DHL WHITE PAPER

DELIVERING PANDEMIC RESILIENCE

HOW TO SECURE STABLE SUPPLY CHAINS FOR VACCINES AND MEDICAL GOODS DURING THE COVID-19 CRISIS AND FUTURE HEALTH EMERGENCIES

SEPTEMBER, 2020

FOREWORD

We find ourselves in a time unlike any we have seen in the last 50 years. The COVID-19 virus was first named just eight short months ago; since then it has infected more than 23 million people and taken the lives of more than 800,000 worldwide. Early in the pandemic, the importance of medical products, such as personal protective equipment (PPE), became clear. It also became painfully clear that disruptions in the supply chain can cause major problems in supplying frontline workers with the equipment they need.

Although supplies of PPE are flowing better now, the work to improve the medical-products supply chain is by no means finished. Vaccines are in development, but their ability to end this pandemic depends on an effective supply chain that can connect diverse production locations to the public. As a global logistics player, highly experienced and specialized in getting mission-critical supplies to the right places when they are needed most, we are looking to shape this conversation. We are committed to doing our part to help improve these systems and ensure medical supplies always find their way to wherever they are needed.

The following white paper draws on extensive sources of knowledge, such as recent discussions with industry experts and NGOs, published research, analytical support from McKinsey & Company as well as our decades of global logistics and supply chain experience to provide a look at what the logistics challenge for medical products, particularly vaccines, might look like in the coming months.

The COVID-19 pandemic will eventually be behind us. However, the question is *not if but when* the next large-scale health crisis will come around. By acting now – with informed planning, teamwork and effective partnerships – we can put ourselves in a better position than ever before.

Frank Appel
CEO, Deutsche Post DHL Group
September 2020

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EXECUTIVE SUMMARY

The COVID-19 crisis emerged with such unprecedented breadth and impact that governments have been compelled to transform – away from their traditional roles as regulators (and managing the societal impacts of a health emergency), and towards the role of active players in the medical supply chain.

Lessons learned since the start of the COVID crisis have demonstrated that sufficient planning and effective partnerships with supply chain partners can be important success factors for governments looking to secure critical medical supplies during health emergencies.

Inbound logistics and distribution as major supply-chain pain points

The height of the first wave of COVID-19 infections revealed several logistics-related challenges in two links of the supply chain – inbound logistics and distribution. Particularly as related to personal protective equipment (PPE), product-quality issues, constrained transportation capacity, complex customs processes and regulations increasing the risk of delays, warehousing challenges, and limited transparency regarding stock levels all posed significant problems. By partnering with a suitable logistics service provider, governments can alleviate these challenges.

Vaccine distribution as the next logistics hurdle

Currently there are some 250 candidates for a COVID-19 vaccine in various stages of development. The diversity and novelty of these potential vaccines – and the unprecedented speed at which they are being developed – raises multiple questions from a logistics perspective. Specifically, the potential vaccines are being developed on multiple platforms with each platform generating the immune response through a different mechanism. Four out of the six vaccine frontrunners, for example, are based on rather new or even experimental platforms, while two are based on traditional platforms. Different platforms will likely come with different temperature requirements for transportation and storage. As a result, regional distribution capabilities, as well as packaging and transportation sustainability, will all likely be a function of whether temperature requirements for safe and efficacious vaccines will be as low as -80°C or end up falling in the +2–8°C range.

Public-private collaboration for an effective supply-chain response

To respond effectively to the next public health crisis, governments need to start putting strategies and structures in place today, rather than relying on reactive, ad hoc measures when the crisis hits. There are five pillars of an effective strategy:

Emergency response plan. While not all activities can be pre-planned, a strategic response plan, established in advance, can determine which activities along the entire supply chain should be ad hoc (e.g. gathering real-time demand data) and which should be pre-planned (e.g. setting up decision-making and governance entities).

Partnership network. Public-private partnerships proved to be critical in addressing medical supply shortages earlier this year, and will remain an important part of crisis response going forward. Government-to-government partnerships will also be important, since many health emergencies disregard national borders.

Physical logistics infrastructure. A strong infrastructure, including a pre-established network of warehouses and transportation capabilities, can help ensure a sufficient stock of critical supplies.

IT-enabled supply chain transparency. Real-time visibility along the supply chain will be key in meeting the demands of a global health emergency. IT tools can provide an up-to-the-minute accounting of inventory and provide important predictive information regarding both future demand and shipment routing.

Organization and resources. A response unit also needs to be in a position to make these critical activities happen. Positioning it high in the government will give it the authority and credibility it needs to act effectively. The unit should also be agile and relatively unconstrained with a clear mandate and an effective communication strategy.

A better understanding of recent disruptions in the medical products supply chain can help governments as well as pharmaceutical and medical equipment companies better prepare for future emergencies. Forming partnerships with logistics service providers who can complement existing network-related capabilities will be a strategic necessity in securing life-saving products and supplies during the inevitable next crisis.

INTRODUCTION

Global public health emergencies pose huge logistical challenges. Demand spikes caused by widespread emergencies and supply shortages – due to factory lockdowns, for example – can make it difficult to get critical supplies quickly to the places they are needed most. The COVID-19 pandemic is the latest example of a health crisis exerting pressure on supply chains. The pandemic has turned medical supplies such as personal protective equipment (PPE) – previously considered mass-market products – into some of the most valuable goods on the planet. It has also exposed significant vulnerabilities in the supply systems associated with these products. At the peak of the first wave of COVID-19 infections, the tremendous pressure on supply chains across the globe resulted in a significant shortage of PPE. Getting these supplies to end users in sufficient quantity and quality is of paramount importance – not just for patients and healthcare providers, but also for governments as well as pharmaceutical and medical equipment companies.

The COVID-19 crisis has transformed the role of some stakeholders in the medical supply chain. Governments and large global NGOs – once focused largely on regulatory matters and alleviating the social consequences of crises – are now moving towards a more active role in the supply chain to finance, secure and provide medical supplies, including PPE, tests, therapeutics and vaccines. As an example, these global stakeholders have joined their private and public sector partners to raise EUR 7.4 billion for the Coronavirus Global Response pledging event. Governments are also reducing regulations, applying purchase guarantees, and offering other incentives to ramp up on-shore production of PPE and ventilators. Finally, NGOs and governments are actively driving distribution of medical supplies such as facemasks within their countries.

While the initial PPE shortages have largely been resolved, the distribution of therapeutics and vaccines – combined with a possible second surge in the demand for PPE – will pose additional challenges that governments, NGOs as well as pharmaceutical and medical equipment companies will need to tackle in the months to come. Looking ahead, governments will need to improve the medium- and long-term resilience of their supply chains in preparation for future crises. The goal of this whitepaper is to support governments as well as pharmaceutical and medical equipment companies globally in three ways:

- By synthesizing lessons learned from the past months. These include the challenges faced in sourcing and procurement and, especially, the pain points in inbound logistics and downstream distribution related to the PPE supply chain as experienced during the first COVID-19 wave.
- By detailing the upcoming challenges in vaccine distribution that result from the significant global demand and potentially stringent temperature requirements.
- By explaining why and how governments should develop detailed emergency response plans, build strong partnership networks, establish high-capacity and tech-enabled logistics infrastructures, and create organizational clarity as top-priority measures moving forward.

>23m
CONFIRMED CASES

>800,000
DEATHS

-8.1%
GLOBAL ANNUAL GDP GROWTH 2020[1]

[1] Based on pandemic scenario which is seen as most likely by executives surveyed by McKinsey.
Source: Johns Hopkins University, Oxford Economics, McKinsey; current as of August 25, 2020.

CHAPTER 1

IDENTIFYING CRITICAL PAIN POINTS ALONG THE COVID-19 SUPPLY CHAIN

Recent months have revealed the particular pain points that governments and NGOs have confronted in trying to ensure a broad, yet targeted provision of medical supplies across the core steps of the supply chain (Exhibit 1).

Demand identification. At the outbreak of the pandemic, timely identification of equipment demands at the national level was challenging not only due to a lack of consolidated transparency on domestic stock levels, but also due to challenges in forecasting. Forecasting demand proved difficult, since this requires a calibrated model for pandemic evolution as well as rigorous reporting and data analytics capabilities, which were often not in place prior to the pandemic. In addition, coordinating demand identification and consolidating demand data from developing countries have posed challenges to NGOs.

Sourcing. The supply of COVID-19 testing supplies and therapeutics was far lower than the globally surging demand, making sourcing and securing volumes a significant pain point. For PPE, the dependence on supplies from overseas, especially from China, posed challenges for governments to rapidly liaise with qualified local suppliers. Fragmented supply and nebulous networks of contract manufacturers exacerbated the sourcing challenge, and attempts to quickly ramp up short-term production had a negative impact on product quality.

Procurement. When procuring PPE from overseas, agreeing to purchase terms with local suppliers has proven difficult for governments who often lack local knowledge and supplier liaisons. In the case of therapeutics and testing supplies, the urgency of the situation – combined with limited supply and lack of clarity regarding regulatory approvals – further complicated the procurement process.

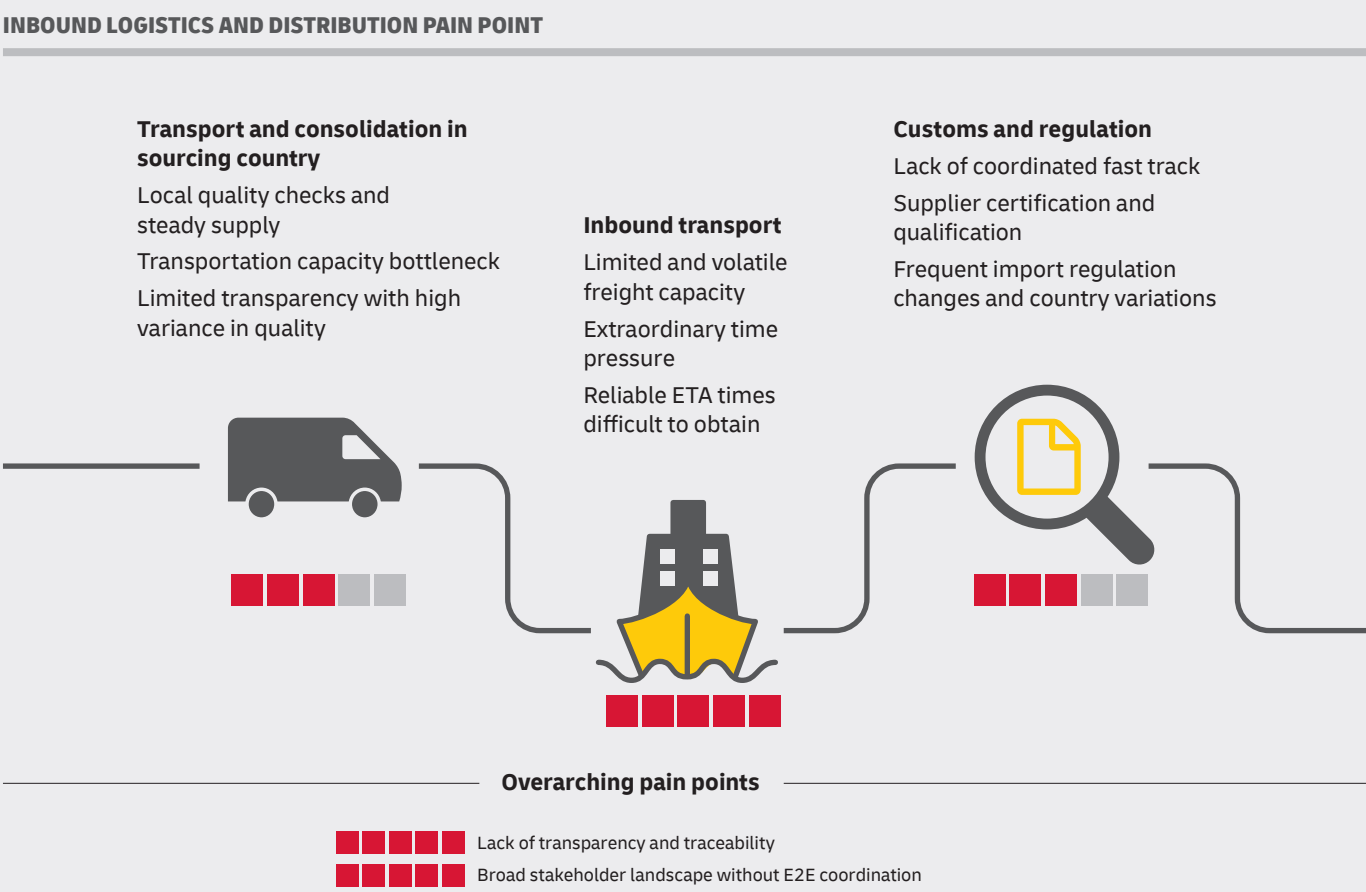
Allocation. Activities related to allocation have also presented challenges for government players. For testing supplies and therapeutics, the wide gap between current supply and surging demand is a driver of the allocation struggle. The higher number of stakeholders and decision-making bodies makes allocation especially challenging for countries with multiple levels of government (e.g. federal, state and local parliaments). Lack of real-time visibility on stock levels has made timely matching of supply and demand across countries even more difficult.

Inbound logistics and distribution. A highly concentrated production footprint and resulting bottlenecks in customs, along with limited air freight capacities, have posed major challenges in the flow of PPE. However, orchestrating a global supply chain of highly sensitive products across multiple transport modes is also a challenge governments face when dealing with tests, therapeutics and vaccines.

While governments are assuming overall responsibility for end-to-end supply chain orchestration, two categories of activities are most relevant from a logistics point of view: inbound logistics and distribution.

KEY ACTIVITIES TO SECURE MEDICAL SUPPLY EXHIBIT 1

■ Major logistics challenges (details in the following)



A CLOSER LOOK: PAIN POINTS AND THEIR ROOT CAUSES IN INBOUND LOGISTICS AND DISTRIBUTION

During the COVID-induced PPE shortages, governments faced a range of different transport challenges. In the race to source PPE, a push-based sourcing approach predominated to ensure volume. This resulted in unpredictable supply in terms of volume, quality and delivery time.

In many cases, local quality checks were insufficient due to time pressure, the increased bargaining power of suppliers, and the fact that many governments lacked access to local testing infrastructure. Outbound shipping was often delayed due to road transport bottlenecks on the way to ports and airports. For PPE, in particular, regional national lockdowns during the peak of the first phase limited not only production, but also much-needed shipping capacity. When supplies finally arrived at outbound ports, reliable estimates for arrival times (ETAs) on the receiving end were hard to come by. And when supplies did reach their destination countries, custom clearance processes added another hurdle.

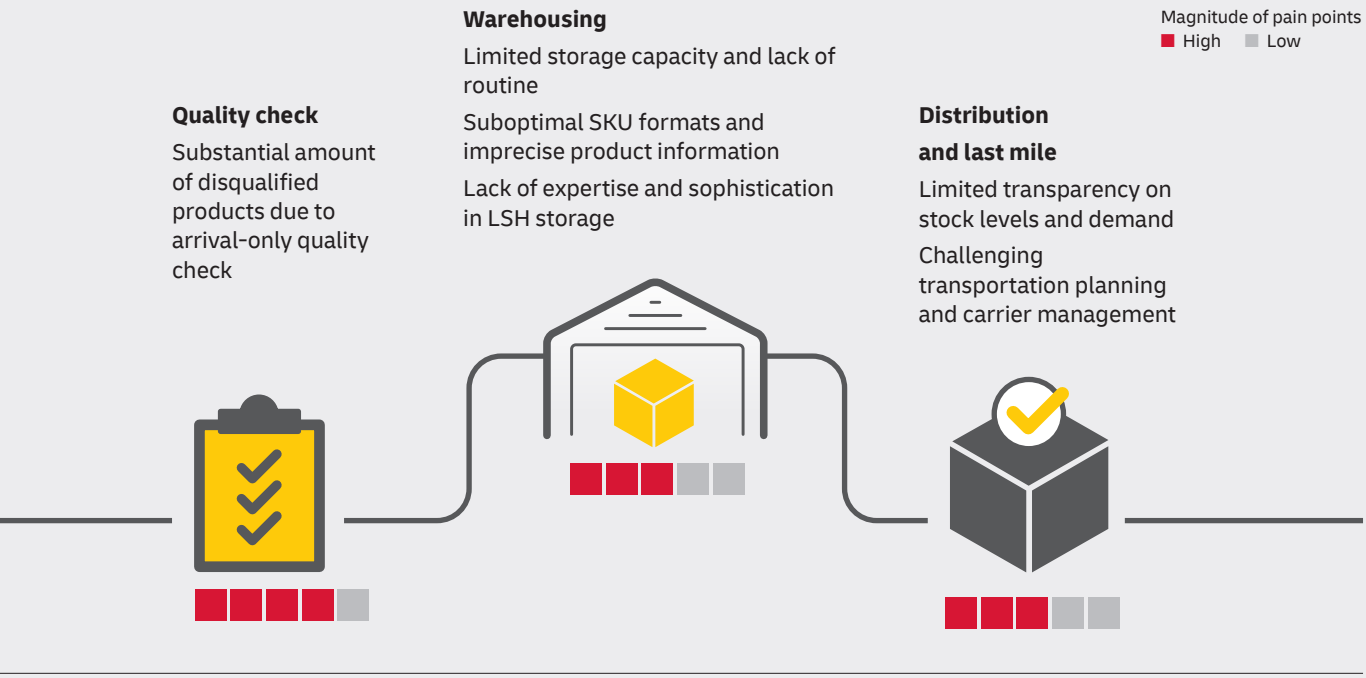
Custom clearance is often a lengthy process due to insufficient personnel and a lack of coordinated fast-track processes. Amid the COVID crisis, governments responded by relaxing custom clearance procedures (to varying degrees) in order to accelerate distribution to end users. As a result, things like supplier certification and product quality were not adequately verified. With less experienced and reliable actors suddenly appearing on the market in this "gold rush" environment, it was quite common to find large amounts of product that was insufficient in terms of quality, or even counterfeit.[2]

The distribution challenges faced by governments were twofold:

First, in warehousing. Due to the time pressure and surging demand, warehouses not actually designated for life science products were nevertheless used for medical supplies, including PPE. This sometimes resulted in damaged or deteriorated supplies (despite relatively short storage times) because necessary conditions were not met

EXHIBIT 2

Source: DHL, McKinsey



(e.g., specialty packaging, precise temperature and humidity management). Even a product as simple as hand sanitizer, for example, requires careful handling due to its alcohol content, especially for longer-term storage. Moreover, products shipped on a push-based approach from various suppliers lacked standardization in terms of stock-keeping unit (SKU) formats and shipment information, which also led to inefficient warehousing operations.

Second, limited real-time transparency on warehouse stock levels significantly limited options for orchestrating an effective last-mile delivery network. This also made it difficult to make reliable promises to end users and created friction in planning processes. Transportation planning and managing multiple carriers posed additional challenges that governments had not faced before.

[2] To tackle this issue, China's Ministry of Commerce, the General Administration of Customs, and the State Administration for Market Regulation jointly issued the Announcement on Further Strengthening Quality Oversight for Exported Pandemic Prevention and Control Supplies on April 26, 2020, allowing specified pandemic-related medical equipment (e.g., test kits, surgical masks, preventive clothing or ventilators) to be exported only if they have obtained foreign certifications or registrations that are accepted by the importing countries.

DEMAND INCREASE – EXAMPLE UNICEF:

>100x
FOR FACE MASKS

>300x
FOR N95 MASKS

>2,000x
FOR MEDICALGLOVES

Source: Unicef
Note: The demand surges represent estimates of UNICEF's procurement as a response to COVID-19, comparing approximate quantities procured in 2019 to 2020. These numbers do not represent global demand surges since numerous actors procured medical supplies during the pandemic.

CHARACTERISTICS OF A SUCCESSFUL LOGISTICS PARTNERSHIP

Beyond the pain points in each of these areas, governments and NGOs have struggled to deal with an increasingly complex stakeholder landscape. This is the result of a fragmented tendering process in pursuit of greater cost efficiency along each step of the supply chain. At the onset of the pandemic, stakeholder complexity collided with high urgency and high levels of competition between countries.

By partnering with a logistics provider throughout the entire supply chain, governments can benefit from integrated logistics planning, consistent quality services, and a simplified stakeholder landscape. In a global health emergency, an effective logistics partner should have the following minimum qualifications and capabilities:

Access to a global shipping network at scale. In times of global health crises, a logistics partner should have access to an established worldwide logistics network. For supply chains consisting of suppliers with global production networks, reliability will depend on a broad range of transportation capacities across modes, as well as established infrastructure for intercontinental shipments.

Local knowledge and access. As the COVID-19 crisis has shown, getting medical supplies to a national port is only half the battle. Local knowledge and access are also key. If a logistics provider is going to ensure a stable supply of life-saving products, it must also have significant local warehousing capacity and experience with in-country logistics through its own infrastructure footprint or via a quality-controlled partner network.

Process excellence. Given the particular requirements of medical supplies, logistics partners should be certified for transporting and warehousing life science products. In a health emergency, a demonstrated commitment and ability to quality-check products at multiple stages – along with the capacity to support smooth and timely customs clearance (preferred handling) – are key to a quick response.

Data-driven transparency and insights. A logistics provider with extensive data capabilities can help overcome the transparency issues experienced during the COVID crisis. Such capabilities allow real-time visibility on shipment status and monitoring of a range of variables that can impact supply, including regulations, supplier health, and epidemiology.

Resilience and crisis experience. The uncertainty inherent to a pandemic or other large-scale public health emergency will test an organization's resilience and adaptability. A resilient lead logistics provider with a track record in crisis situations can rapidly scale up capacity and consistently ensure high-quality services.

CHECKLIST TO SELECT STRATEGIC LOGISTICS PARTNERS EXHIBIT 3

Access to global shipping network at scale

- LSH compliant networks with world-wide coverage
- Access to broad range of transportation capacities worldwide (incl. LLP1)
- Established logistics infrastructure for intercontinental shipments

Extensive local footprints

- Extensive experience in local warehousing and in-country logistics across different economies and geographies
- Comprehensive local knowledge to advise sourcing and transportation overseas

Process excellence

- Certified medical transportation and warehouse provider
- E2E logistics advisory and solution offering
- Strong quality check capacity (local testing capacity, inbound sample testing etc.)
- Integrated custom clearance support (document preparation etc.)

Data-driven insights

- Detailed real time visibility of shipments
- Analytics-driven demand forecast and warehouse management
- Close monitoring and continuous risk assessment (regulations, supplier health, pandemic evolution etc.)

Resilience and crisis response

- Resilience to maintain operations under challenging circumstances
- Capabilities to rapidly secure and scale logistics capacity even in crisis
- Previous pandemic experience and regular crisis rehearsal

CHAPTER 2

PREPARING FOR THE CHALLENGE OF COVID-19 VACCINE LOGISTICS

In Q1 and Q2 2020, managing the PPE supply chain was the major challenge across regions given the spikes in demand, factory lockdowns and a highly centralized production footprint. By summer 2020, the global PPE supply chain was running smoother again, due partly to increased local production. And once all major economies ramped up testing capacity, the once-limited supply of testing kits was, with some exceptions, no longer as critical.

In response to the ventilator shortage, automotive OEMs, including Daimler and GM, repurposed their factories to build ventilators and alleviate production shortages. A UK-based consortium known as "VentilatorChallengeUK" provides a unique example of the power of public-private partnerships to efficiently address critical supply chain challenges. In this case, the national government contracted nearly two dozen corporations – largely outside of the medical equipment sector – to quickly boost the national supply of ventilators. In the earliest days of the pandemic, the UK government commissioned manufacturers – from aeronautics (Airbus), to rail (Thales), to racing (McLaren) – to produce at least 10,000 ventilator units.

Looking ahead, the next major global challenge is likely to be the logistics of vaccines.

As of the writing of this paper, there are some 250 COVID-19 vaccine candidates. Vaccines traditionally utilize inactivated viruses, protein subunits, or attenuated viruses as technology platforms[3]. A number of current vaccine frontrunners make use of two next-generation technology platforms. Moderna and BioNTech/Pfizer (currently in Phase III and Phase II/III trials, respectively) are using a novel RNA platform. Both AstraZeneca/Oxford (the first to start Phase III trials several weeks ago) and Johnson & Johnson (expected to start Phase III trials soon) are building on a viral vector vaccine. This uses live, innocuous viruses, which deliver genetic material inside human cells to produce proteins (typically surface proteins such as the COVID-19 spike protein) that accelerate the immune response. These four companies, along with Sinopharm, have even announced projected timelines for administering under an Emergency Use Authorization (EUA)[4], with the first as early as September 2020. Meanwhile, Russian authorities have approved a vaccine candidate – Sputnik V – and will reportedly commence mass vaccination in October 2020. Given that vaccines, historically, have been developed over the course of 5 to 20 years, the idea that one could go from early development to being broadly administered in less than a year is unprecedented.

With speed of development such an important factor, special approaches in vaccine development, testing and stabilization are needed to accelerate the process. Under non-pandemic conditions, sufficient time is devoted to testing and developing vaccine stability, which is key to determining the environmental conditions under which the vaccine can be transported and stored. In this phase, researchers typically generate vaccine stability data to understand the required conditions, and they may iterate on the formulations to seek improved stability. In the current pandemic, however, researchers are focusing on safety and efficacy, and are seeking EUAs and Fast Track Approvals[5] for their vaccines to put them to use as quickly as possible.

Once a safe and efficacious vaccine is approved for use, transport and logistics promises to be the next challenge in the fight against COVID-19 due to the sensitivity of vaccines to environmental conditions. The exact logistical requirements for transport and storage differ between different vaccines and/or technology platforms, as well as between the different supply chain steps. Nevertheless, it is important to plan ahead and understand in detail the potential temperature requirements and their implications for logistics.

DEVELOPMENT OF COVID-19 VACCINES

~250
VACCINE CANDIDATES FROM

7 **VACCINE TECHNOLOGY PLATFORMS CURRENTLY IN PIPELINE**

Source: Milken Institute, BioCentury, WHO, Nature

[3] A platform is defined by the material at the heart of a vaccine that generates the immune response.

[4] Emergency Use Authorization (EUA) allows unapproved medical products or unapproved uses of approved medical products to be used in emergencies.

[5] Fast track approvals (FTA) facilitate the development and expedite the review of drugs to treat serious conditions and fill an unmet medical need.

TEMPERATURE REQUIREMENTS – THE STATES OF COOLING ALONG THE SUPPLY CHAIN

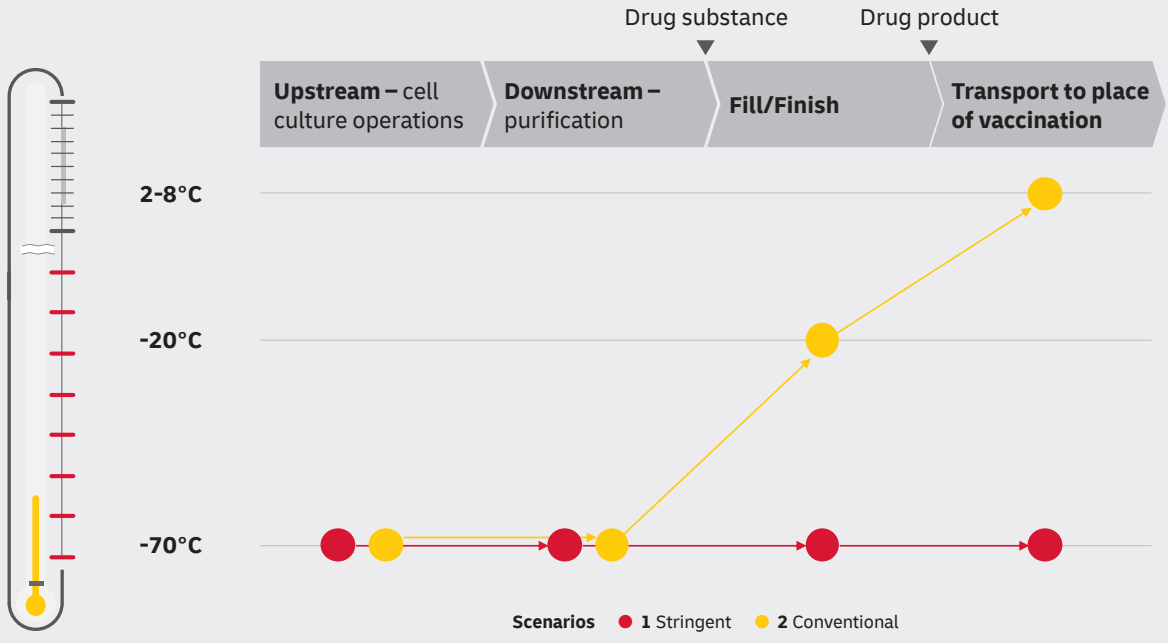
Storage and transportation conditions for future COVID-19 vaccines will likely differ depending on temperature-requirement scenarios along the supply chain. When vaccines enter the market for emergency use (potentially as early as Q4 2020), a potential lack of stability data might mean stricter temperature requirements for the vaccine supply chain (Exhibit 4). In a less stringent scenario, requirements for emergency use are not likely to differ fundamentally from today's standard vaccines logistics.

Stringent scenario: Out of caution, producers of certain vaccines and their logistics providers can choose to adhere to extreme temperature requirements (as low as -80 °C) to ensure that the efficacy of the vaccines is maintained during storage and transport. These conditions are in line with the ones used for certain COVID-19 vaccine clinical trials today. These stringent requirements might be lifted over time if 1) vaccine efficacy at higher temperatures is proven by stability testing or 2) formulations are improved and additional manufacturing steps (e.g. lyophilization) are added to increase stability.

Conventional scenario: However, health authorities, producers and logistics providers would strongly prefer to begin large-scale transport and distribution under the conditions prevalent in pharmaceutical supply chains today (+2–8°C or even higher) as long as stability is not compromised. The certainty of success of a conventional approach partially depends on the vaccine platform. While these less stringent transport requirements have been trialed and tested for a protein-based vaccine, applying a conventional transportation approach to certain current frontrunners (developed on RNA platforms, for example) is riskier and based on less experience and stability data.

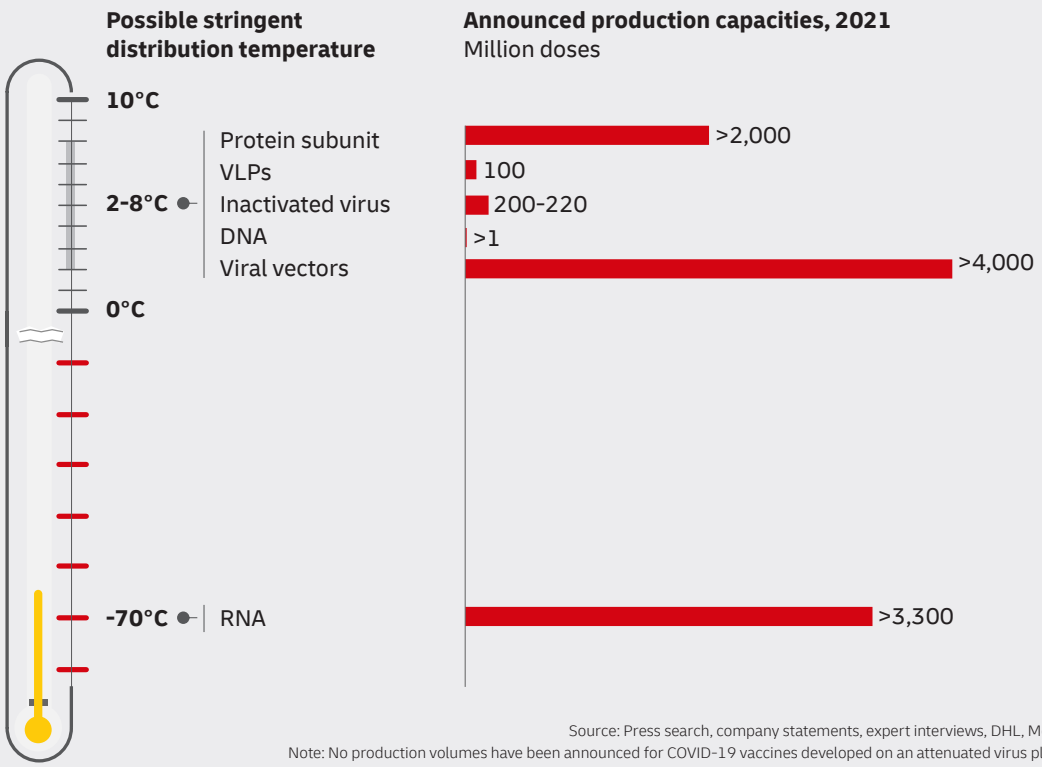
In any scenario, COVID-19 vaccine supply chains will also differ based on the utilized technology platform and individual vaccine. If things go extraordinarily well, the first vaccine that proves to be safe and clinically efficacious could in theory be the ideal candidate, i.e. not only efficacious, but also allows for scalable production and manageable distribution at standard temperatures. However, the announced production capacities are particularly high for vaccines of the novel RNA and viral vector types, and the RNA platform, in particular, presents a higher probability of extreme logistics requirements (Exhibit 5). As a result, under the stringent scenario, pharmaceutical companies, governments, NGOs and logistics providers need to prepare to handle these requirements on a scale far beyond mere clinical trials.

STORAGE AND TRANSPORT REQUIREMENTS ALONG SUPPLY CHAIN PHASES – EXAMPLE FOR SENSITIVE VACCINES EXHIBIT 4



Source: Expert interviews, DHL, McKinsey

ANNOUNCED PRODUCTION CAPACITIES AND POSSIBLE STRINGENT DISTRIBUTION TEMPERATURES EXHIBIT 5



Source: Press search, company statements, expert interviews, DHL, McKinsey
Note: No production volumes have been announced for COVID-19 vaccines developed on an attenuated virus platform. Therefore only 6 platforms shown. Overview current as of August 15, 2020.

IMPLICATIONS AND CHALLENGES OF TEMPERATURE REQUIREMENTS

In preparation for vaccine distribution – in particular in the stringent logistics scenario – it is important to map out the logistics requirements and identify potential bottlenecks along the key supply chain steps of intermediate transport, intercontinental shipment, warehousing, downstream distribution and final short-term storage at the point of use (Exhibit 6). Our analysis suggests different challenges at each step along the supply chain. We can expect

LOGISTICAL IMPLICATIONS OF COLD CHAIN REQUIREMENTS – EQUIPMENT EXAMPLE FOR A POTENTIAL SUPPLY CHAIN SETUP EXHIBIT 6

Source: DHL, McKinsey

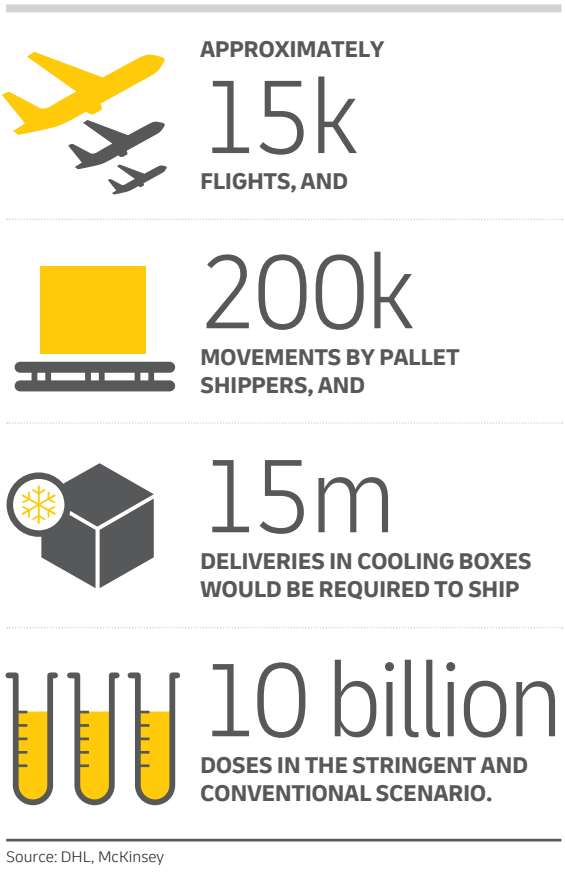
intermediate transport of the drug substance and intercontinental shipment of the drug product to be manageable given the intact logistics infrastructure available at production sites (predominantly in industrialized regions in Western Europe, North America, and India). However, high variance in process duration, for example, in QA/QC release[6] or customs clearance, can pose a challenge given the consistent cooling requirements.

Given the urgency of the pandemic, vaccines will likely be transported via air freight for longer distances. To ensure global coverage for the next two years,[7] some 200,000 movements by pallet shippers on 15,000 flights may be needed. In downstream distribution, accommodating the stringent temperature requirements will be even more challenging, though for a different reason. While process duration is much more plannable and consistent here, the lot size decreases substantially. This poses three operational challenges:

First, the sheer number of shipments – imagine almost 15 million cooling boxes in an exemplary supply chain – paired with the required volume of cooling bricks or dry ice. Dry ice production does not seem to be a bottleneck for vaccine distribution. But even under aggressive assumptions, both the availability of suitable packaging as well as the maximum-allowed quantities of dry ice in air cargo transport could potentially limit shipment possibilities in certain cases if the preparations are not made in time.[8]

Second, ensuring consistent temperature management (in a way that avoids damage to the precious shipments throughout the last-mile network) is much more complex for ~50 boxes/parcels than it is for one pallet shipper.

Third, the physical handling of ultra-deep frozen shipments requires special equipment (such as gloves) and processes to avoid injury. This means that a large number of couriers and consignees need to be informed or even trained.



Source: DHL, McKinsey

[6] Quality assurance (QA) reviews the manufacturing process and issues a certificate of manufacturing if approved. Quality check (QC) reviews the ingredients/components and issues a certificate of quality.

[7] Global coverage assumes approximately 10 billion doses to be distributed.

[8] The reason dry ice capacity on airplanes is limited is because dry ice will sublimate into carbon dioxide gas with time, displacing the breathable oxygen in the cabin. These restrictions in dry ice capacity are there to maintain breathable levels of oxygen in the cabin of the airplane and are calculated by taking account factors such as the airplane's ventilation rate, sublimation rate of dry ice, dry ice packaging, and safe CO2 concentration limits. Currently, all wide-body aircrafts (e.g., B767, B777) can carry a maximum of 816-1088 kg of dry ice, when carried in refrigerated/insulated containers.

SUPPLY CHAIN ARCHETYPES FOR VACCINE DISTRIBUTION

When it comes to implementation, a number of design choices for the vaccines distribution supply chain need to be made. We have defined three end-to-end logistics archetypes from which pharmaceutical companies and public bodies may choose to deliver finished doses of the vaccine (Exhibit 7). The suitability of these archetypes differs depending on the temperature requirements, transport distances, and volumes as well as factors related to cost, lead time, warehouse capacity and the availability of packaging and equipment. All these parameters may differ for each vaccine and need to be considered when selecting the right distribution archetype:

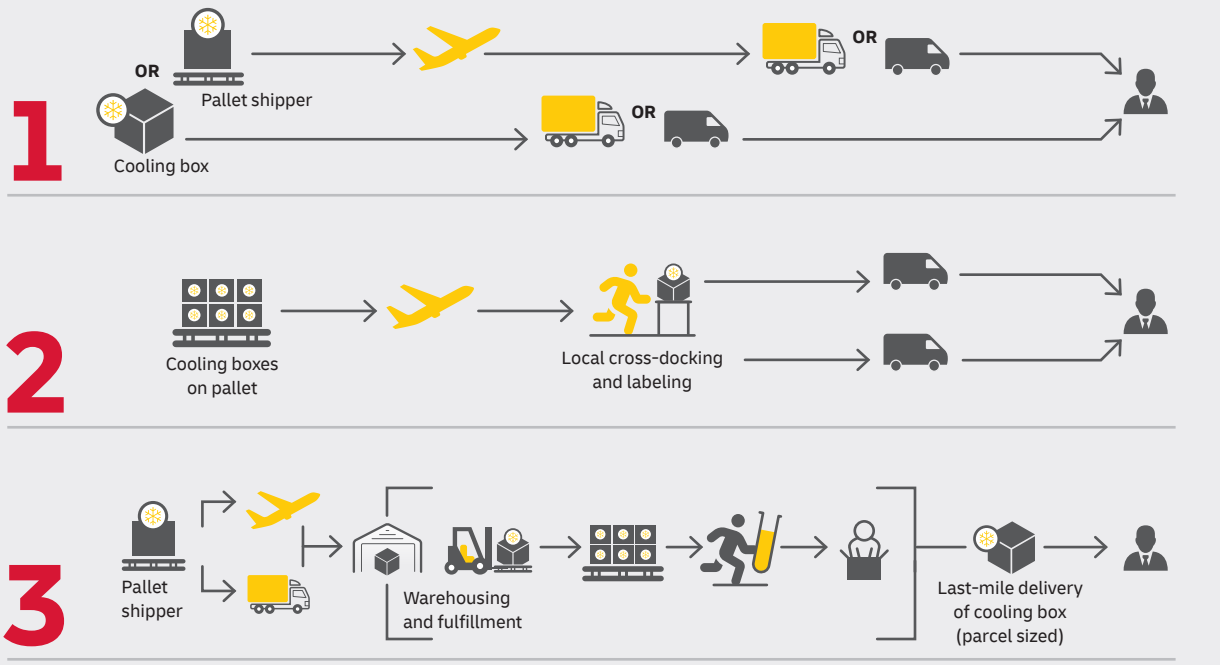
Direct shipment. The most direct and fastest of the distribution archetypes takes vaccines (either palletized or boxed) directly from the fill-finish point to the final destination via truck or air. This mode could make sense for initial global distribution for front-line use, over the long term in small regions, or in cases where the endpoint is in relatively close proximity to the manufacturing point.

Local cross-docking. In this archetype, pallets filled with parcel-sized cooling boxes are flown to the destination country, where they are cross-docked, labeled and then transported via truck to various endpoints. This distribution solution can minimize cross-border shipping costs and works particularly well for small-region destinations that are relatively far from the point of manufacture.

Local warehousing. This distribution archetype makes use of local storage and fulfillment capacities to receive entire pallets and then break them down into parcel-sized units for warehousing and subsequent last-mile delivery. This could be the archetype of choice for large destination regions and a long-term solution for vaccine types that can be transported under less stringent temperature requirements.

THREE ARCHETYPES OF END-TO-END LOGISTICS SOLUTIONS FOR COVID-19 VACCINE DISTRIBUTION EXHIBIT 7

Source: DHL, McKinsey

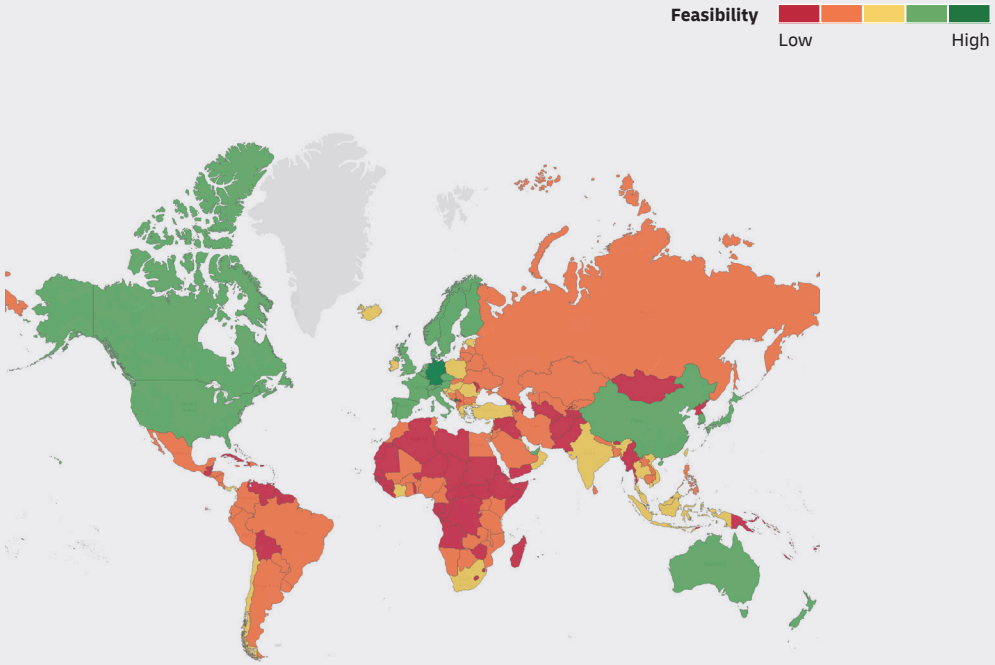


1 Direct shipment to point of use
Direct shipment of pallet shipper or cooling box from fill-finish to point of use

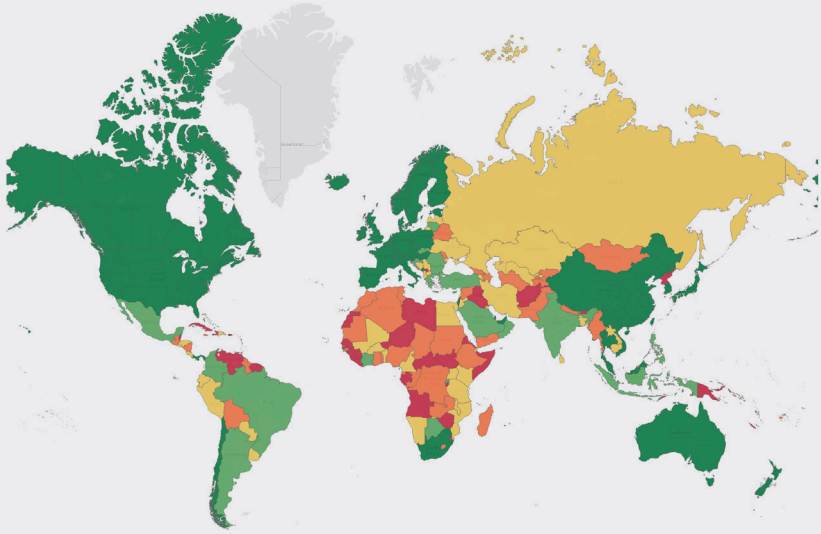
2 Local cross-docking
Local cross-docking of cooling boxes on pallet to reduce cross-border costs

3 Local warehousing
Use of local storage and fulfillment capacities to break-down pallet shipper into cooling boxes

FEASIBILITY OF IN-COUNTRY LOGISTICS AT DESTINATION EXHIBIT 8



Scenario 1: Stringent temperature requirements
High feasibility at scale[1] in ~25 countries with total population of ~2.5bn



Scenario 2: Conventional temperature requirements
High feasibility at scale[1] in ~60 countries with total population of ~5.0bn

[1] "Feasibility" considered as high and relatively high feasibility to distribute COVID-19 within destination countries (marked with dark green and green color code)
Source: World Bank, DHL, McKinsey

THE GEOGRAPHIC VIEW ON VACCINE DISTRIBUTION

While pharmaceuticals production happens mainly in countries with a modern and intact logistics infrastructure, downstream distribution cannot be limited to these regions. Given that temperature requirements are likely to be the main challenge, regions with a particularly warm climate and those with limited cold-chain logistics infrastructure will pose the biggest challenge in a stringent vaccine distribution scenario (Exhibit 8). Furthermore, in-country logistics capabilities must be considered when targeting downstream distribution of vaccines globally. Especially under stringent logistics scenarios requiring dry ice for cooling, bottlenecks are likely to arise at the destination due to centralized dry ice production, especially if refilling is required after 3-5 days.

Transportation under stringent temperature requirements – when shipping frozen vaccines, for example – may require extraordinary measures to reach people outside the ~25 countries with the most advanced logistics systems, which are home to just one third of the world population. Currently, large parts of Africa, South America and Asia could not be readily supplied at scale due to lack of cold-chain logistics capacity suitable for life science products. Governments and NGOs would need to implement special measures to ensure vaccine distribution. Capacity would have to be increased and scaled in order to reach the global population.

Executing the last mile in line with conventional transportation requirements (assuming sufficient shelf life at +2–8°C) is much more feasible; it allows for a more efficient distribution to end users globally since transport can rely on available capabilities and capacities, as well as prior experience and knowledge. However, even when leveraging existing infrastructures, the share of the world's population with good access to a vaccine only increases to ~70%, reaching a total population of ~5 billion in ~60 countries. Feasibility for supplying substantial parts of Africa remains low due to high outside temperatures and limited cold chain infrastructure. It is therefore important to consider innovative and specialized transportation modes to reach populations in less accessible regions.

SUSTAINABILITY IN DELIVERY AND DISTRIBUTION

If one goal in vaccine distribution is to reach as much of the population as possible, another important objective is sustainability along the supply chain. It is critical to consider which types of packaging and modes of transport are reusable, and how to organize reverse logistics in a way that is sustainable. Based on experience in the area of standard reusable parcels, return logistics can be difficult to execute (and ultimately unsuccessful) in certain less developed economies of the world. Nonetheless, one of the largest distribution efforts in history – supplying a COVID-19 vaccine to the global population – should not be carried out using unsustainable means of transport. It is therefore critical to consider innovative packaging solutions, as well as recycling opportunities and optimal waste management in the case of one-way packaging.

The long-term goal of achieving widespread access to COVID-19 vaccines faces several obstacles. Investments in cold-chain logistics must be considered, depending on whether vaccine distribution involves stringent or more conventional temperature requirements. Under very stringent temperature requirements, structural challenges, such as availability of high-performance cold chain logistics for even the most adverse environmental conditions, can only be overcome through technological advances and policy intervention.

Chapter 3 presents a number of effective strategies that governments can implement to overcome the organizational and process challenges they face – and to orchestrate the medical supply chain of the future.

CHAPTER 3

BEYOND COVID-19 – A FRAMEWORK TO TACKLE FUTURE EMERGENCIES

The likelihood of a pandemic has increased in the century since the 1918 flu pandemic. We've seen SARS and MERS emerge, and while COVID-19 is the most recent, it will not be the last. Among the factors driving this trend are increased global travel and changes in land use, and since these factors are expected to increase, we can expect the frequency of pandemics to intensify as well.[9]

Global public health emergencies present immense challenges – and preparedness may save lives when the next crisis hits. Research by the University of Oxford's Blavatnik School of Government, which investigated government responses to the COVID-19 pandemic, suggests that countries with more stringent countermeasures, such as the mandatory use of face masks in public, have had lower COVID-19 infection rates.[10] In many regions, however, supply shortages would have made widespread mask use impossible.

Access to medical products is essential to a successful health-emergency response, and preventing such supply issues in the future should be a clear goal moving forward.

Lessons learned from the COVID-19 pandemic and investments in crisis prevention can help government leaders ensure adequate supplies. The following five pillars of successful crisis response management will be key to meeting the supply chain challenges of future global health emergencies:

(1) Developing and disseminating a clear and pre-defined **emergency response plan**

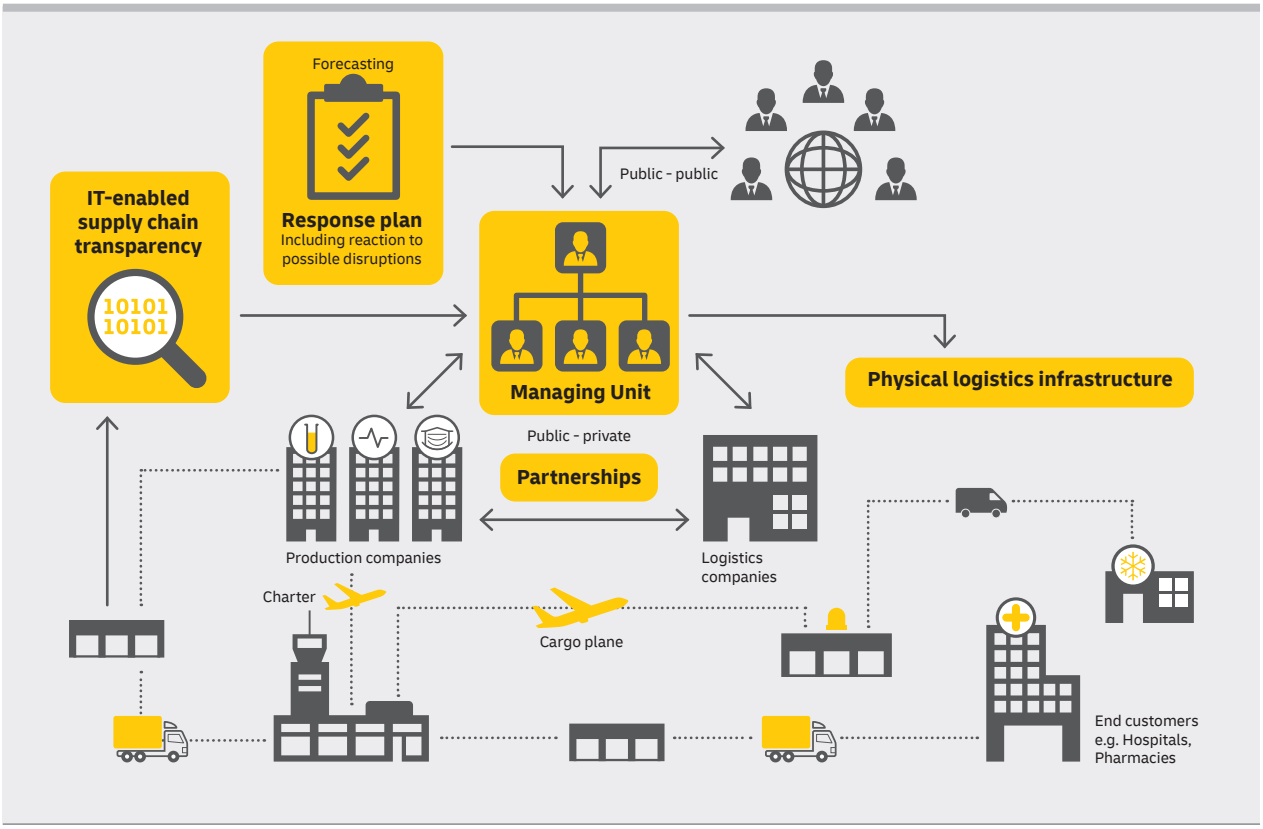
(2) Building a **partnership network** of both public-private and public-public partnerships

(3) Identifying and ensuring access to required **physical logistics infrastructure**

(4) Establishing IT-enabled **supply chain transparency**

(5) Creating **organizational structures and allocating resources** to institutionalize and coordinate the entire response management incl. plan, partners, infrastructure and IT

FIVE PILLAR FRAMEWORK FOR SECURING MEDICAL SUPPLIES DURING PUBLIC HEALTH EMERGENCIES EXHIBIT 9



[9] Jamison, Gelband and Horton et al. 2017.

[10] Oxford COVID-19 Government Response Tracker (OxCGRT) (2020).

EMERGENCY RESPONSE PLAN

Every health crisis is different, but certain aspects apply to all crises. An effective emergency response plan pre-defines any components that can be established prior to a public health emergency (e.g. assigning responsibilities), while identifying other aspects that must be tackled ad hoc (e.g. gathering current demand data). By establishing response strategies in advance, governments[11] can focus their resources on critical unexpected and ad hoc decisions. The goal of an emergency response plan is to ask the right questions in advance, define response strategies, and allow for an agile, efficient response during the crisis.

The following response strategies can be devised for expected scenarios along the supply chain:

For demand identification and forecasting, some crucial steps – such as identifying hot spots and forecasting demand based on infection rate – will have to be handled ad hoc, but key elements can be addressed in advance. These include: clearly defining the product categories where central demand identification is necessary, setting up systems for monitoring infection numbers and corresponding demand, and creating forecasting models using the extensive data available from the COVID-19 pandemic.

For **sourcing,** governments can prepare well in advance by creating supplier lists (long and short lists) based on specific criteria for both product suppliers and logistics providers. They can also work on building relationships and networks with suppliers. The checklist at the end of Chapter 1 provides guidance for identifying suitable candidates.

In the area of **procurement,** governments should create a safety stock of critical supplies in advance to ensure self-sufficiency in the event of a supply chain collapse. In addition, pre-negotiated prices as well as secured volumes can help improve supply chain reliability and cost volatility in times of crisis, yet will most likely come at a cost akin to an insurance premium. Governments can also enable faster procurement with things like pre-approved purchase orders.

For **inbound logistics and distribution,** governments can avoid many common problems by selecting a logistics partner in advance. This way, they avoid having to scramble last-minute to find a supplier, and can instead identify a contact person at the supplier in advance, find available manufacturing and transport capacity, book the required quantities, identify a network of distributors, and ensure capacity when needed.

Allocation can prove particularly difficult for countries with federal systems, i.e. multi-layered governance with semi-autonomous municipalities and provinces or states. Establishing a collaboration model and emergency allocation principles across these various levels of government can be done in advance.

Each country must decide individually on specific activities at each stage and whether response strategies can be devised. Especially for countries within multi-national entities, such as the EU, responsibilities must be clearly assigned on each level (from federal to local) and cooperation models defined. Regardless of the particular governance structure, security must be central to the implementation of all activities. Any breach along the supply chain can foil even the best-laid plans. Especially when dealing with medical supplies, all activities – from design to implementation – should be carried out with supply-chain reliability and security in mind.

[11] Throughout the text, the term "governments" is used to refer to health care authorities and other key decision makers in a country. In parts of the developing world, this may also incorporate international organizations and NGOs.

PARTNERSHIP NETWORK

A partnership network can greatly relieve pain points experienced by governments by helping prevent disruptions along the supply chain and meet unprecedented challenges successfully. Partnerships should encompass both public-private and public-public partnerships.

Public-private partnerships should be in the form of three-way agreements between medical supply producers, logistics service providers and health authorities/governments. During COVID-19, partnerships with private companies from non-health related industries also proved important. As part of the "VentilatorChallengeUK", over two dozen companies, including major automotive players, stepped up to help produce ventilators. So-called community masks have also alleviated the PPE bottleneck in many countries, enabling mandatory wearing of face masks.

Partnerships amongst governments of (neighboring) countries and relevant trans-national committees, such as the EU, should be an additional goal. Because pandemics are generally global or multi-national in nature (due to both pre-symptomatic incubation periods and increasingly higher levels of international travel), countries should not try to tackle them alone.

Building a partnership network in advance of a global health emergency is important to enabling a timely, effective response. While new partnerships can be formed in response to unexpected challenges, most partnerships and networks should be pre-established.

PHYSICAL LOGISTICS INFRASTRUCTURE

Robust physical infrastructure – including available stock of medical supplies, and access to the required warehousing facilities and logistics capabilities – is key to a successful emergency response. Without safety stocks, sudden surges in demand of medical supplies cannot be met reliably as evidenced by the long lead times seen for PPE in Q1/Q2 2020. In addition, access to a pre-established network of warehouses and sufficient transport capacity are both important for orchestrating in-country logistics in the event of an emergency.

National safety stocks and production capacities: In general, investment into safety stocks should be seen as an insurance premium for mitigating bigger health crisis risks. Sufficient stock levels allow a country to compensate for disrupted supply chains during an emergency, and thus bridge potential supply shortages. In the COVID-19 crisis, for example, the PPE peak crisis lasted several months. Countries that had accumulated national safety stocks and were following stockpiling strategies, such as Singapore and Taiwan, were less affected by these breaks in supply. Prior to a health emergency, a government should therefore identify which medical supplies to stock, at what quantities and at which locations.

When making these investment decisions it is important to consider 1) the acquisition and holding costs that will be incurred and 2) the value losses due to limited shelf life of the medical supplies discussed here. One example of strategic stockpiling and maintenance comes from Taiwan, where the country's Center for Disease Control established a 3-tier PPE stockpiling framework that ensures safety stocks across three involved parties: the central health authority, local health authorities and medical institutions. In addition, the framework ensures more effective use of limited government funds and achieves the goal of sustainable management. To avoid product expiration issues and ensure the availability and maintenance of minimum stockpiles, the oldest stock should be regularly replaced with the same amount of new, high-quality products. Australia and Singapore, among other countries, build on contractors' support to manage similar stock-cycling solutions involving national hospitals and clinics. This minimizes waste, storage and disposal costs while

reducing the need for regular replenishment.

Operationally, governmental entities must determine optimal stock locations throughout the country – a decision highly dependent on country size, population density distribution, and available logistics networks. Apart from logistical considerations, cost, compliance and safety will need to be considered in alignment with the reliability and security imperative outlined above.

At the same time, the COVID-19 crisis has highlighted the risks of global production and supply chains. Local production of medical supplies shortens the supply chain and reduces associated risks. Incentivizing local production thus represents an alternative approach to securing supply and reducing risk, and can be seen as a complement to safety stocks. In addition, cross-utilization of production capacities proved highly valuable during the onset of COVID-19, with automotive OEMs stepping in to alleviate capacity bottlenecks in the ventilator industry.

Comprehensive and high-capacity logistics infrastructure: In times of crisis, governments not only need direct access to supplies or supply production, but also access to logistics infrastructure and capabilities. Pre-determining logistics partners, supply routes, and transport modes, along with transparency on delivery times from factory to point of use, can help reduce the need for ad hoc decisions in a crisis. To be effective, governments need to plan all of these measures for different scenarios with varying impact on the logistics infrastructure (e.g. local incidents).

IT-ENABLED SUPPLY CHAIN TRANSPARENCY

As we learned from the first months of the COVID-19 pandemic, real-time visibility along the supply chain is a critical asset in a pandemic response. At the macro level, visibility on global supply chain systems is the foundation for government decision-making on trade policies, transport node operations, and the security of key industries in a global health emergency. At the micro level, visibility on trade flows enables reliable tracking of medical supplies and early detection of potential transportation bottlenecks. However, achieving visibility remains challenging due to the limited willingness of data owners to share data, the complexity of supply chains and the lack of data standardization and interoperability of stakeholders. In order to achieve real-time visibility, a strong IT-backbone and data-sharing mechanisms need to be established. Governments should specify clear data-capability requirements when selecting suppliers and logistics providers. Stakeholders should provide timely and accurate data in standardized formats – from sourcing all the way to points of end use, such as testing centers and clinics. In addition, governments should build effective data sharing mechanisms, which address the complexity of supply chains and generate E2E insights on the entire supply chain.

While currently no existing platform covers all visibility needs for a response, multiple data-sharing initiatives have been successful in certain focused areas, leveraging advanced data analytics and blockchain. Ecommerce-led platforms, for example, are able to provide near real-time shipment visibility, smart routing and demand forecasting. Forwarder-led data sharing platforms are able to monitor and predict potential risks, such as volatile transportation, distressed suppliers and other disruptions. Adapting existing solutions to emergency response management could greatly ease some of the challenges experienced in the past months. Shipment visibility, inventory management, demand forecast and disruption monitoring are features that are largely transferable to a public health emergency supply response. By partnering with private sector players, governments can also leverage their established IT-infrastructure and enable these features at scale.

ORGANIZATION AND RESOURCES

The fifth pillar ensures that all plans and tools are implemented effectively. The goal here is to centralize the supply effort – from needs identification to action planning – and facilitate fast, clear and transparent decision-making in a crisis situation. Establishing a specific unit charged with carrying out this effort will help institutionalize the work. Three specific characteristics will allow the unit to work effectively:

Authority. The unit must be positioned in the upper levels of government, so that it is powerful enough to drive the response quickly and efficiently. This includes authorization to make decisions quickly, both ad hoc and based on clear decision-making rules.

Agility. Despite the large number of tasks and stakeholders, as well as the administrative environment, the unit must be agile and unbureaucratic enough to react quickly and independently, e.g. when hiring personnel or deploying funds.

Credibility. To operate effectively, the unit must be fully accepted by (and in good standing with) government and other public sector representatives. The team should consist of prominent agents and practitioners to ensure the participation of relevant stakeholders.

The benefits of a centralized approach include more efficient processes, increased transparency, and minimizing the redundancies and fragmentation associated with traditional procurement processes. It also brings a scale advantage, which is critical in widespread health emergencies.

The following guiding questions can help governments establish a crisis response organization before a public health emergency arises:

Composition. Who are the key members of the crisis response organization, which functions should be represented through experts, and who should be leading the organization?

Communication and logistics. How do members convene offline and online? How is collaboration facilitated? For transparent communication, the technology backbone described earlier can be used to facilitate virtual communication channels between actors.

Decision-making. Which decision-making bodies are in place? How often do they meet? What are their competencies and responsibilities?

Task mandate. Which tasks are pre-defined, and which teams/units within the organization are assigned to each of the predefined tasks? What additional ad hoc responsibilities are there?

Partner structure. How are supply-chain partners incorporated into the organization and which of these partnerships are established ahead of time?

With so much already in place, these response units can quickly transition to “active mode” in the event of a public health emergency. In addition to the crisis unit, other committees may be formed to manage specific aspects of a crisis response. In this case, the function, membership, responsibilities, accountabilities, decision-making and reporting structures of such committees should be defined in advance.

To ensure the overall transparency of the crisis unit and other entities, it is important **to define the key organizational elements in the emergency response plan.** This should include an overview of the organizational structure, its members, necessary personnel and technical resources, as well as infrastructure and logistics. The emergency response plan should also include a chart outlining the crisis organization’s core tasks, such as standardized reporting formats.

CHECKLIST TO APPLY THE PANDEMIC SUPPLY MANAGEMENT FRAMEWORK EXHIBIT 10

Emergency response plan

- **Demand identification:** Define critical product categories and set up demand monitoring and forecast model
- **Sourcing:** Pre-define long and short lists of suppliers for medical supply and logistics services
- **Procurement:** Build up safety stock and secure supply at pre-negotiated prices in advance
- **Inbound logistics:** Select logistics provider in advance based on capabilities
- **Allocation:** Establish efficient collaboration model and allocation principle

Partnership network

- **Public-private partnerships:** Establish three-way agreement between medical supply producers, logistics provider and government
- **Partnerships among governments:** Establish transnational collaboration model

IT-enabled supply chain transparency

- **Data sharing:** Adapt existing solutions to set up a logistics data sharing platform
- **Data collection:** Reinforce timely, accurate and standardized data collection

Physical logistics infrastructure

- **National safety stock:** Build up national safety stock and ensure efficient stock cycling
- **Logistics infrastructure:** Pre-determine logistics partners, supply routes and transportation modes under different scenarios

Institutionalized core unit

- **Task force:** Pre-establish task force with authority, agility and credibility
- **Organization:** Capture key organizational elements in the emergency response plan

The COVID-19 pandemic has brought one long-term goal into focus for all governments around the world: the capacity to successfully weather the next global health crisis. This will require a resilient and adaptive medical equipment supply chain. Success will hinge on the ability of governments to identify and implement both pre-planned and ad hoc measures, forge organizational partnerships, maintain supply and logistics infrastructure, achieve real-time visibility along the supply chain, and establish a core response unit empowered to act swiftly and decisively.

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