

Cascading supply chain disruption: impact on water industry during COVID-19

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ABSTRACT

The impact of COVID-19 on the lives of people and businesses across the globe was devastating. While governments across the world had undertaken a slew of measures to control the spread of the COVID-19 virus within their geography, many of these measures had long and unintended consequences. The restrictions imposed by the governments on the movement of people and goods across the world brought supply chains to a grinding halt. This study identifies the cascading effects of supply chain disruptions on the water sector. Since these systems are closely integrated and the impact of COVID-19 needs to be analysed at a much broader level, this study uses a systems-thinking approach to study the effect of supply chain disruptions on water services. The study develops a causal loop model to gain further insight into how supply chain disruptions caused by COVID-19 affected the coping capabilities of society and how critical services were affected.

Keywords

Qualitative systems model, COVID-19, water sector, supply chain disruptions, disaster management

INTRODUCTION

Supply chain disruption (SCD) is an unexpected event that stops or slows the normal flow of material with potentially negative consequences to supply chain members (Chopra and Sodhi, 2004). At a broad level, SCDs are usually classified based on their causes, such as acts of nature (e.g. flooding, earthquakes, hurricanes and pandemics). While this cause-based classification identifies the underlying reasons for these disruptions, it is often much more useful to gain further insights into the effects and stage of disruption and this has led to other classifications of SCDs. For instance, Ivanov et al. (2017) classified SCD based on the level or echelon at which the disruption has occurred. Chopra and Sodhi (2014) classified SCD based on the causes other than natural or manmade disasters and identified that SCDs can be caused by delays in commerce systems, forecasts, intellectual property, etc. Other classifications for SCDs are based on frequency of occurrence (Tang et al., 2014), nature and their source of origin (Christopher et al., 2011) and who they affect, from broad to specific (Dolgui and Ivanov, 2021). The impact of SCDs on businesses can be operational, marketing and financial (Katsaliaki et al., 2021). Operational impacts can be product unavailability, partially fulfilled orders, late deliveries, logistic challenges, etc. (Jabbarzadeh et al., 2018; Wagner and Neshat, 2012). While marketing impact can be increase in customer

complaints, damage to brand reputation, loss of customers, breach of supplier contracts, penalties etc. (Ponomarov and Holcomb, 2009). And finally, financial impacts are, loss of sales and revenue, reduced market share, complaints, damage to brand reputation, loss of customers, breach of supplier contracts, penalties etc. (Ponomarov and Holcomb, 2009).

However, what has been lacking in studies related to SCDs is their impact on the security of the supply of critical services, such as quality of water for daily use including drinking and bathing. The revised Drinking water directive (2020) by the EU parliament defines essential quality standards for water intended for human consumption. It requires Member States to regularly monitor the quality of water by using a ‘sampling points’ method. The revised directive updates existing safety standards and improves access to safe drinking water along the lines of the latest recommendations of the World Health Organization (Curmei and Kurrer, 2023). Furthermore, the directive also focuses on building more resilient drinking water system and designates the water infrastructure as a “critical entity” (European Commission, 2020). This has led to the creation of a water security plan for prompt response and recovery from intentional or unintentional contaminations affecting the drinking water supply system, reducing the impact severity such as the potential escalation to service disruption and disease outbreaks which could have catastrophic consequences (Teixeira et al. 2019).

During the peak COVID-19, the focus on personal hygiene and cleanliness has been at the peak. This had led to rapid increase in the domestic water consumption. However, the lockdown also had a negative impact on the businesses, and this led to a rapid drop in the industrial water consumption. Overall, this mismatch in the demand profile had affected the revenues of the water companies and further affected the operations of many water companies. World bank (2020) estimated that there was a drop of about 40% where many countries had suspended the water charges to give some financial relief to their citizens during the economic slowdown during COVID-19. Furthermore, there were widespread interruption of operations due to absenteeism, labor cost and procurement of adequate personal protective equipment for staffs and limited supply of essential chemicals for water treatment during the COVID-19 pandemic were other challenges COVID-19 posed to the water sector (Joo and Trindade, 2023). This was further complicated with SCDs owing to the internal restriction set by multiple countries affecting both capacity and transportation of necessary chemicals and spare parts used by the water management companies to ensure safe water services. Thus, in this study, we explore the impact of the SCD caused by COVID-19 on the water industry and how it can contribute to the conversation of security of supply (water) of daily operations of a water utility’s system and help to detect other safety issues as well as supply chain disruptions (e.g. shortage of key workers; shortage of key chemical supplies).

BRIEF LITERATURE REVIEW

Supply Chain Disruption

In decades, supply chains have moved towards efficiency and cost reduction. To improve the efficiency, economies of scale, reduction in safety stock and focus on the sole source of suppliers has been leveraged by many supply chain managers (Parmigiani et al., 2011). However, the major side effect of these activities was that the supply chains became extremely fragile and would break down even at the slightest disruption since it lacked enough cushion (Ivanov et al., 2016). This was most evident during the COVID-19 pandemic, when supply chains were under severe stress owing to supply and demand shocks (Atkinson et al., 2020).

SCD severity is influenced by design characteristics and mitigation capabilities, highlighting the need for resilience planning and business continuity planning (Craighead et al., 2007). Furthermore, it is seldom that SCD effects remain localized and often they propagate along the supply chain. Their severity and intensity of SCD propagation depends on the nature of disruption, structure of supply chains, and managerial decision-making (Scheibe and Blackhurst, 2018). SCDs often has a cascading effect across the entire supply chain network (SCN). The propagation of a disruption across the SCN and its associated impact is called the ripple effect and is distinct from the well-known bullwhip effect (Dolgui et al., 2018). In more severe cases, the ripple effect can cause some nodes and arcs in the SCN to become temporarily dysfunctional (e.g. due to a material shortage and capacity loss) (Dolgui et al., 2018).

To understand the supply chain ripple effect, it is imperative to understand risk propagation in the SCN. In practice, a disruption to an SCN often begins locally, with a trigger event affecting any one or a group of nodes in the network usually located within the same vicinity. This impact spreads to other firms (or nodes) through their relationships. Consequently, the impact might propagate to parts of the network through a set of cascading effects and affect nodes that are far from the origin of the impact (Scala et al., 2021). The extent to which the

impact propagates in the supply network is also a testament to the resilience of the network (Li and Zobel, 2020). Dolgui et al. (2018) discussed the main reasons for the systemic vulnerabilities that make SCNs more prone to the ripple effect when presented with a disruption in any or multiple nodes within the SCN. These reasons can be broadly classified into four main categories: sourcing strategy risks, production planning risks, inventory management risk and control risk.

COVID-19 and Water Sector

Prior to COVID-19, the water industry across the globe were impacted by five major trends. These included, (a) global warming led increase in extreme floods and droughts, challenging the resilience of water and sanitation systems, (b) increasing number of people living in areas facing water stress (currently 2 billion), which increases water supply vulnerabilities, (c) rapid urbanization, which strains existing water resources and ecosystems, (d) the emergence of megacities, which adds the challenge of extending water and sanitation services to about 1 billion people living in informal settlements not served by water grids, (e) aging infrastructure, which has increased pressure to accelerate investments in more advanced markets, following decades of underinvestment (Butler et al., 2020). Along with the pre-existing challenges, some of the major impact of COVID-19 on water services are summarized below.

With the nationwide lockdowns, there was a marked increase in the household consumption of water and a significant decrease in the non-household or industrial consumption. With the increase in the household consumption, thereby increasing the cost of water production (Ong and Nielsen, 2020). However, revenue from metered household customers has increased because of increased demand and companies with comparatively more metered customers saw a greater increase in household revenue in the short-term, while the ones with industrial consumers saw a significant drop in their revenues (Ong and Nielsen, 2020).

On the other hand, the Health and Safety Executive (HSE) in the UK advised business including water sector to prioritize becoming “COVID-secure” by adapting to current guidance and implementing measures to control the risk of COVID-19 to protect workers and others. These steps included carrying out COVID-19 risk assessments adhering to HSE guidance, enhancing cleaning, hand washing, and hygiene procedures, taking all reasonable steps to help people work from home, etc. To comply with these mandates, water companies have had to adapt various measures, including regulatory inspections, limited site visits, phone calls (remote working), and collection of visual evidence (photos and video footage), etc. (Frontier, 2020; HSE, 2020). The pandemic had disrupted the water sector's revenue and growth projections. Hence there was a need for readjustment for the rest of the Asset Management Period (AMP) to reprioritize projects supported by Ofwat (England and Wales a agency that Promotes competition, sets price limits, ensures that water companies can finance and carry out their functions, promotes economy and efficiency) (Horton and Laikin, 2020). This further affected the capital investments both in term so of maintenance and upgrading the water systems. The cost structures and lack of funding sources in the post pandemic environment put halt on the new capital expenditures for both maintenance and modernization of the water system. The tariffs were insufficient to recover operating costs and the water utilities require support from other sources, usually the government budget had also reduced during peak COVID-19 (Butler, et al., 2020). A decline in demand from large industrial and commercial users due to lockdowns and travel restrictions significantly reduced revenues to water utilities. Specific measures adopted by the governments like (a) deferrals on or exemptions from utility bill payments for vulnerable groups, (b) moratoriums on cutting off the water supply, and (c) suspensions of meter reading and invoicing also affected the revenues of the water industry (Butler, et al., 2020).

WASH and COVID-19

The water supply and sanitation services must be considered within a larger framework of integrated water management, water quality, ecosystem health and governance and is crucial for public health and human development (Gaddis et al., 2019). Mukhtarov et al., (2022) argued that COVID-19 and water management will have long term mutual impact on each other. The direct impact includes prioritizing WASH at the expense of other crucial challenges such as climate change adaptation, land use patterns, ecosystem health and energy. Furthermore, lesser public funds will be made available for water infrastructure and management and the danger of oversized influence of private financial capital in the water sector might cause lower quality of water related infrastructure. On the other hand, the long-term indirect impact will be securitisation of WASH that may lead to day-to-day and fragmented management. With private financial take-over of water infrastructure and services, the attention to techno-fixes with a relative neglect of social and political aspects of water management and governance may be affected in long term and might as well take a back seat in long run.

SYSTEMS THINKING AND METHODOLOGICAL FRAMEWORK

Systems thinking has been used as a tool to study complex interactions in supply chain research. The “system” is defined as ‘a whole consisting of two or more parts, where each of which can affect the performance or properties of the whole, none of which can have an independent effect overall, and no subgroup of which can have an independent effect on the “whole”. In brief, a system is a whole that cannot be divided into independent parts or subgroups of parts’ (Ackoff, 2010). In the same vein, Ackoff (2010) defined systems thinking as looking at relationships (rather than unrelated objects), connectedness, process (rather than structure), the whole (rather than just its parts), the patterns (rather than the contents) of a system and context (Ackoff, 2010). This view of systems thinking aligns with the supply chain function, in which various aspects of the supply chain need to relate to an established process to communicate with various parts of the supply chain to fulfil consumers’ demands (Wilden et al., 2022). According to Wieland et al. (2023), supply chains are not only complex adaptive systems but also have close connections with social, economic, ecological and political contexts within which they are embedded. While not referring to systems thinking directly, Sarkis et al. (2020) took systems view to critique the weaknesses in the supply chain and promote resilience measures, in addition to detailed lessons learned from a post-COVID perspective (Sarkis, 2020). Elias et al. (2021) used systems thinking to holistically analyze the complexities involved in the adoption of a sustainable wood supply chain in Amazon and to develop strategic interventions to improve the system.

System dynamics, a research approach based on systems thinking, often uses group model building (GMB) to identify complex relationships between various entities and subsystems (Vennix et al., 1999). GMB has been the favored approach for the system dynamist for three main reasons: first, to capture the required knowledge in the mental models through the various stakeholders; second, to increase the chances of implementation of model results; and third, to enhance the stakeholder learning process (Vennix et al., 1997). GMB exercises allow stakeholders to voice their individual perceptions of reality and help them develop a shared mental model of their perceptions as a group (Elias, 2016).

For this study, an exploratory approach using the GMB method was adopted to gain an understanding of the complex nature of SCDs due to COVID-19 and its impact on the water sector (Rouwette et al., 2002). Due to the exploratory nature of the research, the discussions were semi-structured to enable the researchers to discover the varying causal influences that the participants perceived to occur in practice (Graham et al., 1992). The subsequent sections broadly explain the main parts of the research process. The research process was divided into four main steps, as described below (Hovmand et al., 2021).

- The first step included an initial literature review and identification of the main impact on the water sector due to SCDs caused by COVID-19
- The second stage involved initial data collection based on a questionnaire developed by the gatekeepers, which was shared with the sCience and human factOr for Resilient sociEty (CORE) consortium members to gather insights into the impacts of supply chain disruption on the water sector due to COVID-19.
- The third stage involved a GMB workshop in Helsinki, in which the participants developed an initial set of relationships between the variables and helped identify an initial set of relationships. As part of initiating GMB, experts in HUMLOG were contacted and invited to be part of GMB.
- The fourth stage involved final model building and validation, where the model was shared with members of the CORE consortium project.

CAUSAL LOOP MODEL FOR WATER SECTOR

The impact of COVID-19 on water sector has not received much attention. However, it is not to say that the impact has been any less. This section discusses the main impacts COVID-19 had on water sector through a causal loop model developed through GMB.

The lockdowns had a significant impact on the water industry. Due to the lockdowns and increase in the remote working, a lot more people have spent significant amount of time indoors. Therefore, the domestic water consumption had increased significantly. While, on the other hand, the industrial water consumption had reduced. this had significant impact on the revenues generated by the water companies. However, the lockdown induced domestic consumption had a lot more impact than merely an increase in the domestic water consumption. With a significant amount of time spent indoors, people started using more water at home for water intensive activities such as gardening, swimming, etc. This is represented by the RW1 is a positively reinforcing loop which captures the impact of household water consumption for WASH demand which has a positive impact on reducing the risk of infection.

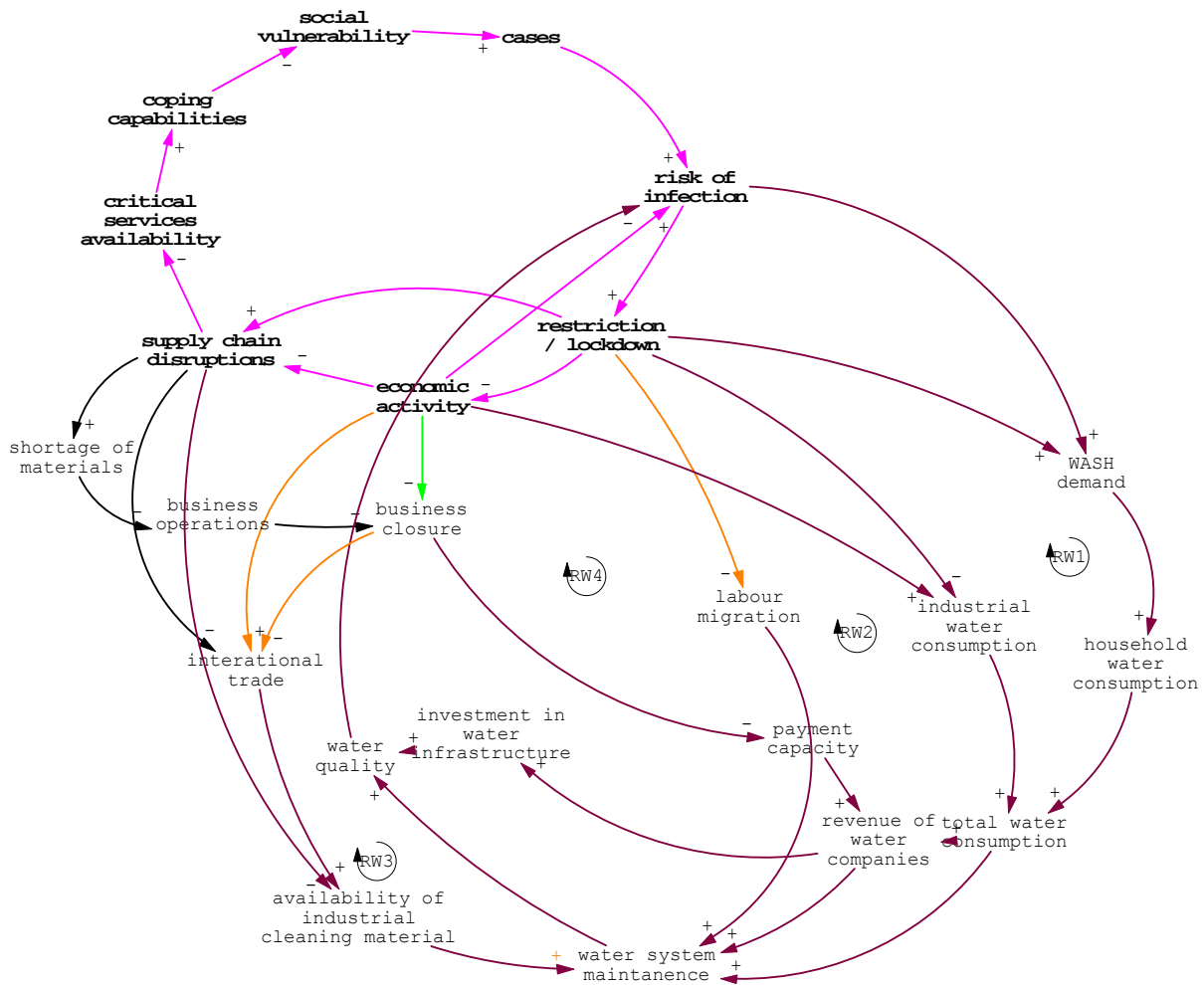


Figure 1. Causal Loop Model

However, this increase in the domestic water consumption had other unexpected impact on the water systems as well. It was observed that people were flushing down and putting things that were not supposed to be put into the drains. For instance, due to the shortages in the toilet paper (owing to international lockdowns and supply chain disruptions), many were forced to use alternatives which were not supposed to be flushed in the drains. These kinds of behaviours had cost significant blockages along the drains and sewers, which had put additional pressure on the water companies in terms of maintenance. Thus, it became significantly more expensive for water and water systems management. Furthermore, the household demand offset the reduction in the non-household demand and as a result the water production cost for the companies had increased significantly during this time. This is represented by the negative reinforcing loops RW2 in the figure 1. RW2 captures the impact of reduction in the revenues of water companies due to that restrictions and lockdowns and thereby the substantial reduction in the industrial water consumption along with the increased expense to maintain the water systems from collapsing due to the excess stress on the already aging water filtration systems due the increase in the domestic water consumption.

The supply chain disruption due to COVID-19 had significant impact on the quality of water itself. While multiple transmission modes of COVID-19 were being closely evaluated, it was identified that COVID-19 virus could be transmitted through water as well, especially through the sewage systems from residential (toilet, shower, washing, etc.) and through medical centres. Thus it became the priority of the both local and national governments to ensure that water treatment was carried out properly and the water companies had been mandated to ensure that there is no lax in the water treatment protocols. However, frequent water quality checks revealed that there were increased viral levels even in the treated wastewater which indicated that the wastewater treatment was not carried out with adequate efficiency to remove COVID-19 viruses. One of the main reasons cited by the water companies for this lack of efficiency in filtration systems was due to the age-old equipment that had not received proper maintenance or in many cases were passed their due life. Secondly, it was also identified that in many cases the water companies were not able to source the chemicals and components for the filtration systems due to the supply chain disruptions. Since many are of the chemicals used in the water filtration systems are not manufactured within

Europe and is usually imported from Asia, the disruption of the international trade had led to a severe shortage of chemicals required for the water filtration. These challenges to water is represented by the reinforcing loop RW3. However, RW3 is a negatively reinforcing loop representing the impact of supply chain disruptions due to the restrictions and lockdowns on the availability of industrial cleaning material which had an impact on the water maintenance system and thereby the quality of water increasing the risk of infection through the water systems.

Finally, COVID-19 severely affected the modernization and capacity expansion plans of the water sector. Due to the reduced revenues and supply chain disruptions, many water companies decided to halt or slow down engineering investments in improving the water and sanitation systems. For instance, Ofwat, the water management authority in the UK had given clear instructions to the water companies to meet core service obligations which is, to provide water and wastewater services and not to prioritise engineering projects in the meanwhile. This was also affected due to the lack of temporary and seasonal labourers who are critical in large scale engineering projects. As mentioned earlier, the availability of these labourers was affected due to the border closures and lockdowns. The supply chain disruptions also had an impact on procuring raw materials and parts which would have been used in these engineering projects. Furthermore, the COVID-19 pandemic had further disrupted the sectors demand and growth projections. With an increase in the domestic water consumption, many were wary about the long term shift in the water consumption pattern. Another major impact on the revenues of the water companies was the non-payment of dues by the existing businesses. Due to the lockdown, both industrial and non-industrial small-scale businesses had to be shut down temporarily. This had affected the revenue streams of these small businesses and many of them did not have the capability to pay for the outstanding bills of the water companies. This led to an increase in the accounts receivable for the water companies which further affected the revenues and financial outlay for large scale engineering projects. This is shown by the reinforcing loop RW4 in figure 1.

As shown in figure 1, the water quality has a direct impact on the risk of infection, which further effects water for WASH. while the risk of infection leads to further restrictions or lockdown, it has a direct impact on the industrial water consumption. The reduction in the economic activities lead to business closures and the payment capability of both individuals and businesses thereby further reducing the revenue for water companies. Furthermore, the supply chain disruptions leads shortage of materials and availability of industrial cleaning items. All these factors affect the maintenance of water systems which further negatively affects quality of the water and the loop continues.

CONCLUSION

Global supply chains and connectivity make it possible for us to source, produce, and consume goods from all over the world through the integrated network of supply chains that run continually throughout. And thus, business have realized the importance of keeping the supply operational and spend billions to ensure that there are no disruptions to this SC operations. The effects of SCDs on enterprises have been thoroughly investigated in the past. Nevertheless, little focus has been placed on how they affect people's lives on day-to-day basis and, consequently, the vulnerability of society. Business owners and policy makers have become aware of this due to the recent global SCDs due to COVID-19. Previous studies, while having studied exogenous risks from SCDs, usually do not consider both supply-and demand-side risks caused by SCDs. This study offers a novel outlook into the role of exogenous risks from SCDs, especially in the water sector, which can have both supply and demand implications. Furthermore, the study uses a system thinking approach to develop a holistic view of how SCDs produce ripple effects on the water sector. While this study offers a holistic perspective using systems thinking, more empirical research needs to be conducted to quantify the real impact of SCDs across the water value chain.

This study was carried out as part of Work Package 4, Task 4.3, under the CORE project, to study the impact of SCDs due to COVID-19 on creating social vulnerabilities. This was explored through the impact of SCDs on the water sector. Since this sector is critical to the functioning of society, it is imperative to ensure that it functions without disruption. The study also explores how SCDs affected the operational capabilities of the water sector and how they influenced both short-term and long-term operational capabilities.

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