Supply Chain Resilience: Push and Pull in Catastrophes

Philip J. Palin

Editor's Note: ***This is the second in an invited two-part series on supply chain resilience in catastrophes. The first installment, "Food and other Supply Flows in Case of Catastrophe, appeared in the Journal's Spring/Summer Edition. It presented a data driven, scalable analytical process to assess grocery and other supply flows in Washington State's Puget Sound. The methodology is adaptable to other metropolitan areas.[1] The current article examines how U.S. supply chains have generally responded to COVID-19 and the pandemic's impact thus far on grocery supply chains. Using these and other insights, the food supply chain repercussions of a destructive earthquake in the 4.2 million population Puget Sound Region are addressed. The first U.S. case of COVID-19 occurred in Washington State, and the region is designated as an earthquake hot zone.[2]***

Keywords: Supply Chain Resilience, food supply, grocery distribution, supply volume, supply velocity, covid-19, earthquake, catastrophe

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Large populations require large volumes of water, food, and other supplies. Delivering large volumes—especially over considerable distances to dense populations at an affordable price—depends on achieving high velocity flows.

The first article in this two-part series concluded with:

> *Infrastructure will fail. Cyclones, major seismic events, and cyber strikes will happen. Pandemics, wildfires, and floods can overwhelm. Many nodes and links will be destroyed. Flows will be seriously disrupted. Hundreds of thousands will be at risk. But what we have also seen—as in Japan on 3/11 and Puerto Rico in 2017—is that human networks can be very creative when other sorts of networks break, especially when humans have prepared themselves for broken possibilities.*

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1 Palin, Philip. 2020. "Food and Other Supply Flows in Case of Catastrophe." *Journal of Critical Infrastructure Policy* 1 (1): 51-67.

2 The exposition of this article departs from standard Journal format in order to facilitate its use in disaster planning by public administrators, emergency managers, and other professionals.

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The January 2020 pre-pandemic text gives particular attention to "feedback loops" that shape channels of transportation, communication, and financial transactions across demand and supply networks. The text argues, "Fast, accurate feedback is fundamental to velocity. Without velocity, enormous volume can self-create congestion." Most disaster management approaches tend to focus on supply-push and volume, especially featuring federal, state, and charitable emergency distributions of water and shelf-stable-food. The prior article proposed that commercial flows featuring demand-pulling delivery speed with accurate targeting are at least as important—even more important in catastrophes involving large populations.

Pandemic outcomes—in China, the United States, and elsewhere—have now dramatically confirmed this strategic principle.

How should this demand-pulling-velocity principle inform strategic and practical responses to catastrophically destructive events? The first installment and most of what follows focuses on adapting this principle to the implications of a Cascadia megathrust earthquake in the Puget Sound region.

The first recognized case of Covid-19 was confirmed in Puget Sound. Until mid-March, Puget Sound was the epicenter of the U.S. outbreak. Despite (or because of?) this challenging start, Puget Sound has—so far—avoided many of the worst pandemic outcomes.[3] Because of preparedness for a Cascadia seismic event, Puget Sound was better prepared for the pandemic. Because of its pandemic experiences, Puget Sound can now be better prepared for a megathrust earthquake—*if the region recognizes what has worked and why* in terms of Supply Chain Resilience. The same insights are relevant to most jurisdictions and catastrophic contexts.

The demand and supply networks described in the first installment are shifting. The fundamental character of demand is evolving. Sudden-onset mass-unemployment, continued pandemic risk, and acceleration of long-emerging technological, demographic, and social trends are transforming prior patterns. There are, however, also very stubborn factors of time, distance, density, capacity, cost, and physics that constrain change. The ability to monitor and understand both constancy and change is key to Supply Chain Resilience.

Pre-Pandemic Fundamentals[4]

In most of the United States and many other places, large populations depend on high volume, high velocity demand and supply networks. Over-time—and especially over the last thirty-plus years—the interactions of demand and supply have created lattice works of physical infrastructure, technological capabilities, fi-

3 Institute for Health Metrics and Evaluation, Covid-19 Projections (Washington), September 18, 2020.

4 Please see first installment in this series: "Food and Other Supply Flows in Case of Catastrophe," *Journal of Critical Infrastructure Policy*, Spring/Summer 2020.

nancial connections, market competition, and social relationships optimized to deliver what consumers want, when, and where wanted with a price and quality that targeted consumers are ready to accept. The resulting—emergent—network-of-networks has evolved into a complex adaptive system that is robust and resilient in many disaster contexts. But as with other complex adaptive systems, contemporary demand, and supply networks also display aspects of self-organized criticality, a structural predisposition toward unexpected unraveling and even collapse.[5] Such *systemic* failure is an existential threat to large populations. Given the volumes, velocities, and complexities of such demand and supply networks, it is not possible to quickly replace lost capacity or capabilities. To avoid significant human suffering, demand and supply networks must continue largely intact or quickly recover preexisting flows.

Pandemic Observations, Confirmations, and Questions to Date

Most disasters disrupt or destroy physical networks in specific places defined by the reach of an "external" event: tornado, flood, hurricane, earthquake, wildfire or other major event. Outside this space, preexisting network capacities and capabilities persist. Early studies of disaster response observe the surviving and surrounding "cornucopia ... deluging the impact area."[6] External capacity is deployed to establish a new equilibrium of supply and demand. In contrast, the novel coronavirus has depended on the cornucopia to facilitate its widening circulation. Rather than destroying physical networks, the virus has coopted these connections.

The virus has sometimes been contained or constrained by slowdowns, shutdowns, or lockdowns of demand and supply networks. The choices involved in slowing or shutting or locking have prompted epidemiological, strategic, social, and political controversies.

Some of the most dramatic consequences of the pandemic relate to sharply increased demand threatening to drain available supplies while curtailing flows to the most vulnerable. Preexisting weaknesses in demand and supply networks—for food, health care, internet access, and more—have been made more obvious by pandemic consequences. In some situations, purposeful shaping of network behaviors to contain the virus may be as disruptive or *more* disruptive than the direct impact of the virus; for example, mass unemployment resulting from shutdowns. Another example: the persistent preference of many to share interior spaces and physical proximity has, again and again, provided the virus its own high volume, high velocity opportunities. Contemporary demand and supply networks do not require crowding into badly ventilated interiors. But the virus is poised to exploit such behavior.

5 Palin, Philip J., Supply Chain Resilience: Diversity + Self-Organization = Adaptation, Homeland Security Affairs Journal, August 2013.

6 Wallace, Anthony F.C., Tornado in Worcester, National Academy of Sciences, 1954.

This interplay of the coronavirus with demand and supply networks has amplified several core characteristics of network behavior. Many of these characteristics have long been recognized or hypothesized, but difficult to extract from the "noise" of normal network behaviors. Careful data analysis and synthesis are still needed, but given what has been observed since February 2020, there is now greater cause to be confident of the especially influential role of three factors:

1. Demand drives and organizes supply

   Persisting and accurate demand-signaling reinforces resilience and energizes networks. This was especially obvious in the extraordinary response of the grocery supply chain in the United States (and elsewhere).[7] Food producers, shippers, truckers, distributors, and retailers responded creatively, effectively, and quickly to increase flow volume and velocity. At the same time, they were disciplined in minimizing inaccurate expressions of demand and related "bull-whipping"[8] of supply chains. This contrasted with confused[9] and chaotic demand[10] signaling in the medical-goods sector (related to number 3 below). But every example—good or bad—reinforces that to advance Supply Chain Resilience, it is essential the network receive full-scale demand signals with full fidelity.

2. Movement may matter most

   Where functional and physical channels (lanes, links, edges) persist, Supply Chain Resilience is possible**.** The pandemic has not destroyed nor physically disrupted infrastructure. Non-Pharmaceutical interventions (NPIs, like retail shutdowns) have certainly disrupted network functions. Friction has increased across many networks. But flow *capacity* has not yet been systemically reduced. There have been instances of disease-outbreaks or fears of disease reducing production or transportation capacity. But at least so far, in the United States these capacity-reductions have been short-term and non-material in terms of network-behavior. This persistence of network flow should not be taken for granted. In February and even into March, the Chinese transportation network was much more fragmented by NPIs and other pandemic consequences than has been experienced in the United States or most of Europe. As a result, in the United States essential supplies have mostly remained

7 IRI, CPG Demand Index, ongoing.

8 Inventory fluctuations in increasingly larger waves as one goes up the food supply chain in response to consumer demand. Thus, in the case of grocery, the largest variation occurs among food and other raw producers responding to increased consumer demand.

9 Keskinocak, Pinar and Ozkaya, Evren, US pharmaceutical supply chain unprepared for COVID-19, Healio (April 2020).

10 Lin, Liza and Xiao, Eva, China's Medical Goods Market is Wild West Amid Surging Coronavirus Demand, *Wall Street Journal* (April 2020).

abundant, except where there has been a problem with number 3 immediately below. So, "debris clearance"—where debris is understood to be either physical or functional or regulatory—has been seriously reinforced as a Supply Chain Resilience priority.

3. At any point in time, capacity is essentially fixed

   High-volume, high-velocity, decentralized demand and supply networks have resilient strategic capacity. Low-volume, low velocity capacity cannot be quickly increased. Where *preexisting* capacity fulfilled high-volume, high-velocity demand, networks have demonstrated significant adaptability to shifts and spikes in demand during the pandemic. The US freight market[11] has been amazingly agile. The grocery sector quickly increased gross volumes[12] flowing to consumers. But even in grocery, where there was less volume, less velocity, or higher concentration, resilience has been challenged. Pork production in the United States is highly concentrated.[13] As a result, disease-related disruption at just a few pork production nodes seriously impacted network capacity. Pre-pandemic production of most Personal Protective Equipment (PPE), such as gloves and masks, was a low-volume category (compared to grocery volumes) characterized by low velocity and high concentrations distant from the United States. As such, the capacity did not exist to fulfill exponential increases in demand. PPE production capacity is still insufficient.[14] [15] Given the time and expense usually required to increase (or replace) capacity, a preexisting lack of capacity to fulfill current demand is more about strategic realism than strategic empowerment. But in any case, recognizing the scope and scale of the problem is essential to any effective strategy.

Pre-existing—surviving—capacity is a key consideration in all potentially catastrophic contexts. The pandemic persuasively demonstrates that production and processing capacity can be stubborn. "Inelastic" is the term used by Federal Reserve economists.[16] Where possible, producers have added shiftwork. Lower-demand products have been discontinued to increase throughput of higher demand products. The resulting absence of product variation is expected to persist for many grocery categories through calendar year 2020 and with some products well into the new year. When worker absence and facility closedowns impacted

11 Jaillet, James, Freight volumes reach pre-covid levels, Overdrive (June 2020).

12 Leatherby, Lauren and Gelles, David, How the virus transformed the way Americans spend their money, *New York Times*, (April 2020).

13 Phipps, John, The current crisis for pork producers is unlike the 1990s, *Pork Business* (June 2020).

14 Parshley, Lois, Remember the N95 mask shortage? It's still a problem. *Vox* (June 2020).

15 Behnam, Mohammad et al., Medtech's Call to Action, McKinsey & Company. (September 2020).

16 Saitone, Tina and Sexton, Richard, Concentration and Consolidation in the US Food Supply Chain, Federal Reserve Bank of Kansas City, 2017.

pork, chicken, and other food processing, the subsequent loss of flow demonstrated the preexisting network's careful calibration, efficiency, and self-organized criticality. But even with these structural constraints, during the first six months of the pandemic, high volume, high velocity networks could mostly close-the-gap with much higher-than-expected demand.

In contrast, when demand surged for previously low volume product categories (such as many forms of PPE, medical goods, or COVID-19 testing), the production capacity simply did not exist to substantially increase volumes in a timely way. Given the capacity and adaptability of freight markets, velocity could sometimes be increased but this mostly caused finite supplies to crater faster. Creating new capacity is an entirely different strategic problem (or opportunity) than exploiting existing capacity.[17] Accurately understanding the strategic context vis-à-vis capacity is crucial in any high-risk context. If disease penetration requires long-term shutdowns of food processing facilities during the pandemic, this loss of capacity will not be readily replaced. Workforce absence is also likely to constrain capacity following a Cascadia seismic event. Permanent loss of some workplaces is also possible.

Supply Chains, at their most basic, facilitate movement of goods and services in response to an expression of demand. Early in the pandemic (March-May 2020), the grocery supply chain in the United States experienced unprecedented increased demand, increased movement, and significant shifts in production and processing. Much more money was spent at grocery stores. This stimulated more movement by more trucks delivering more volume. To deliver high demand products, unused or underutilized production capacity was redirected. In many cases, production capacity for lower demand products was repurposed to increase production of higher demand products. In most cases, overall production capacity did not increase, but the output volume for high demand products was substantially increased by adapting existing capacity to new demand levels.

The maps and methods set out in the next section (and in the first installment) identify the preexisting strategic capacity that feeds the four million-plus residents of Puget Sound. These maps and methods help answer fundamental questions: Has capacity been lost? If so, why? What are the key dependencies and interdependencies? What has been temporarily disrupted? Why? What network linkages—transportation, water, electricity, workforce or whatever—will most quickly restore the most capacity? Given the confusion and uncertainty of the crisis, how should priority be given to reestablishing food production capacity? If twenty percent of capacity is lost, what does that mean for the surviving population? If forty percent is lost, what does that mean? What if more than forty percent is lost? That food mostly persisted flowing during the early stage of the pandemic, despite significant challenges, largely reflects the systemic continuity of capacity

17 Delivering Pandemic Resilience, DHL Research and Innovation Group (September 2020).

and channels (so far) and the power of demand to stimulate and sustain flow. How does this inform strategic options for a very different sort of disruptive event, such as a huge earthquake?

Supply Chain Resilience and a Cascadia Megathrust Event

On January 26, 1700, one of the most powerful earthquakes known displaced the earth's surface from at least the Columbia River to Vancouver Island. The Cascadia Subduction Zone (CSZ) is where three remnants of the primordial Farallon plate are bending beneath the much larger North American plate. Subduction faults produce the planet's most destructive seismic shifts. Several studies suggest a recurrence pattern for magnitude 8.0 and above that ranges between 250 and 500 years.[18] A CSZ Event is not the only catastrophic threat to the Puget Sound region.[19] But a Cascadia event's wide-area physical consequences will be especially challenging for demand and supply networks.

The M9 Project at the University of Washington has simulated fifty Cascadia scenarios.[20] Consequences vary considerably depending on several variables, especially the location of the epicenter.[21] Even after it happens—and with after-shocks, keeps happening—the strategic context will remain uncertain for a considerable time. But projections and estimations are dire. A 2015 piece in *The New Yorker* describes a generally accepted "big picture."

> *When the next very big earthquake hits, the northwest edge of the continent, from California to Canada and the continental shelf to the Cascades, will drop by as much as six feet and rebound thirty to a hundred feet to the west—losing, within minutes, all the elevation and compression it has gained over centuries. Some of that shift will take place beneath the ocean, displacing a colossal quantity of seawater .... The water will surge upward into a huge hill, then promptly collapse. One side will rush west, toward Japan. The other side will rush east, in a seven-hundred-mile liquid wall that will reach the Northwest coast, on average, fifteen minutes after the earthquake begins. By the time the shaking has ceased and the tsunami has receded, the region will be unrecognizable.*[22]

Depending on point of origin, Cascadia event seismic waves will cause long-duration shaking (perhaps up to six minutes). This is tough on everything

18 United State Geological Survey, Cascadia Subduction Zone, Earthquake Hazards Program.

19 *Washington State Magazine*, Dangers of a major Cascadia earthquake, Fall 2012.

20 University of Washington, M9 Project.

21 Wirth, Erin, Understanding the Big One: Estimating Shaking in Cascadia's Next Great Earthquake, American Association for the Advancement of Science (February 2020).

22 Schulz, Kathryn, The Really Big One, *The New Yorker*, July 2015.

but will have an amplified effect on tall and long structures built on Puget Sound's sedimentary soils. The U.S. Geological Survey (USGS) describes the Puget Sound as an earthquake "hot zone," with a seventy-five percent or greater probability of experiencing a massive earthquake in the next 100 years.[23]

Channels, Sources, and Signals

Channel Clearing and Alternate Routing

Long duration violent shaking results in landslides,[24] displacement of masonry structures,[25] dam failure, fracturing of water and fuel networks, and disruption of the electrical grid. Skyscrapers, bridges, elevated roads, and pipelines are especially vulnerable.[26] [27]

Saturated sedimentary soils, common to Puget Sound, tend toward liquefaction. Snohomish County, north of Seattle, tells its residents, "A major quake threat rests in the Cascadia subduction zone off the Washington Coast. If it lets loose, experts predict widespread damage to bridges and overpasses, likely shutting down the region's transportation system for weeks."[28]

Figure 1shows "poor condition bridges" in Washington and parts of Oregon and Idaho.[29] The second map (Figure 2) identifies the principal channels used by five major grocery distribution centers (three shown as diamonds) serving the Puget sound region. The color-coded lines are rough approximations of comparative volumes flowing from these key sources to retail locations served by each. Together these supply and demand nodes sell approximately seventy percent of the groceries (Food-At-Home) consumed in the region. Figure 3 is a close-up of "poor condition" bridges. Even without landslides, liquefaction, and more it is obvious the post-Cascadia grocery distribution network will be seriously disrupted.

Fulfilling demand requires moving supplies. Given Puget Sound's tight topography and limited road-network, alternative routing is not easy. It will be even more difficult after a major seismic event. Fundamental to channels starting to flow post-Cascadia will be:

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23 Peterson, Mark, et al. 2019. The 2018 Update of the US National Seismic Model: Overview of Model and Implications. *Earthquake Spectra* 36 (1) (November 2019).

24 Washington State Department of Natural Resources, Landslides, Geologic Hazards.

25 Gilbert, Daniel and Doughton, Sandi, Buildings that Kill, *Seattle Times*, May 2016.

26 Berman, Jeffrey, Effects of Simulated Magnitude 9 Earthquakes on Structures in the Pacific Northwest, American Association for the Advancement of Science, February 2020.

27 Marafi, Nasser, Eberhard, Marc, and Berman, Jeffrey, Effects of Deep Basins on Structural Collapse during Large Subduction Earthquakes, *Earthquake Spectra*, January 2020.

28 Snohomish County Hazard Mitigation Planning, Earthquake Faults.

29 US Department of Transportation, National Bridge Inventory, Federal Highway Administration, 2019.

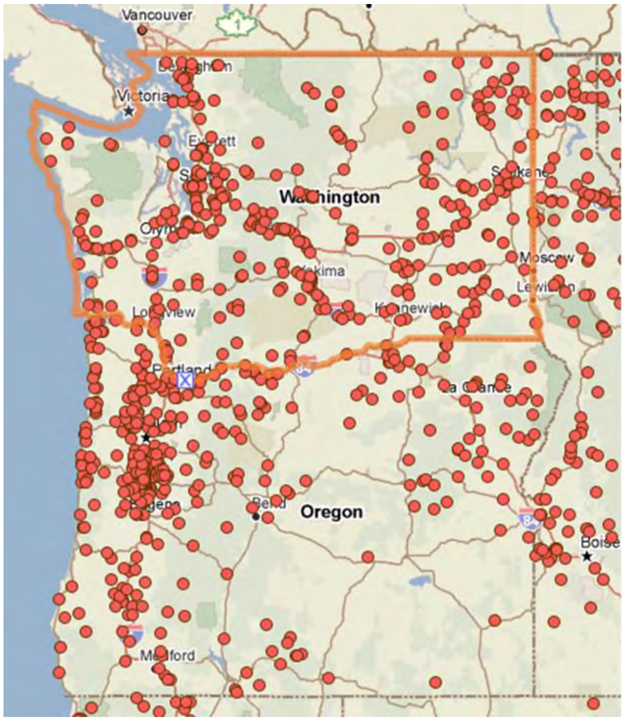

Figure 1. Poor Condition Bridges
(US Department of Transportation 2019, courtesy of PolicyMap)

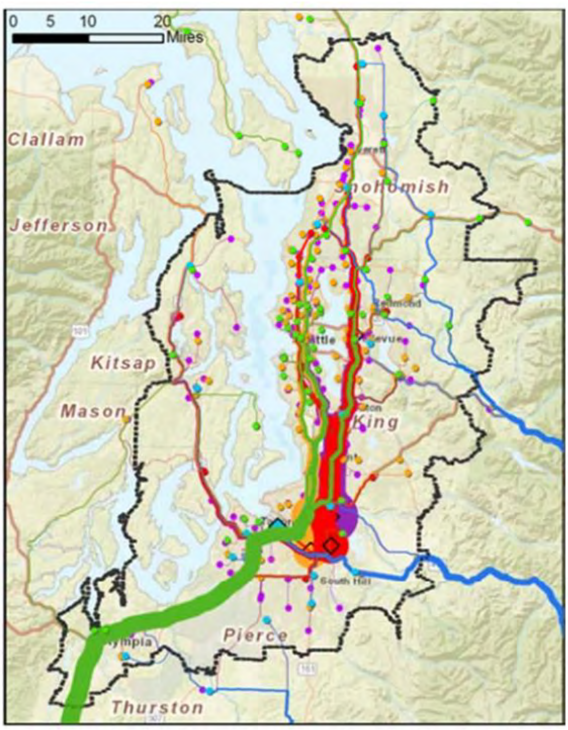

Figure 2. Proportional Grocery Flows (CNA, Institute for Public Research, 2019)

Figure 3

1. Rapid Assessment of key nodes and channels
2. Communication of assessment findings and priorities
3. Debris clearance where possible, timely, and as prioritized
4. Repairs where possible, timely, and as prioritized
5. Temporary workarounds to facilitate flow where repairs are not possible or timely
6. Rerouting flow to maximize network recovery

The first five functions are mostly public sector activities. To undertake these functions in the early hours of the crisis requires many hours of preparation before the crisis. What are the key nodes and channels? How will post-event status be known? Who needs to know—especially what supply chain operators need to know—the post-event status? How will this status be communicated and updated? Given what can be discerned regarding the strategic context, what principles should drive priorities for debris clearance, repairs, and workarounds? Who is making these critical decisions related to Supply Chain Resilience? Rerouting may also benefit from proactive private-public consultations both before and after the event.

Before the pandemic, jurisdictions in Puget Sound were actively working with the private sector to develop capabilities to deliver all five of these functions and to assist with rerouting when necessary. But elsewhere in 2019, other U.S. jurisdictions facing serious seismic and other risks explicitly decided that emergency management agencies do not have the personnel capacity or competence to conduct meaningful Supply Chain Resilience assessments. One region facing a seismic risk similar to Puget Sound's decided it could not give operational priority to grocery deliveries. Most emergency management agencies in the United States have not even begun to consider the issue.

Maximizing Surviving Source Capacity

More than half—potentially more than sixty percent—of Puget Sound's groceries are trucked into the region.[30] Most of these trucks use Interstate-5. Portland is a significant source of food for Seattle (just as Seattle is a major source of food for Portland). After a major Cascadia event, the I-5 is expected to be impassable in several locations for a matter of months. Truck volumes on I-90 crossing Snoqualmie Pass (Annual Average Daily Truck Traffic: about 7,000) are about one-third to half those on the I-5 between Olympia and Tacoma.[31] [32] Interstate 90 is expected to better survive the event, at least until it traverses the sedimentary basin that begins about sixteen miles east of downtown Seattle. I-90 is the corridor that FEMA intends to use post-Cascadia to move supplies from an air hub at Moses Lake in Eastern Washington. The I-90 is the most promising alternative for moving food from Northern California, Eastern Washington, and other food processing sources outside the impact zone.

Between Seattle and Portland both food sources and transportation channels are likely to be seriously disrupted. For example, dairy production in Eastern Washington (see map below) will continue even as many of the dairy plants along the I-5 corridor will be disrupted or destroyed.

As the dairy map (Figure 5) and the maps in Figure 6 indicate, Puget Sound is itself a significant food processing center. Depending on what is being measured, roughly one-third to nearly half of food consumed in Puget Sound is locally processed/packaged. These flows will be seriously disrupted by a major Cascadia event. Some processing facilities will be destroyed, other facilities will be physically isolated, most will lose access to grid power and public water for a considerable period of time. Identifying surviving capacity and reclaiming this capacity as soon as possible is clearly crucial.

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30 Please see the first installment in this series for more details on the grocery supply chain serving the Puget Sound region.

31 Washington State Department of Transportation, Traffic GeoPortal.

32 Washington State Department of Transportation, Freight System Plan, 2017.

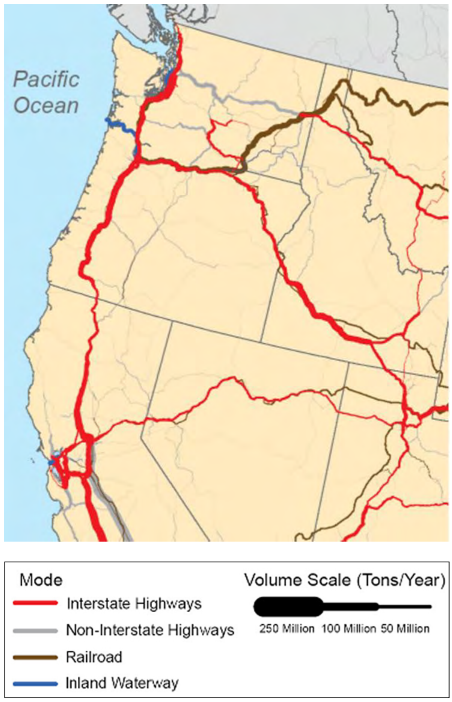

Figure 4A and 4B. Major Freight Routes, Freight Analysis Framework, USDOT, BTS

Demand

Signals and Demand Management

As with other aspects of reality, there is a predilection to conservation of energy and momentum. Human systems and structures are inclined toward continuity. Once flow is well-established, flow tends to persist. Analogies with Newton's laws of motion and fluid dynamics can be helpful.[33] Such analogies are a focus of academic study and design principles for supply chains.[34, 35, 36] In March 2020, the

33 Newton, Isaac, Philosophiæ Naturalis Principia Mathematica (1687):

Law I: Every body persists in its state of being at rest or of moving consistently straight forward, except insofar as it is compelled to change its state by force applied.

Law II: The altered motion is ever proportional to the motivating force applied; and in the direction of a straight line where that force is applied.

Law III: To every action there is always an opposite and equal reaction: or the mutual actions of two bodies upon each other are always equal and directed to contrary parts.

34 Klug, Florian, The Supply Chain Triangle: How Synchronisation, Stability, and Productivity of Material Flows Interact, Modelling and Simulation in Engineering, 2013.

35 H. Schleifenbaum, J. Y. Uam, G. Schuh, and C. Hinke, "Turbulence in production systems—fluid dynamics and its contributions to production theory," in *Proceedings of the World Congress on Engineering and Computer Science*, October 2009.

36 R. Wilding, "The supply chain complexity triangle—uncertainty generation in the supply chain," *International Journal of Physical Distribution and Logistics Management*, 1998.

already high-volume, high-velocity flows of food serving major urban areas, including Puget Sound, were rapidly doubled and more by increasing time-worked, pallets picked, and truckloads delivered while reducing variations in production and distribution. This was possible by streamlining preexisting production capacity and preexisting channels.

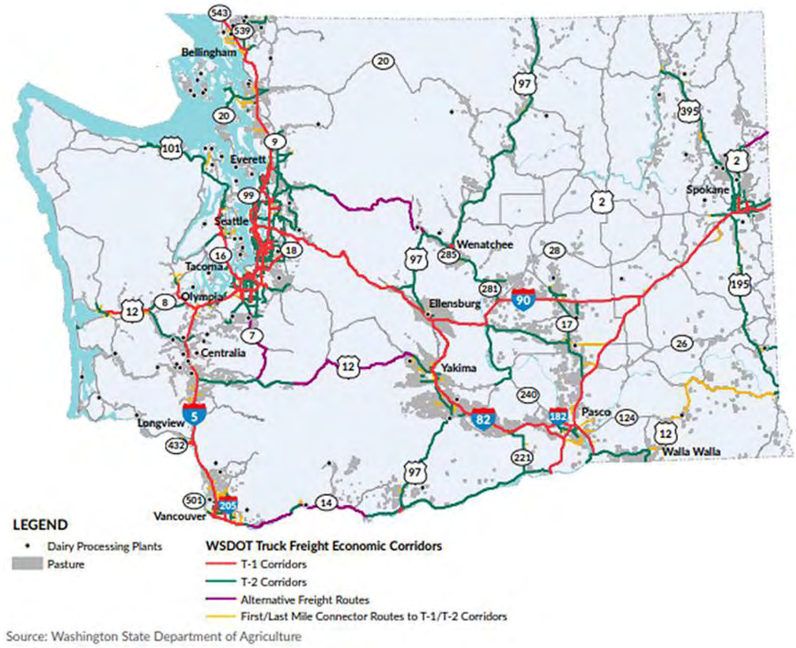

Figure 3

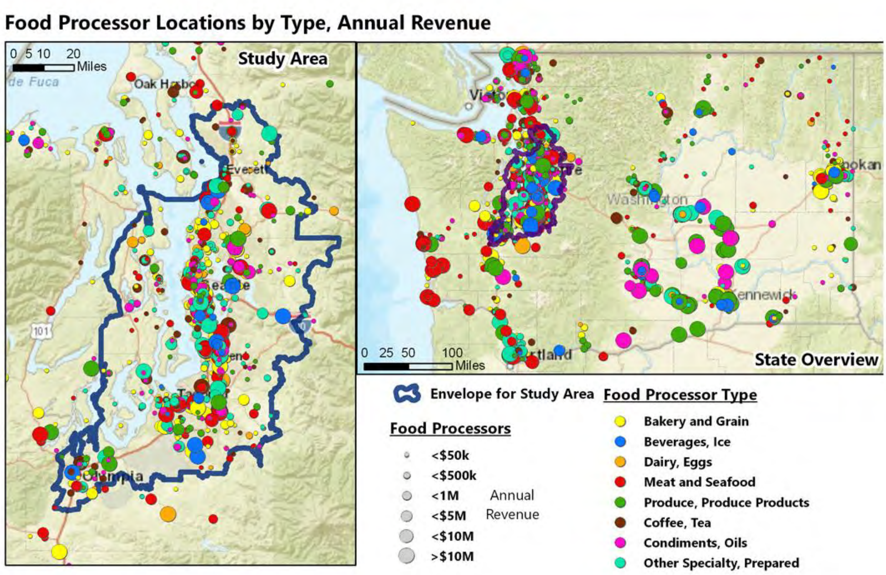

Figure 6. Proportional concentration of food processing capacity (CNA, Institute for Public Research, 2019)

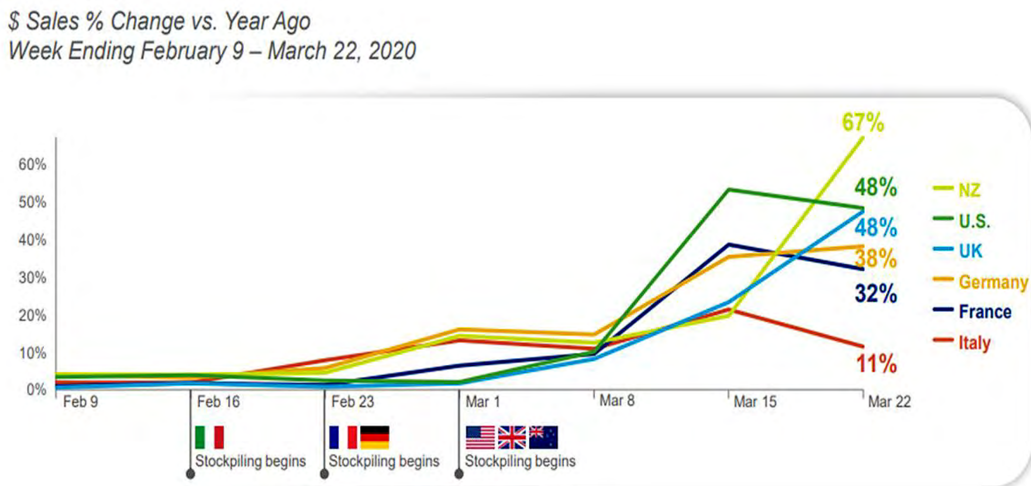

Figure 7. Sales in Grocery Stores for Six Nations (IRI and Boston Consulting Group)

The "motivating force" (a la Newton) for this dramatic reaction was increased consumer spending (see chart above). Over the last three decades grocery networks in the United States (and many other places) have developed large-scale processes and tools that facilitate just-in-time fulfillment of consumer demand. Effective response to demand is the principal survival technique in this highly competitive industry. In March 2020 and since, despite very real human and financial costs, the grocery supply chain in the United States "altered motion ever proportional to the motivating force applied."

The grocery supply chain is organized and habituated to effective proportional response—and early in the pandemic this network responded accordingly. Post-Cascadia it is absolutely in interest of all survivors that this motivating force be maximized.

During the pandemic, grocery networks have also endeavored to manage demand. Some of the practices[37] deployed include:

- Limiting quantities of certain products purchased per customer per visit,
- Reducing hours of service, allowing for restocking, cleaning, and reducing marginal pull,
- Restricting the number of simultaneous customers in any enclosed space, mostly to support social distancing, but this can also contribute to reducing marginal pull on supply.

In a Cascadia seismic event consumer demand for groceries will surge. Similar to the pandemic, it will be a sudden onset surge. But in contrast to the pan-

37 FMI, Coronavirus and Pandemic Preparedness for the Food Industry, January 2020 and updates.

demic, it will be much more difficult for consumers to *express* their demand. The ability of the supply chain to *hear* the pull signal is likely to be seriously complicated or entirely cut-off.

Grocery demand is expressed primarily through some sort of digital transaction at the point of sale. In recent years, roughly three-quarters of U.S. grocery purchases have been made with some sort of card. In April 2020, about forty-five percent of grocery shoppers used a credit card and thirty-nine percent utilized a debit card.[38] Over eight percent of U.S. grocery purchases are made with an Electronic Benefits Transfer (EBT) card connected to the Supplemental Nutrition Assistance Program (SNAP).[39] These systems have adapted effectively to pandemic-related shifts.[40]

The flow of groceries in the aftermath of Cascadia will be as or more important as it has been during the pandemic. If the network cannot receive pull signals, the network does not know where to push supply. With grocery distribution centers damaged or worse, bridges gone, and roadways seriously disrupted, push will be much more difficult post-Cascadia than during the pandemic.

Digital transactions are typically routed over public telecommunications networks. Both electric power and telecommunications connections are needed to successfully complete financial transactions. Landline, cellular, and WiFi are the most common modes of connection. According to projections, "In a great Cascadia earthquake, millions of customers could lose service as a result of broken cables and equipment failures at telecommunications centers. The earthquake may damage cell towers, throw antennae out of alignment, and break fiber connecting cables, thereby disrupting service to many cellular customers as well. It is likely that the earthquake will sever major undersea transpacific cables, disrupting service not only to East Asia, but also cutting Alaska off from the rest of the United States. It could take two to three months to restore these important connections."[41, 42]

Two- or three-days dark is probably recoverable. But if digital transactions for groceries are not possible for two or three months, the implications are dire for the 4 million-plus people of Puget Sound.

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38 Siegal, Barri, Consumers added to card debt during pandemic, CreditCards.com, May 2020.

39 Bolen, Ed, and Wolkomir, Elizabeth, SNAP boosts retailers and local economies, Center for Budget and Policy Priorities, May 2020.

40 Carvalo, Vasco et al., Tracking the COVID-19 Crisis through the Lens of 1.4 billion Transactions, VoxEU.

41 Cascadia Region Earthquake Workgroup, Cascadia Subduction Zone Earthquake, 2013.

42 Walmart's Point-Of-Sale transaction system utilizes a private satellite network. In case of a seismic event, digital transactions should continue to be made and pull supply if the facility survives and has a source of electric power.

Strategic Summary and Synthesis

In any potential catastrophe—even in many disasters short of catastrophic—the operational and tactical responses will be complex beyond full comprehension. The more complex, the more unpredictable, the less controllable. In this profoundly uncertain context, crafting an effective, coherent, and consistent strategy is as crucial as it will be difficult. What advantages can we deploy against the disadvantages anticipated?

We can now retrospectively recognize that from March to May 2020, an effective pandemic response by the U.S. grocery supply chain exposed three crucial strategic issues:

- The adaptability and limitations of preexisting capacity,
- The flexibility of U.S. freight markets,
- The motivating and organizing influence of consumer demand.

With the benefit of this shared experience, we can also recognize how these same three strategic issues were at the core of feeding millions of survivors of the Triple Disaster in Japan,[43] the aftermath of Hurricane Maria in Puerto Rico,[44] and other catastrophes.

Because the Puget Sound region has already been actively engaged in a private-public, data-informed process of researching and assessing Supply Chain Resilience, it is possible to confidently conclude that in case of a major Cascadia Seismic Event, the region will:

- Lose a substantial proportion of preexisting local capacity to process food
- Lose its principal route for transporting food produced/processed outside the region
- Lose a substantial proportion of preexisting ability to conduct digital transactions

The result—unless mitigated—is such a substantial loss of pull, push, and flow of food as to seriously endanger the population that survives the initial event and subsequent after-shocks. Given the population's size, no credible alternative source of calories can be deployed in a timely way. These three losses must be prevented or mitigated to avoid significant fatalities and human suffering. Whenever a potential catastrophe impacts a large population, issues of push capacity, flow connections, and pull capacity are fundamental strategic concerns.

43 M. Horia and K. Iwamoto, The Run on Daily Foods and Goods, March 2013.

44 Featherstone, James, et al., Strengthening Post-Hurricane Supply Chain Resilience, National Academies of Sciences, Engineering, and Medicine, January 2020.

To repeat the prior paragraph with a different tone: Trying to urgently replace a high volume, high velocity supply chain that serves millions is delusional. Gap-filling capabilities can be very helpful in disasters. But for the four million-plus residents of Puget Sound (and millions more impacted by the Cascadia Seismic Event), the preexisting grocery network (pharmaceutical, medical goods, fuel and water networks) will either quickly adapt and recover or thousands will die. Other practical alternatives are entirely insufficient. These three issues are not the only strategic priorities, but they are clearly part of a small set of strategic priorities.

This is true for a Cascadia Seismic Event. It will be true when a Category 5 hurricane buzz saws from Miami to Orlando. It will be true when the New Madrid fault shifts. It will be true in a whole host of catastrophic contexts. A January 2020 report of the National Academies of Sciences is especially clear on the policy implications of this reality. It recommends, "Shift the focus from pushing relief supplies to ensuring that regular supply chains are restored as rapidly as possible through strategic interventions."[45]

What Are These Strategic Interventions?

The fundamental questions for feeding a large population are the same during a pandemic as for an earthquake as for any potential catastrophe: What and where is preexisting pull capacity? What and where is preexisting push capacity? Where are the principal channels for flow? What has survived? What can be done to maximize surviving capacity?

How do we—individual decisionmaker, commercial enterprise, locality, state, and nation—answer these questions?

First, we cannot wait until the potentially catastrophic event happens. We need to know what and where before the seismic fault shifts—before the pandemic rages—before the cyberattack. Most major US jurisdictions have—or soon can have—answers to these what and where questions. The first installment in this two-part series outlines how Puget Sound has deployed a specific method for answering the questions.[46]

To find and know sources for pushing groceries, food regulation agencies, tax authorities, business associations, consulting firms, and the food manufacturers have answers. Transportation departments, regional planning agencies, trucking firms, and shippers know the principal nodes, links, and alternative routes needed to push food toward demand. This information exists. Options are available for pre-consideration. We need to organize the answers for disaster mitigation

45 Ibid.

46 Palin, Philip, "Food and other Supply Flows in Case of Catastrophe," Journal of Critical Infrastructure Policy, May 2020.

and response purposes. We need to be in relationship with the principals who operate these sources and connections. But the answers are available.

With this information appropriately organized and relationships in place we can be much better prepared for rapid assessments that will tell us what has survived and help us understand the network implications of non-survival. This will also inform choices to prioritize reconnection and recovery of nodes and links that have survived but been disrupted. In the case of Puget Sound, it will be especially important to reopen links to external freight flows. Whenever and wherever possible maximize utilization of preexisting channels. Food will continue to be loaded on trucks, travel on trucks, and be delivered by trucks over roads from existing places of production and processing. Rather than try to replace, reusing and adapting preexisting structures to the altered context is preferrable. Recognize the gaps. Be creative in filling gaps. But honor the principles of conservation of energy and momentum. Starting from scratch is a very bad option, especially at the start of a catastrophe.

Consumer pull is also knowable, but more difficult. The characteristics of retail demand are carefully studied by each player in the grocery network and not readily shared among players. U.S. Census Bureau population and economic data starts to answer the what-and-where of pull. SNAP data tells more. There are grocery, restaurant, and other food system data sets that offer credible historical and future estimates. In Puget Sound, there is a concept of "population islands" and related "infrastructure islands" that serve as an organizing principle for post-Cascadia strategy and operations.

Pushing More Attention to Pull

Because of its preparedness for a Cascadia megathrust earthquake, during the first weeks of the pandemic, Puget Sound decisionmakers understood the need to preserve flows of demand and supply. They knew—better than most jurisdictions—how the population is fed and who delivers what to hospitals. Puget Sound decisionmakers actively communicated with these sources of supply before making decisions, shaped their decisions to maximize flow, and adapted decisions to unfolding shifts in demand. Puget Sound decisionmakers, both public and private, took extraordinary measures intended to shape demand.

Where many other jurisdictions were reduced to binary choices of open or closed, Puget Sound worked together to consistently communicate and coordinate while recognizing the reality of local variations in demand and supply. While many U.S. freight markets showed increasing stress over Spring 2020, the Puget Sound freight market demonstrated—amazing—consistency, neither flood nor drought, but persisting flow. This is a helpful lesson-learned for Puget Sound and anyplace else that will pay attention.

The coronavirus pandemic is, in many ways, endemic to demand and supply networks. The contagion spreads through social encounters, many involving commercial activities. Transmission has often been combatted by constricting commercial activities, which in turn impacts related demand and supply behaviors. The virus itself and efforts to combat the virus have prompted demand shocks, supply shocks, and sustained stress on many supply chains. The pandemic has conducted a real-time stress test of the innate dynamics of demand and supply networks.

The pull of demand on supply chains has long been recognized as fundamental to flows. But disaster response has not yet given enough emphasis to the strategic *primacy* of pull. Because contemporary demand and supply networks are organized around pull signals the loss of this element can be especially devastating. During the Spring 2020 pandemic response, we have also seen that where pull persists, supply networks are tenacious pushing toward pull. Reduce pull and supply chains will not be as resilient. Preserve or quickly restore pull and this will energize surviving elements of the supply network to push whatever, whenever and wherever possible. Post-Cascadia and in most disasters both demand and supply are seriously disrupted. There are many well-practiced methods for surging supply. We need to develop new playbooks for reclaiming effective expression of demand.

Author Capsule Bio

One of the nation's preeminent food supply chain specialists, *Phillip Palin* served as the principal investigator for Supply Chain Resilience with the Institute for Public Research of the nonprofit CNA Corporation and with the Resilient America Roundtable of the National Academies of Sciences, Engineering, and Medicine. He is the subject matter expert for Supply Chain Resilience with the FEMA-National Integration Center Technical Assistance Program and served as team leader for FEMA's supply chain Ecosystem Assessment. He recently received the American Logistics Aid Network's Lifetime Achievement Award.