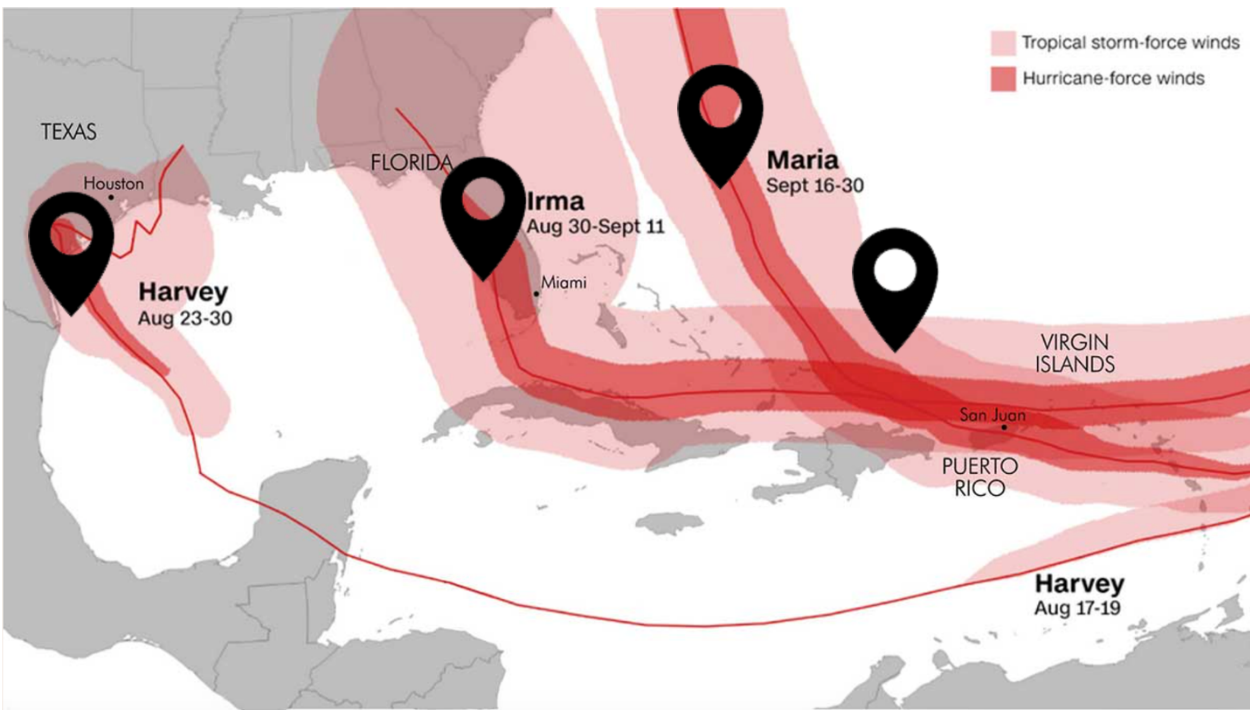
STRENGTHENING POST-HURRICANE SUPPLY CHAIN RESILIENCE

Observations from Hurricanes Harvey, Irma, and Maria

The 2017 hurricanes Harvey, Irma, and Maria—each unique and record-setting storms occurring in quick succession—stretched the response capacity of emergency management and strained supply chains that facilitate the flow of critical commodities. These experiences revealed many strengths and the vulnerabilities in national and regional supply. Lessons learned from these hurricanes can inform future strategies to improve supply chain management.

OVERVIEW OF PATHS AND SUPPLY CHAIN IMPACTS OF HURRICANES HARVEY, IRMA, AND MARIA (2017)



Texas/Harvey: Supply chains in the South Texas region proved largely flexible and resilient during Hurricane Harvey, but the event illustrated that even the most prepared organizations and systems will have great difficulties functioning when flooding is too severe and critical infrastructure is damaged.

Florida/Irma: Irma illustrated some important limitations and vulnerabilities of current systems in terms of meeting fuel demand in the face of massive evacuation, maintaining an inflow of supplies despite serious transportation bottlenecks, and ensuring adequate coordination in the movement of trucks and supplies across state lines.

Puerto Rico/Irma and Maria: These hurricanes exposed fundamental vulnerabilities in coordination of emergency preparedness systems, electric power and communications infrastructure; limited understanding of the island's critical supply chains; and diminishing response capacity and exacerbating bottlenecks across supply chains.

U.S. Virgin Islands/Irma and Maria: A small main port with limited space led to competition for resources between relief supply chains and regular commercial supply chains. Efforts to repair and rebuild damaged structures were hampered when relief supplies such as tarps and water bottles were given priority for shipment over cement and other construction materials.

SUPPLY CHAIN GEOGRAPHIES FOR AREAS AFFECTED BY 2017 HURRICANES

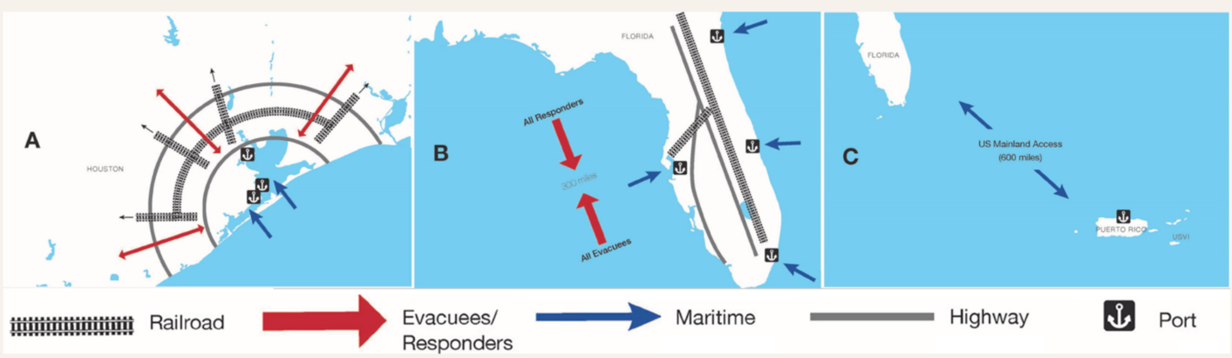


Illustration of the different "supply chain geography" context for (a) South Texas, (b) South Florida, and (c) Puerto Rico and the U.S. Virgin Islands.

A. South Texas

Houston is highly flood-prone due to low elevation and flat topography, which offer no natural physical drainage pathways for intense rainfall. The Texas coastline is long and exposed, but accessible from inland areas, and thus not largely dependent on water-bound shipments when relief efforts are needed. Inland evacuation is a possibility. At the same time, the region's widely dispersed residential, commercial, and industrial development patterns means that the distribution of goods and services requires considerable, reliable road transport capacity.

B. Florida

Much of Florida is flood-prone due to low elevations and development patterns that undermine natural drainage systems. South Florida has underlying porous limestone that allows floodwaters to arise from underground and has coastal exposure to both Atlantic and Gulf Coast storms. As an 800-mile long, densely developed peninsula with just a few main transport corridors, Florida's geography exacerbates challenges when there is a mass evacuation from vulnerable areas along congested routes or large-scale delivery of critical goods and services into affected areas.

C. Puerto Rico and the U.S. Virgin Islands

These islands rely entirely on delivery of goods and relief supplies by ship and barge, primarily from U.S. ports more than 1,200 miles away. Transit times and delays for delivery of goods are thus an important factor in emergency response planning. Puerto Rico has one large natural harbor (housing the Port of San Juan, a critical node for most supply chains), plus a number of smaller ports located around the island. The island also has mountainous terrain that poses challenges for emergency response and goods delivery. On the island of St. Thomas the main industrial port has very limited space for unloading shipping containers and staging of large-scale relief supply deliveries, and there is even less port capacity on the other islands. Evacuation from an island requires considerable advance planning.

COMMONALITIES ACROSS STORMS AND AFFECTED AREAS

1. Post-hurricane bottlenecks and disruptions arose more frequently at the distribution level than at the production level.

    - There were massive shortages of trucks and drivers for goods delivery
    - Personnel shortages occurred when workers themselves became storm victims
    - Damage to critical infrastructure impeded the distribution and selling of goods
    - Unsolicited donations sent to affected areas caused unexpected bottlenecks, which drew critical resources away from more strategically targeted needs

2. Many large companies had invested in continuity planning partnership with government officials, employee assistance programs, and resources to harden and back up critical systems. Comparatively, small businesses generally had much less capacity to prepare for and avoid supply chain disruptions.

3. Vulnerable infrastructure, especially for power and communications, is a predictable vulnerability, and the speed with which supply chains can recover often heavily depends on the resilience of this infrastructure. Investments by state and local governments in

strengthening infrastructure made a difference in minimizing storm disruptions and thus bolstering the speed with which local economies could resume normal operations.

4. Limited pre-storm assessment of vulnerable and critical supply chain nodes, together with information disruptions resulting from power and communication loss constrained the ability of emergency managers to understand post-storm supply chain bottlenecks. This in turn limited emergency managers' ability to make optimally prioritize the allocation of relief supplies and to know when to stop the push of relief supplies into an area.

5. There was often confusion regarding the priorities and practices of emergency management officials for providing generators and fuel to parties in need of assistance—in particular, priorities and practices around supporting private entities that are critical nodes in local or national supply chains.

ABOUT SUPPLY CHAINS

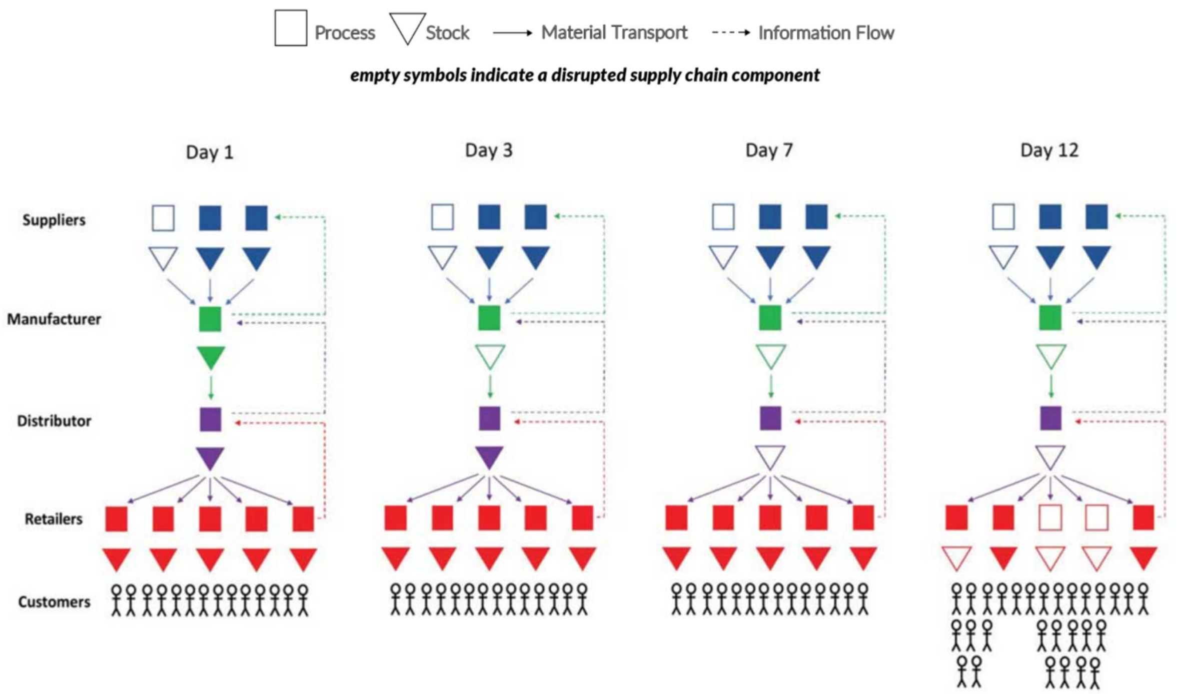
Drawing on lessons learned from these disasters, *Strengthening Post-Hurricane Supply Chain Resilience* recommends ways to make **supply chains***—the systems that provide populations with critical goods and services, such as food and water, gasoline, and pharmaceuticals and medical supplies—more resilient.

Supply chain management aims to match supply with demand in a responsive, accurate, and cost-efficient manner. Post-hurricane bottlenecks and disruptions arise mostly at the distribution level– often because infrastructure damage impedes processing, delivery, and selling of goods.

[See below for key supply chain terminology and concepts]

***Supply Chains** are the network that facilitates the timely flow of materials and products from suppliers to manufacturers to distributors (wholesalers) to distribution channels (e.g., retailers, clinics/hospitals, nongovernmental organizations), and finally to the end users. It does this by transmitting demand information upstream (and other related information downstream) to guide production, transportation, and distribution decisions.

EXAMPLE OF CASCADING FAILURE IN A SUPPLY CHAIN



Supply Chain resilience depends on how bottlenecks and lead times are affected by such disruptions and what capabilities exist for swift restoration after a disruption.

The above graphic schematically describes a scenario in which a disaster-related supplier outage, possibly exacerbated by amplified demand, has resulted in a severe bottleneck at a single supplier, which has led to lack of product availability at the retail level. This is a simplified representation of reality, however, in that processes are represented as simply on/off, which neglects the possibility that a disruption could reduce the capacity of a process rather than eliminate it.

RECOMMENDATIONS TO STRENGTHEN SUPPLY CHAIN RESILIENCE

1. SHIFT THE FOCUS FROM PUSHING RELIEF SUPPLIES TO RESTORING REGULAR SUPPLY CHAINS AS SOON AS POSSIBLE.

Flooding an area with relief supplies for an extended period can have the unintended effect of delaying the area's recovery, because relief supply chains often rely on contracting local resources—such as trucks, ships, and delivery drivers—that are the same resources needed by local businesses to get their supply chains back to normal.

The traditional focus on bringing relief supplies to an affected area to meet unmet demand must be augmented with a focus on understanding the causes of unmet demand—that is, identifying bottlenecks, gaps, and broken links in local supply chains—and pursuing strategic interventions to assist local stakeholders in returning regular supply chains to normal operation as rapidly as possible.

2. STRENGTHEN EMERGENCY MANAGERS' UNDERSTANDING OF LOCAL SUPPLY CHAIN DYNAMICS.

When planning for and responding to a hazardous event, it is important to understand how supply and demand drive the flow of critical goods and services into an area, how hurricanes and other disruptions can affect those flows, and interdependencies among different parts of the supply chain. [Figure 4.1]

3. IMPROVE INFORMATION-SHARING AND COORDINATION AMONG PUBLIC AND PRIVATE STAKEHOLDERS.

Among the factors most critical for building supply chain resilience are clearly defined processes and mechanisms for coordination and information sharing—especially across levels of government and across public and private sector organizations.

4. PROVIDE TRAINING TO EMERGENCY MANAGERS ON SUPPLY-CHAIN DYNAMICS AND BEST PRACTICES.

Many individuals engaged in emergency response have had little or no direct experience working with private sector entities or training specifically for evaluating a disaster's impacts on local supply chains. For a deeper dive, explore Chapter 5 and Appendix D for more information on the federal role in disasters.

KEY SUPPLY CHAIN TERMS AND CONCEPTS

The fundamental challenge of supply chain management is to match supply with demand in a responsive, accurate, and cost-efficient manner. Two features of supply chains complicate this fundamental challenge, both under normal conditions and, especially, under emergency conditions like those posed by a hurricane. These include demand variability and cycle time.

- **Variability:** fluctuations in both demand and supply over time, both predictable (e.g., seasonal demand shifts) and unpredictable (e.g., sudden equipment failures). Variability occurs in the transportation phase as well as production processes of a supply chain.

- **Cycle time:** the total time from start to finish of a process. Because cycle times for production, transportation, and distribution processes in a supply chain are non-zero, decisions about what to make, ship, and sell must be made before customer demands occur.

Bottlenecks

The bottleneck can be understood as the point in a supply chain that limits its flow. This bottleneck could be the production process for a raw material, component, or finished product, or the transportation process between any of the stages in the supply chain, or even the distribution process (e.g., retail outlets).

- A **process** in a supply chain refers to a production, transportation, or distribution system that makes, moves, or delivers goods and services. Process stages can be parallel (for example, multiple manufacturers and retailers) or serial (such as machines within a factory or legs in a transportation route).

- The **capacity** of a process stage is the maximum rate at which it can produce/move product. This can be measured in widgets per week or through any number of other metrics that represent flow per unit time.

- The **utilization** of a process stage is given by the ratio of demand rate to capacity. When this ratio is less than or equal to 100 percent, it represents actual utilization—the fraction of time the resource is busy over time. Because actual utilization cannot exceed 100 percent, when the ratio is above 100 percent, this indicates the extent to which the resource is overloaded.

By identifying the process stages of critical supply chains that are at risk of becoming bottlenecks, one can better pinpoint and prioritize actions to harden supply chains against disruption; and by identifying bottlenecks that arise after a disruptive event, one can focus on strategic efforts to return the supply chain to normal operations.

Inventory and Lead Time

Another factor that is key to understanding normal and emergency behavior of supply chains is inventory, the quantity of material (raw materials, components, or finished goods) stored at any point in the supply chain. While responsiveness from a production perspective is measured by cycle time, responsiveness from an end user standpoint is measured by lead time, which is the duration of time from the end user's request for a service or product to its delivery.

When inventory is present in a supply chain, lead time can be shorter than the corresponding cycle time. Inventories of raw materials, components, in-process products, or finished goods can dramatically shorten, or even eliminate, customer lead time to receive a product.

What does this mean for emergency response? Under normal conditions, the capacity of a supply chain is determined by its bottlenecks, while the responsiveness of a supply chain is determined by its lead times. How resilient the supply chain is to disruptions, such as hurricanes, depends on how these bottlenecks and lead times are affected by the disruption and what capabilities exist to restore them after the disruption.

TYPES OF SUPPLY CHAIN DISRUPTIONS

An extreme event such as a hurricane can disrupt a supply chain in three primary ways.

1. Demand shift: A hurricane can distort demand patterns before and after the storm. Demand for gasoline, generators, batteries, and food items often spikes before a hurricane, while demand for bottled water, chainsaws, garbage cans, tarps, and other recovery supplies are usually elevated afterwards. Such demand spikes can push utilization of bottlenecks above 100 percent, even if only some parts of the supply chain are disrupted by the storm.

2. Capacity reduction: Examples of capacity reductions that occur in the wake of a hurricane include a production or transportation process that is limited by lack of plant, power, or people: a factory (plant) unable to produce due to physical damage, a retail outlet unable to store perishable products due to lack of electricity (power), trucks unable to deliver goods for lack of drivers (people).

3. Communication disruption: A hurricane can interrupt the normal channels by which information is communicated up the supply chain. For example, normal operations of a supply chain can be impeded by power or cell phone outages, broadband interruptions, point-of-sale system failures, and absence of key individuals. Furthermore, the exceptional relief supply chains established to deliver essential products in the wake of a hurricane lack the sophisticated communication systems utilized in many commercial supply chains, and therefore struggle to match supplies with demand.

Each of these supply chain disruptions can reduce capacity and lengthen lead time. Higher utilization will inflate cycle time and, depending on inventory levels, may also increase lead time and result in delays in getting products to people. If the bottleneck utilization exceeds 100 percent, then the supply chain will be unable to keep up with demand, leading to shortages that will not be filled until after capacity is restored. Disruption of communications can further exacerbate the problem by obscuring information about demand and stock levels, making it impossible to direct the available supplies to the users that need them most.

The objective of supply chain resilience initiatives is to minimize the impact of a disruptive event (e.g., a hurricane) on the affected population and to do so as efficiently as possible. Policies for achieving these can be classified into three categories.

1. Readiness: Examples of steps that can be taken in advance of a hurricane include building up inventories of components and/or finished goods as protection against capacity outages (a strategy often employed by emergency managers through "prepositioning" of critical supplies in or near the affected area), and hardening key production and distribution processes (e.g., equipping selected service stations or gas pumps so they will be able to dispense fuel during a power outage).

2. Response: The classic response to the need for emergency goods and services in the wake of a hurricane is to set up special relief supply chains. The special-purpose relief supply chains used by these organizations can undoubtedly save lives and reduce human suffering. They are, however, less efficient and less precise in meeting demands than the supply chains they attempt to replace.

3. Recovery: Because regular supply chains have been optimized over time in response to profit motivation and market competition, they will always be more efficient at matching supply with demand than special-purpose emergency supply chains. Hence, a vital management response is to restore these supply chains as quickly as possible. The private sector will often seek to do this in service of companies' business objectives. But a lack of coordination among government, nongovernmental organizations, and private companies can slow the restoration of regular supply chains.

SUPPLY CHAIN RESILIENCE: ANALYSIS AND ENHANCEMENT

Supply Chain Mapping - Conceptual (graphic) representations of supply chains are useful for identifying candidate policy options. Prioritizing actions among those options during an event requires the strategic use of data, for example, to understand where bottlenecks exist or will emerge, or to assess the full impacts of a given activity on the reinforcement, replacement, or repair of a bottleneck.

Strategic data sources to support analysis

- ***Past experience.*** Leveraging lessons learned from previous hurricanes can inform the development of policies for dealing with future events. Although each event is different, identifiable patterns recur, and past events also provide evidence of the efficacy of various policies.

- ***Fault tree analysis*** is a top-down, deductive analysis method used to understand how systems can fail and to identify the best ways to reduce risk of a particular system-level (functional) failure.

The following concepts are helpful in framing such an analysis:

- ***Criticality*** of a network node, link, or other component measures the extent to which a disruption of the component will degrade the functionality of the network (which could be measured as the on-time delivery of supply to the end customer). A simple way to think about criticality is to identify process stages in a supply chain for which significant reductions in capacity will lead to severe bottlenecks. This helps us recognize, for instance, that a supply node for which a ready backup exists is not critical because its failure will not result in a bottleneck.

- ***Vulnerability*** measures the likelihood that a node or link will be disrupted. For example, a production facility in a hurricane-prone region is more vulnerable than one that is not in a hurricane-prone region; and facility with sophisticated fire protection is less vulnerable than one without.

A node or link that is both critical and vulnerable constitutes a major source of risk that a disruption could cause adverse impacts on a supply chain. Addressing such risks is a key opportunity to make a supply chain more resilient.