Some industry trends are creating vulnerabilities that may produce systemic supply chain risks.

Systemic Supply Chain Risk

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Several significant natural and manmade disasters caused major supply chain disruptions during the past decade. But, although many observers lamented parts shortages and production delays, we argue that the global economy has not yet experienced a systemic supply chain disruption. However, the impacts of the recent disruptions may be harbingers of things to come and may require coordinated attention from industry bodies and governments.

Background and Definitions

The World Economic Forum (WEF) Global Agenda Council on Logistics and Supply Chain Systems focuses on systemic supply chain risks, and its 2012 and 2013 reports identified four types of events that may cause systemic disruptions to supply chain networks: environmental, geopolitical, economic, and technological (World Economic Forum 2012, 2013). The reports summarize current thinking about supply chain risks and their management, but do not address some fundamental issues of industry structure that may explain why a systemic supply chain risk may be growing.

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We define a *systemic supply chain risk* as the probability of a *systemic supply chain disruption*, an event that causes the widespread sustained shortage of a product or service with no alternatives or substitutes available. It is unclear that the world has experienced an occurrence that may qualify as such a disruption.

Clearly, natural disasters, wars, and political upheavals can create shortages in the affected areas, but we do not classify those as systemic supply chain disruptions unless they disrupt the ability to deliver goods and services outside the affected area. Similarly, entire industries can be affected in the short term by large-scale economic disruptions such as the "Great Recession" of 2008–2009 and the euro crisis, and in the long term supply chains will also be affected by certain trends such as global warming and population aging in the developed world. But while such risks may be systemic, they are not specifically supply chain risks.

Nonsystemic Supply Chain Disruptions

Given our definition, it is difficult to consider even the most frequently cited disruptions—such as those that followed the 2011 Japanese earthquake and tsunami, the 2011 Thailand floods, or the 2010 Eyjafjallajökull volcanic eruption—as systemic supply chain disruptions. None of these events caused widespread shortages, as we explain in the following specific accounts.

The Japanese triple disaster of earthquake, tsunami, and radioactive release caused a Japanese plant of Merck, which is the only producer of a pigment called Xirallic, to stop production, suspending the availability of certain metallic paint used by General Motors, Ford, Chrysler, BMW, and Volkswagen. While this affected several car companies and a few models, the fact that some customers were not able to obtain an Audi automobile with certain black shimmery hues or a Chrysler Jeep with the Bronze Star color can hardly qualify as a systemic disruption. Even the fact that France's PSA Peugeot Citroën had to slow production due to a shortage of air flow sensors made by Hitachi in Japan, or that GM idled its Shreveport truck manufacturing plant for a week (with 70 days' worth of finished product inventory on dealers' lots) cannot be described as systemic disruptions.[1] And while Japanese automobile manufacturers (mostly Toyota and Honda) had more significant production disruptions that lasted longer, Nissan was able to resume production quickly (Bunkley 2011). Furthermore, had the disruption persisted, other manufacturers were ready to fill the void and gain market share. At no time was the availability of automobiles in the world market, or in any region, in jeopardy. Alternatives were clearly available.

Supply chains will be affected by trends such as global warming and population aging, but such risks are not specific to supply chains.

An individual company may, of course, face an existential threat when caught unprepared, as happened when a fire in March 2000 at a Philips Electronics fabrication plant in Albuquerque caused Ericsson, the Swedish manufacturer of mobile phones, to exit the handset business. The disruption did not change the fate of any other mobile phone makers, and in fact Nokia—a close competitor that relied on the same Philips plant—recovered quickly and ended up increasing its market share (Sheffi 2005).

Similarly, when the only US plant of Folgers Coffee, in New Orleans, was flooded in the aftermath of Hurricane Katrina, Procter & Gamble, the brand owner, was unable to manufacture and distribute the product for three weeks (Dash 2005). Yet there was no coffee shortage in the United States—other manufacturers filled the gap. In fact, the herculean efforts of Procter & Gamble to restart the plant were motivated by the reality that competitors were there to take up the slack.

Thus the robust capacity and multiple offerings of almost every product and service in today's world, and the increasing spread of engineering and manufacturing knowledge, are such that it is difficult to imagine a systemic shortage in which an entire industry is not able to operate its supply chains for a significant length of time.

The question, then, is, Do *any* systemic supply chain risks exist? The answer is "maybe."

[1] The plant was closed to divert certain parts that were expected to be in short supply to the manufacture of other, more profitable vehicles in other plants, but it turned out that this action was not necessary as the shortage never materialized.

Systemic Supply Chain Risks (1): Capital and Labor

Systemic supply chain disruptions are rooted in an unexpected change in an industry's ecosystem that affects either the demand or factors of production. When such disruptions are large, unexpected, or not mitigated ahead of time, governments may step in, particularly when the disruptions involve capital or labor.

Capital and Credit Risks

After the 9/11 terrorist attacks most US airlines experienced such a shortfall in demand that it threatened their existence. In response, Congress passed a massive aid package ($15 billion) that (at least temporarily) saved most of the domestic airlines from bankruptcy.

Governments also generally help individual leading companies if they are considered "too big to fail," as was the case during the 2009 financial crisis when the US government bailed out General Motors, with over $50 billion in loans and equity investment and another $14 billion in tax breaks.

A severe demand reduction can affect most industries but is not typically rooted in the supply chain function.

Clearly a severe demand reduction can affect most industries and is not typically rooted in the supply chain function, as was illustrated by the threat of capital shortage in the form of a credit squeeze during the 2008–2009 Great Recession. Leading companies had to attend to their supply chain partners, which were not able to obtain credit and were in danger of bankruptcy. To ensure uninterrupted materials and part supplies, companies such as Procter & Gamble, Intel, and Ford helped their suppliers by shortening payment schedules, extending loans, and even taking equity positions in their suppliers.

Labor Risks

Labor is another factor of production that presents systemic business risk. Labor disruptions can pose systemic supply chain risks because labor is organized by industry.

In 2002 the US West Coast ports lockout, the result of a conflict between the International Longshoreman and Warehouse Union and the Pacific Maritime Association representing the ports' users, lasted 10 days. It halted the gargantuan flow of containers through 29 West Coast ports that are responsible for $320 billion in imports and exports each year. The ports typically process about 30 containers per minute, 24 hours a day, 7 days a week, so any disruption was bound to create costly chaos. Canadian and Mexican ports did not have the capacity to handle the huge amount of cargo that flows through US West Coast ports, and the post-Panamax container ships serving the Asia-US lanes were too big to pass through the Panama Canal to the East Coast. So the ships created a logjam all along the West Coast, placing a growing inventory of materials and products within sight but out of reach. As the cost of the lockout mounted, then-president George W. Bush intervened, invoking the Taft-Hartley Act of 1947 to force open the ports and push the parties back to the negotiating table (King et al. 2002).[2] The government intervened because this labor disruption caused a systemic risk to the US economy.

Vulnerability to labor disruptions may be limited in the United States owing to the government's legal recourse to prevent unions and companies from interfering for long with the flow of product. But this is not the case in many other countries; witness, for example, the power of labor unions in France, Greece, Italy, and Spain to shut down the economy.

Systemic Supply Chain Risks (2): New Vulnerabilities

Some industry trends are actually creating vulnerabilities in supply chains that may lead to systemic supply chain risks. The consequences of such trends usually are not well understood, take a long time to develop, and, even when pointed out, are beset by controversy and mired in debates between political ideologies.

Mergers and Geographic Concentration

One such trend is the merging of parts suppliers and their concentration in a few locations. These developments create points of vulnerability for entire industries and may contribute to systemic risks. Consider the tes-

[2] The United States may be less vulnerable to a similar disruption with the planned opening of the expanded Panama Canal in 2015.

timony of Ford CEO Alan Mulally before the Senate banking committee on November 18, 2008:

> If any one of the domestic companies should fail,…there is a strong chance that the entire industry would face severe disruption. Ours is in some significant ways an industry that is uniquely interdependent—particularly with respect to our supply base, with more than 90 percent commonality among our suppliers. Should one of the other domestic companies declare bankruptcy, the effect on Ford's production operations would be felt within days—if not hours. Suppliers could not get financing and would stop shipments to customers. Without parts for the just-in-time inventory system, Ford plants would not be able to produce vehicles.
>
> Our dealer networks also have substantial overlap. Approximately 400 of our dealers also have a GM or Chrysler franchise at their dealership. The failure of one of the companies would clearly have a great impact on our dealers with exposure to that company.
>
> In short, a collapse of one of our competitors here would have a ripple effect across all automakers, suppliers, and dealers—a loss of nearly three million jobs in the first year, according to an estimate by the Center for Automotive Research.

This would not have been the case when Ford was producing the Model A in the late 1920s and early 1930s: the company ran an integrated manufacturing complex at the River Rouge plant with raw materials flowing into the plant and finished cars coming out at the other end. The plant made every component the cars required. The complex also had its own power plant, steel mill, glass plant, casting plant, stamping plant, and much more. At that point, the collapse of a rival manufacturer or a tsunami in Japan would have had no effect on Ford.

In 2008, however, the industry looked very different. Many companies now focus on core competencies and outsource many manufacturing operations to both domestic and offshore suppliers. Thus General Motors and Ford spun off their Delphi and Visteon parts units, respectively, with the expectation that these large suppliers would serve all the automotive companies, and that is what happened. Visteon sells parts and systems to Ford, GM, VW, Tata Motors, and many others; few automotive suppliers match its breadth of product offerings. The unintended consequence of this was that in 2008 the CEO of Ford had to plead with Congress to save his competitors—the entire US automotive industry depended on a few large suppliers and could not afford their bankruptcy or liquidation (Lynn 2009).

Similar changes have taken place elsewhere. After a 1997 fire destroyed an Aisin plant making proportional valves for Toyota, all Toyota automotive manufacturing plants in Japan came to a standstill. The carmaker was able to recover relatively quickly with massive help from companies in the Toyota and Aisin keiretsu systems. Other car companies or suppliers in Japan were unaffected, and they assisted Toyota in its recovery efforts.

The entire US automotive industry depends on a few large suppliers and cannot afford their bankruptcy or liquidation.

In the past two decades, however, the Japanese keiretsu systems have adopted Western-style manufacturing architectures, in which original equipment manufacturers (OEMs) such as Toyota, Sony, and others procure parts and subassemblies from suppliers outside their keiretsu "ecosystems" (Lynn 2012).

In July 2007 automotive part maker Riken had to close a plant in Kashiwazaki city because of damage from an earthquake off the Japanese coast. Again, Toyota had to halt production in dozens of Japanese plants—but so did Nissan, Fuji Heavy Industries (makers of Subaru), and Honda: Riken supplied $1.50 piston rings to all of them. Again, the lost production was overcome relatively quickly but the event demonstrated the reliance of whole industries on certain key suppliers.

Emergence of Single, "Super" Suppliers

The outsourcing trend has allowed suppliers to grow by serving more customers, merging with each other during economic downturns (thus becoming "super suppliers"), and developing innovative parts and selling them to multiple OEMs.

Denso Corporation, for example, was spun off from Toyota in 1949 (although it remained in the carmaker's keiretsu for many years). Now it is a leading supplier to most automotive, trucking, and heavy equipment companies around the world, with revenues exceeding

$40 billion. Similarly, Bosch, the $65 billion German automotive supplier, furnishes most automotive OEMs with electronic and electric components, gasoline and diesel systems, car multimedia, control components, steering technology, and many other systems.

A strike, sabotage, financial problem, or cyberattack can shut down a supplier, affecting its entire operation even if it has multiple plants. The result may halt the operations of most OEMs in an industry, creating a systemic disruption.

The effect of a single supplier on multiple OEMs was illustrated in the April 2013 recall of more than 3 million vehicles worldwide by Toyota, Honda, Nissan, and Mazda. All were using improperly manufactured airbags made by Takata, a large Japanese automotive supplier that is the world's third largest automotive airbag manufacturer. And many US pet food manufacturers experienced a similar problem in April 2007, when they had to issue a massive recall after an FDA investigation of pet deaths traced the cause to a single Chinese supplier of tainted wheat gluten.

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Multitiered Supply Chains

Outsourcing has contributed to the creation of "deep" multitiered supply chains in which OEMs depend on tier 1 suppliers that, in turn, depend on tier 2 suppliers, and so on. It becomes impossible for OEMs to monitor deep-tier suppliers or even know who they are. Lower-tier (upstream) suppliers are typically reluctant to disclose their sources because the information is part of their intellectual property and a factor in their competitive advantage. In this way the suppliers also protect themselves from the likelihood that their customer (the OEM) might bypass them to buy directly from the lower-tier supplier.

Because suppliers may not know who their upstream deep-tier suppliers are, it can take a long time for the magnitude of a large disruption to become apparent. Three days after Japan's triple disaster of March 2011, General Motors' supply chain department identified 390 part numbers at risk. Procurement professionals looked for alternative suppliers for parts and materials, and engineers tried to find workaround solutions and qualify different parts and materials for use on the production lines. Despite the continuous work of the engineering, supply chain, and procurement divisions, the volume of part numbers at risk kept climbing, and reached a peak of 5,850 part numbers *11 weeks later*! This delayed visibility was due to the depth of the supply chain, the inability of OEMs to know the identity of deep-tier suppliers, and the lack of visibility into inventories throughout the chain.[3]

Geographic Concentration of Suppliers

Another type of vulnerability is rooted in the geographic concentration of suppliers. For example, almost a quarter of the world's integrated circuit (IC) design and fabrication capacity is concentrated between Taiwan's Hsinchu area and Taipei, which are only 40 miles apart. Taiwan is also home to almost 70 percent of the world's IC foundry capacity as well as most of the global capacity for IC packaging and testing. A Taiwanese disruption would affect most industries since most machinery now involves electronics. In fact, such a disruption took place in September 1999 when an earthquake disrupted semiconductor makers that account for 40 percent of the world's memory chip production. This occurred during a period of tight supplies, and the spot price of computer memory climbed fivefold all over the world, disrupting operations at many electronic suppliers and hampering the launch of certain Apple laptops (Lynn 2005).

The geographic concentration of suppliers in a single country may also expose supply chain operations to geopolitical risks. Interdependence theory holds that no nation will disrupt the flow of vital goods because that nation in turn depends on outside suppliers for other vital goods. Clearly, however, there are exceptions, and states have been known to withhold work in much the same way a labor union does to achieve some political or economic objective, as was the case when China decided in 2010 to embargo the shipment of rare earth

[3] It is a testament to the innovation, collaboration, and hard work of GM employees and their suppliers during the crisis that the Japan disaster did not affect GM production in any meaningful way.

metals to Japan during a dispute over territory and when Russia cut off Ukraine's gas supply (most recently in 2014) for political effect.

Industry Adaptations

In the aftermath of various global disasters and smaller disruptions, many companies have beefed up their crisis response teams and procedures, and started investing in more robust early warning and early mitigation processes. Even so, a fire and explosion at an Evonik plant in Germany on March 31, 2012, affected the supply of a crucial component for automakers around the world. The plant produces almost 50 percent of the global supply of CDT (cyclododecatriene), a chemical precursor used to produce nylon 12, which is the only material qualified for use in automobile fuel handling systems and brake lines. Emergency engineering changes and hurried qualifications of alternative sources by automotive OEMs prevented production shutdowns and a systemic supply chain disruption for the automobile industry.

Such "near misses," however, may be warning signs. For a variety of technical and commercial reasons, firms rely in major parts of their operations on single suppliers and often even on a single plant as formulations from different plants may vary enough to cause problems. Vulnerabilities often lie with suppliers that, at deep tiers of the supply chains, are not visible to the OEM. This is an Achilles' heel of many companies' business continuity efforts.

Companies may thus develop vulnerabilities without being aware of them. Leading manufacturers that recognize the issue work to diversify their sources, but commercial and technical factors limit the extent to which this can be done. And the mitigation of such vulnerabilities cannot be the purview of each company alone. While clearly OEMs and leading suppliers have the responsibility to protect their business—and they do—disruptions that affect entire industries are not always of major concern to them since their competitors are likely to be affected too, as was illustrated above by the experiences of Ford, Toyota, and other major manufacturers.

Consider also the response of AT&T after tropical storm Sandy, as reported in the *Wall Street Journal*[4]:

> John Donovan, AT&T's technology chief, said in an interview that all carriers' networks had been hit hard in Manhattan because the landline infrastructure that connects cell phone transmitters to the wired telecom network had been damaged in the storm. He said AT&T conducted extensive drive testing in Manhattan this week and found negligible difference in performance of the wireless network.

This quote illustrates the fact that part of AT&T's concern was its performance vis-à-vis competitors.

Firms may rely on a single supplier or even a single plant as formulations from different plants may vary enough to cause problems.

Individual companies may appear to show a lack of concern about systemic risks, and from their point of view this may be a rational position. One never knows how much should be invested in disaster recovery and resilience, since it involves preparations for low-probability, high-impact events, so one metric for "enough" investment in preparedness is the "industry standard"—what competitors and others in the industry are doing. The development of guidelines for minimal risk assessment and preparedness may be an appropriate task for an industry body or a regulator, but companies can often gain a competitive advantage by going beyond the minimum and developing their own resilience systems.

Identifying and Mitigating Systemic Risks

The roots of systemic supply chain risks can be classified as follows:

- Geographic concentration: the clustering of many suppliers in a single region
- Supplier integration: the emergence of "super suppliers" who can put an entire industry at risk if they fail
- Deep-tiering: the reliance of many manufacturers in a given industry on a single supplier or a small set of clustered suppliers buried deep in the supply chain

Geographic concentration of tier 1 and tier 2 suppliers is something that many leading companies monitor already. They rate their vulnerability to various suppliers

[4] Anton Troianovski and Sarah Portlock, "Outage Exposes Carriers' Backup Plans," *Wall Street Journal*, November 2, 2012.

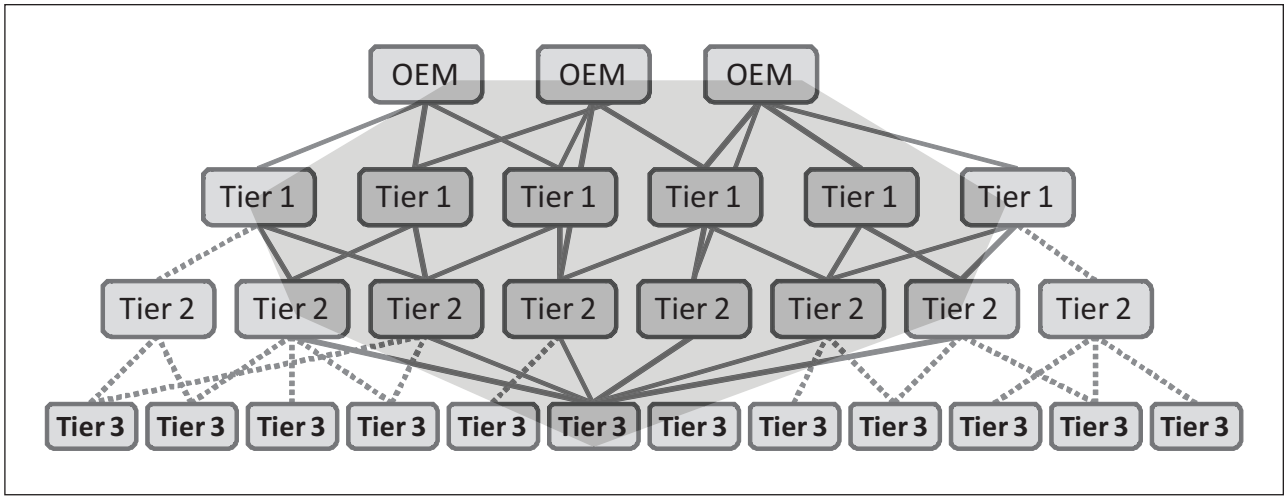

FIGURE 1 An industry supply chain schema with a "diamond" vulnerability.

and, based on assessment of the risk, may qualify new suppliers or even dual-source at times. But some mitigation efforts are too expensive and therefore are not pursued.

As shown in Figure 1, a diamond shape illustrates the dependence of multiple OEMs in the supply chain on a single deep-tier supplier. This dependence is highlighted by the solid lines representing parts flow; the dashed lines represent parts flows that depend on other tier 3 suppliers. The solid lines reveal a diamond structure (shaded in the background) as opposed to a tree structure, which characterizes typical supply chains based on the bill of material. If the tier 3 supplier at the sharp end of the diamond is producing a large fraction of what the industry consumes, without ready alternatives, a systemic risk looms.

This diagram could similarly depict dependence on suppliers in a single geographic location or national control of supplies critical to an industry.

Concluding Thoughts

Governments have the tools to intervene in the case of certain significant disruptions, regardless of their nature. They use their resources after floods, hurricanes, and earthquakes to help affected communities rebuild, and are also involved in predisaster mitigation efforts, collaborating internationally in antiterrorism activities and in efforts to develop standards and processes for mitigating other global risks. They even take coordinated actions, such as the joint navy operations to fight piracy off the coast of Somalia.

Another role for the government may be to watch for the danger associated with supplier integration. The US Justice Department, Federal Trade Commission, and European Directorate General for Competition scrutinize possible mergers for their effect on consumers, mainly to prevent monopolies. But these agencies are not equipped to review mergers in terms of their effect on systemic supply chain risk—to assess whether, for example, certain suppliers may become "too big to fail." Such a review might entail preventing certain suppliers from merging or extracting certain merger conditions, such as a requirement to diversify parts of the merged business or to operate multiple plants of certain types.

Overcoming companies' reluctance to invest in strong mitigation efforts may require an audit, whether by financial auditors or specialty firms, to point out systemic supply chain vulnerabilities and, ideally, bring market discipline to mitigation efforts. Alternatively, discovery of unknown risks may be better accomplished by either extending the purview of existing industry bodies (e.g., the Automotive Industry Action Group, the Electronic Industry Citizenship Coalition) or creating new groups for this purpose.

The time may have come—before a systemic supply chain disruption actually takes place—to develop these capabilities.

References

Bunkley N. 2011. Toyota and Honda bounce back. New York Times, October 13.

Dash E. 2005. At least some can wake up and smell coffee in New Orleans. New York Times, September 21.

King N, Cummings J, Tejada C. 2002. Bush takes steps to end West Coast dock lockout. Wall Street Journal, October 8.

Lynn BC. 2005. End of the Line: The Rise and Coming Fall of the Global Corporation. New York: Doubleday.

Lynn BC. 2009. How Detroit went bottom-up. American Prospect, September 19.

Lynn BC. 2012. Built to break: The international system of bottlenecks in the new era of monopoly. Challenge 55(2):87–107.

Sheffi Y. 2005. The Resilient Enterprise: Overcoming Vulnerability for Competitive Advantage. Cambridge, MA: MIT Press.

World Economic Forum. 2012. Outlook on the Logistics & Supply Chain Industry 2012. Global Agenda Council on Logistics & Supply Chains 2011–2012. Geneva.

World Economic Forum. 2013. Building Resilience in Supply Chains: Industry Agenda. Geneva.