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In the End, It's All About People

COVID-19 vaccine production reveals dependency on supply chains, labor workforce in the U.S.

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The COVID-19 pandemic has dramatically revealed how dependent we are on supply chains and the availability of labor. Without the human element, meatpacking plants cannot function; fresh produce cannot be picked; grocery stores cannot be shelved; PPEs cannot be produced and distributed; and products cannot be delivered to our homes through e-commerce. Also, COVID-19 vaccine production may lack the human resources to ensure product quality and efficacy, as well as its distribution and ultimate administration into our arms. Without healthcare workers to administer COVID-19 vaccines, the battle against the coronavirus cannot be won. Many hospitals are already short-staffed because of the pandemic.

As an operations researcher who studies supply chains, including perishable product ones, from food to pharma [1], I have been struck from the onset of the pandemic by the volume of supply chain disruptions, clearly exacerbated by the impacts of there was insufficient labor to pick and package it. Now vaccines lie fallow, while time is running out, since there are, in many cases, an insufficient number of healthcare workers to administer them.

Furthermore, with the additional stresses and uncertainty placed on labor, the workers' productivity suffered [2]. It is estimated that disruptions to the labor force in fruit and vegetable production alone will cause millions of dollars in lost production, with the heaviest losses concentrated in large fruit- and vegetable-producing states. By mid-September 2020, COVID-19 cases had been identified in at least 494 meatpacking plants; more than 42,534 workers at such plants had contracted coronavirus, and over 203 had died [3]. Toward the end of December 2020, more than 2,900 U.S. healthcare workers died from COVID-19 since March [4].

Labor problems and a lack of taking them into account in supply chain networks have contributed in a major way to supply chain disruptions, with the pain and suffering being global in nature. In my recent research, I expanded on the investigation of how to optimize perishable product supply chains, from blood and food to pharmaceuticals and vaccines [2], so that needed products are delivered in a timely manner and in good quality and without spoiling, to include the critical labor resource [5]. To do this effectively, I calculate the resources that are needed and associated costs. I also investigate what happens if there are insufficient resources, whether the warehouses don't have enough capacity, the supplies needed for production are limited or there are not enough trucks for deliveries [6].

Optimization and Supply Chain Networks

Specifically, I construct models and algorithms to identify how to enhance supply chain operations as well as identify their vulnerabilities. Supply chains have evolved as networks that tie raw material providers with other suppliers, manufacturers and partners, such as warehouse managers, freight service providers, distributors and retailers. Hence, my perspective on supply chains is that of networks with links corresponding to important activities of production, transportation, storage and distribution [6, 7]. Pathways in supply chains carry the flow of products from origin nodes to the destinations, with other important flows being financial ones in terms of prices and payments, as well as information flows.

Utilizing a network formalism allows one to see the similarities and differences between different product supply chains and investigate the impacts of additions (or deletions) of links and nodes on product flows, prices and costs, as well as profits of firms and other relevant criteria, from emissions generated to waste. Furthermore, one can associate arc multipliers with links, resulting in generalized networks, which are extremely useful in studying many of the supply chains that have suffered the greatest impacts in the pandemic, such as food and even blood [2], critical to healthcare, and now convalescent plasma [8].

In a recent paper inspired by the COVID-19 pandemic [5], I developed a generalized supply chain network optimization model for perishable food products with the inclusion of the critical resource of labor in the supply chain network economic activities. Many food items, including fresh produce, meat, fish and dairy are perishable food products and their quality deteriorates even under the best conditions [9, 10]. The negative impacts of labor shortfalls and decreases in productivity are being felt in all supply chain network economic activities from production to distribution, and it was important to be able to have a rigorous modeling and algorithmic approach for quantification purposes. The work extends that of Yu and Nagurney [9] to include labor and its associated levels of availability on links of the supply chain network and adds to the literature of both operations research and economics. We present a series of numerical examples based on a fresh produce product in which the quality deterioration is also captured. We consider the impacts of labor disruptions in terms of availability, as well as productivity and the potential of direct-to-consumer demand markets on the food firm's profit, demand market prices, product flows and the demands.

Game Theory and Supply Chain Network Competition

The fact that this healthcare disaster is not limited in time and space has resulted in intense global competition for many products, including medical supplies. The supply chain network optimization model with labor was, therefore, extended [11] to include multiple competing entities, such as firms, in a supply chain network game theory model that included not only product flows, but also labor and its availability, as represented by three different sets of constraints, from the most restrictive, and associated with labor capacities at the link level, to the most general, with a single labor amount and labor mobility not only

This scenario is relevant to the farming sector, because farmers compete for seasonal migrant workers for harvesting of the products, with COVID-19 creating shortfalls of such labor in many parts of the globe. Furthermore, due to shortfalls in labor in the healthcare sector in the United States, some nurses have traveled thousands of miles to assist with COVID-19 patients, and this has also resulted in increases in prices for labor with some traveling nurses getting paid as much as $10,000 per week [2]. The governing concept is that of a Generalized Nash Equilibrium.

Our research reveals the benefits of sharing workers, as well as having labor reallocated to different supply chain network activities, as the needs arise [11]. We also emphasize that proper training of workers may allow for greater mobility of labor across distinct supply chains [2]. This has been occurring in Europe where some airline workers are being retrained to work in healthcare. Relaxing constraints on labor so that workers can engage in other supply chain activities as needed can have immense positive effects on product flows and even firms' profits. On the other hand, a labor shortage in a single link – be it in freight, storage, manufacturing or processing – can result in a big decrease in product availability.

Speaking of game theory, I would be remiss not to further highlight the incredible competition for PPEs (as well as such medical supplies as ventilators), which has been another notable feature of the pandemic, with shortages still continuing in parts of the United States. The intense competition for PPEs led to a dramatic increase in the price, with some prices rising by more than 1,000%, according to the report by The Society for Healthcare Organization Procurement Professionals [12] and with some medical professionals going to extreme measures to procure PPEs for the healthcare workers [13].

With co-authors, we constructed a game theory model to capture the competition for medical supplies [14]. The model features salient characteristics of the realities of this pandemic, such as limited supplies globally, as well as uncertain demands due to the fact that so much about this novel coronavirus remains unknown and has yet to be discovered. Healthcare organizations such as hospitals and nursing homes, but also medical practices, etc., compete with one another for the limited supplies, and given the prices and their associated logistical costs as well as the expected loss due to possible shortages or surpluses, the model is also a Generalized Nash Equilibrium model.

The Vaccine Cold Chain and Challenges Remain

Much of my work also entails mitigation against disasters [15, 16, 17]. We are now in the midst of a healthcare disaster that has adversely affected millions of workers in the United States and around the globe. Much research has been done on identifying critical links in supply chains, inspired in part by various natural disasters impacting supply chain activities [18]. But until recently, few researchers have quantified the impacts of labor disruptions on product supply chains, along with the associated costs. This may be because previous supply chain disruptions were localized in terms of both geography and time period. Mitigation and recovery procedures reduced the impacts.

Indeed, until the pandemic struck, few people paid much attention to the role of labor in the role of supply chains. And product shortages were few and far between for necessities such as toilet paper and cleaning supplies.

Now the demand for the COVID-19 vaccine has reached a crescendo [19]. With approval of two mRNA vaccines – Pfizer-BioNTech and Moderna – in mid-December, and the R&D approval occurring in record time thanks to the incredible work of scientists as well as pharmaceutical companies and regulatory agencies, there is hope, but moderated with caveats [20, 21]. In disaster management, we teach four phases, with preparation being the first phase. In vaccine supply chains, not only is manufacturing essential but so are the logistics associated with vaccine storage, distribution, as well as the critical last mile, plus the preservation of the cold chain, which must be maintained for vaccine quality and efficacy [22].

In the case of the vaccine supply chain, there are tiers of interacting stakeholders and decision-makers, each with their own objective function and constraints. Furthermore, the two approved vaccines to date require two doses for the tested efficacy, which is about 95%, quite remarkable for a vaccine. Supply targets that were promised by the end of December were not met [23], and the decentralized decision-making in the U.S. associated with the vaccination rollout at the individual state level (and lower) has led to numerous issues with prioritization differing in many states from that proposed by the federal government [21]. Many states have only used about one-third of the doses provided, while others taking individual action are having much greater success. Frontline healthcare workers were prioritized first, as well as those in long-term care facilities such as nursing

As we know from disaster management, cooperation and careful coordination are key, along with transparency and solid information sharing and dissemination. The vaccines are perishable, high-value products, and their quality must be ensured as well as their delivery and use in a timely manner. Numerous tools in our rich operations research supply chain tool portfolio can be applied to assist.

I know that operations researchers will continue to be at the forefront of the modeling, analysis and solution of complex supply chain network problems in the pandemic and beyond. In the end, it's all about people.

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26. Additional resources, including a link to the *Resoundingly Human* podcast with Anna Nagurney, thanks to Ashley Kilgore of INFORMS, can be found at: https://pubsonline.informs.org/do/10.1287/orms.2021.01.08p.

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