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Business Responses to a Pandemic in a Global Economy: Case Studies Detailing the Impact of COVID-19 on Medical Supply Chains

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Thesis Summary

The thesis details the best practices of three multinational medical supply companies in their efforts to overcome supply chain disruptions stemming from the coronavirus pandemic. Following its outbreak in early 2020, the COVID-19 pandemic created an array of disruptions across the business landscape, particularly for medical supply companies with global operations and manufacturing facilities in China. With transportation disruptions, workplace absenteeism, production halts, and surges in demand for medical products, U.S. medical supply companies were unable to rely heavily on China for the manufacturing and sourcing of medical supplies at the beginning of the COVID-19 pandemic, and many American companies found themselves in supply chain crises when COVID-19 hit the United States and domestic demand for medical supplies skyrocketed. The responses of 3M, Becton Dickinson, and Honeywell, three key medical supply companies, to coronavirus disruptions highlight the strengths and weaknesses of their respective supply chains, company cultures, and mitigation strategies and provides insight into what actions medical supply companies will need to make going forward to prevent and reduce supply chain disruptions amidst future global pandemics. Through a series of case studies, this paper highlights how each company was influenced by COVID-19 and how each dealt with and attempted to overcome supply chain disruptions between January and December of 2020. By analyzing the supply chain disruptions and mitigation efforts 3M, Becton Dickinson, and Honeywell, three companies that excelled in their responses to coronavirus supply chain disruptions, we are able to draw conclusions about the most useful pandemic mitigation techniques, namely leveraging technology to increase supply chain visibility, using regional manufacturing models, creating pandemic contingency plans, and expanding current production capabilities. Additionally, we suggest for companies that produce essential products, such as

medical supplies, to ensure that their supply chains don't run too lean and to reconsider manufacturing critical components of products in areas of high political and economic risk. Lastly, we highlight some of the pitfalls of globalization, namely increased supply chain disruptions and the inability to import foreign-made goods during times of global crisis and suggests the possibility for a contraction in the globalization of business or at least an influx in the number of American multinational companies re-establishing domestic facilities to manufacture the nation's most critical products.

Introduction

COVID-19

In December 2019, COVID-19 first appeared in Wuhan, Hubei Province, China when, as epidemiologists theorize, a human possibly came into contact with an infected animal sold at a seafood market (*About COVID-19*, 2020). Dubbed SARS-CoV-2 because it causes acute respiratory syndrome, the virus was categorized as a coronavirus. The disease caused by the virus is known as COronVIrusDisease-2019, or COVID-19 (*Identifying the Source of the Outbreak*, 2020). When contracted, COVID-19 varies both in its level of severity and in the symptoms presented by those infected. In particular, adults 65 years and older and people with underlying medical conditions are at higher risk for developing more severe complications from COVID-19 (*About COVID-19*, 2020). In order to minimize the spread of the potentially deadly and infectious virus and protect those most vulnerable within the population from contracting the disease, communities have relied on a variety of mitigation techniques, including social distancing, mask mandates, event cancellations, and temporary community and business shutdowns.

Following its origination in Wuhan in December 2019, the virus began to spread throughout China and had made its way into other parts of the world by the end of January 2020. On January 20, 2020, coronavirus had spread to Thailand and Japan, and a day later, on January 21, 2020, a resident of Washington state became the first person in the United States with a confirmed COVID-19 case. In the following months, the virus continued to spread rapidly throughout the world, and on March 19, 2020 the novel coronavirus was declared a pandemic by the World Health Organization (Cucinotta & Vanelli, 2020). Throughout 2020, the number of reported coronavirus cases steadily rose, with an estimated 85.2 million confirmed cases and

1.85 million coronavirus-related deaths as of December 31, 2020 (*COVID-19 Map - Johns Hopkins Coronavirus Resource Center*, 2021). With the widespread transmission of the illness came an increase in fearfulness over the disease and broad economic and societal implications.

The impact of the virus can largely be attributed to its threat to public health, the globalization of business, and the interconnectedness of international economies (Paasschen, 2015). Supply chain disruptions have made it difficult for firms to finish their products, consumers have been spending less and staying home, unemployment reached 14%, and economic uncertainty caused from fear of the virus led to a historic 2,997.10-point drop in the DOW Jones Industrial Average on March 16th and an overall decrease in interest rates and stock prices during the summer months (*Prepare Your Supply Chain for Coronavirus.*, 2020)(McCabe et al., 2020). These factors, combined with mass absenteeism in the marketplace and a lack of industry and healthcare resources, have had dangerous implications for the global economy and businesses worldwide (DeCambre, 2020).

Coronavirus in a Globalized Economy

As mentioned previously, the immediate economic shocks and supply chain disruptions felt by the coronavirus pandemic can largely be attributed to the increase in globalization of the world's economy over the past twenty years. The interconnectedness of the world economies and the constant movement of people across the globe allowed COVID-19 to spread more quickly around the world and caused the virus's economic implications to be realized immediately. In addition to the rapid transmission of the virus and the immediate economic impacts, today's globalized economy heightened the severity of the pandemic from a commercial sense.

Economic globalization refers to the increasing interdependence of world economies due to the growth of international trade and the rapid exchange of capital and technologies between

countries (Shangquan, 2000). Multinational corporations have become the leading carriers for economic globalization, organizing global production and sourcing operations to best maximize profits (Shangquan, 2000). In other words, these corporations have shifted much of their production to countries with lower costs of labor and raw materials in order to realize increased profits.

As a result of having a globalized economy, U.S. multinational companies have manufacturing and distribution centers headquartered in emerging market countries, such as India, China, Malaysia, Thailand, and Brazil. Additionally, the United States relies heavily on goods manufactured in those foreign countries, and if supply chain disruptions occur, the United States struggles to make up for lost production. As expected, when COVID-19 emerged in China, which was a hub of production for many American multinational companies, and international trade borders were shut down in the hopes of mitigating the spread of the virus, the United States faced supply chain disruptions and shortages of critical foreign-made items.

Medical Supply Chain Disruptions

Not only did the coronavirus pandemic broadly highlight the potential pitfalls of a globalized economy, but it also explicitly called attention to the risks of having a globalized medical supply industry. The medical supply industry in the United States was significantly influenced by the coronavirus pandemic because it relies heavily on global manufacturers and suppliers, particularly those in China. According to The U.S. Food and Drug Administration, more than 60% of FDA-regulated products imported from China are medical devices (Heyl, 2020). Additionally, U.S. firms have invested more than $800 million in China's medical technology sector over the past 15 years by constructing new manufacturing facilities and

expanding upon existing factories (Heyl, 2020). As a result, the U.S. medical device industry is heavily reliant on China's supply chain infrastructure.

With the countless investments made in China by many multinational companies, China now serves as one of the primary medical supply producers for the U.S. and the world. The Peterson Institute for International Economics reports that China accounts for more than 40% of the world's imports of masks, gloves, goggles, visors, and medical garments, thus positioning China as a critical supplier of the world's medical supplies (O'Keeffe et al., 2020). Additionally, nearly half of all surgical masks, a highly coveted item during the pandemic, are made in China (Kaplan, 2020). The central hub of medical supply production and distribution occurs in Hubei Province, China, which is home to more than 3,451 medical equipment and supply wholesalers, many of which are centered in Wuhan, Hubei's capital (Evans & Hinshaw, 2020; *Medical Equipment & Supply Wholesalers Companies In Wuhan, Hubei, China*, 2021).

As expected, when COVID-19 emerged in Wuhan in December 2019 and later spread throughout China in early January, many medical supply manufacturers in Hubei were forced to halt production, and China's medical supply industry was disrupted. A statement on the extent of the disruption of China's medical supply chains was given on March 13, 2020:

> Contract manufacturers of both components and finished devices in China are struggling to keep plants open and staffed. It has been reported that as a result, the volume of devices being manufactured has dropped. Transportation of these devices is being delayed as flights to/from impacted geographies are canceled. Further, even when products are exported, once those products reach their destinations, concerns regarding

> the source of those goods and even, some reluctance by workers to open boxes that originated in China are triggering delays on import release (Heyl, 2020).

The production and distribution of medical supplies outsourced from China were crippled by a variety of factors. During the months of January and February, there was a decrease in the workforce due to COVID-19-related illnesses, quarantine periods, virus-related deaths, Chinese New Year vacation, and government mandates to temporarily halt work. In conjunction with workforce absenteeism and a temporary halt in factory production, there was a surge in demand for medical supplies throughout China. The Chinese government also mandated that medical supplies produced domestically would be used solely for domestic purposes (Kaplan, 2020). In addition to the surge in domestic demand for medical supplies and a lack of resources to meet the demand, there was also a growing demand for medical supplies by foreign parties as the virus began to spread across the world.

However, even when the Chinese government eventually approved the export of medical supplies, there was a global halt in air travel, one of the two primary forms of transportation for medical devices (Frost & Paper, 2020). Heyl detailed the extent of the transportation issues faced by medical supply exporters at the beginning of 2020:

> In mid-February, it was reported that there are 25,000 fewer flights operated to, from and within China when compared to before the Chinese New Year (January 25, 2020), with 30 airlines halting services completely. England, Singapore, Korea, France, Russia, Japan, Netherlands, Israel, Sweden, and Switzerland all suspended flights. At the same

time, major carriers such as DHL and UPS stated they would not be adding freight flights to take up the lost supply (Heyl, 2020).

The temporary suspension of air travel and the inability of freight flights to take up lost supply led to a decrease in trade around the world and caused many logistical issues for companies attempting to transport medical equipment out of China. Together, mass workplace absenteeism, temporary factory suspension, and the crippling of international transportation during the beginning of the COVID-19 outbreak caused a temporary loss of medical supplies from China.

American medical supply companies had to rely heavily on their domestic facilities and supply chain infrastructures to quickly ramp up production and meet the nation's surge in demand for medical equipment. Like the factories in China, the U.S. was subject to a variety of supply chain disruptions. Domestic facilities had to endure stay-at-home orders, social distancing, shipping delays, and a loss of the workforce due to a general aversion to being in populated areas and quarantine periods. As such, American medical supply companies had to rely on a variety of strategies to overcome supply chain disruptions and meet the demand for their products.

Introduction to Case Analyses of 3M, BD, and Honeywell

Because U.S. medical supply companies were unable to rely heavily on China for the manufacturing and sourcing of medical supplies at the beginning of the COVID-19 pandemic, many American companies found themselves in supply chain crises when COVID-19 hit the United States and domestic demand for medical supplies skyrocketed. The response of key medical supply companies to coronavirus disruptions highlights the strengths and weaknesses of

their respective supply chains, company cultures, and mitigation strategies and provides valuable insight into what actions medical supply companies will need to make going forward to prevent and reduce supply chain disruptions amidst future global pandemics. The paper will highlight how COVID-19 influenced the supply chains of three major American multinational companies, 3M, Becton Dickinson, and Honeywell, and how each dealt with and attempted to overcome supply chain disruptions between January and December of 2020.

We will analyze the supply chain disruptions and mitigation efforts of 3M, Becton Dickinson, and Honeywell because they excelled in their responses to coronavirus supply chain disruptions, they have traditionally supplied much of the U.S.'s medical supplies and equipment, and their items were in high demand during the coronavirus pandemic. For most of 2020, each company also had to rely primarily on domestic production and innovative supply chain practices to meet surges in national demand.

Comparisons of Company Responses to COVID-19 Disruptions

3M, Becton Dickinson, and Honeywell can also be used as benchmarks for how to effectively respond to supply chain disruptions. Through a series of case studies on the three companies, we will uncover how the coronavirus pandemic influenced each supply chain, the unique mitigation strategies employed by each company, and the commonalities among their mitigation approaches. The comparisons of the company responses to COVID-19 disruptions will provide crucial insight into actions multinational companies can take to protect themselves from significant supply chain disruptions in the future.

The tables below summarize the most notable supply chain disruptions faced by each company, namely transportation disruptions, workplace absenteeism/production halts, and demand surges, and detail the unique ways in which each company leveraged technology, pre-

existing supply chain strengths, regional manufacturing models, pandemic contingency plans, and built-in surge capacity, among other strategies, to react quickly to changes in supply and demand and adjust their supply chains to better accommodate market changes. These key insights will also be discussed in more detail in the case study section for each company.

Exhibit 1 focuses on 3M, Honeywell, and BD's responses to transportation disruptions stemming from the Chinese government's export halt, the suspension of global aviation, and the resulting inability to easily transport goods across international trade borders. Because of the numerous pandemic-induced transportation disruptions, the firms had trouble exporting and delivering supplies on time and importing sourced components and had to employ a variety of tactics to ensure the continuity of their operations.

Exhibit 1: Comparison of Company Responses to Transportation Disruptions

Response	**Results**		
	3M	**Honeywell**	**BD**
Regional manufacturing model	3M circumvented many material shortages, export bans, and trans-continental transportation issues	A semi-deployed regional model helped Honeywell bypass many transcontinental transportation disruptions and easily plan for regional production facilities to ramp up.	BD avoided many internal supply shortages and ramped up production to meet the surge in demand for its products.
Supply chain technology system	Using ERP, 3M mapped alternative suppliers and alternative forms of material and product transportation prior to pandemic and then utilized these alternates when faced with disruptions.	The tactical operations center combined an integrated supply chain team and data analytics to track real-time data about material shortages, transportation disruptions, and supplier vacancies, allowing the company to quickly seek out new suppliers and find alternative	BD's digitally integrated supply chain and control tower allowed BD to monitor and flag logistics issues.

Response	Results		
	3M	**Honeywell**	**BD**
		transportation modes when needed.	
Sourcing strategy	By producing base materials in-house, 3M faced fewer production halts stemming from a lack of critical mask components like non-woven polypropylene, which was in short supply during the pandemic.	-------	Prior to the pandemic, BD's Global Procurement team created a domestic and global pandemic plan, identified alternate suppliers, and practiced routine risk monitoring. BD relied on these actions to anticipate disruptions, create prepared responses to logistic disruptions, and alternate suppliers when material shortages occurred.

Each company also faced workplace absenteeism and production halts due to temporary factory closures, social distancing, and fear of coronavirus. During 2020, the three firms and their suppliers had trouble maintaining their internal processes and quickly ramping up production and, as highlighted in Exhibit 2, struggled to utilize a variety of mitigation tactics to overcome labor and production disruptions.

Exhibit 2: Comparison of Company Responses to Workplace Absenteeism/Production Halts

Response	Results		
	3M	**Honeywell**	**BD**
Supply chain technology system	-------	As the outbreak evolved, Honeywell used its tactical operations center to continuously monitor its suppliers to ensure they remained operational and provided support to help them reopen if they experienced temporary closures.	-------
Endure	3M had to weather this issue and ramp up production as soon as the company was able.	Honeywell had to weather this issue and ramp up production as soon as the company was able.	BD had to weather this issue and ramp up production as soon as the company was able.

Each firm also faced surges in demand for pandemic preparedness supplies. Widespread safety precautions and a desire to limit transmission of the virus created a demand surge for N95 masks produced by 3M and Honeywell, and the anticipation of a COVID-19 vaccine created a surge in demand for BD's vaccine syringes. The U.S. relied on 3M and Honeywell to meet its demand for 300 million N95 masks per month, and it called for BD, one of the largest producers of syringes, to meet its demand for 850M additional syringes by the end of 2020. Because of the surge in demand for their products, the three companies had to rely on a variety of strategies, highlighted in Exhibit 3, to ramp up production and supply the nation with much-needed pandemic preparedness supplies.

Exhibit 3: Comparison of Company Responses to Demand Surges

Response	**Results**		
	3M	**Honeywell**	**BD**
Agile and flexible supply chain	3M's transformation capacity and vertically integrated manufacturing allowed the company to control most of its production process, make alterations in supply chain practices when new disruptions arose, and quickly adjust inventory.	Honeywell condensed sales, inventory, and operations planning process to weekly cycles in order to sense demand changes and quickly realign inventory and production schedules. Robotic fulfillment centers allowed Honeywell to make quick switches in production and efficiently handle large influxes in production and distribution of masks.	Past experience with pandemics and inflexible supply chains inspired BD to maintain enough inventory to ensure it could meet surges in demand. Adequate inventory allowed BD to avoid a more severe syringe shortage.
Surge capacity	Idle machinery, dormant factory lines, alert suppliers, and emergency teams were in place prior to the pandemic and were used to increase	-------	-------

Response	Results		
	3M	**Honeywell**	**BD**
	production levels when demand increased.		
Online ordering platform	-------	Honeywell launched e-commerce websites for items in high demand during the pandemic to enable customers to receive product information and place orders quickly and efficiently.	-------
Digitalization and heightened visibility in supply chain	3M's geometric network, supply chain mapping, and digital infrastructure allowed the company to quickly adjust production, monitor inventory, and respond to disruptions in its supply chain.	Honeywell's cloud software, industrial IoT, machine learning data analytics, and autonomous systems allowed for end-to-end visibility and helped Honeywell optimize its inventory positions and communicate more quickly and accurately with customers about orders.	Digitalization via Microsoft's Azure Cloud tool inspired agility and visibility, allowing BD to view its entire supply chain in real-time and from one central location and quickly resolve over-supply, backorders, and supply chain disruptions through the collaboration of its global facilities.
Factory expansions	The expansion of 3M's Aberdeen, SD plant in May 2020 allowed 3M to increase domestic production to 95M N95 masks per month by the end of 2020.	The new N95 production line at its Smithfield, RI factory, and Honeywell Aerospace in Phoenix, AZ allowed the company to produce 20M more masks per month.	Factory expansions in the Columbus-West and Holdrege facilities in Nebraska and the addition of 350M units of manufacturing capacity for glass barrel pre-fillable syringes allowed BD to commit over 800M syringes to COVID-19 vaccine campaigns globally.

A Case Study of 3M Company

3M Company

Because of the usefulness of N95 masks in preventing the spread of disease and the large volume of masks it manufactures, the COVID-19 pandemic greatly influenced 3M. 3M Company, formerly known as Minnesota Mining and Manufacturing Company, is a diversified American manufacturer of a wide range of products, including abrasives, adhesives, tapes, office supplies, and health care products (*3M: Science. Applied to Life.*, 2020). Most notably, 3M is one of the largest suppliers of personal protective equipment, and it serves as one of the few critical suppliers of N95 masks for the United States.

Headquartered in St. Paul, Minnesota, 3M has a strong global presence, with more than 100 manufacturing plants worldwide, nine of which are located in mainland China (Shafer, 2017). Out of its many production facilities, 3M produces N95 masks in China, Singapore, Europe, Latin America, Aberdeen, South Dakota, and Valley, Nebraska.

As a successful global Fortune 500 company, 3M is known for its highly innovative culture and desire to promote profitability in the short term and in the future. These qualities have allowed the company to remain successful throughout its one hundred and nineteen years of business and overcome global crises, such as the COVID-19 pandemic (Govindarajan & Srinivas, 2013). The following pages will discuss how 3M's dedication to maintaining these ideas and its pre-existing supply chain strengths aided the company in creating an effective pandemic mitigation strategy and ultimately enabled the company to overcome supply chain disruptions caused by the COVID-19 pandemic, with regards to mask production.

An Overview of 3M's Supply Chain Before COVID-19

Because of its global reach, 3M has a large and complicated supply chain. A $30 billion multinational company, 3M operates a global supply chain that includes roughly 200 manufacturing plants, 100 warehouses, and 25 customer-facing divisions (Banker, 2017). Although complex and extensive, 3M's supply chain has consistently been considered one of the best supply chains worldwide.

In 2019, 3M was ranked #17 in Gartner's "The Supply Chain Top 25". Gartner's ranking for 2019 was based on three factors: personalization at scale, leveraging ecosystems, and business-led digital strategies (Griswold et al., 2019). Listed as one of the top 25 supply chains in the world, 3M was commended for excelling in these areas and for its supply chain's "demonstration of demand-driven leadership and Corporate Social Responsibility" (Griswold et al., 2019). More specifically, Gartner highlighted how 3M has been working on "leveraging its supply chain center of excellence (COE), driving scale in operations, reducing manufacturing locations and investing in disruptive manufacturing technologies" to generate company growth (Griswold et al., 2019). The company's investments in data science and analytics have also been working to increase its point of sale demand generation (Griswold et al., 2019).

3M's supply chain strength also stems from the strategies it uses to mitigate risk in volatile markets. The company has significant holdings in countries with high political and economic risk, such as Brazil and China, but employs supply chain risk management practices to mitigate the risk of supply chain disruptions in these countries (DiPietro, 2017). Their mitigation techniques include focusing on systems and processes of continuous improvement, diversifying portfolio and geographic breadth, and controlling its own assets (DiPietro, 2017).

3M diversifies its geographic breadth to protect against supply chain risk through its regional for regional model for manufacturing and sourcing. Under this model, 3M "sources materials from the area near its assembly plants and serves customers reasonably close by" (Gruley & Clough, 2020). This strategy not only explains why 3M has hundreds of manufacturing plants around the world, but it also demonstrates the company's efforts to minimize the risks derived from relying on distant vendors, which can be subject to tariffs, export bans, long-distance shipping problems, and shortages.

3M is also able to defend itself from operational risk by controlling its assets through the vertical integration of its supply chain. 3M conducts the majority of its operations in-house (Roman & McGranahan, 2020). As such, it is responsible for manufacturing and producing most of its base and raw materials. For example, in 2017, 85% of the items sold by 3M were manufactured in a 3M facility (DiPietro, 2017). By bringing many of its previously outsourced operations in-house and controlling the production of raw and base materials, 3M has "greater control over its production processes," "information flows more freely," and it has "greater flexibility in adapting to changes in demand"(*Vertical Integration: Bringing in Previously Outsourced Operations in-House*, 2020). The increase in control of its operations allows 3M to better prepare for and mitigate supply chain risk because 3M can quickly adjust its inventory to better meet changing customer demand, and 3M is not reliant on a multitude of intermediary suppliers throughout its manufacturing process. In other words, 3M has a secure availability of materials to produce its products and is less vulnerable to those materials becoming more expensive or difficult to obtain during critical times.

Not surprisingly, when COVID-19 struck 3M's facilities in China in late 2019/early 2020, 3M relied heavily on these built-in supply chain mitigation strategies to overcome its

supply chain disruptions and continue to provide customers with critical personal protective equipment, specifically the highly sought-after N95 masks.

COVID-19's Impact on 3M's Supply Chain

As mentioned previously, China produces half of the world's supply of face masks. When COVID-19 rapidly spread throughout China, the Chinese government halted all exports of PPE and N95 masks and demanded in-country manufacturers, like 3M, to ramp up production to meet the domestic demand for these materials (Gruley & Clough, 2020, p. 3). However, as COVID-19 matriculated out of China and the number of cases increased worldwide, shortages of N95 masks and PPE began to appear around the world, and the U.S. called for 3M to meet the surge in national demand.

Prior to COVID-19, 3M produced N95 masks at a global rate of roughly 50 million per month or 500 million per year. Of these 50 million masks produced per month, 22 million were produced in the U.S. (*3M and Trump Administration Announce Plan to Import 166.5 Million Additional Respirators into the United States over the next Three Months*, 2020; *3M Named Supplier of the Year by Supply Chain Dive*, 2020). When COVID-19 reached pandemic levels within the United States, 3M needed to quickly increase its production levels to meet the 300 million per month that public health officials estimated were needed to fight the pandemic in the United States (Hufford, 2020).

Not only did Chinese government mandates initially prevent 3M from producing large quantities of masks to be exported to the United States, but the panic surrounding the disease also resulted in the temporary suspension of China's aviation industry (Heyl, 2020). With fewer planes available to ship equipment abroad and fewer goods available to be shipped, 3M and its United States distributors were faced with a mask shortage (O'Keeffe & Lin, 2020).

3M also faced supply chain disruptions from shortages in globally sourced mask materials. Although 3M produces most of its raw and base materials in-house, some components of N95 masks and protective equipment, such as straps and metal nose clips, are made and imported from 3M factories abroad (Esposito, 2020; Plume, 2020). Therefore, when air travel was suspended, exports were restricted, and demand for personal protective equipment to fend off the virus surged, on-shore 3M factories struggled to acquire all the necessary components to ramp up production of N95 masks in the United States. Coupled with the fact that 3M was one of only a few suppliers of N95 masks for the United States, 3M assumed a huge burden to meet demand.

3M's Response to Supply Chain Disruptions

In order to meet the surge in demand for its N95 masks, 3M relied on its domestic factories and pre-existing supply chain infrastructure to meet the nation's demand for N95 masks. More specifically, 3M relied on the flexibility of its supply chain, its regional model of manufacturing and sourcing, commitment to digitalization, built-in surge capacity, and facility expansions to respond to and overcome supply chain disruptions caused by COVID-19.

3M's flexible and top-ranked supply chain enabled the company to have a fast and prepared response to the coronavirus pandemic. In May 2020, 3M's Chairman and CEO, Mike Roman, remarked that 3M's strengths in handling the crisis had been its transformation capacity and vertically integrated manufacturing, which have allowed the company to adjust inventory and to do so quickly (Roman & McGranahan, 2020). 3M's flexible supply chain capabilities helped the company respond quickly to rapid changes in demand and tweak its production planning as necessary in order to meet as much demand as possible.

In addition, 3M's regional for regional model of manufacturing and sourcing also aided the company in its response to the coronavirus pandemic because it could devote its factories to serving customers only within the immediate vicinity. In May 2020, Mike Roman mentioned how the regional model benefited the company in the wake of coronavirus, stating that 3M "invested in manufacturing in China to serve customers in China, not to export out of China"(Roman & McGranahan, 2020). He went on to remark, "The large majority of what we sell in China is what we produced in China for that marketplace"(Roman & McGranahan, 2020). When coronavirus hit China in late 2019, 3M's ability to supply global customers with N95 masks and PPE was not irreversibly hindered. 3M was able to devote its factories in China to serving its Chinese customer base and devote its fleet of N95 manufacturing facilities located outside of China to meeting the needs of its customers in the United States and the rest of the world. In order to combat shortages in globally sourced mask materials, 3M also employed its regional for regional model to source materials from regional suppliers instead of far-off locations (*3M Taps Regional Suppliers to Meet Soaring Demand for Masks*, 2020).

3M also avoided many of the supply chain disruptions faced by other medical supply companies because it produced most base materials for N95 masks in-house. For example, nonwoven polypropylene, a critical component of N95 masks, was in short supply during the height of coronavirus. Unlike companies such as Medicom, who relied on outside suppliers to provide the material, 3M produced sheets of nonwoven polypropylene fabric in several of its own factories—a part of its vertically integrated supply chain (Hufford & Evans, 2020). When the demand for N95 masks skyrocketed and nonwomen polypropylene was in short supply, 3M was mostly immune to the shortage (Hufford & Evans, 2020).

Over the past few years, 3M has demonstrated its commitment to innovation by digitalizing its supply chain, and its effort to modernize and digitalize its supply chain ultimately helped the company mitigate and manage coronavirus-related supply chain disruptions. Striving to promote the timely facilitation of accurate information across its supply chain, 3M created a "geometric network." The network connects the factories of critical suppliers with 3M factories and allows for direct communication between individual systems (Banker, 2017). For example, the geometric network created with one of 3M's largest chemical suppliers, BASF, allows for BASF to see 3M's consumption of materials and for 3M to see BASF's upstream production (Banker, 2017). This type of communication, essentially supply chain mapping, allows for engagement across companies and suppliers and allows the parties involved "to document the exact source of every material, every process, and every shipment involved in bringing goods to market" (*What Is Supply Chain Mapping?*, 2015).

Not only did 3M implement supply chain mapping during its digital revolution, but it also gained access to critical point of sale data "on how their products are selling and how much inventory resides in different portions of a retailer's network," further enhancing the company's ability to collect and interpret important supply and operational data (Banker, 2017). 3M's innovative supply chain mapping and digital infrastructure played a vital role in 3M's response to the COVID-19 pandemic. The digitalization of its supply chain and the company's access to critical data provided crucial intel that allowed the company to quickly adjust production, monitor inventory, and respond to disruptions in its supply chain infrastructure. Ultimately, these capabilities enabled 3M to minimize supply chain disruptions in order to meet the high demand for N95 masks and PPE during the peak of the pandemic.

Another significant piece of 3M's digital transformation was the implementation of its new global operating model and streamlined structure in April 2019. The new global operating model's optimization and improvement of existing supply chain processes and effective use of data to inform decision making across the supply chain improved the company's growth and operational efficiency (*3M Accelerates Pace of Transformation Journey*, 2020). Under the new model, 3M established supply chain "Centers of Excellence" around the world. The Centers of Excellence consolidated and managed 3M's supply chain with a regional focus rather than country by country, aiding the company in developing its regional manufacturing and distributing model. In addition, the Centers of Excellence allowed for increased visibility and therefore better management of distribution channels and manufacturing activities and enabled the company to minimize working capital requirements, overhead costs, and tax rates. (*M&A, R&D, Centers Of Excellence Are Key Growth Drivers for 3M*, 2015).

3M also implemented Enterprise Resource Planning initiatives within each region of service to maximize production and efficiency (*M&A, R&D, Centers Of Excellence Are Key Growth Drivers for 3M*, 2015). Under the Enterprise Resource Planning initiative, 3M mapped alternative suppliers and alternative forms of material and product transportation prior to the COVID-19 pandemic. When the pandemic began and 3M was faced with many supply chain disruptions, it was able to reevaluate its global supply chains and adjust its practices to best minimize operational strain and meet the growing demand for products worldwide. In other words, the Enterprise Resource Planning initiative helped 3M source enough raw materials to meet its increased order volume and employ alternative transportation methods for its products when necessary.

3M also used surge capacity to overcome supply chain disruptions and increase its production of N95 masks amid the coronavirus outbreak. Aware of its position as an irreplaceable supplier of medical equipment, 3M had been planning and preparing for a crisis situation like the COVID-19 pandemic for several years. Recent medical crises such as SARS, H1N1, and Ebola exposed the company's inadequate response strategy and small production capacity in the time of medical crisis (Roman & McGranahan, 2020). Following the SARS pandemic of 2003, "the company realized it wasn't fully equipped to handle unexpected explosions of demand in the event of a crisis, or what it calls an 'X factor'" and decided to build surge capacity into its N95 respirator factories worldwide (Gruley & Clough, 2020). It "added assembly lines that would stay dormant until needed, suppliers were put on alert, and emergency response teams were assembled to leap into action whenever catastrophe beckoned" (Gruley & Clough, 2020). The crises that succeeded the SARS pandemic (2003), H1N1 pandemic (2009), Ebola panic (2014), and natural disasters that followed allowed the company to test and refine its emergency response.

In a press conference held in May of 2020, 3M's Chairman and CEO, Mike Roman, explained how the company relied on its past experience to battle coronavirus. He stated, "3M invested in capacity to be ready for next pandemic and to have idle capacity in PPE and have it regionally capable in order to serve demands around the world" (Roman & McGranahan, 2020). Between the months of January and April, 3M used its idle machinery and built-in surge capacity to double global N95 mask production to 100 million per month and ramp up domestic mask production to 35 million per month in the United States (Roman & McGranahan, 2020).

In May of 2020, the company also expanded its manufacturing capacity in the United States, adding 120,000 square feet of manufacturing lines and automated equipment to its

Aberdeen, South Dakota plant. The expansion of the Aberdeen plant helped 3M ramp up its monthly N95 production to 95 million per month at the end of 2020. Together, 3M's surge capacity and plant expansion aided the company in its efforts to quickly ramp up domestic production and begin to meet the nation's surge in demand for N95 masks.

Overall, 3M's flexible pre-existing supply chain infrastructure, regional model for manufacturing and sourcing, commitment to digitalization, built-in surge capacity, and plant expansions helped 3M overcome its reliance on supplemental N95 mask production from China and pandemic-induced supply chain disruptions.

Results & Concluding Remarks

Although 3M faced numerous disruptions and operational setbacks at the beginning of the COVID-19 pandemic, it was able to quickly and effectively overcome pandemic-induced supply chain disruptions. 3M's regional for regional model for manufacturing, vertically integrated supply chain, supply chain mapping, digital infrastructure, and idle machinery not only attested to its innovative culture and foresight but also allowed the company to better meet domestic demand for N95 masks. Beginning in January 2020, 3M utilized surge capacity to ramp up its production of N95 respirators, double its global output to 1.1 billion a year, and increase its domestic output to 35 million a month within three months. 3M also invested in additional assembly lines, robots, and factory labor in order to produce over 2 billion N95 respirators globally by the end of 2020 (*How We're Helping Fight the Pandemic*, 2020). Additionally, once the Chinese government lifted its export ban and international shipping restrictions were lifted, 3M was able to export 228.4 million additional N95 masks, 166.5 million of which came from China to the United States (*3M and Trump Administration Announce Plan to Import 166.5*

Million Additional Respirators into the United States over the next Three Months, 2020; *3M Named Supplier of the Year by Supply Chain Dive*, 2020).

A further testament to its successful mitigation strategy, 3M was also one of three companies to participate in a $133 million contract with the federal government. In mid-April of 2020, 3M was contracted to produce 13 million N95 masks over the course of three months in an effort to eliminate the nation's reliance on foreign supply. Out of the three companies, 3M received the largest contract for $76 million (Tiron, 2020). In December 2020, Supply Chain Dive also named 3M "Supplier of the Year" for its pre-pandemic surge capacity and real-time visibility, which allowed the company to manufacture and distribute medical supplies in a time of unprecedented demand (Kapadia, 2020).

Over the course of 2020, 3M not only overcame major supply disruptions to increase mask production, but it also increased the production of other products, including hand sanitizers, disinfectants, and filtration products, to contain the spread of COVID-19 (Kapadia, 2020). Ultimately, because 3M was proactive in preparing for potential medical crises and embodied its company values of innovation, growth, and digitalization, it was able to fight competitively against the global supply chain disruptions in the U.S. and export-dependent China and continue to provide value to customers worldwide.

A Case Study of Becton, Dickinson and Company

Becton, Dickinson and Company

Becton, Dickinson and Company, commonly known as BD, also played a vital role in supplying the nation with critical medical supplies during the COVID-19 pandemic. BD is a global medical technology company involved in the development, manufacture, and sale of a broad range of medical supplies, devices, laboratory equipment, and diagnostic products (*Becton Dickinson and Co*, 2020). A Fortune 500 Company with annual revenues of more than $17 billion, BD manufactures and supplies a broad range of medical products for the United States, including swabs, vials, syringes, needles, reagents, and testing kits (Reiss, 2020). Headquartered in Franklin Lakes, NJ, BD is also a global company with locations in more than 50 countries around the world and facilities in Suzhou and Shanghai, China (*BD Statement on COVID-19 (Coronavirus)*, 2020).

When COVID-19 emerged in China in December 2019 and spread throughout the world, BD was faced with supply chain disruptions and growing demand for nearly all of its medical products, in particular syringes, which would be needed to administer COVID-19 vaccines. Prior to the pandemic, five companies made up the majority of the U.S. syringe market, manufacturing roughly 663 million syringes (used only for vaccinations) a year. Of the five companies supplying the nation with vaccine syringes, BD manufactured 58% of the 663 million syringes used in the U.S. each year (Glenza, 2020). When the coronavirus pandemic emerged in early 2020, and the healthcare industry began to anticipate a future vaccine, the nation relied on BD, the largest producer of needles and syringes, to provide an ample supply of this critical medical product. The company, therefore, had to utilize its pre-existing supply chain strengths and

employ a variety of additional mitigation techniques to meet the nation's surge in demand for syringes.

An Overview of BD's Supply Chain Before COVID-19

As a medical technology company that produces a wide array of products, BD relies on an network of over 360 global facilities to manufacture and distribute its products. This subsection details how BD uses continuous improvement, digitalization, a highly specialized global procurement team, and a regional model of manufacturing and distributing to efficiently and effectively run its global supply chain.

Based on the idea of continuous improvement, BD employs lean and waste reduction measures, such as Six Sigma. However, it limits these principles to ensure the company can withstand unpredictable surges in demand. Many companies within the medical industry feel pressured to reduce inventory in order to minimize costs and lose flexibility within their manufacturing operations ("Gaps in the Global Medical Supply Chain," 2018). Unlike many of its competitors, BD recognizes that these inflexible, highly lean supply chains are threatened by surges in demand and phantom demand and likely will not be able to withstand unpredictable disruptions. BD is not blindly committed to lean and waste reduction measures and instead maintains enough inventory to ensure the company can meet surges in demand. The company's past experiences with an inflexible supply chain and subsequent struggle to meet demand during the H1N1 pandemic and natural disasters that followed forced BD to increase its inventory's flexibility ("Gaps in the Global Medical Supply Chain," 2018). To do so, the company has spent the last decade focusing on "improving information sharing, coordination, and communication across the supply chain" ("Gaps in the Global Medical Supply Chain," 2018).

In order to improve its information sharing, communication, and coordination, BD built a highly ranked agile supply chain equipped with state-of-the-art digital technology. In 2019, Gartner ranked BD's supply chain as the 12th best medical supply chain for its emphasis on agility and digitalization (*Gartner Announces Rankings of Its 2019 Healthcare Supply Chain Top 25*, 2019). The company's agile supply chain is able to "quickly respond to changes in both customer demand and supply sources, without incurring extra costs or penalties," and it allows the company to insulate customers from supply disruptions and harness control over demand spikes (O'Daffer et al., 2019).

BD uses digital technology to improve its agility, information sharing, and coordination with customers' supply chains. For example, the company recently partnered with Microsoft and began using Microsoft's Azure cloud tool. Microsoft Azure allows the company to organize and process large amounts of data to make population-based health decisions (Rogan, 2018), and it ultimately enhances BD's medication management solutions for customers by monitoring product usage and inventory levels (O'Daffer et al., 2019). BD also recently implemented a highly technical supply chain control tower. The system collects product and supplier data in order to provide visibility across its supply chain, help the company react quickly to influxes in demand, and reroute products to areas of insufficient supply (Banker, 2020a). As discussed in a later subsection, the heightened visibility of its supply chain allows BD to view its entire supply chain in real-time and from one central location and quickly resolve over-supply, backorders, and supply chain disruptions through the collaboration of its global facilities. Together, BD's Microsoft Azure software and control tower provide data and visibility to help the company react quickly and effectively to supply chain disruptions and changes in demand. Ultimately, these

digital technologies proved to be useful during the coronavirus pandemic when BD faced innumerable disruptions and growing demand for its medical products.

BD also has a strong "BD Global Procurement" division that aids the company in the supplier selection process. BD Global Procurement employs the BuySmart buying platform to "buy indirect goods and services, receive and process invoices, and offer visibility for suppliers and stakeholders into the status of their transactions" (*BD Global Procurement*, 2020). BD Global Procurement is useful because it tweaks BD's supply chain strategy for each region based on its knowledge of the external market, industry trends, and government regulations. It develops mitigation plans for areas of high political and economic risk (*BD Global Procurement*, 2020). As discussed in a later section, BD's Global Procurement Division was responsible for BD's global and domestic pandemic planning and played an important role in helping the company overcome COVID-19 supply chain disruptions.

Like 3M, BD also operates primarily under a regional for regional model for manufacturing and distributing. In other words, its facilities in the United States mostly produce products for the U.S. market, and its facilities in other areas of the world primarily produce products for their respective domestic markets. However, not all of BD's products and raw materials are regionally manufactured and sourced. For example, BD's Veritor products, which provide rapid immunoassay test results for healthcare providers, were manufactured in China and exported to the U.S. prior to the COVID-19 pandemic (Stein, 2020). BD also has key suppliers in China that provide raw materials and components for BD manufacturing plants around the world. When coronavirus emerged in China in early 2020, BD's regional model for manufacturing and distributing helped the company avoid many internal supply shortages and ramp up production to meet the surge in demand for its products.

When COVID-19 hit BD's facilities in China at the end of 2019 and later reached pandemic levels in the United States, BD relied on its preexisting flexibility, award-winning agility and digital technology, global procurement team, and regional supply chain model to mitigate disruptions and continue to provide customers around the world with syringes and needles.

COVID-19's Impact on BD's Supply Chain

When COVID-19 emerged in China at the end of 2019 and reached pandemic levels as it spread throughout the globe, it influenced BD's global operations. BD has over 360 global facilities to manufacture and distribute its products, including manufacturing facilities in the United States, China, Europe, South America, and other parts of Greater Asia. Operating under a regional for regional model for manufacturing and distributing, most facilities manufacture products to serve their domestic markets or the markets of regions within close proximity. There are a few exceptions, though. BD's Veritor products, which provide rapid immunoassay test results for healthcare providers, are manufactured in China and exported to the U.S., and BD has key suppliers in China that provide raw materials and components to BD manufacturing plants around the world (*BD Statement on Coronavirus*, 2020).

When the virus emerged in China in early 2020, BD temporarily shut down its Chinese operations until late February in order to prevent the virus from spreading. Because of its regional model for manufacturing and distribution, many of BD's inventory levels around the globe were unaffected. However, products that were produced in China or relied on materials sourced from China were at risk. Fortunately, because it operated under a regional model of manufacturing and distributing, BD manufactured syringes in Columbus, Nebraska, Cuautitlán, Mexico, Fukushima, Japan, Le Pont-de-Claix, France, Swindon, United Kingdom, and

Tatabánya, Hungary prior to the COVID-19 outbreak and was able to devote these facilities to serving their local markets during the pandemic (*BD to Invest $1.2 Billion in Pre-Fillable Syringe Manufacturing Capacity Over Next Four Years*, 2020).

Although, when BD wanted to begin ramping up production of syringes in the United States in preparation for a COVID-19 vaccine, it was faced with several disruptions. At the beginning of the pandemic, BD was faced with social distancing measures, stay-at-home orders, shipping delays, and workforce absenteeism due to quarantine periods. As communities began to open back up during the summer months, BD also lacked the production capacity to fully meet the nation's demand to deliver enough Covid-19 vaccines en masse.

Prior to the outbreak of coronavirus, BD and the other four major syringe manufacturers in the United States were producing a total of 663 million syringes (intended only for vaccinations) per year, with BD manufacturing 58% of the nation's annual syringe volume (Stein, 2020). According to Peter Navarro, the White House director of trade and manufacturing policy, an estimated 850M additional needles and syringes would be required to deliver a vaccine and reach herd immunity in the United States, and as of May 7, 2020, the Strategic National Stockpile had only 15 million needles and syringes (Glenza, 2020). At the annual production rate of 663 million syringes, it would take two years of manufacturing to produce the necessary number of syringes required to reach herd immunity and continue to deliver routine vaccinations.

In addition to the nation's pressing need for syringes, BD also received orders for syringes from many other countries. In 2020, BD received orders for more than 800 million syringes from governments around the world. The U.S. government, for example, placed orders

for 286 million needles and syringes from BD, with 256 million to be supplied by January 2021 (*Pellets to Pallets to Patients: Delivering Injection Devices for COVID-19 Vaccinations*, 2020).

In order to meet the world's demand for syringes, BD needed to increase its production levels and had to employ a variety of mitigation techniques to meet the nation's surge in demand while still providing enough syringes for ongoing patient needs, such as childhood immunizations and annual flu vaccines. Faced with the supply chain disruptions discussed above and a growing need for its critical syringes, BD relied on several supply chain mitigation techniques to overcome operational hurdles and meet customer demand.

BD's Response to Supply Chain Disruptions

In order to meet the surge in syringe demand, BD relied on its pre-existing supply chain infrastructure as well as digital technology, proactive planning, and the expansion of its domestic facilities to increase its syringe production and overcome supply chain disruptions caused by COVID-19.

BD used its digitally integrated supply chain to generate flexible, fast responses and quick fixes to the disruptions caused by the COVID-19 pandemic. Eric Miller, BD's Senior Director of Global Logistics Solutions and Optimization, spoke about BD's implementation of its global control tower to combat what Miller called the "largest supply chain disruption in history" (Banker, 2020a). BD's control tower "integrates planning with logistics data, has real-time visibility to important supply chain events across the end to end supply chain, and provides playbooks and situation rooms for problem resolution" (Banker, 2020b). Specifically, BD collects data from its suppliers and customers regarding sales orders, shipments, inventory, and lanes, and it uses built-in key performance indicators to monitor performance and identify issues across its supply chain. The control tower relies on these amounts of data to provide adequate

intel to supply chain analysts and create visibility from BD plant to BD distribution center, from BD warehouse to customer, and from supplier shipments within BD facilities and internal manufacturing processes (Banker, 2020b).

The highly technological control tower was one of BD's greatest assets when mitigating coronavirus supply chain disruptions. The end-to-end visibility across BD's supply chain permitted the company to easily monitor its global logistics and transportation network, inventory, and customer ordering during the pandemic, a period of high product demand and stringent supply (Banker, 2020a). Additionally, the tower allowed BD to place at-risk items on order review to prevent hoarding behavior and to place manual inventory allocation on items of high demand such as swabs, vials, prepackaged kits, reagents, COVID-19 tests, point of care testing portfolio, vascular access and injection-related products, infusion sets, and infusion pumps (Banker, 2020a)(*BD Statement on COVID-19 (Coronavirus)*, 2020). Lastly, BD's control tower helped the company redirect resources in short supply to other manufacturing areas with ample supply or capacity. Together, these capabilities enabled BD to account for gaps in production and quickly respond to and recover from a variety of pandemic-induced supply chain mishaps. Overall, the control tower was one of BD's greatest assets when fighting the pandemic because it allowed BD to access real-time information, maintain a high level of customer service, and provide quicker, more beneficial solutions to over-supply, backorders, and supply disruptions (Banker, 2020a).

BD also employed preexisting mitigation strategies to battle coronavirus supply chain disruptions. Before the advent of the coronavirus pandemic, the company had teams in place, such as the BD Global Procurement division, that were responsible for BD's domestic and global pandemic planning. The teams were proactive in protecting the company prior to the pandemic,

and they developed mitigation strategies based on market trends and past pandemics ("Gaps in the Global Medical Supply Chain," 2018). For example, Brad Noe, who is responsible for BD's needle and syringe pandemic planning, sought out potential risks for BD's needle and syringe business and developed precautionary measures and mitigation strategies to minimize the chance of disruptions occurring in the event of a pandemic. Noe stated that because the company recognized the risk in the common trend of consolidating raw materials suppliers, "BD is increasingly purchasing its raw materials from multiple sources when possible, and avoiding sources located in politically or otherwise unstable regions"("Gaps in the Global Medical Supply Chain," 2018).

He continued, discussing how the company also realized the importance of limiting the supply chain risks associated with marketplace constrictions and consolidation of industries in areas like China, which produces most of the world's PPE and medical supplies. In order to mitigate this risk, BD "continually seeks new suppliers, a costly effort, consuming about half of the company's budget for research and development" ("Gaps in the Global Medical Supply Chain," 2018). In other words, BD routinely monitors the levels of risk associated with its suppliers and reevaluates whether it is in the company's best interest to continue sourcing materials from those suppliers. BD's actions embody the common supply chain risk management theory, risk monitoring. According to a journal article published in the *International Journal of Physical Distribution & Logistics Management*, supply chain risk, which in this case is derived from suppliers, "needs to be continuously monitored to evaluate how risk sources are developing and if any changes to the treatment strategies need to be applied" (Fan & Stevenson, 2018). Although costly, BD's precautionary, routine monitoring came in handy when COVID-19 emerged. These measures allowed the company to easily anticipate the disruptions that would

occur as the virus spread and helped the company quickly secure alternative suppliers of raw materials for their most sought-after products like syringes (*BD Statement on COVID-19 (Coronavirus)*, 2020).

BD also used supply chain agility stemming from the recent expansions of its U.S. facilities to respond more quickly to influxes in demand, shield customers from supply chain disruptions, and quickly increase its production levels of syringes during 2020 (Reiss, 2020). BD's Columbus-West facility located in Columbus, Nebraska is the company's flagship needle and syringe facility. When COVID-19 reached pandemic levels, and BD realized it would need to increase its production levels of needles and syringes, the company relied on this facility to meet the nation's needs for more syringes. As such, it ramped up production in its Columbus-West facility, operating around-the-clock to produce syringes, at the beginning of 2020. On July 8, 2020, BD announced a $70 million expansion of its Columbus-West and Holdrege facilities in order to better meet the nation's demand for syringes (*BD Receives Additional Orders For 177 Million Injection Devices For U.S., Canada COVID-19 Vaccine Preparations*, 2020). The money was used to increase the Columbus facility's capacity for cannula grinding, a part of the process to manufacture needles, and the remaining funds were used to install new syringe and needles production lines in the Holdrege facility (Bebensee, 2020). These upgrades, along with BD's addition of 350 million units of manufacturing capacity for glass barrel pre-fillable syringes in 2018, helped BD manufacture hundreds of millions of additional needles and syringes by the end of 2020 and into 2021.

Results & Concluding Remarks

During the COVID-19 pandemic, BD used its regional supply chain model, digital technology, proactive planning, agile supply chain, and expanded domestic facilities to increase its production of syringes and begin to meet the nation's demand for syringes. By the end of 2020, BD had committed more than 800 million needles and syringes to COVID-19 vaccine campaigns globally, and the company was able to provide the United States with approximately 250 million additional needles and syringes while still maintaining its supply of syringes for ongoing patient care.

Although BD was able to ramp up its syringe production to manufacture more syringes than it does in a typical year, its production capacity was limited due to BD's lack of ample surge capacity. Only after several expensive upgrades was BD able to quickly increase its production speed and begin to produce syringes at a rate fast enough to approach the nation's new annual 850 million syringe threshold.

Going forward, BD has plans to further increase its syringe production capacity and pandemic preparedness. In December 2020, BD announced its plans to "invest approximately $1.2 billion over a 4-year period to expand and upgrade manufacturing capacity and technology for pre-fillable syringes and advanced drug delivery systems across its six global manufacturing locations and add a new manufacturing facility in Europe" (*BD to Invest $1.2 Billion in Pre-Fillable Syringe Manufacturing Capacity Over Next Four Years*, 2020). The upgrade will provide added manufacturing capacity for BD's facilities and will "position BD to have the needed surge capacity for increased pre-fillable syringe demand during times of pandemic response or periods of significant growth of new injectable drugs and vaccines" (*BD to Invest $1.2 Billion in Pre-Fillable Syringe Manufacturing Capacity Over Next Four Years*, 2020).

Hopefully, this upgrade will be sufficient and will allow BD to fully meet the nation's and world's demand for syringes in 2021.

A Case Study of Honeywell International, Inc.

Honeywell International Inc.

Honeywell International Inc., another American company supplying the nation's PPE, also faced supply chain disruptions when COVID-19 emerged in China at the beginning of 2020 and spread to the United States. Honeywell International Inc., commonly referred to as Honeywell, is a Fortune 100 industrial manufacturer and technology company. The company is involved in several industries, producing aerospace products and parts, home and building technologies, performance materials and technologies, and safety and productivity solutions (*Honeywell*, 2020). Honeywell's safety and productivity solutions serve over half a billion workers around the world each year, and this number increased when the demand for its respiratory devices and other personal protective equipment spiked amid the coronavirus pandemic (*Honeywell*, 2020).

An international company, Honeywell owns a number of facilities around the world and relies heavily on its international footprint for manufacturing, distribution, and earnings. A decent portion of its business is conducted in China. Out of its 970 sites located in 70 different countries, 21 of these facilities are located in China, including sales offices in Beijing, Chengdu, Guangzhou, Shanghai, and Suzhou (*Honeywell*, 2020; Mitchell & Adamczyk, 2020). Like 3M and BD, Honeywell's facilities primarily serve customers in regions of close proximity. However, when COVID-19 emerged in China and quickly made its way into the United States, Honeywell found itself with inadequate national production capacity and the inability to export N95 masks from China, where its products were also in high demand, and its production capacity was larger. Honeywell, therefore, faced supply chain disruptions when the coronavirus pandemic

shut down the world's economy in early 2020 and there was a growing demand for N95 masks and other types of personal protective equipment.

An Overview of Honeywell's Supply Chain Before COVID-19

In order to support its extensive global operations and overcome supply chain disruptions, Honeywell relied heavily on the values and Honeywell Operating System (HOS) implemented by its former CEO, David Cote. When Cote took over as Honeywell's CEO in 2002, he turned the business around by unifying the company around twelve core behaviors, which included "customer focus, self-awareness, and championing change" (Donlon, 2013). The behaviors later became the basis of the Honeywell Operating System (HOS), a system based around ideas of innovation and continuous improvement that the company has slowly integrated into its operations over the past two decades (Donlon, 2013). A 2014 article detailed this significant transformation from "one of America's most messed-up firms to one its best," and credits Cotes with much of the company's rebirth, stating, "The factory has experienced a leap in productivity due largely to the successful application of management theories: including Six Sigma, which sanctifies an intense regard to quality, and Japanese 'lean manufacture', which is based on minimizing waste, keeping inventories low and doing things 'just in time'" (*Honeywell International: From Bitter to Sweet*, 2012). The article continues, calling these principles "integral to HOS, which is a customized version of the celebrated Toyota operating system" (*Honeywell International: From Bitter to Sweet*, 2012).

In a 2012 conference, Pasquale Abruzzese, Vice President of Honeywell's Transportation Systems Integrated Supply Chain, and Mike Owens, Vice President of Honeywell's Aerospace Integrated Supply Chain, described the Honeywell Operating System and its focus on leaders acting as coaches, continuous improvement, investing in its operators, and highly innovative

culture (Abruzzese & Owens, 2012). The leaders also referred to the revamped operating system as "a jet engine for growth" because of its "foundation of continuous improvement, lean tools and standardization, outreach, customer satisfaction, and cost leadership" (Abruzzese & Owens, 2012). Abruzzese and Owens also contained customer feedback on the success of the transformation, featuring comments from companies like Boeing, which stated, "Overall, HOS provides the framework for gains in productivity and quality beyond that typical in manufacturing. It is an industry best practice" (Abruzzese & Owens, 2012). As discussed in a later section, Honeywell's Operating System, characterized by its prioritization of innovation and customer commitment, played an important role when the company was faced with numerable supply chain mishaps stemming from the coronavirus pandemic.

When David Cote stepped down from his position in 2017 and Darius Adamczyk became CEO, Honeywell faced another important supply chain transformation; this time a digital one. Under Adamczyk's leadership, Honeywell implemented cloud software and cybersecurity, industrial internet of things, machine learning and data analytics, and autonomous systems across its global supply chain. In doing so, the company has created multiple safety mechanisms and efficiencies throughout its manufacturing processes (Crimm, 2019). The new software enhancements also boosted the supply chain's visibility, productivity, and reliability (Smith, 2018). With the digitalization of its supply chain, Honeywell had heightened end-to-end visibility of its supply chain and was able to gather real-time data on its products, inventory, orders, and financial transactions as they worked their way through the supply chain, allowing the company to optimize its inventory position, route shipments more efficiently, foster collaboration among its facilities around the world, and communicate more quickly and accurately with customers ("Honeywell's Transformation: Industrial Giant to Digital Standout,"

2019). Like the strong culture and operating system implemented under Cote's tenure, Adamczyk's initiatives have helped the company overcome supply chain disruptions and played an important role in the company's response to the coronavirus pandemic.

COVID-19's Impact on Honeywell's Supply Chain

Honeywell faced a variety of supply chain disruptions during the COVID-19 pandemic. Like BD and 3M, which faced many of the same issues, Honeywell's supply chains were influenced by temporary site closures, staffing shortages, difficulties accessing its facilities, and transportation and logistics disruptions. According to Honeywell's CEO, Darius Adamczyk, on February 19, 2020, Honeywell had resumed production in all of its Chinese facilities after a two-week closure. Although the operating facilities posed good news for the company at that time, it still had plenty of production to catch up on (Mitchell & Adamczyk, 2020). In addition, Adamczyk mentioned that Honeywell has "about 36 critical suppliers . . . and [only] 60% had started up" as of mid-February (Mitchell & Adamczyk, 2020). The halt in production of its suppliers posed a risk for Honeywell's inventory levels, putting them in danger of running out of raw materials.

Honeywell also faced staffing shortages. Between January and February, the Chinese workforce was out of commission, essentially shutting down Honeywell's Chinese facilities for two months. The staffing restraints seen in China spread along with the virus to the Honeywell facilities in other parts of the world. In a first-quarter earnings call held on May 1, 2020, Adamczyk stated, "approximately 15% of [Honeywell's] sites are currently experiencing staffing constraints in select regions around the world, including sites in Mexico, Europe, and the Asia Pacific, where governments have mandated up to 25% to 75% reductions in staffing"(*Q1 2020 Honeywell International Inc Earnings Call - Final*, 2020). Even in May of 2020, when 100% of

Honeywell's factories and 90% of Honeywell's suppliers had resumed operations, the factories were still not operating at full capacity because not enough people were willing or able to go back to work (*Honeywell International Inc at Goldman Sachs Industrials & Materials Conference (Virtual) - Final*, 2020). Ultimately, the staffing constraints hindered Honeywell's ability to maintain high, consistent production levels.

Honeywell's ability to maintain production levels amidst rapid changes in supply and demand was also hindered by the company's numerous "transportation and logistics disruptions"(*Q1 2020 Honeywell International Inc Earnings Call - Final*, 2020). Like 3M and BD, Honeywell fell victim to Chinese government mandates that halted exports and airline services at the beginning of 2020 and later were hindered by shipping delays in the United States. As such, Honeywell often faced issues with completing deliveries and providing services, especially in a timely manner (*Honeywell International Inc at Goldman Sachs Industrials & Materials Conference (Virtual) - Final*, 2020).

In addition to the supply chain disruptions mentioned above, Honeywell faced a surge in demand for its safety and productivity solutions, most notably its N95 masks. Darius Adamczyk stated that Honeywell faced "record-level demand for respiratory masks and other personal protective equipment" and that "PPE orders were up triple digits in the first quarter, with strength in respiratory, head, eye, face, gloves and clothing categories" (*Q1 2020 Honeywell International Inc Earnings Call - Final*, 2020).

Prior to the COVID-19 pandemic, Honeywell manufactured and shipped 1 million N95 masks to health care and industrial supply companies and home-improvement retailers (Freedman, 2020). Compared to 3M, the largest supplier of N95 masks for the United States, shipping 50 million masks a month globally, Honeywell was a much smaller supplier. However,

when COVID-19 reached pandemic levels, the country needed millions of additional N95 masks to protect healthcare workers and others from the transmission of coronavirus. As mentioned previously, public health officials estimated that the United States needed 300 million N95 masks a month to properly fight the pandemic. Honeywell, as one of the nation's few suppliers of N95 masks, was called on to help meet the nation's demand, but, as a relatively small manufacturer of N95 masks, Honeywell had to rely on the built-in features of its supply chain, such as its culture, operating system, and digitalization, and implement several new mitigation strategies to overcome the pandemic induced-disruptions and begin meeting customer demand.

Honeywell's Response to Supply Chain Disruptions

Honeywell relied on its pre-existing supply chain infrastructure, Honeywell Operating System values, and a variety of mitigation strategies to respond to the supply chain disruptions caused by the coronavirus pandemic. Honeywell's mitigation strategies included setting up a tactical operation center, using a variety of digital platforms, implementing an agile supply chain strategy, pursuing a regional production strategy, and expanding its manufacturing capabilities.

The launch of Honeywell's tactical operations center was one of Honeywell's most notable mitigation strategies. In Honeywell's first-quarter earnings call, Darius Adamczyk discussed how Honeywell's integrated supply chain team was working to implement business continuity processes, such as the tactical operations center, to maintain production levels. He stated that following the coronavirus outbreak in China, Honeywell set up a tactical operations center in January to monitor and manage global supply risk and established processes to identify and assist suppliers in financial distress. As the outbreak evolved, Honeywell also continuously monitored its suppliers to ensure they remained operational and provided support to help them reopen if they experienced temporary closures (*Q1 2020 Honeywell International Inc Earnings*

Call - Final, 2020). Honeywell's integrated supply chain team used its expertise and the company's pre-existing software capabilities to overcome transportation and logistics issues and to track products with imbalances in supply and demand. The team actively monitored changes in transportation and worked to secure multiple modes of transportation and freight to ensure the availability and delivery of critical products like N95 masks (*Q1 2020 Honeywell International Inc Earnings Call - Final*, 2020). Using machine learning and big data, Honeywell's operations center was able to track and process real-time data about material shortages, supplier vacancies, and demand fluctuations, allowing the company to quickly and accurately seek out new suppliers, alter manufacturing patterns, and change production speeds. Honeywell's autonomous systems, or robotic fulfillment centers, also helped the company accommodate for quick switches in production and efficiently handle influxes in production and distribution of PPE (Crimm, 2019).

Honeywell also implemented a series of more detailed ordering platforms to make it easier for the company to meet customer needs. Living out the company's commitment to customer satisfaction, Honeywell launched e-commerce websites for items in high demand during the pandemic "to enable transactional customers to receive product information and place orders quickly and efficiently" (*Q1 2020 Honeywell International Inc Earnings Call - Final*, 2020). One group of customers positively influenced by this platform were those of Honeywell's research chemicals business who performed important lab work associated with the COVID-19 pandemic. Thanks to the site launched by this group, the customers were able to "quickly and easily replenish their laboratory supplies" (*Q1 2020 Honeywell International Inc Earnings Call - Final*, 2020).

In addition, Honeywell implemented an agile supply chain strategy to minimize interruptions caused by the COVID-19 pandemic. As mentioned in the analysis of 3M and BD, an agile supply chain is able to "respond quickly to sudden changes in supply or demand, handle unexpected external disruptions smoothly and cost-efficiently, and rover promptly from shocks" (Lee, 2004). Striving to embody an agile supply chain, Torsten Pilz, Honeywell's Senior VP & Chief Supply Chain Officer, stated that Honeywell followed demand and the condition of suppliers very closely for months after the advent of the coronavirus pandemic and was "very reactive and fast in [its] actions" to weather changes in demand (*Q1 2020 Honeywell International Inc Earnings Call - Final*, 2020). In Honeywell's 2020 first-quarter earnings call, Darius Adamczyk explained the company's agile supply chain strategy, stating, "We condensed our sales, inventory and operations planning process from a traditional monthly cycle to a weekly cycle. Combining this with sales leading indicators, we are sensing demand changes and realigning our inventory and production schedules faster than ever" (*Q1 2020 Honeywell International Inc Earnings Call - Final*, 2020). Using an agile supply chain strategy to weather demand shocks and changes in customer needs, Honeywell was able to uphold its commitment to customer satisfaction and foster a flexible supply chain, an asset during a time of rapid, unpredictable changes in the marketplace.

In order to better reach its customers and distributors while dealing with transportation and logistics disruptions, Honeywell began moving toward a regional manufacturing strategy similar to the one discussed in the analysis of 3M. By following a regional model, the company bypassed many transcontinental transportation disruptions and planned for the production facilities within each region to ramp up production to meet the specific product needs for that area.

Honeywell's expansion of its on-shore manufacturing operations exemplifies its effective shift to a regional production model. In making the expansion, the company embodied the Honeywell Operating System's commitment to innovation and was able to better accommodate for the large spikes in demand for respiratory, head, eye, face, gloves, and clothing products. In particular, Honeywell built a new production line at its manufacturing facility in Smithfield, RI, which typically produces industry safety gear, to increase the company's domestic production of N95 masks and support the nation's increased demand (*Honeywell Expands Face Mask Production*, 2020). In addition, the company added new N95 manufacturing capabilities at Honeywell Aerospace in Phoenix, AZ. Together, the new modifications allowed the company to produce 20 million more masks per month while continuing to produce its normal industry gear and aircraft technology products. The new manufacturing equipment also allowed Honeywell to become the second new US manufacturing line contracted to supply the national stockpile of N95 masks (*Honeywell Expands Face Mask Production*, 2020).

Ultimately, Honeywell employed a tactical operations center; digitalization through automation, machine learning, big data, and an online ordering platform; agility within its supply chain; a regional production model, and expanded its domestic production capabilities to overcome supply chain disruptions caused by the coronavirus pandemic. It relied on the synergies between each mechanism, the Honeywell Operating System, and the company's dedication to customer satisfaction, continuous improvement, and innovation to lessen the impact of the pandemic-induced supply chain disruptions that influenced its worldwide operations and meet the world's pressing need for large quantities of PPE.

Results & Concluding Remarks

After COVID-19 emerged in China and began to spread around the world, Honeywell International Inc. faced supply chain disruptions resulting from temporary site closures, staffing shortages, difficulties accessing facilities, transportation and logistics disruptions, and an increase in demand for virus-shielding PPE, such as N95 masks. In order to meet the world's needs for safety and protective equipment, Honeywell relied on its Honeywell Operating System and core values to successfully implement a variety of mitigation techniques. Beginning in January of 2020, Honeywell set up a tactical operation center, used a variety of digital platforms, implemented an agile supply chain strategy, began pursuing a regional production strategy, and expanded its manufacturing capabilities to minimize supply chain disruptions resulting from the coronavirus pandemic. In doing so, the company was able to recover from a temporary halt in production at the beginning of 2020, maintain traditional production levels during the first quarter, and then ramp up production of highly sought-after N95 masks by the beginning of summer.

On April 17, 2020, Honeywell announced it would make over 20 million N95 masks per month, twenty times its pre-COVID production rate, with the use of its domestic facilities, and it continues to consistently meet the nation's surge in demand for critical respiratory, head, eye, face, gloves and clothing products. Honeywell was also one of three companies contracted by the federal government to supply the nation's stockpile of N95 masks. Under the contract, Honeywell received $27.5 million dollars to produce 13 million N95 masks per month between May and August of 2020 (Tiron, 2020). Honeywell's ability to fulfill this contract while still meeting the spikes in demand for its other safety and protective equipment and continuing the

operations of its seven business units attests to the success and importance of its pandemic mitigation strategies.

Conclusion

Common Mitigation Strategies

When faced with workforce absenteeism, transportation and logistics mishaps, export restrictions, and surges in demand for medical supplies during the COVID-19 pandemic, 3M, Honeywell, and BD had to employ a variety of supply chain mitigation techniques to ramp up U.S. production and meet customer demand. The most common mitigation strategies involved leveraging technology to increase supply chain visibility, using regional manufacturing models, creating pandemic contingency plans, and expanding current production capabilities.

Leveraging Technology to Increase Supply Chain Visibility

3M, BD, and Honeywell all demonstrated the usefulness of leveraging technology to improve supply chain visibility. 3M's geometric network, supply chain mapping, and digital infrastructure played a vital role in its response to the COVID-19 pandemic. The digitalization of its supply chain and the company's access to critical real-time data provided crucial intel that permitted the company to quickly adjust production, monitor inventory, and respond to disruptions in its supply chain infrastructure. Ultimately, these capabilities enabled 3M to minimize pandemic-induced supply chain disruptions in order to better meet the high demand for N95 masks and PPE during the peak of the pandemic.

BD's Microsoft Azure software and highly technical supply chain control tower heightened the visibility of its supply chain. These technologies enabled BD to view its entire supply chain in real-time and from one central location and quickly resolve over-supply, backorders, and supply chain disruptions through the collaboration of its global facilities. Together, BD's Microsoft Azure software and control tower provide useful data and visibility, which helped the company react quickly and effectively to supply chain disruptions and changes

in demand. Ultimately, these digital technologies proved to be helpful during the coronavirus pandemic when BD faced enumerable disruptions and growing demand for its syringes.

Honeywell's cloud software and cybersecurity, industrial internet of things, machine learning and data analytics, and autonomous systems across its global supply chain allowed it to have heightened visibility in its supply chain during the pandemic. With the digitalization of its supply chain, Honeywell acquired end-to-end visibility of its supply chain and was able to gather real-time data on its products, inventory, orders, and financial transactions as they worked their way through the supply chain, allowing the company to optimize its inventory positions, route shipments more efficiently, foster collaboration among its facilities around the world, and communicate more quickly and accurately with customers. These initiatives helped the company overcome supply chain disruptions and played an important role in the company's response to the coronavirus pandemic. The heightened visibility of 3M, BD, and Honeywell's supply chains inspired end-to-end visibility across their operations and quick reactions to rapid changes in demand and supply shortages.

Regional Model for Manufacturing and Distributing

Each company also demonstrated the usefulness of using a regional model for manufacturing and distributing. As discussed, the regional for regional model of manufacturing and distributing encourages facilities in a certain region to manufacture and distribute products to its customers within close proximity. 3M primarily used its factory in Aberdeen, South Dakota, to manufacture N95 masks for the United States, and it utilized its facilities in other parts of the world to provide N95 masks for their respective regions. Similarly, BD used its facilities in Nebraska, which historically manufactured syringes for the U.S. market, to manufacture syringes for the United States during the coronavirus pandemic. Likewise, Honeywell relied on its

domestic facilities in Smithfield, RI, and Phoenix, AZ to establish new manufacturing lines and begin producing N95 masks for the United States. Overall, 3M, BD, and Honeywell employed regional models for manufacturing and distributing their most critical products in order to overcome global transportation and logistical issues and export restrictions and better meet customer demand.

Pre-COVID-19 Pandemic Planning

Planning for the possibility of a pandemic also proved to be an important, if not the most important, mitigation strategy for all three companies. 3M used its knowledge and experience gained from previous pandemics to overcome COVID-19 supply chain disruptions and increase its production of N95 masks and PPE amid the coronavirus outbreak. Aware of its position as an irreplaceable supplier of medical equipment, 3M had been planning and preparing for a crisis situation like the COVID-19 pandemic for several years. Recent medical crises such as SARS, H1N1, and Ebola exposed the company's inadequate response strategy and small production capacity in the time of medical crisis, so 3M decided to build surge capacity into its N95 mask factories worldwide. The surge capacity was essential to 3M's COVID-19 response because it facilitated a quick increase in its production of N95 masks.

Similar to 3M, BD also relied on pre-existing contingency plans to mitigate coronavirus supply chain disruptions. The company had pandemic mitigation teams in place before the advent of the coronavirus pandemic, such as the BD Global Procurement division, which was responsible for BD's domestic and global pandemic planning. The company sought out potential risks for BD's needle and syringe business and developed precautionary measures and mitigation strategies to minimize the chance of disruptions occurring in the event of a pandemic. These precautionary measures came in handy when COVID-19 emerged because they allowed the

company to anticipate the disruptions that occurred as the virus spread and helped the company quickly secure alternative suppliers for the raw materials of its most sought-after products.

Unlike 3M and BD, Honeywell did not have a comprehensive pre-existing pandemic response plan. However, as the pandemic evolved in early January 2020, Honeywell launched a tactical operations center to monitor and manage global supply risk, overcome transportation and logistics issues, and track products with imbalances in supply and demand. Using machine learning and big data in its tactical operations center, Honeywell's operations center was able to track and process real-time data about material shortages, supplier vacancies, and demand fluctuations and help the company quickly and accurately seek out new suppliers, alter manufacturing patterns, and change production speeds.

Expanding Current Production Capabilities

Each company also had to rely on expanding its manufacturing capabilities in order to better meet the nation's surge in demand for medical supplies. 3M added 120,000 square feet of manufacturing lines and automated equipment to its Aberdeen, South Dakota plant in order to ramp up its monthly N95 production to 95 million per month by the end of 2020. BD issued a $70 million expansion of its Columbus-West and Holdrege, Nebraska facilities and a $1.2 billion investment over the next four years of its global syringe manufacturing facilities in order to produce 250 million additional syringes for the U.S. by December 2020. Honeywell built a new production line for N95 masks at its manufacturing facility in Smithfield, RI, and added new N95 manufacturing capabilities at its Honeywell Aerospace facility in Phoenix, AZ, enabling the company to produce 20 million more masks per month by the end of 2020.

Although one of the most valuable methods of improving each company's ability to meet demand surges, these expansions were often costly and took several months to complete. As

such, they did not offer the best solution to each company's supply chain disruptions. In addition, there is a risk that the expansions will not be utilized once the COVID-19 pandemic is over, but even if the new expansions are dormant following the coronavirus pandemic, it may be proactive for the companies to preserve the added capacity of these facilities in order to prepare ample surge capacity for future pandemics and demand surges.

Overall, by employing the common techniques discussed above, in addition to several other strategies, 3M, BD, and Honeywell were able to demonstrate agility within their supply chains, overcome supply chain disruptions in 2020, and transform their domestic supply chains to better meet the nation's surge in demand for N95 masks and syringes. Although the companies had not yet fulfilled the nation's total anticipated demand for medical supplies at the end of 2020, each had made significant progress toward meeting those goals and was on track to produce ample amounts of critical medical supplies in 2021.

Why Do Some Companies Not Utilize These Strategies?

Although the mitigation strategies discussed above enabled 3M, Honeywell, and BD to act as industry exemplars for their quick responses to coronavirus supply chain disruptions and abilities to quickly ramp up U.S. production of medical supplies, not all companies are able to emulate their tactics. The following section will explore why some multinational companies do not leverage technology to increase supply chain visibility, use regional manufacturing models, create pandemic contingency plans, or expand their current production capabilities.

Inability to Leverage Technology

As mentioned, 3M, Honeywell, and BD each relied on robust company-wide technological infrastructure to manage and overcome the coronavirus supply chain disruptions. 3M relied on a geometric network, supply chain mapping, and digital infrastructure to quickly

adjust production, monitor inventory, and respond to disruptions in its supply chain infrastructure. BD's Microsoft Azure software and supply chain control tower heightened the visibility of its supply chain and helped the company quickly resolve over-supply, backorders, and supply chain disruptions through the collaboration of its global facilities. Likewise, Honeywell's cloud software and cybersecurity, industrial internet of things, machine learning and data analytics, and autonomous systems across its global supply chain allowed it to gather real-time data on its products, inventory, orders, and financial transactions as they worked their way through the supply chain and optimize its inventory positions, route shipments more efficiently, foster collaboration among its facilities around the world, and communicate more quickly and accurately with customers. During the pandemic, one of 3M, Honeywell, and BD's biggest strengths was their ability to properly utilize their digitalized supply chain and use it to increase visibility across their supply chains and react quickly to rapid changes in supply and demand. No doubt, their effective technology uses primarily stemmed from their focus on the development and implementation of these solutions.

Although the digitalization of their supply chains enabled them to effectively mitigate supply chain disruptions, not all companies are able to emulate 3M, Honeywell, and BD's strategy of leveraging technology to increase supply chain visibility. Many companies lack proper technology infrastructure, and those that do possess proper infrastructure often fail to fully reap the benefits of digitalization due to improper implementation. Whether it is because they lack ample funds, manpower, or digital leadership, many companies lag behind in their adoption of technology and technological maturity. In 2019, only 25% of 1200 companies surveyed were classified as having high digital maturity, or a high aptitude for creating positive business transformation from its digital initiative (Gurumurthy et al., 2020). Additionally, out of

350 supply chain and operations professionals surveyed in a recent DHL report, 95% claimed to fail to see the full benefits of digitalization (Marci, 2018). Of the professionals surveyed, 73% are investing in Big Data analytics, 63% in cloud-based applications and robotics, 54% in internet-of-things solutions, 51% in blockchain, 46% in machine learning, 40% in autonomous vehicles, 34% in the sharing economy, 33% in 3-D printing, and 28% in augmented reality and drones (Marci, 2018). Despite their wide adoption of these technology solutions, these professionals and the companies they work for lack the resources, manpower, and necessary top-down approach to implementation and have struggled to fully utilize these solutions during a time of crisis like the coronavirus pandemic.

Employing a Global Model for Manufacturing and Distributing

3M, Honeywell, and BD also employed a regional model for manufacturing and distributing for their most critical products in order to overcome global transportation and logistical issues and export restrictions and better meet customer demand. Many multinational companies do not employ regional models for manufacturing and distributing, though. Rather, they operate under global models of manufacturing and distributing where they manufacture products in a handful of facilities located in emerging markets, or parts of the world with cheap labor and close proximity to natural resources, and then export their goods to customers around the world. Companies often utilize a global operating model in order to minimize their production costs. As such, they are typically not interested in shifting to the regional operating model employed by 3M, Honeywell, and BD.

There are downsides to the global model of manufacturing and distributing, though, because the strategy often exposes companies to operational risks, longer lead times, and hefty shipping costs, and during times of global crisis, these companies are unable to easily overcome

global transportation and logistical issues and export restrictions. Unfortunately, even if the regional model of manufacturing and distributing does prove to be more cost-effective and companies wish to transition to this type of model, the transition is often time-consuming, expensive, and therefore unrealistic for many multinational companies. Even though the regional model of manufacturing and distributing proved to be an asset to 3M, Honeywell, and BD in their COVID-19 response, it is not always a desired or practical operational model for all multinational companies.

The Importance of Pre-Pandemic Planning

3M and BD also employed pre-COVID pandemic planning to mitigate coronavirus supply chain disruptions and meet changes in demand. The two firms recognized their positions as important suppliers during times of medical crisis and allotted time prior to the outbreak of the pandemic to plan for surges in demand. Prior to the COVID-19 pandemic, 3M learned from its struggles to overcome disruptions stemming from previous medical crises such as SARS, H1N1, and Ebola and built surge capacity into its N95 mask factories worldwide. Similar to 3M, BD also had pandemic mitigation teams in place before the advent of the coronavirus pandemic and used these teams to seek out potential risks for BD's needle and syringe business and develop precautionary measures and mitigation strategies to minimize the chance of disruptions occurring in the event of a pandemic.

However, not all companies are able to emulate 3M and BD's pandemic planning strategies and justify investing in built-in surge capacity and the establishment of pandemic planning teams. Surge capacity is a hefty investment, one that many companies are not able to afford. Incorporating surge capacity into pre-existing operations is expensive, time-consuming, and requires designating limited factory space and machinery to sitting idly for long periods of

time until it may need to be utilized in the event of a supply chain disruption. To some companies, this hefty opportunity cost is not worth the investment. To them, the funds could be utilized in ways that better increase company value and shareholder wealth.

In addition, not all companies have enough cash on hand to be able to afford establishing built-in surge capacity. 3M, whose net income was $4.57B in 2019, is a highly profitable company that has ample funds to dedicate toward building surge capacity (*3M Reports Fourth-Quarter and Full-Year 2019 Results; Implements New Global Operating Model and Streamlined Structure; Provides Full-Year 2020 Guidance*, 2020). Conversely, a company that is struggling financially has to prioritize maintaining its fundamental operations, paying suppliers, and compensating employees over-investing in surge capacity, so although surge capacity serves as one of the best mitigation strategies, it is not always an attainable solution.

Likewise, not all companies are able to justify establishing a pandemic planning team. As a global medical technology company that specializes in manufacturing swabs, vials, syringes, needles, reagents, and testing kits, BD is uniquely positioned as a critical medical supplier and has a responsibility of assuring its supply during pandemics. Consequently, it critical for BD to have excellent pandemic mitigation teams in place before the pandemics occur. For a company that doesn't operate within the medical industry or share the responsibility of supplying the world's most critical pandemic-fighting supplies, investing in a pandemic planning team is likely not the best use of its limited funds and personnel. Additionally, not all medical supply companies have the financial means to establish pandemic planning teams. As such, although the establishment of pandemic planning teams serves as a valuable and effective mitigation strategy, it is not always a justifiable or realistic solution.

Expanding Current Production Capabilities

Lastly, 3M, Honeywell, and BD also all relied on expanding their manufacturing capabilities in order to better meet the nation's surge in demand for medical supplies. 3M expanded its Aberdeen, South Dakota plant, BD expanded its Columbus-West and Holdrege, Nebraska facilities and embarked on a four-year investment of its global syringe manufacturing facilities, and Honeywell expanded its manufacturing facility in Smithfield, Rhode Island, and Phoenix, Arizona. Together, the new modifications allowed each company to increase the production of its most sought-after medical products by the end of 2020.

As mentioned previously, because of the cost of adding new manufacturing lines and constructing new factory space and the amount of time required to finalize these additions, expanding a company's production capability was not an ideal solution to coronavirus supply chain disruptions. Once established, there was a risk that the expanded production capacity would not be utilized once the COVID-19 pandemic ends. Additionally, the coronavirus pandemic affected different companies in different ways. Medical supply companies saw surges in demand for medical supplies, but some companies faced a decrease in demand or lumpy demand for their products, such as those in the foodservice, home improvement, landscaping, and consumer electronics industries (Abdelnour, et al., 2020). For companies experiencing a decrease in demand or lumpy demand, adding more production capability would not have solved their supply problems and would instead have been a waste of resources. For these reasons, many companies did not rely on expanding their manufacturing capabilities to overcome coronavirus-induced supply chain disruptions.

Going Forward

Overall, the case analyses of 3M, BD, and Honeywell reveal supply chain best practices during times of crisis and can be used as guides for how to overcome pandemic-induced supply chain disruptions in a globalized economy. The analysis advocates for a multi-faceted approach to mitigation and suggests that there is no "one-size-fits-all" policy for how to overcome supply chain disruptions. Instead, excellent mitigation strategies require foresight, innovation, cross-functional participation, and continuous monitoring and improvement of supply chain processes. Using technology to increase supply chain visibility, employing regional manufacturing models, creating pandemic contingency plans, and expanding built-in surge capacity can also help multinational companies react quickly to changes in supply and demand and adjust their supply chains to better accommodate market changes. Yet, these strategies are not useful for all companies, and they are not the only strategies multinational companies should employ to minimize future supply chain disruptions.

Companies that produce essential products like medical supplies should also ensure that their supply chains don't run too lean. Although cost-effective and efficient, lean medical supply chains can be risky in the case of demand spikes or loss of supply. Without ample safety stock of critical medical supplies, companies can struggle to quickly ramp up their production and fall short of meeting changes in demand or supply (Gereffi, 2020; Gulledge, 2020).

In addition, multinational companies should reconsider manufacturing critical components of products in areas of high political and economic risk, specifically in areas where export restrictions or transportation issues may be possible. As demonstrated with the Chinese export ban, companies cannot always rely on foreign subsidiaries to supply the United States and other global parties. Luckily, the companies discussed in this paper, 3M, BD, and Honeywell,

were able to ramp up the production of many of their critical medical products domestically in order to meet the nation's needs. However, some companies, such as those in the pharmaceutical industry, which rely on China and India as their primary source of active pharmaceutical ingredients, were unable to easily overcome shortages in critical drugs to serve the U.S. market (Harney, 2020; Miller & Cohrssen, 2020).

Thus, the coronavirus pandemic highlights some of the pitfalls of globalization, namely increased exposure to supply chain disruptions and the inability to import foreign-made goods during times of global crisis. Perhaps as a result of the COVID-19 pandemic, there will be a contraction in the globalization of business or at least an influx in the number of American multinational companies re-establishing domestic facilities to manufacture the nation's most critical products.

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