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Coronavirus, Tariffs, Trade Wars and Supply Chain Evolutionary Design

Events of the last three years are posing new threats to supply chain models of globalization as never before. The recent separation of the U.K. through Brexit, the tariffs imposed by the Trump administration against China, and the Coronavirus (COVID-19) epidemic have all raised questions on whether we are moving towards increasing disruptions of global supply chains, and perhaps a new and chaotic "de-globalization" of the economy (Roscoe et al, 2020). Indeed, the COVID-19 crisis is proving to be the greatest challenge to the global economy since the Second World War, according to the Brookings-Financial Times Tracking Indexes for the Global Economic Recovery (TIGER)[1]. The common theme here is that organizations have sought out the lowest cost sources of supply while forgoing more expensive regional suppliers and that executives should now begin to reconsider these actions. Some even suggest that we may begin to move towards resurrecting "lean" and "localized" modes of production, with some manufacturing now in China moving back to the United States, the EU, and South America (van Hoek, 2020)

These suggestions need to be tempered with a reflection on how long it takes to establish sources in another country. Our discussions with manufacturing executives suggest that once an organization commits to outsourcing to third parties in low-cost countries, there is a minimum planning horizon of five years involved, as this requires supplier qualification, audits, start-up, quality certification, and on-going ramp-up. Supply chains have been noted to go through life cycle stages (MacCarthy et al, 2016), and the maturity of a supply base may require periodic refreshes in the global sourcing strategy. In practice these changes may be "one way", since in many industries, sourcing executives have embedded their supply chains in Asian regions, noting that *"…these jobs will never return to Western countries.*" As an example, 80% of the world's production of automotive brake pads are produced by four manufacturers in one province in China. To establish alternative sources that are competitive, qualified, and at-scale would cost much more than the 25% tariffs automotive companies are paying today in the U.S. to import from China.

[1] https://www.brookings.edu/research/april-2020-update-to-tiger-the-coronavirus-collapse-is-upon-us/

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An implicit assumption in the press is that COVID-19 caught everyone by surprise and that executives foolishly ignored the risks of outsourcing to China, and are now paying the price. However, noted scholars and epidemiologists have been warning of the threats of pandemics since the SARS virus (Ensirink, 2004; Colizza et al., 2007), noting especially the role that air travel plays in spreading viruses. The pundits further posit that in their pursuit of low-cost production, global corporations made naive assumptions that nothing could disrupt them. The tariffs imposed by governments were simply a passing political inconvenience, while Brexit restrictions would somehow be negotiated away with Brussels in subsequent years. In this paper, we offer an alternative viewpoint; *the major disruptions of the global economy are a function of events that are indeed part of the natural evolution of supply chains, which follow the constructal law of physics*, as applied to supply chains. This law, developed by physicist Adrian Bejan more than twenty years ago, posits that almost any system can be characterized by an evolution of design, and therefore, based on the laws of physics, are *predictable* (Bejan, 2016; 2020).

Using the constructal law of physics, we seek to provide guidance on understanding the evolution of global supply chain design. This is reassuring, given how seemingly unpredictable the COVID-19 crisis has proven to be. Further, through two case studies we are developing, we report interview findings with two senior VPs[2,3] from two global corporations being disrupted by COVID-19. In this paper we identify how this and recent events will impact on the design of future global supply chains. We begin by reviewing key flawed assumptions in supply chain management that have been exposed by COVID-19, and then explain them in the context of constructal law, and what we deem as a "new supply chain law".

What are the key supply chain issues being highlighted by COVID-19?

The Coronavirus is impacting both upstream and downstream flows of material in the supply chain, but in the last twenty years these have been shaped largely by the forces of globalization in pursuit of "lowest landed cost". Supply chain scholars and epidemiologists have long warned about the threats of pandemics to the fragility of a global supply chain system driven by accountants, who do not understand more subtle and pervasive forms of risks that exist in

2 Interview with the Senior Operations Director/Vice President of Manufacturing and Supply Chain Management. The firm supplies high technology components and parts for the automotive industry (2nd March, 2020).
3 Interview with the Head of Global Supply Chain Management. The firm is a manufacturer of earth-moving equipment (20th March, 2020).

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supply chains that are hidden from the view of most observers. Research has noted the importance of having a diverse supply base (Kahiluoto, et al., 2020), but this is clearly not enough when there is a disruption of this nature that occurs. From our interviews, we have identified that the effects of the virus that seem to be emerging are related to four specific areas: i. state of globalization; ii. a unique bullwhip effect; iii. the resurrection of lean and local production, and iv. risk-recovery contingency.

i. State of Globalization

Over the last 10-15 years, we have seen a relentless pursuit for the "lowest landed cost", which with the significant growth in China and Southeast Asia has fueled the globalization of the manufacturing supply network.

> *"The result has been increases in the supply lead-time and varying degrees of sophistication to mitigate the risks of lead-time and variation. These have included response strategies, such as the strategic positioning of inventory in the value chain with varying levels of sophistication and multi-echelon optimization. However, the basic problem has not changed: the longer the actual (end-to-end) lead-time, the more likely one is exposed to variation and unforeseen events; and the question of resiliency comes into play."*
>
> (Head of Global SCM, earth-moving equipment manufacturer)

OEMs and their Tier-1 suppliers have become overly-dependent on extended global supply networks. Recent geopolitical events may have started to change the playing field. For instance, increasing costs of transportation, environmental considerations, and the resurgence of trade tariffs as nations try to improve their economic positions have accelerated the phenomenon of "re-shoring", where large Southeast Asian OEMs are starting to establish themselves in countries like Mexico. The strategy in this case is to position themselves to maximize the U.S. domestic market through favored trade agreements while maintaining the product design and supply advantage they have developed from their home-base.

ii. A Unique Bullwhip Effect

The concept of the bullwhip effect, first introduced by Forrester (1957, 1961) is a foundational theory for the operations and supply chains management discipline. The theory points out that

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an unforeseen spike in consumer demand will travel upstream to the supply chain and amplify its effect due to forecasting safety ranges, leading to short-term product shortages, overproduction in response, and logistics bottlenecks as a consequence.

> *"The initial impact of the pandemic on businesses seemed to be limited to the supply side: factories shut down, manufacturers couldn't get parts, and there weren't enough boats and planes to move products around the globe. Also, there was a shortage of tools. But what many firms have not mitigated for is the impact the virus is having on people, their workforce. In addition, the prioritizing and sourcing of protective equipment for employees, such as masks, gloves, protective coats, and hand sanitizing gels. Also, staff absences include those that are not solely with direct engineering workers, but also the array of supporting workers, such as cleaners and ancillary workers, security, receptionists, warehousing, and logistics staff."*
>
> (Head of Global SCM, earth moving equipment manufacturer)

On the demand side, because more people are staying in and working from home — or being quarantined —there are substantially fewer people out in the world buying goods. In effect, we have a unique "bullwhip effect" where demand is attenuated in some sectors while other demand sectors are amplified, with variations in attenuation and amplification across regions.

Retailers, other than supermarkets, pharmacies, and banks, for example, are seeing a dramatic downturn in demand for their products or services. This is due to consumers being on "lockdown", forcing restrictions on gatherings such as sporting events, school and university closures, social distancing, and movement that is highly restricted to essential journeys. Subsequently, consumers in these demand sectors order less from wholesalers, wholesalers order less from manufacturers, and manufacturers order less from their suppliers. Therefore, many non-food or pharmaceutical manufacturing firms are facing a 60-day lag in the supply of parts and tools, as well as a shortage of workers and ancillary staff, logistics services, and warehousing capacity whilst their demand has collapsed. Many of the grocery story channels for restaurants and schools, for instance, were not able to transition their products to consumer channels because of their rigid efficiency-driven cost structures and supply chain networks,

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and a resulting lack of responsiveness (Kahiluoto et al., 2020). This brings up another subject – why we need lean supply chains more than ever.

iii. The resurrection of lean

U.S. and European manufacturers have primarily become dependent on efficient Southeast Asian suppliers. This has largely occurred as a result of the pursuit of low landed cost (i.e. labor costs). The principles of lean advocate free-flow of information; agile and quick response, visibility to demand, pull systems, and real-time response to shifts in demand (Handfield and Linton, 2017). But we all know that supply chains are complex systems, which are often engineered and managed to deliver products and services to customers at the lowest cost. In fact, the principles of lean focus on the optimization of supply chain processes to ensure enterprises make a profit, delivering products and services of a consistent quality, at a defined rate that is generally equivalent to the rate and mix of demand for these products and services (Ohno, 1988). Lean systems do not always mean having *less inventory everywhere* in the system, but rather having the right amount of inventory in the right locations to ensure flow is not disrupted.

Lean systems also need to be able to adjust capacity up and down over time and may need to stockpile inventory in some locations to make them more resilient if there is risk present (Craighead et al., 2007). But there is no hard and fast rule dictating that lean systems always have more inventory, but rather demand should be managed so that it is predictable. When there is unpredictable demand, however, lean systems can still be effective, assuming managers have evaluated a supply chain against a range of possible threats and determined where to invest in inventory to provide the most flexibility and resilience at the lowest cost.

Yet many of these principles of lean have been shunned, as organizations moved to a "globalized supply chain", characterized by long lead times and low landed cost items. This is best expressed by an executive we met with recently:

> *"It's as if we have forgotten about the principles of lean manufacturing, the theory of constraints, etc., stripped our own industry of expertise and put the accountants in charge. If the only differentiating factor is labor, and manual labor is taking ever-decreasing importance; local (or domestic) supply and manufacturing should win; furthermore, local manufacturing should be less*

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subject to the vulnerability of the extended lead time associated with a global supply network."

(Head of Global SCM, earth-moving equipment manufacturer)

It is fair to note that we are now seeing a limited resurgence of lean, efficient manufacturers, and policymakers are now calling for increased local inventories of healthcare supplies[4], but in most cases, this is much too late for this pandemic. The lessons are hitting hard during the COVID-19 pandemic, as shortages due to limited global trade are exposing the fragile and vulnerable supply chains it has created. There was not sufficient inventory, and hence, no resilience.

iv. Risk-recovery contingency

Adapting Kraljic (1983) and the Sourcing Portfolio Matrix, we mapped out "sourcing risks" against "value" with a senior executive from the automotive sector. In terms of preparedness, each of nine product categories from this company was dual-sourced. However, risks vary significantly across different product categories. With nine product categories, the probability of disruption varies significantly between them. For instance, even though they were a billion-dollar company and the most important customer for suppliers of climate and thermal systems, they were not a powerful buyer when it came to the buying of auto-lighting, electronics, and powertrains. The e-powertrain was deemed the highest risk item prior to COVID-19 due to product development advancing faster than process development.

"There is a lot of waste in the production process as we are struggling to match the correct processes of manufacturing with the rapid advancements taking place in e-powertrain product development. The technology was racing forward with process improvement lagging many months behind."

(Senior Operations Director/Vice President, automotive sector)

Therefore, the high-risk items that were going to grind to a halt first were automotive lighting, electronics, and e-powertrains[5], as shown in our risk-value sourcing matrix shown in Figure 1.

[4] https://thehill.com/policy/healthcare/495192-senate-dems-unveil-bill-to-federalize-medical-supply-chain-boost-production

[5] Electronically controlled powertrains.

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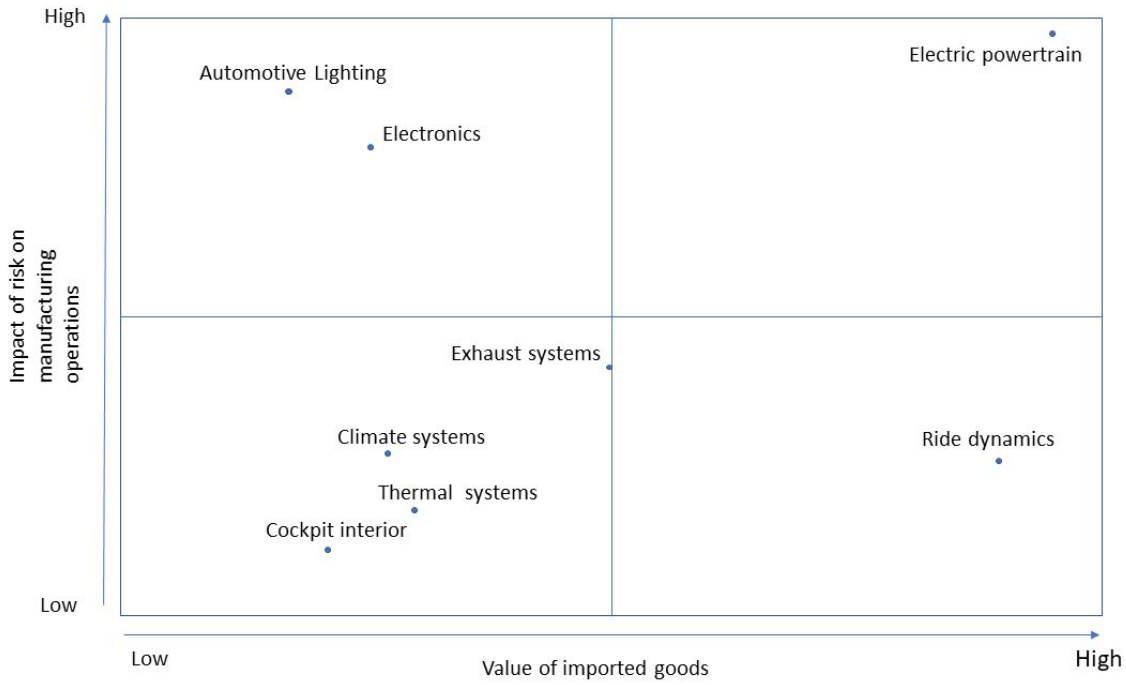

Figure 1: Risk-Value Sourcing Matrix

As well as initial disruptions from parts suppliers in China, they were also facing huge problems of shutdowns due to sickness amongst their workforce with their suppliers located in Northern Italy. This was coupled with embargos being put in place for air travel and port entry. A COVID-19 impacted unit with a senior vice president in charge was established in order to deal with the mounting supply. This senior vice president noted:

> *"A major problem is that we are operating with no extra capacity in the supply chain, we have very limited storage capacity near to the plant and neither do our suppliers. Literally, I would ring for a part, and that would be delivered within minutes. We don't store parts in the plant, and the only storage of note is with the parts suppliers who have typically bought in bulk from China and their stock mountains (i.e. anticipatory stock).*
>
> (Senior Operations Director/Vice President, automotive sector)

When interviewed, they were optimistic that due to sluggish demand in the months prior to the outbreak, they could keep operating until the staffing levels and parts supply fell below 60% of normal operating levels. However, on 18th March 2020, the firm announced they were

suspending production for the foreseeable future, citing the collapse in car sales due to the COVID-19 outbreak, difficulty obtaining parts due to disruption to their supply chains, and a desire to protect staff and their families from the virus.

Constructal Law and the New Supply Chain Law

Constructal law is a law of physics that accounts for the phenomenon of evolution (configuration, form, design) throughout nature, including inanimate flow systems and animate systems together. Stated more precisely, Adrian Bejan (1997) developed the constructal law of thermodynamics:

> *Constructal Law of Thermodynamics: For a finite system to persist in time (to live), it must evolve freely in such a way that it provides easier access to the imposed currents that flow through it.*

constructal law "accounts for the arrow of time, which is the direction of the evolution of flow organization over time" (Duke University, n.d.-a). It is part of the general field of thermodynamics in physics, which "*…owes its immense power – its utmost generality – to the fact that its laws apply to any imaginable system…thermodynamics is a discipline. It has precise rules, words, and laws. Any analysis, any discussion, must begin with defining the system unambiguously, and sticking with it*" (Bejan, 2016, p. 2). It has been said that "constructal theory predicts natural design and its evolution in engineering, scientific, and social systems" (Duke University, n.d.).

We propose the idea that supply chains are also subject to constructal law. The design of a supply chain is an integral part of any organization's competitive footprint, but it can also be influenced by the decisions that managers make when confronted by major disruptions, such as trade wars or global pandemics. In physics, the few large entities in a system interact and co-evolve together. However, they cannot eliminate the many small entities that may exist, but rather they evolve together in a balanced multi-scale system toward higher fitness levels, for the improvement of the whole flowing system (Bejan, 2016, p. 230). Building directly on Bajan's pioneering work, we posit a parallel and aligned law for supply chains that is consistent with this observation:

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Supply Chain Constructal Law: Supply chains evolve freely through forces of change, and their design will evolve to a position maximizing output for the fewest inputs, resulting in lowest total cost in a predictable fashion.

This perhaps seems like an obvious statement – every supply chain has to change to adapt to its ecosystem, but the nature of change has rarely been compared as a property of evolutionary design. Although we acknowledge that there have been comparison of supply chain and co-evolution (see Choi et al., (2001)). However, the concept of "lowest total cost" needs to be qualified for context. Total cost includes the relative trade-offs made in terms of flexibility vs economies of scale (Bergman & Mäler, 1982), responsiveness vs efficiency (Ganga & Carpinetti, 2011), and lowest price vs lowest risk (Holweg et al., 2011). Most supply chain managers focus on "landed cost" (defined as lowest price plus lowest transportation and trade import costs). However, the lowest total cost includes the inherent costs of increased inventory; lower working capital; increased risks of disruption, and other factors, which are often not included in traditional landed cost analysis. Because of their primary focus on landed cost and not total cost, supply chain managers tend to be iterative and focused on making small and subtle tweaks to their current supply chain and way of thinking, very often seeking to squeeze suppliers for a lower price, pursue trade arbitrage for lowest labor cost, or negotiate better price contracts with suppliers.

In the current environment, however, such activities have proved to be of little consequence compared to the massive forces of economic disruption of the last three years. In the face of significant global shifts to the ecosystem, small changes resulting from incremental iteration is a death sentence, and is the equivalent of doing the same thing over and over hoping it will improve the situation. It is part of the supply chain manager's gestalt to continue to focus on a negotiated cost savings of 5% to 10% for logistics or purchase price, but not to strive for anything more such as integrated design changes to improve the overall supply chain design as an integrated system, and resulting improvements in total cost and resiliency. Such savings do not amount to much when an entire month's worth of orders is wiped off the books by the COVID-19 virus, by Brexit, or by 25% increases in trade deal tariffs.

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Application of Constructal Law

So how can we make sense of the events of the last three years and, specifically, the events unfolding with COVID-19 supply chain disruptions in the context of constructal law? From a constructal law perspective, think of the pandemic and supply chain disruptions as an outcome of the natural progression of events that follow the extreme levels of globalization that we have gone through over the last twenty years. We could speculate that the reaction of the Trump administration to globalization is a direct outcome of the dissatisfaction of his voting base who had their jobs displaced when they moved to China. And speculate that Brexit followed anxiety about immigration levels by some of the U.K. population. Some may point to the emergence of the Coronavirus as a freak event, but we are reminded that it is also a simple evolution of the flu, and could just as easily recur on a more frequent (even predictable and seasonal) basis (Fox et al, 2017) .

Perhaps these events are not freakish at all but were easily predictable as part of the natural design of global commerce and highly interdependent global supply chain ecosystems. In other words, it is not "if" but "when": they were simply a matter of time, and the details merely a function of global supply chain "thermodynamics".

But were these trade wars and global epidemics destined to occur? The iterative tendencies of supply chains to seek the lowest total cost can be viewed as a natural but managed progression, defined by the flow of goods and services and driven by human decisions that will follow their natural path toward higher efficiency – higher output at lower cost. When water flowing through a river encounters a barrier, whether it is a mountain, woods, or a shift in elevation, it is redirected to a new path, and over time the river may shift and be diverted along a completely different route. We believe that this, by analogy, may be what is happening today in global supply chains and that the context of these events can be viewed in a similar fashion – as new obstacles that will redirect the flow of supply chain designs of global organizations. We believe that supply chain designs are evolving, focusing less exclusively on profit and low landed cost, and more on other metrics such as sustainability, lower working capital, lean production, resiliency, low emissions, and better risk-recovery strategies.

Organizations that understand these "natural laws" of global supply chain design will allow the invisible hand of the market to help them understand the dynamics and evolutionary flow of

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what is happening in a particular channel. Intelligent executives realize there is a reason why the price or cost is so low in a country, and this is ultimately reflected in the equation of total cost, which includes the cost of poor quality, late delivery, impact to the brand, supply chain disruptions, and other impacts such as the cost of unsafe and inhumane working conditions, which is being regulated by national governments.

As these product design and supply chain design shifts occur over time, the evolutionary flow of these supply chain designs is altered forever. People do not realize that the fall-out from many of the trade wars is permanently shaping how global companies do business, including shifts in the long-term allocation of resources and capital. The move towards localization of global supply bases is beginning already, and being spurred on by political events as well as current and newly-anticipated future global pandemics.

Supply chains that evolve through change are naturally a function of executives that seek to innovate. When confronted by significant barriers, such as a global pandemic, executives will convene and find intelligent alternatives. This may lead to short-term suffering and economic displacement. Factories will shut down, customer orders will be cancelled, revenue may drop, and share prices plummet. Before the Coronavirus hit, many apparel manufacturers had already pulled out of China but were still reliant on intermediate goods that can shut down their supply chains[6]. These are all-natural occurrences that accompany change, and creative forces are triggered by such discontinuities in supply. Because global change is inevitable, Bejan points out that evolutionary design is required to adapt to the shifts that occur in supply chain ecosystems. Instead of "weaponizing" trade through tariffs designed to punish countries that are not opening borders, we may be seeing a shift towards new supply chain designs that are a natural outcome of such shifts.

Innovative companies seek to re-think the way that decisions are made and to update how supply chains can operate dynamically. Evolutionary supply chain design requires that individuals constantly look for emerging patterns in how material moves through their supply chains. Force or action must be taken to change the path of supply chain flows, to compress the time inventory remains in the system or impacts on how cash is consumed over time.

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[6] https://www.wsj.com/articles/companies-that-got-out-of-china-before-coronavirus-are-still-tangled-in-its-supply-chains-11583686996?mod=hp_lead_pos2

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Lessons learned so far from recent disruptions and COVID-19

Supply chain managers tend to be iterative and focused on making small and subtle changes to their current system and way of thinking, very often seeking to optimize cost or negotiate better contracts with suppliers. In the current environment, however, such activities have proved to be of little consequence compared to the massive forces of economic disruption of the last three years.

Organizations that have more tightly compressed and responsive supply chains are enjoying a significant benefit during the COVID-19 crisis and are no longer being held hostage to the impacts of political decisions of governments of another country. During a crisis, countries become very selfish, as illustrated by the hoarding of N95 masks in China by the Communist Party, even though a large number of masks are produced by 3M, an American company with a factory in China.

It was indicated in the cases we are developing that it is going to take manufacturers on average one month to recover from 4-6 days of disruption. Whilst China is just starting to recover (i.e. managing to get back up to the required through-put rates and work through the backlog in demand), the rest of the world was initially able to continue because there was a lot of inventory in supply pipelines. Now these pipelines have been emptied and there are big gaps. For instance, Original Equipment Manufacturers (OEMs) are no longer able to expedite freight or keep factories producing efficiently. Of more concern, both senior vice presidents outlined that there is grave uncertainty regarding the economic outlook and whether demand will take such a long time to recover, raising concerns that their supply chain will be overburdened with inventory as consequences of the bullwhip effect, or if state-sponsored initiatives in infrastructure will stimulate demand.

> *"In a controlled economy, such as China this might work; we are already seeing signs of increasing domestic demand; unfortunately, the opposite is occurring in the Americas and Europe, and we are probably 2-3 months away from any forward-looking picture."*
>
> (Head of Global SCM, earth-moving equipment manufacturer)

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It is clear that the COVID-19 response introduced a bullwhip effect in the manufacturing sector on a never-before-seen scale. For scholars, we would suggest four pathway topics going forward. These topics include the future state of global sourcing; the unique nature and a combined "demand and supply shortage" bullwhip effect; the resurrection of lean and local production systems; and the development of risk-recovery contingency strategies to deal with pandemics. Or in the words of the earth-moving equipment manufacturer:

> *"Approaches to mitigate the bullwhip effect vary, but the fundamental problem to solve is to shorten overall end-to-end lead-time. This will require a resurgence in manufacturing and rebuilding of manufacturing operations know-how, on a competitive level that can outstrip any re-shored Southeast Asian supplier. We have to think LEAN; we have to adopt process automation (physical and transactional). Note: most of the fixed costs of a manufacturing organization (planning, production management, requirements management, can be automated to a level that was not possible only a few years ago. It is possible to change the game; most Chinese factories are highly productive, quality is excellent; however, they still rely on highly skilled engineers performing planning and automatable tasks; this is a legacy we can leap-frog. We will have to have industry-sector initiatives, partnerships with local government and education establishments to pull it off, and the post-pandemic might be the opportunity we need for a lean manufacturing renaissance."*
>
> (Head of Global SCM, earth-moving equipment manufacturer)

The iterative tendencies of supply chains to seek the lowest total cost can be viewed as a natural progression, defined by the flow of goods and services that will follow their "natural" path. When water flowing through a river encounters a barrier, whether it is a mountain, woods, or a shift in elevation, it is redirected to a new path, and over time, the river may shift and be diverted along a completely different route. With COVID-19, the global supply chain hit a dam with little forewarning. In many places as demand dropped to zero, there were no outlets to unload supply. It was unlike any other force ever encountered before.

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While Brexit and the U.S-China trade wars impacted supply cost and modified the landed cost equation, COVID-19 impacted both supply and demand factors and shut down every economy in the world in less than a two-week period. Although Brexit did initially impact demand and led to some stockpiling, this did not happen concurrently with anticipated disruptions to supply, and it happened over an extended period. The massive force of a global pandemic was a rapid disruption that few supply chain managers had ever paused to think about, in terms of realizable risks. Adopting the approach of Bejan, we believe that this may be what is happening today and that the context of these events can be viewed in a similar fashion – as new obstacles that will redirect the future flow of supply chains that are designed less by cost and influenced more sensibly by multiple factors, such as sustainability, low emissions, and better risk-recovery strategies. Then, they can deal more effectively with the short and long-run economic, social, and human effects of pandemics.

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