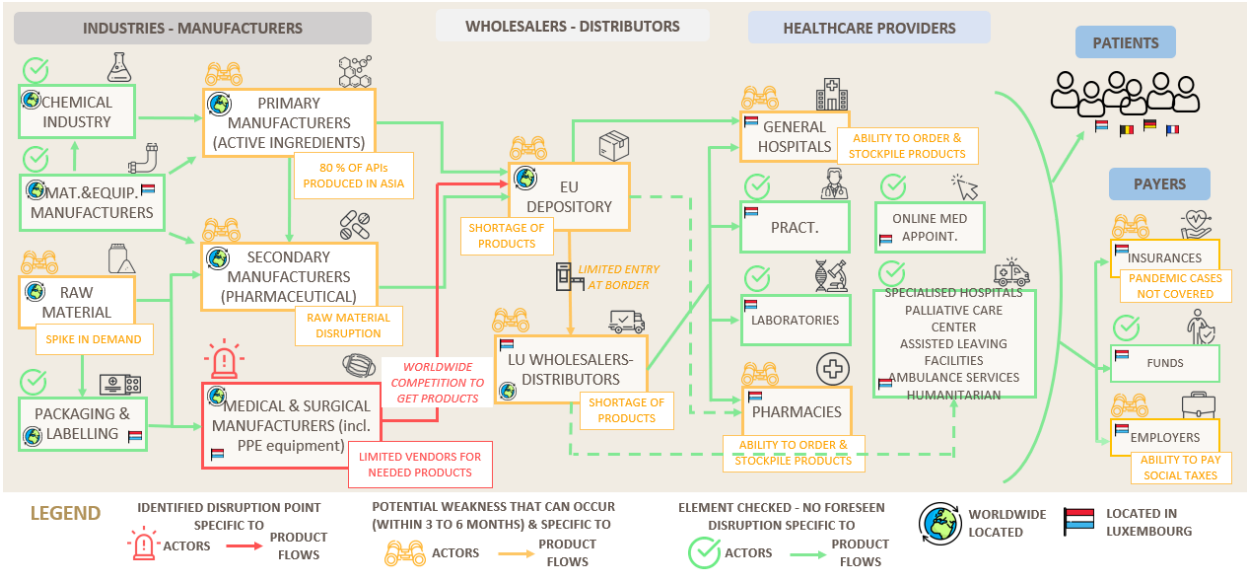

Figure 16: Healthcare Supply Chain Risk Map (source: Ministry of the Economy and INCERT)

4.1.3 Recommendations

The analysis of the healthcare sector given the ongoing COVID-19 crisis gives rise to three core recommendations.

- **Consider establishing a strategic stockpile of healthcare products (pharmaceuticals, medical and surgical).**
  When? Short term (3 months).
  Why? With the ongoing spread of the COVID-19, demand for essential healthcare products (e.g., medicines) is expected to remain high. In this context, some concerns have been expressed in other countries for the risk of shortage of supply of essential medicines for treating COVID-19. Supply shortage may amplify if another COVID-19 wave materializes and/or a natural disaster (e.g., floods, cyclones) occurs in regions where primary and secondary manufacturers are located (mostly in Asia), resulting with potential disruption to the production of healthcare products (pharmaceuticals, medical and surgical). In the short and middle term, it is challenging to identify alternatives to existing manufacturers (such alternatives can include establishing production facilities in EU), especially accounting for the complexity level of some of these products. In the long term, however, this approach should be considered at a European level.
  How? The strategic stockpile could be nationally coordinated with current Luxembourgish wholesalers-distributors, or at a higher level (possibly European), depending on the overall strategy adopted by the government. The strategic stockpile should provide 2 months visibility given the fact that health providers have a default stockpile

with a 1 month visibility, and they have expressed difficulties to extend their storage facilities.

It is worth noting that existing storage facilities (such as FreePort or Data Centres) could offer the required conditions to store healthcare products, and could temporarily be used for this purpose.

- **Consider establishing a monitoring system to identify "early stage warnings" of disruptions at manufacturer's production facilities (pharmaceuticals, medical and surgical) or in transportation/logistics.**
  When? Middle term (6 months).
  Why? The production of healthcare products may be disrupted (due to raw material disruption or reduced labor force) and their delivery may be impacted (due to limited and controlled departure of products at borders). Identifying such issues upfront would support key stakeholders when taking decisions and inducing corrective actions.
  How? The monitoring system could be composed of the following components:

  – Several sources of information, such as publicly available online or from global distributors having a subsidiary in Luxembourg and willing to share data.

  – Ground field feedback collected from Luxembourgish embassies and consulates located in specific regions.

  The following projects should be considered while establishing the monitoring system:

  – The [16]

  – ACTING NoW project – A Control Tower for the early identification of distress in logistics networks and essential supply chains – A 6-month project funded by the FNR and led by LIST, University of Luxembourg's LCL, and INCERT.

- **Consider increasing efforts in the establishment of strategic production of PPE.**
  When? Middle term (6 months).
  Why? As highlighted in Figure 16, main existing disruption points are located at "Medical & Surgical Manufacturers" (which includes PPE) with limited vendors, spike in demand and a worldwide competition to get the concerned products.
  In addition, it has to be noted that some products (such as masks) ordered from foreign manufacturers are delivered with a quality that can not be controlled before their shipment.
  How? The following steps are envisioned.

  – Identify and reference national producers of PPE (including hydro alcoholic gel).

[16] See `https://www.ema.europa.eu/en/news/launch-enhanced-monitoring-system-availability-medicines-used-treating-covid-19`.

- Evaluate with referenced producers their production capacities with regard to PPE, and discuss with them if these capacities could be maintained/ramped up in the future once they return to normal operations. This is a critical point as numerous organisations have manufactured PPE while replacing their default business activities.
- Consider the usage of innovative technologies to supply certain PPE (such as 3D printing for masks).
- Compare the estimated PPE offer with the demand (relying, e.g., on statistics from `https://www.epi-covid19.`). In case of a demand higher than the offer, consider diversifying the acquisition of PPE based on a shorter distribution channel approach.
- Formalize the inventory of national producers, the usage of innovative technologies, the estimated PPE needs, the diversification approach in terms of PPE acquisition, in a dedicated Business Continuity (or Resilience) Plan that could be activated on demand.

4.2 Agriculture and food

4.2.1 Overview

Agriculture and food are essential to Luxembourg if only to make sure citizens retain access to food during the coronacrisis. Figure 17 shows a simplified food supply chain. Food is a relatively simple product and the supply chain is therefore much simpler and more localized than the supply chain of consumer electronics, for example.

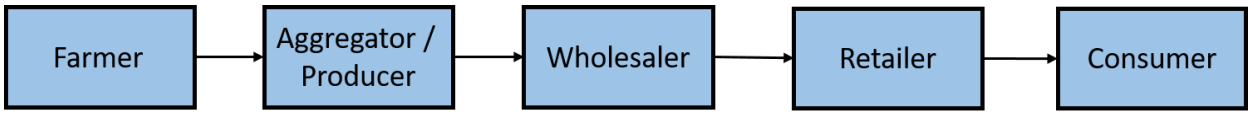

Figure 17: Food and Agriculture Supply Chain (Source: Directorate Logistics, Ministry of the Economy, Luxembourg)

4.2.2 Preliminary mapping of the sector

Luxembourg has several important companies in agriculture and food. These include Luxlait, Cobolux, Panelux, Ekabe and others. The hospitality industry (HORECA) is at the downstream end of the food supply chain and is hit hard by the current crisis. More upstream parties, who are mainly involved in processing, sorting, and packaging goods are less hit by the crisis as food consumption overall remains relatively stable. Although some food supply chains that operate globally or where access to labor for harvest is currently scarce

due to the crisis face some issues [17], local food supply chains are mostly safe. The most pressing risk is the shortage of labor to complete the harvest when such labor is supplied by border-workers.[18]

Figure 18 provides a preliminary list of stake holders in this sector, whereas Figure 19 illustrates a preliminary overview of food supply chains related to supply of food in Luxembourg.

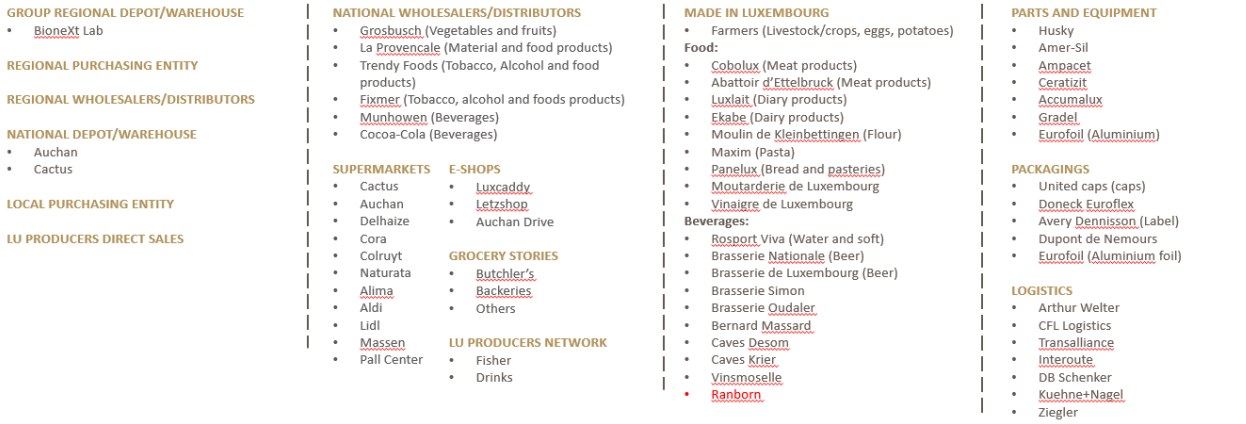

Figure 18: Preliminary list of main actors active in Luxembourg within the food and agriculture supply chain (Source: Ministry of the Economy, INCERT and Fedil)

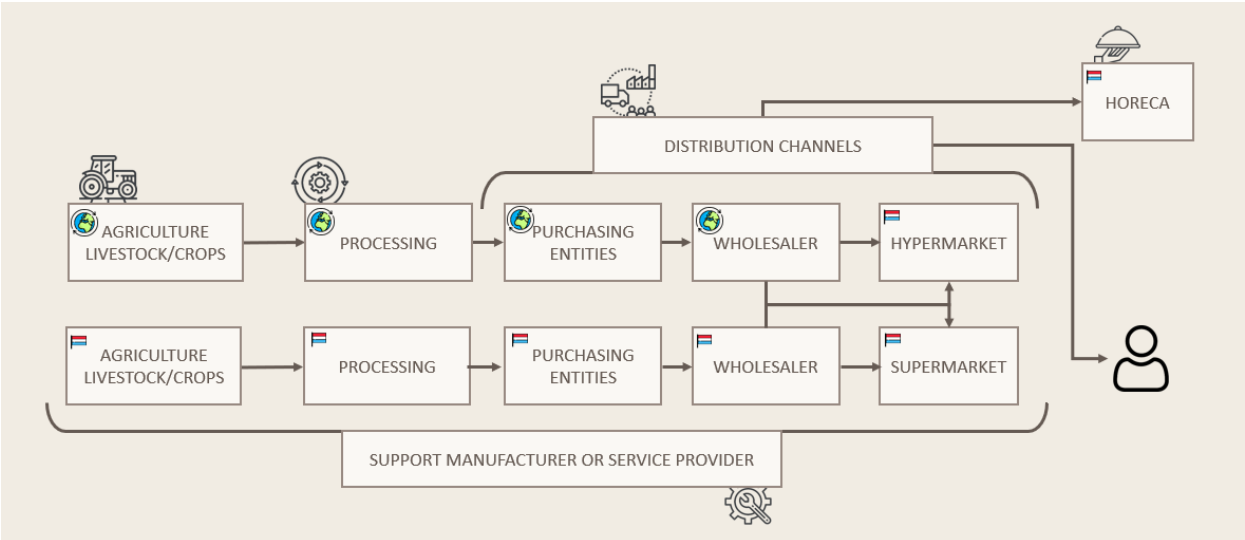

Figure 19: Preliminary mapping of the food and agriculture supply chain (Source: Ministry of the Economy and INCERT)

[17] https://www.reuters.com/article/us-health-coronavirus-food-explainer/explainer-how-the-coronavirus-crisis-is-affecting-food-supply-idUSKBN21L0D2

[18] There are several sources on this e.g. from The Economist. See https://www.economist.com/europe/2020/04/04/when-borders-close-who-will-pick-the-crops for example. It is worth mentioning the jobswitch.lu initiative as a mitigation approach.

Food supply chains are recognized as essential in the western world and many countries have made considerable efforts to keep these supply chains transparent as a matter of food safety. The relative simplicity of the final product also means that food supply chains are more localized than many other consumer goods. Food supply chains are more susceptible to weather conditions that can induce considerable production volatility through crop loss or flourishing. The perishability of many food and agricultural products also makes it difficult to maintain inventories along the supply chain.

4.3 Automotive

4.3.1 Overview

The automotive industry is a global industry. Figure 20 provides a simplified illustration of the main tiers in this industry, depicting the car manufacturers as the original equipment manufacturers (OEMs) with their Tier 1 suppliers being system manufacturers, Tier 2 suppliers being parts manufacturers, and Tier 3 suppliers being the material manufacturers. As is evident, with these global players, every car contains materials and components from very different parts of the globe.

According to Toyota[19], an average car has about 30,000 parts. According to Dave Andrea, the Center for Automotive Research in Ann Arbor, Michigan, every assembled piece in a car is supported with a supply that goes 10 or 20 levels deep.[20] Thus Figure 20 gives a highly simplified overview of automotive supply chains. In fact, in the course of production, parts of cars cross borders so many times that they are often referred to as “Industrial Tourists". In NAFTA countries, it is estimated that a car crosses borders 8 times before completing assembly (Wilson 2011).

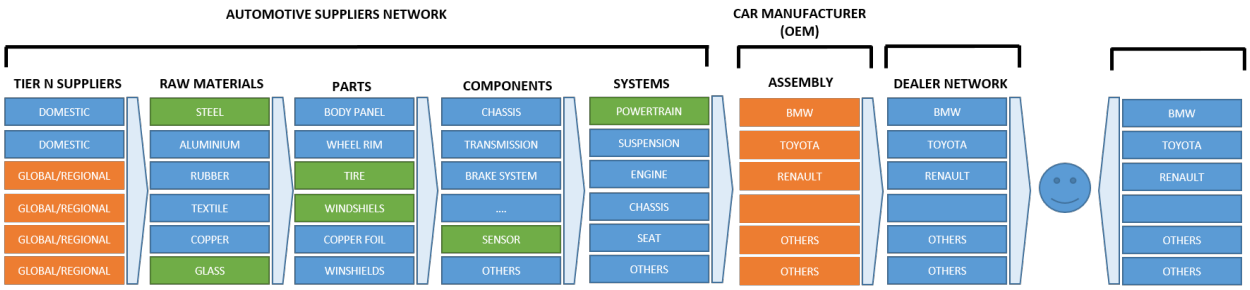

Figure 20: An illustration of the automotive supply chain; the green boxes are elements of the supply chain with activities in Luxembourg (Source: Directorate Logistics, Ministry of the Economy)

In this sector, the different companies develop special arrangements with their suppliers. For instance, this industry is well known for Just-in-time and Kanban strategies, according

[19]Source: `https://www.toyota.co.jp/en/kids/faq/d/01/04/`.

[20]Source: `https://www.marketplace.org/2017/03/24/when-it-cones-nafta-and-autos-parts-are-well-traveled/`.

to which a company will inform its suppliers on the future supply needs so that they can plan ahead and make sure all parts are delivered to the next tier just in time for the next step in the supply chain.

Additionally, as the product is complex, companies specialize in certain aspects of the production, oftentimes limiting the scope of sourcing alternatives.

4.3.2 Preliminary mapping of the sector

In Luxembourg, there are several companies that operate in this sector. For instance, IEE S.A., which provides sensors to this industry. Though the company is expanding its portfolio of products and customers to include building management and security, input devices, as well as sports and healthcare. For instance, IEE's Smart Foot sensor is now embedded in Saphenus Medical Technology. Delphi based out of Bascharage also supplies to the automotive industry.

Figure 18 provides a preliminary list of stake holders in this sector, whereas Figure 19 illustrates a preliminary overview of the automotive supply chain.

Figure 21: Preliminary list of main actors active in Luxembourg within the automotive supply chain (Source: Ministry of the Economy, INCERT and Fedil)

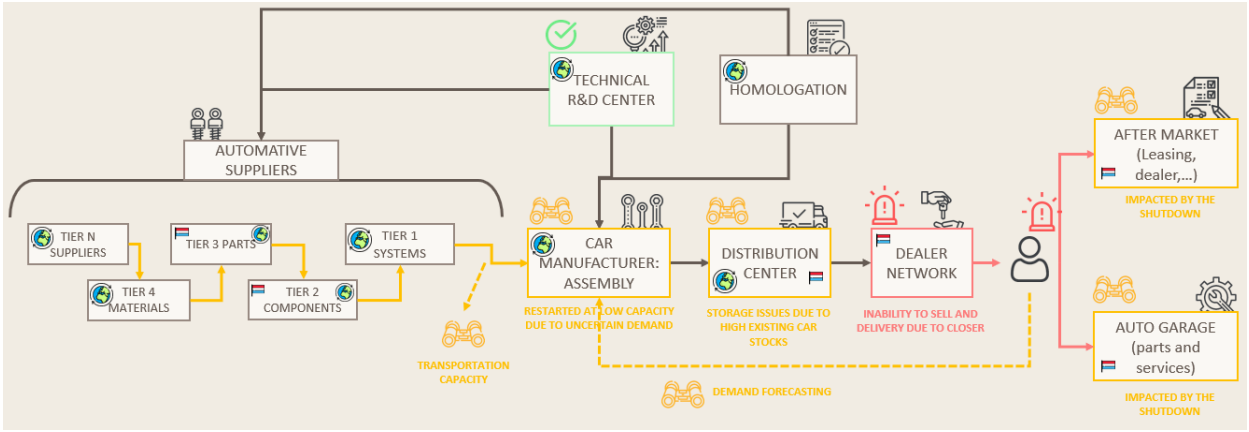

Figure 22: Preliminary mapping of the automotive supply chain (Source: Ministry of the Economy, INCERT and Luxinnovation)

A relatively recent survey of managers in the automotive industry conducted in March 2020[21] reveals that especially managers in Europe perceive this COVID-19 crisis as a major supply chain disruption. Problems reported include

1. lack of supply of raw materials from upstream supply chain partners,
2. lack of demand from downstream supply chain partners, and
3. labor shortage to run production operations.

Especially, the second of these concerns is perceived as likely to have a longer lasting effect on the supply chain as demand for vehicles has plummeted during the crisis and may not pick up quickly afterwards.

[21] https://cdn.ihsmarkit.com/www/pdf/0320/Auto-COVID-19-Supply-Chain-Survey.pdf

5 Characteristics of supply chains

In this section, we identify key characteristics of supply chains which manifest themselves differently in various sectors.

The degree to which supply chains in each industry are resilient to the current COVID-19 situation can be summarized in terms of seven factors:

- **Degree of globalization:** This factor refers to the degree to which companies in an industry are dependent on supplies (e.g. have production facilities or receive inputs from) and on customers in markets other than the domestic market. Moreover, this factor also takes into account the distances to or reachability of these markets. The greater the degree of globalization, the greater the possibility of disruptions in the production and demand fulfillment process. For example, the supply chain of apples from a local vineyard has a low level of globalization (farm-to-fork) whereas electronics often have a very global supply chains with components and materials supplied form different places all over the globe. In that context, 1 means highly localized supply chains and 5 relates to globalized operations.

- **Product Complexity:** This factor refers to the number of components or inputs in the final product, each of which may be produced by a different firm. The greater the product complexity, the more vulnerable the industry. For example, a car cannot be assembled with a missing part. In that context, 1 means a fairly simple product and 5 indicated a highly complex product.

- **Supply slack:** This factor refers to the degree to which companies in an industry carry excess inventory to respond to supply shocks. The more inventory a company carries, the less susceptible it is to supply shocks. At the other extreme, companies harness lean operations, in which case, flows of goods between members of the supply chain are highly coordinated to minimize waste. In that context, 1 means high level of slack, and 5 refers to lean operations.

- **Length of supply chain:** This factor refers to the number of stages in the supply chain as well as the lead time required to move a product along the entire supply chain. Long supply chains have many production steps (e.g. semiconductor manufacturing) and long lead-times (e.g. due to contained shipping from the Asia-Pacific to Europe). In that context, 1 means a short supply chain while 5 indicates a long one.

- **Narrowness of supply chain:** This factor refers to the degree to which companies in an industry have alternatives in terms of their supplier and customer base (i.e. few versus many suppliers or customers). The larger a supplier and customer base, the lower the probability that a company faces supply or demand shocks as they can divert to other parties in the supply chain. For example, diamond supply chains are quite

narrow (value of 5) as they are only used in jewelry and cutting tools and are mined in relatively few places.

- **Opacity:** This factor refers to the degree to which supply chains are intransparent or opaque in an industry. The more opaque a supply chain is, the more difficult it is to identify and respond to issues as they come up. For example, the supply chain of palm oil has recently seen a rapid decrease in opacity (or increase in transparency) as companies have invested to make sure that practices are verifiably sustainable along the supply chain. In that context, 1 means transparent supply chain and 5 means an opaque one.

- **Production volatility:** Production is volatile when it is susceptible to yield issues induced by outside factors. For example, crops are susceptible to weather conditions such as drought and excessive rain. A value of 1 refers to stable production whereas 5 indicates a volatile production.

Figure 23 illustrates key supply chain characteristics. Specifically, it juxtaposes two supply chains—that of a bread and that of a car—which feature quite opposite characteristics. Specifically, we can observe that in terms of product complexity, car has on average 30,000 parts whereas bread has only a handful. The amount of slack can differ, but generally automotive supply chains are lean with a limited amount of inventory, whereas bakeries usually have enough inventory of flour to keep operating for a few days. The degree of narrowness relate to the number of alternative suppliers: in the automotive sector the degree of specialization does not lend itself to facilitate substitution between different parts providers, while bread bakers can find alternative sources for flour relatively easily. The length of the supply chain tend to be long in the automotive sector with 10-20 tiers for many of the components. At the same time the number of tiers between the baker and the farmer is quite limited. This is somewhat related to the degree of opacity: oftentimes bakers know where their flour comes from, they may even be able to trace back to the farmer, but automotive supply chains are quite opaque with very limited visibility beyond two tiers. Automotive supply chains are rather global with raw materials and components sourced from different countries and most of the time from different continents. Flour tends to be sourced locally, within the same country or nearby countries. Lastly, while not depicted, the degree of production volatility relate to the uncertainty of yield: farmers are susceptible to weather conditions whereas mining is generally indifferent to the weather conditions.

The table below ranks a sample of industries on a scale from 1 to 5, where 1 is low and 5 is high. We note that the ranking provided and associated with each of these industries are the authors' rough estimates based on publicly known practices and is not based on inside knowledge of these industries. As such, the values provided should be treated as illustrative only. It is important to recognize that companies and products may evolve around different supply chain designs based on managerial choices and trade-offs made by practitioners as

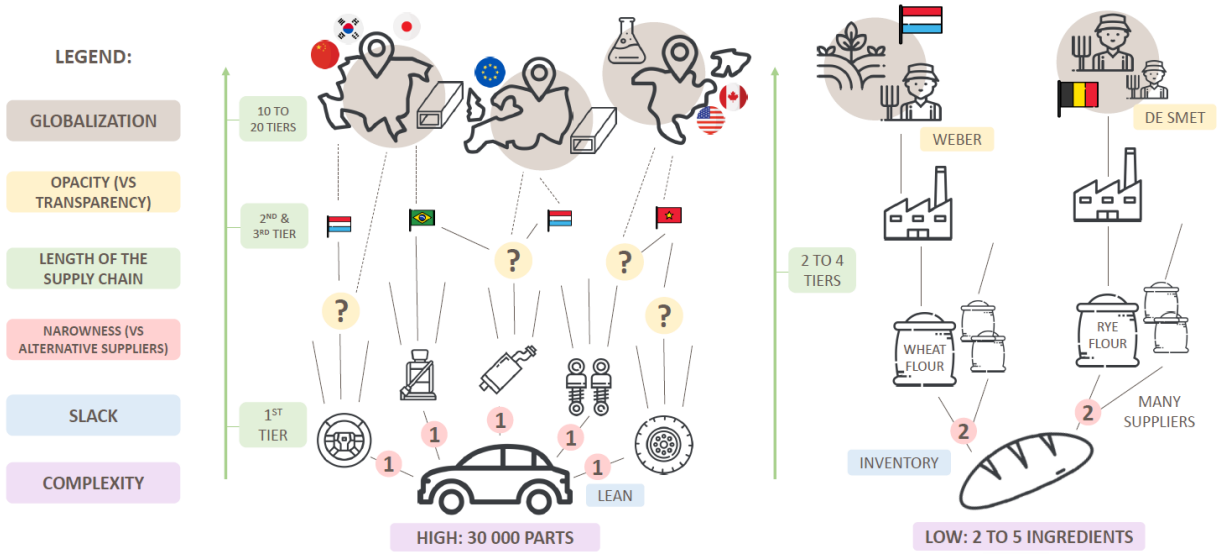

Figure 23: An illustration of key supply chain characteristics

well as other context-specific factors, that may be beyond the scope of knowledge of the authors.

Managers understand that they need to secure their supply chains are therefore racing to mitigate the effects imposed by the COVID-19 crisis on their operations. To that end, they implement diverse measures to ensure viable operations. Measures include, among others, transporting inventory away from quarantine zones, securing capacity from suppliers, ahead buying of inventory and raw material of which supply may become limited in impacted areas, transitioning between transportation modes (e.g., by securing future freight capacity), facilitating product substitution (e.g., searching for alternative suppliers[22]), product redesign, contract renegotiation with suppliers and customers, and demand shaping (e.g., through discounts or different terms).[23] Nevertheless, supply chains are likely to be affected severely, not only in the short term, but in the longer term as well. A recent PWC report [24] indicates that about 40% of CFOs in the US are now reconsidering their supply chains to ensure better resistance against future disruptions. In Section 6 resilience and management of risk in supply chains is discussed in more depth.

[22]This also means being able to qualify potential suppliers in advance. A lesson learned from the crisis is to be able to assess the company's capacity to select, qualify and establish a contractual agreement with suppliers while being in crisis mode. This is thus increasing the complexity of properly managing all these steps. If potential suppliers are pre-qualified, it may ease the transition period.

[23]`https://www.pwc.com/us/en/library/covid-19/supply-chain.html`

[24]`https://www.pwc.com/us/en/library/covid-19/pwc-covid-19-cfo-pulse-survey.html`

Table 2: Assessment of supply chain resilience in different industries across different resilience indicators

Industry	Degree of Globalization	Product Complexity	Supply Slack	Length of supply chain	Narrowness of supply chain	Opacity	Production volatility
Food and Agriculture	1-3	1-2	3	1-2	1-2	2	3
Healthcare: Pharmaceuticals and Technology	1-3	4-5	2-3	4-5	2-4	2-4	1
Automotive	4-5	4-5	4	4-5	3-5	4-5	1
Construction	1-2	3	2	2-3	2-3	4-5	1
Telecommunication	4-5	4-5	2-3	4-5	4-5	4-5	2
Apparel	4	1-2	1-3	2-4	1-3	4-5	2-3
Consumer Electronics	4-5	4-5	3	4-5	3-4	4-5	1

5.1 Critical sectors

The identification of critical sectors is to some degree subjective although most will agree on some sectors. The U.S. Department of Homeland Security Cybersecurity & Infrastructure Security Agency (CISA) identifies the following segments as part of the critical infrastructure (CISA 2020): Healthcare and public health, Transportation systems, Water, Information Technology, Nuclear reactors, materials and waste, Food and agriculture, Government facilities, Energy, Financial, Emergency services, Defense industrial base, Dams, Critical manufacturing, Commercial facilities, Chemical, and Communications.

Clearly not all these sectors are even present in Luxembourg (e.g. Nuclear reactors). Though it worth noticing that there are a few of them not too far from the border with potential implications for the country in case of a crisis.

5.2 Supply and demand

The trade war between the US and China, the tariffs that the Trump's administration has imposed on numerous goods imported from China as well as the uncertain environment associated with sourcing from China, has unleashed a wave of companies migrating operations away from China. For instance, Apple is diversifying its supply base, while Nintendo and

Foxconn are increasing their production capacities in Vietnam.[25] The US Government has leveraged the opportunity to pressure companies to move out of China, and as Commerce Secretary Wilbur Ross commmented in late January "It will help accelerate the return of jobs to North America". Evidently, then, supply chains started shifting. However, we need to keep in mind that this is a lengthy process, as relocating production facilities may take years. In fact, this process has already started taking place long before COVID-19; yet, the current crisis is accelerating the trend.

The current pandemic is not only an issue of supply, but also of demand. Stackline has reported the changing patterns in e-commerce identifying key emerging and declining categories. Their list reports a surge in home fitness products and cooking equipment (such as bread machines) vis-a-vis a decline in outdoor sport categories; the broad implementation of work-from-home policies is behind the rise in computer equipment and peripherals; travel related goods (luggage, cameras, swimwear etc.) experience a major drop in demand; formal apparel is also on the decline. A complete list of top 100 and bottom 100 categories is available at Stackline's website.[26] A similar picture emerges more locally. As noticed by Paperjam[27], local grocery stores report a sharp increase in non-food products such as kitchen knives, board games or potting soil, while consumers are shying away from textiles and take-away food.

5.3 Upstream vs Downstream

Although we assess the resilience of the supply chain of an entire industry in this Section, this does not mean that decisions along the entire supply chain should be the same. It makes a considerable difference whether a company is upstream or downstream in any given supply chain. In general, the company that is all the way downstream is dependent on the entire supply chain upstream to keep moving. At the same time, companies all the way upstream (typically this includes mining) feed the supply chains of different industries. (Iron mines feed into automotive as well as medical equipment supply chains.) In general, a company that is further upstream is also part of more supply chains.

The current crisis stopped the flow of many supply chains by legislation. The further upstream a company operates in a supply chain, the easier it is to resume operations. Companies in the automotive industry in Luxembourg are relatively well positioned in this regards, at least relative to car assembly plants.

[25]Source: https://www.nytimes.com/2019/07/30/technology/trump-trade-war-vietnam.html

[25]Source: https://www.nytimes.com/2020/03/05/business/coronavirus-globalism.html?referringSource=articleShare.

[26]https://www.stackline.com/news/top-100-gaining-top-100-declining-e-commerce-categories-march-2020?fbclid=IwAR0UHMPDQIB_2cyxObZ_rDcgk01Xdy50QN30gep-WT7wjMrEfAbR8S3CRKk

[27]https://paperjam.lu/article/cuisine-bricolage-ces-produits?fbclid=IwAR366vc-N_M5ZjoJNZj16JzIqumrgtQgV3LcCSmVhpu8es-0iUaoZmoMdPw

5.4 Supply Chain Survey

How easy or difficult it is for a firm to start operating again after lock down measures are relieved depends on three main questions:

1. **Supply Constraints:** Is there sufficient supply of raw materials to resume operations?

2. **Demand Constraints:** Is there sufficient demand for the product to resume operations?

3. **Labor Constraints:** Are there sufficiently many people with the right skills available to resume operations?

These questions should be addressed at the company level and are posed in a survey WP13 plans to carry out in the near future. This survey is to gain an overview of supply chain implications and constraints in ramping up economic activity in Luxembourg as part of the exit strategy. In particular we seek to answer the following policy questions:

1. Which industries are constrained in ramping up economic activity due to a lack of supply?

   (a) What are the goods for which there is a (global) lack of supply?

   (b) When can this lack of supply be expected to resolve?

2. Which industries are constrained in ramping up economic activity because of temporary lack of demand for their product?

   (a) Which (global) industries are not seeking supply?

   (b) When are these (global) industry expected to ramp up and require supplies again?

3. Which industries can ramp up economic activity while some or all of the COVID-19 measures stay in place?

   (a) What percentage of nominal production capacity can be attained when social distancing measures stay in place?

   (b) How much production capacity (if any) is lost due to COVID-19 related convalescence?

Ultimately, the survey will be accessible at `https://identials.lu/incert/registration/supply-chain`.

5.5 Characteristics of Supply Chain: Take away insights

As the current the COVID-19 situation forces many decision makers to consider their supply chains, below we highlight some of the take aways with respect to the characteristics we have outlined:

- **Degree of globalization:** Global chains allow access to a broad portfolio of suppliers who compete often quite intensively. Nevertheless, they expose firms to global risks that could have, otherwise, been contained. Local chains are generally based on different level relationship, as stake holders often speak the same language, share cultural background and are able to meet more frequently to bond a higher level of trust. Possibly, the balance in recent years have tipped toward a higher degree of globalization, whereas the current pandemic may induce decision makers to rethink their degree of globalization in their supply chains.

- **Product Complexity:** Simplify products to the degree possible. Simplification of products leads to simpler and shorter supply chains. Also, as mentioned in Section 4, complexity also adds to the probability of a plant disruption.

- **Supply slack:** Find a new balance between lean operations and safety buffers in inventory. This is a delicate trade-off as regular operations are often focused

- **Length of supply chain:** Shortening supply chains can be achieved by reshoring and seeking alternative suppliers with closer proximity. This can enhance control and improve the resilience of the business.

- **Narrowness of supply chain:** Companies can search for alternative/additional suppliers as well as markets to sell their products. Companies shall embrace dual- and multiple-sourcing for key components.

- **Opacity:** In order to manage and mitigate risk, it is important to gain more visibility into upstream activities in the supply chain. Push for visibility can be achieved by increased communication with suppliers while redesigning contracts for improved visibility. Digital solutions (such as Blockchain) may play a role in embedding traceability throughout the supply chain.

Lastly, as operations are affected not only externally but also internally, the current pandemic may speed up the investment and commitment to embrace various technologies ranging from 3D printing and additive manufacturing, through robots and autonomous vehicles, to artificial intelligence/machine learning/deep learning and internet of things (IoT)

6 Supply chain resilience and risk management

Supply chains are subject to disruptions. The aftermath following the September 11 attacks revealed the degree of fragility of companies that relied on just-in-time practices and off-shore production Sheffi (2015). The importance of risk management is evident from numerous examples of supply chain disruption, which include, but are not limited to the Hurricane Katrina (2005), the Japanese earthquake and tsunami (2011) and the clothing factory fire in Bangladesh (2012). These events have triggered far reaching consequences throughout their respective supply chains. While these events are rare, the magnitude of their impact is staggering. Companies cannot prepare for any possible outcome, but they can certainly embed proper risk mitigation planning into their processes.

6.1 Scenario planning and business continuity planning

The art of supply chain resilience involves companies in scenario generations. Consider the following scenario which was created in 2006 by the MIT Center for Transportation and Logistics (Rice 2020): “US-based cell phone company Vaxxon has suffered a 45% drop in its stock price, is facing costly legal action from suppliers and customers, and looks set to miss a make-or-break opportunity to revive its fortunes with the launch of a new phone. The company’s problems began when the outbreak of a deadly virus in China crippled suppliers in that country. As fears of a pandemic swept through global markets, Vaxxon failed to implement an effective response. Will Vaxxon survive the crisis?"

Having addressed and prepared for such a scenario—one out of many that a company could and should debate—would have made many companies far better prepared for the current outbreak. Companies like Cisco and Intel engage in the regular exercise of scenario planning. This is a critical exercise as it structures their responses to emerging disruptions while handling their constantly changing dynamics. Importantly, learning from the past is key. Disruptions are not new and embed many commonalities.

As Sheffi cites in his book (Sheffi 2015) the past president of the Institute for the Future: “We tend to overestimate the effect of technology in the short run and underestimate the effect in the long run" and scenario planning is a way to avoid such missteps in forecasting associated with long-term trends, long-term risks and strategic responses. As Sheffi notes, the point is not to engage in attempts of assessing likelihoods of changing technologies, political realignments, urbanization as well as many other possible trends. The focus is on “what-if" scenarios. Some events, even if their likelihood is very small, may unleash catastrophic outcomes.

Figure 24 schematically illustrates the distribution of events. Many companies operate and plan their activities to address regular operations. Regular operations can feature diverse variations, such as changes in prices, demand, weather conditions, traffic congestion and so forth. However, these variations, while carrying impact on daily/weekly operations,

are of limited impact on the livelihood of the company. A resilient company can address less likely events that have a larger magnitude of effects, such as earthquakes, flooding, labor disruptions, and product failures. Such events can cripple a company for extended periods of time and even take it down. Scenario planning and business continuity planning, which we describe next, prepares companies to tackle such scenarios. In the more extreme end of the distribution of events (Figure 24), we find the Black Swan, a concept introduced by Taleb (2005) to describe rare un-predicted events with catastrophic outcomes.[28] Such events include wars, financial meltdowns, and the ongoing pandemic. As indicated by Mantin (2020) back in February: "The coronavirus could be the black swan of our generation." Resilience strategies can further support preparation for such events.[29] Such events are often harder to contain, they are not limited to a specific region or domain, and as such are systemic and expose many to the same challenge, thereby amplifying the magnitude of the effects.

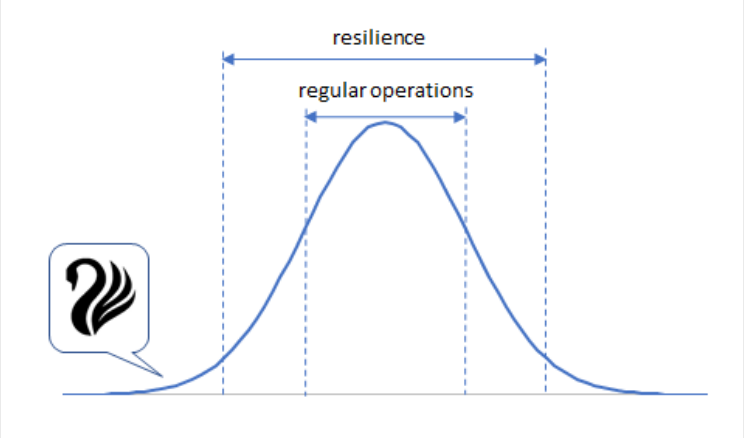

Figure 24: Illustration of distribution of events and Black Swan

Many companies realize the need for business continuity planning (BCP) and accordingly have some plans in place. However, these planning processes tend to be somewhat limited and not sufficiently thorough (Rice 2020). Such exercises can form the backbone of contingency plans to ensure continuity of operations as a response to specific types of disruptions.

[28]Taleb actually argues that practically the current pandemic is not a black swan and merely a weakness embedded in globalization (and, hence, it is a white swan). Still, from technical perspective, the magnitude and likelihood follow the standard definition of the term.

[29]The story goes as follows: throughout the entire history till the 1600s all swans were assumed to be white. Finding a black swan was un-thought of. This gave rise to the token "rare as a black swan" indicating an improbable happening. However, as Europeans explored the world, they did find black swans in Australia. Nevertheless, the real black swan did not bring catastrophic outcomes to Europeans. Black Swans do.
Black Swans are not limited to the business domain and appear in other contexts as well. Consider for example, securing flights. The likelihood of someone seeking to take down a plane is extremely low. However, the consequences of such an event are of grand magnitude. Accordingly, governments invest considerable amount of money to ensure the safety of the passengers. Similarly, all cars come with numerous safety measures, at a cost, that ultimately save lives.

Thus, BCPs will outline the actions that need to be taken in specific disruptions such as a flooding or a labor disruption. Such plans, however, have limited value for other types of disruptions. Thus, a better approach is to develop BCPs that focus on the predictable outcomes rather than on specific types of disruptions.

It is important to notice that different disruptions result with similar outcomes. These potential outcomes are essentially loss of some core capacity of the firm. These core capacities are (Rice 2020):

- The capacity to communicate
- The human resources available to support company operations
- The available transportation systems
- Financial liquidity (having cash capacity to operate)
- Internal operation capacity
- Availability of supply

Clearly, planning for these six primary categories of losses is far more efficient than planning for every possible event or disruption. Specifically, supply may be lost due to different reasons (supplier is flooded, export/import restrictions, or a competitor is paying more to monopolize your supplier's output), but regardless of the reasons for the loss of this core capacity, the bottom line is that the company is short of supply and needs to replace it somehow.

BCPs deliver two components. The first is the action plan. For instance, it may guide you to activate an emergency operations center (EOC), contact key contacts (at suppliers, government), protect staff, enable alternative sources. The second is the option of capacity restoration. The current pandemic reveals the many companies simply do not have an alternative option for sourcing in China. This is a key vulnerability, and it is the worst time to discover this vulnerability just when the disruption is raging.

6.2 Resilience – why not and how yes?

Memories from past epidemics, such as SARS, MERS, Swine flu and Ebola, are all still fresh in our recollection.

Despite the far-reaching consequences, a MIT SCALE network study found that about 60% of managers do not actively engage in supply chain risk management or that they simply wave such action as ineffective (Sáenz et al. 2018). This is a surprising finding that deserves more attention. A number of things me be in place that could explain this observation:

- **Prioritization.** In regular times, the need for resilience planning is not urgent, companies are focused on their day-to-day operation, engaged in competitive environments, seek to reduce cost and try to make their supply chains leaner and faster, thereby pushing resilience considerations aside.

- **Focus on short term performance.** To generate value for stake holders, companies oftentimes focus on immediate success. Accordingly, performance bonuses are tied to short term achievements, shifting away attention from investment into containing future impact into containing current cost.

- **Lack of success examples.** Another answer offered by Sáenz et al. (2018) is that this domain of supply chain management is still a young domain and with limited examples of success stories that companies can harness and decide to embed in their strategic planning.

- **Mechanisms still evolving.** As this domain is still fairy young, it is not well understood what are the key mechanisms that companies need to focus on. Namely, he financial economics of making resilience investments is not well understood (Rice 2020).

- **Black Swan.** Going back to the Black Swan idea, since the likelihood of such a rare event is extremely low, managers can safely assume that this is unlikely to take place during their tenure and hence delegate the investment to the next cohort of managers.

Investing in resilience is costly. When supply chain risks do not materialize then resilience seems a bad idea in hindsight. No one receives credit for solving a problem that did not happen which is why resilience does not always receive the attention we wish it should have received to enable us to circumvent the current crisis.

Recognizing the importance of this exercise, we now provide a framework, based on Sáenz et al. (2018). Companies organize their supply chains based on their respective industry's idiosyncrasies. Understanding how supply chains are organized provides key input for managers to address potential vulnerabilities and correspondingly identify and implement risk mitigation measures resulting with supply chain resilience by design. Accordingly, companies shall construct their supply chains by optimizing operational procedures while keeping in mind the goal of resilience. Figure 25 illustrates the framework.

Facing market and industry mandates, how the supply chain is designed has implications to how the firm deals with potential supply chain related risks. With the target market in mind, the company then shall account for two key considerations: the scope of the supply chain (being local or global) and the competitive priorities (being responsive or reducing cost). Next, the focus is on the risks that these choices entail, encapsulating internal (e.g., employee theft) and external risks (e.g., weather) alike.

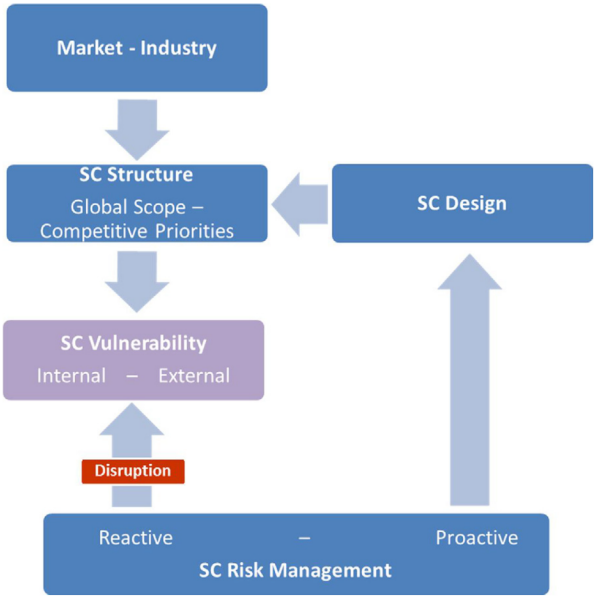

Figure 25: The dynamics of building supply chain resilience (Source: Sáenz et al. (2018))

Table 3 illustrates some metrics for consideration when companies discuss their supply chain competitive priorities and their supply chain global scope and provide the dimension of performance along the respective spectrum.

Table 3: Metrics associated with supply chains' competitive prioirities and global scope, adopted form Sáenz et al. (2018)

SC competitive priorities	**Metrics**	**Supply chain responsiveness**	**Supply chain cost optimization**
	Lead times	Respond quickly/agility	Lowest possible cost
	Inventory turnover	Flexible inventory	Minimize inventory
	Product configurations	Easier to customize	Low customization
	# of SKUs and # of standardized components	Configured-to-order	Build-to-order
SC global scope	**Metrics**	**Supply chain local**	**Supply chain global**
	# of supply chain nodes and dispersion	Compact	Dispersed
	Number of countries	Intranational	International
	Cultural distance	Culturally homogeneous	Culturally heterogeneous

All-in-all, these choices can be classified into four quadrants based on the choices made by companies. Figure 26 illustrates the four quadrants based on the dimensions of internal vulnerability (x-axis) and external vulnerability (y-axis), summarizes the key features associated with these choices along with some example of companies that can be associated with such choices.

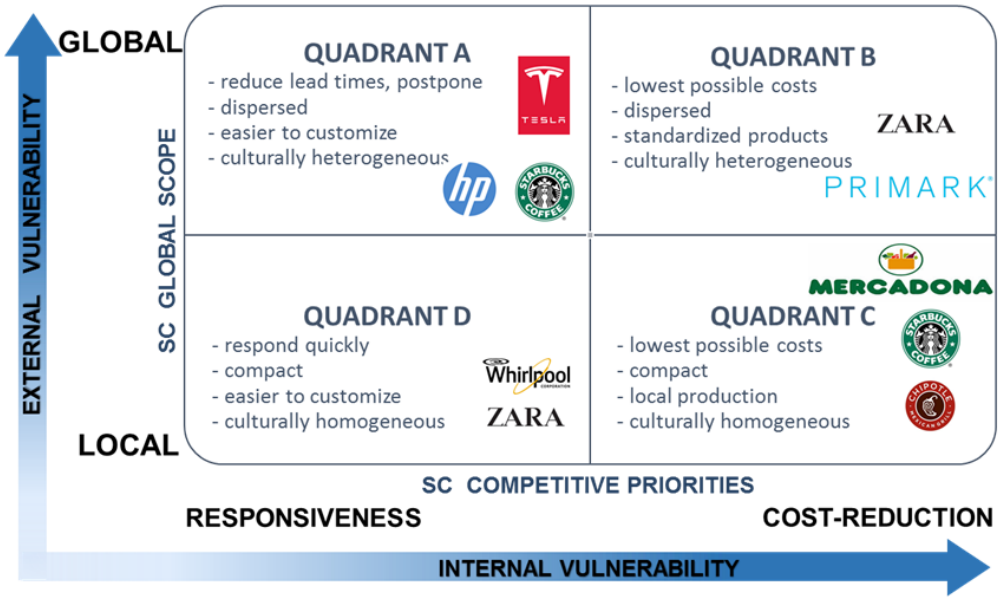

Figure 26: Supply chain structure and its vulnerability (Source: Sáenz et al. (2018))

7 Conclusions and recommendations

The changes to supply chains are paramount as they are triggered both by supply as well as demand disruptions. The impacts on different chains vary, quite dramatically, based on numerous features, which include, but are not limited to, the degree of globalization, product complexity, length of the supply chains, and the degree of supply chain opacity. This is probably just the beginning of the journey faced by many, as supply chains—how they are organized and how companies communicate and approach resilience consideration—are likely to change substantially in the foreseeable future.

We conclude with some overarching recommendations. This list does not aim to offer a complete action plan, rather provide some guiding principles for decision makers at different levels.

We start with some broad recommendations for government decision makers. In the **short and middle term** the following are instrumental aspect.

- **Timeline of measures reversal.** Identify and prioritize sectors destined to resume operations as usual. In this report, we have provided and focused only on supply chain related characteristics. Given the dependencies between the different companies in their respective supply chains, companies need to coordinate with their suppliers and customers the resumption of usual operations. To that end, there is a need to consult with companies, either directly or through a supply chain survey, for immediate supply chain related needs. This could include extended space for inbound inventory (waiting for in-house production to resume) or outbound inventory (waiting for customers' production to resume), identifying alternative suppliers or customers, extending financial terms, and so forth.

- **Monitor supply chains.** It is key to monitor the performance of the economy and how supply chains in different sectors resume their usual operations. To that end, it is instrumental to carry out regular surveys to assess the implementation of physical distancing in different facilities and how they restrict their operations, monitor the change in sales, and so forth. Aligned with Deloitte (2020), we also recommend the creation of control towers, with possible foci on different sectors. Actions to consider:

  - Supply chain survey as outlined in Section 5.4. This survey could provide additional insights to the current state of supply chains, potential (immediate) threats and an overview on the recovery prognosis of different industries.

  - Dashboard, and at a later stage, control tower, for certain sectors. This can follow the template of ACTING NoW—a project which aims to deploy a "national control tower" to assess and monitor the status of the logistics networks and essential supply chains. This project is a collaboration between LIST, Uni/LCL and INCERT, and it is financially supported by an FNR grant (COVID-19 Call).

It envisions a national control tower that will provide visibility, multi-party, artificial intelligence (AI) to support insights and decision making while monitoring Luxembourg's logistics platforms and networks.

To support decision-makers in selecting the right approach, the project team believes that the logistics sector can take advantage of the Digital Twin technology that Gartner (2019) ranks among the top 10 Strategic Technology Trends of the last three years. Already in November 2019, before the COVID-19 outbreak in China, Gartner (2019) recommended to "change the supply chain planning (SCP) paradigm from deterministic to resilient by leveraging the combination of new technologies [...] Model and simulate the physical supply chain and align decision making across the supply chain by using a digital supply chain twin [...] Drive from unknown uncertainty toward known variability by utilizing artificial intelligence (AI) and machine learning (ML) for better predictions."

For this short-term implementation, we plan to start developing a first-of-its-kind experiment of a Digital Twin for Logistics at country-wide level to provide a Minimum Viable Product (MVP). This effort will become part of the larger Nation-Wide Digital Twin initiative that LIST is launching in the next few weeks together with LISER and the University of Luxembourg.

In the **longer term** additional measures can be implemented and considered.

- **Emergency national stockpiles**. Many national emergency stockpiles primarily focus on healthcare. For instance Canada's National Emergency Strategic Stockpile (NES) includes items such as medical equipment and supplies, pharmaceuticals, as well as social service supplies (e.g., beds and blankets).[30] Many countries extend their stockpiles to fuel—for example, Germany holds a strategic reserve of petroleum equivalent to 90 days of domestic consumption[31]—and diverse food items. Switzerland, for instance, even stores coffee in its national stockpile. While the Government can directly manage this stockpile, the Swiss approach is worth consideration. The Swiss Government has a list of essential goods and producers of goods on this list are required by law to store a certain amount for which they are paid by the government to cover the cost of storage.[32] This can be expanded to include other supplies.

[30] https://www.canada.ca/en/public-health/services/emergency-preparedness-response/national-emergency-strategic-stockpile.html.

[31] https://www.bmwi.de/Redaktion/EN/Artikel/Energy/petroleum-emergency-oil-supply-and-oil-crisis-management.html.

[32] https://www.bbc.com/news/world-europe-50402048.

- Carry out a **supply chain resilience study**. This study, envisioned as part of the ACTING NoW project mentioned above, expects to explore how companies in Luxembourg prepare and manage supply chain risk analysis.[33] Some expected takeaways may include:
  - **Stress points.** What are the stress points faced by different companies in different industries and identifying whether commonalities emerge among local companies.
  - **Emergency national stockpiles - Industrial**. A conversation with industry can reveal what stocks are important on a national strategic level. Specifically, to ensure availability of certain goods during times of crisis, we need to ensure availability of required components and raw materials. For example, a report in the US (National Research Council 2008) aimed at military supplies, strongly recommends supply chain considerations to ensure continuity.
- Facilitate **supply chain resilience workshops**. Such workshops will educate managers on the theory and practice of supply chain risk management, facilitate discussion on the topic, share knowledge and encourage companies to act.
- At a country level, **assess the resilience of locally prominent industries and communicate the results back** to those industries along with knowledge about how to create resilient supply chains and enterprises. This ensures those industries become aware of risks to which their are susceptible and become educated about measures they can take to make their supply chains and operations more resilient for future crises.
- **Resilience of transportation network.** Assess the risk of the transportation network—road, air, rail and river—to identify potential weaknesses and improve resilience, if necessary.

[33]The study is excepted to take place via the following link: `https://identials.lu/incert/registration/supply-chain`.

[33]One example in a military context is that weapons cannot be produced without the metals, so supply of metals has to be available. In the context of other industries, for instance, in the production of Tyvek, certain chemicals need to be available. It is up to decision makers to assess the resilience of supply chains and decide what stocks are necessary in time of emergencies.

7.1 Recommendations and pointers for industry

Along with points that have been discussed earlier regarding actions that companies need to take during disruptions, we would like to share some additional thoughts, considerations and recommendations for manufacturers and industry at large:

- **Diversification strategies: Identify opportunities.** When demand for certain products dries while for other emerges, repurposing facilities can provide a solution to keep facilities running, even if for a limited period of time. Companies like LVMH, L'Oréal and Coty have stepped into production of hand sanitizers by repurposing their fragrance and hair gel facilities.[34]

- **Invest in new technologies.** 3D printing and additive manufacturing is experiencing a golden moment as it steps in to provide immediate production capacity for certain components that are in short supply, primarily in the healthcare industry. This could be enlarged with robots and autonomous vehicles, e.g., for home deliveries but of course it might raise concerns about loss of employment. Other domains include artificial intelligence/machine learning/deep learning, blockchain, internet of things (IoT) and so forth.

- **Inventory bounce.** Companies need to be aware of the inventory bounce. Consider a company facing a monthly demand of 100 units. It takes the company a month to detect changes in demand and it carries a stock of 100 units, i.e., of one month. Now assume that due to a shock in demand, demand drops to 90 units. This means that at the end of the month the company now has 110 units in inventory. As it adjust its inventory level down to 90 units, for one month it will decrease production down to 70 before aligning the production capacity with the monthly demand of 90 units. When demand bounces back to 100 units per month, the same process takes place, but in reverse. This means that as the company adjusts its inventory level from 90 units back to 100 units, the inventory bounce commands a temporary increase in production to 120 units (since inventory is down to 80, this requires a boost of 20 units to a level of 100) before aligning with a monthly production rate of 100 units. Thus, demand fluctuations and, accordingly, adjustment in inventory levels facilitate bigger, even if temporary, fluctuations in production.

[34] https://www.ft.com/content/e9c2bae4-6909-11ea-800d-da70cff6e4d3?segmentid=acee4131-99c2-09d3-a635-873e61754ec6

- **Bullwhip effect.** The inventory bounce effects described above can trigger even more dramatic changes known in supply chain management as the bullwhip effect (Lee et al. 1997b,a). This effect is often initiated by a real small and temporary change in demand but leads to much greater consequences as you move upstream in the supply chain. Indeed, in the example of the previous paragraph, the upstream supply chain party has reacted with higher production fluctuations than the demand fluctuation faced by this supply chain party. If each party along a supply chain reacts in similar fashion then order and production fluctuations upstream are much more extreme than the fluctuation that initiated this bull-whip. Parties along a supply chain can avoid this egregious effect by coordinating among themselves how they will handle the downstream fluctuation. This can be done by the following mechanisms (which strongly relate to resilience actions):

  1. **Sharing of demand information** (rather than only order and shipment information).
  2. **Sharing of information about inventory** levels along the supply chain.

- **Degree of globalization:** The current pandemic may induce decision makers to rethink their degree of globalization in their supply chains.

- **Product Complexity:** Simplifying products and the Bill-of-Materials (BOM) can induce simpler and shorter supply chains, with the added benefit of reduced probability of plant disruptions.

- **Supply slack:** Find a new balance between lean operations and safety buffers in inventory. This is a delicate trade-off as regular operations are often focused

- **Narrowness of supply chain:** Seek and pre-approve suppliers and embrace dual- and multiple-sourcing for key components.

- **Opacity:** Enhancing visibility and transparency can help companies manage and mitigate the risk they face. Accordingly, information sharing with suppliers is a critical asset.

To conclude, this report has reviewed the state of the logistics in Luxembourg along with an assessment of supply chains, in general, with a focus on key sectors, in particular. The insights and points raised can guide decision makers in industry and government alike in their path to improved resilience. Thank you for reading this document. Let's make it happen!

DISCLAIMER

The present document may be updated from time to time, without prior notice, following new data received from participants of the surveys, or direct contributions from WP13 members. The present document does not legally bind any WP13 members, and the organisation he/she is representing. In providing the present document, WP13 and its members make no representation, warranty, assurance, or inducement, expressed or implied, as to its adequacy, sufficiency or freedom from defect of any kind, including, but not limited to, freedom from patent infringement that may result from the use of such document, nor shall the WP13 and its members incur any responsibility or obligation by reason of such document. Accordingly, neither the WP13 nor its members, shall have any liability resulting from the use of the present document.

CONTACT

If you have questions concerning the present document, please contact WP13_TF-COVID19@lih.lu.

Licensing

References

CISA (2020) Guidance on the essential critical infrastructure workforce: Ensuring community and national resilience in covid-19 response version 2.0. https://www.cisa.gov/publication/guidance-essential-critical-infrastructure-workforce, Last accessed on 2020-04-07.

Deloitte (2020) Covid-19. orchestrating the recovery of organizations and supply chains. *white paper* URL https://www2.deloitte.com/ca/en/pages/finance/articles/covid-19-orchestrating-recovery-of-organizations-supply-chains.html.

Directorate Logistics (2020) Logistics hub luxembourg. *Ministry of the Economy, Luxembourg, Presentation* .

Gartner (2019) Mastering uncertainty: The rise of resilient supply chain planning. https://www.gartner.com/document/3975265, Last accessed on 2020-05-06.

Inman RR, Blumenfeld DE (2014) Product complexity and supply chain design. *International Journal of Production Research* 52(7):1956–1969.

Lee HL, Padmanabhan V, Whang S (1997a) The bullwhip effect in supply chains. *Sloan management review* 38:93–102.

Lee HL, Padmanabhan V, Whang S (1997b) Information distortion in a supply chain: The bullwhip effect. *Management science* 43(4):546–558.

Mantin B (2020) The coronavirus and its impact on global supply chains. *Paperjam* URL https://paperjam.lu/article/the-coronavirus-and-its-impact.

National Research Council (2008) *Managing materials for a twenty-first century military* (National Academies Press).

Rice J (2020) Covid-19: Will we learn the lessons or make the same mistakes? *medium.com* URL https://medium.com/mitsupplychain/covid-19-will-we-learn-the-lessons-or-make-the-same-mistakes-ef8860aa677c.

Sáenz MJ, Revilla E, Acero B (2018) Aligning supply chain design for boosting resilience. *Business Horizons* 61(3):443–452.

Sheffi Y (2015) *The power of resilience: How the best companies manage the unexpected* (MIT Press).

Sheffi Y (2020) Commentary: Solving the health-care equipment supply shortage. *Wall Street Journal* URL https://www.wsj.com/articles/commentary-solving-the-health-care-equipment-supply-shortage-11586512801?mod=searchresults&page=1&pos=1&utm_source=MIT+Center+for+Transportation+%26+Logistics&utm_campaign=b077def998-EMAIL_CAMPAIGN_2020_01_16_01_52_COPY_01&utm_medium=email&utm_term=0_37e260243a-b077def998-84391219.

Taleb N (2005) The black swan: Why don't we learn that we don't learn. *NY: Random House* .

Wilson CE (2011) *Working together: Economic ties between the United States and Mexico* (Woodrow Wilson International Center for Scholars).