Constraints in Optimized Networks – Evidence from the 2017 Hurricane Season

The Mathews Bridge reaches 146 feet above the St. Johns River, leaving lots of room for ships moving past Jacksonville and into the Atlantic. From high in his emerald green Prostar rig, Joe Albright[1] scans the cranes to his left that line the river at the Port of Jacksonville (JAXPORT). This morning, he has a short haul of groceries for Atlantic Avenue. This afternoon, he is scheduled to deliver to Blanding Boulevard.

In square miles, Jacksonville, Florida, is the largest city in the United States. With 880,000 residents, it is the most populous city in Florida.[2] Long before Mickey Mouse arrived in Orlando, well before Miami was imagined, Jacksonville was a major transportation hub. As late as 1920, the population of Duval County (Jacksonville) was more than double that of Dade County (Miami). [1] Joe came to the area to serve on the USS *Forrestal*, met a local girl, and raised his family here.

In 2017 more than 1.3 million containers were loaded at JAXPORT. [2] Jacksonville is the largest maritime center in Florida. Both CSX Transportation and Norfolk Southern operate major intermodal terminals in Jacksonville. All rail traffic serving Florida transits through Jacksonville. Interstate 10, originating in Santa Monica, California, terminates in Jacksonville at I-95 (which originates at the Canadian border and continues to just south of downtown Miami). The annual average daily traffic (AADT) count for the I-95 bridge crossing at Jacksonville is over 155,000. At the I-295 bridge, the AADT is more than 125,000. [3] The Mathews Bridge mostly connects Jacksonville to its beaches, less than 20 miles east. Still, its AADT is more than 67,000. In 2012 Jacksonville's wholesale trade was valued at over $18 billion, and its retail trade was nearly $12 billion.

[1] "Joe" is a composite of several people active in the Jacksonville transportation sector

[2] US Census Bureau 2016 Estimates: Miami: 453,000, 55.25 square miles. Jacksonville is 875 square miles

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When Joe drove for Crowley, he mostly moved containers back and forth from huge barges arriving and departing the port. With Cowan Systems, he drives vans back and forth from the huge 170-plus door cross-dock BJ's Wholesale Club that operates on the western edge of Jacksonville. The American Community Survey estimates more than 13,000 people in Jacksonville are involved in "material moving." [4]

Along the St. Johns River, there are several docks and fuel jetties. Crowley, TOTE, Trailer Bridge, and other shippers use Jacksonville as their principal port serving the Caribbean. For example, 80 percent of the groceries consumed in Puerto Rico are shipped out of Jacksonville. [5] Several fuel farms and five active fuel racks also line the river's bank. According to the US Energy Information Administration, about 10 percent of the fuel consumed in Florida flows through Jacksonville [6]. From downtown to Blount Island, there are roughly 10 densely packed miles of critical infrastructure and key resources. Taken together, this port can seem to be a very big network node. With a wider lens, the Port of Jacksonville is only the neck between huge upstream sources of supply and downstream needs and wants.

Farther west, there is another 10-mile stretch along the I-10 (either side of the intersection with I-295) that has emerged as a critical link in the retail food and fuel (and likely other) supply chains. In addition to BJ's cross-dock, there are large distribution centers for Publix, South East Grocers, Zephyr Dairy, UPS, Southeast Toyota Distributors, Henry Schein, Owens & Minor, and several other major suppliers. Kangaroo and Pilot truck stops are also located here. Jacksonville touts its role as the "gateway" to Florida. According to the US Cluster Mapping Project at Harvard University, 30 percent of the Jacksonville area economy serves markets outside Northeast Florida and Southwest Georgia. [7-8] Medical devices are among the top-10 product categories that Jacksonville trades outside its region, an asset reflecting the city's important connection with Puerto Rico. While Jacksonville is the 49th largest economy among US metropolitan areas, it is the 23rd largest trader of medical devices. This concentration of maritime, surface transportation, and related assets concentrates considerable potential *and risk* in the Jacksonville region.

Geographic and functional concentration is not unusual. There is some evidence that supply chain concentration is increasing. [9] Yossi Sheffi, an MIT scholar of supply chains, has written [10]:

> *Logistics clusters offer their members other advantages, most of which are rooted in the interchangeability of transportation and logistics assets. The basic logistics operations: storage, removal, transportation, tracking, delivery, etc. are similar regardless of the item being handled. Consequently, transportation and logistics assets can handle packages containing a large variety of goods in a standard manner. Furthermore, rail cars, containers, trailers, barges, and airplanes all come in standardized sizes and capacities, dictated by regulations, international standards, or prevailing conveyance designs. Thus capacities, reach, and velocities are similar regardless of the*

company logo on the tractor's door, ocean shipping container side, or airplane tail. Both of these factors mean that companies in logistics clusters can share certain assets, allowing them to serve their customers better than firms not participating in a cluster and allowing them to better adjust to fluctuating business volume.

These advantages are of crucial importance as supply and demand networks attempt to serve increasing density and expectations of rapid delivery.

In the last 50 years, the population of Florida has increased from 6.8 million to over 20 million. Since 1970, Jacksonville's metropolitan area population has increased from 612,000 to 1.6 million, Tampa's has increased 1.1 million to 2.8 million, Orlando's has increased 523,000 to 2.4 million, and Miami's has increased 1.3 million to 5.5 million. This rate of growth and this level of densification requires high-volume, high-velocity supply chains. To also supply demand at affordable prices—even intensely competitive pricing—arguably requires supply chains that are highly optimized, meaning they deliver what customers are ready to buy when and where they will buy it.

The use of Advanced Planning and Scheduling (APS) concepts and technology emerged in the late 20th century with the availability of real-time transaction data and the computing power to more accurately predict patterns of consumer demand. Data analysis and modeling have allowed supply chains to be better organized around the temporal and spatial character of demand, significantly reducing inventory and transportation costs. APS—especially in its attention to production planning—has also driven much more detailed mapping and management of supply chain components and dependencies to enhance the speed and accuracy of delivering what is needed, where it is needed, when it is needed. In recent years, a tension has emerged within planning/scheduling about whether to optimize for predictability or to optimize for unpredictability. But in either case, optimization is intended to shape supply system behaviors to accurately anticipate and serve demand.

Hurricanes, earthquakes, and other calamities play havoc with traditional notions of predictability. The 2017 Hurricane Season was especially challenging. The response of the Jacksonville logistics cluster to Hurricane Irma and Hurricane Maria revealed both its strengths and weaknesses. The following are four examples of adaptation involving grocery, fuel, maritime, and medical goods networks.

These brief case studies reflect a risk that recurred during the 2017 Hurricane Season. Demand and supply networks are often described as having an hourglass structure.[11-13] Demand can be conceived as the lower bulb in an hourglass "pulling" supply. This structural observation can also serve as an operational analogy: many contemporary supply networks are organized to deliver just in time—just when the consumer is ready and able to buy. Considering a wide array of hourglass structures, one recent study notes, "The presence of

these critical modules at the waist (the 'constraints') limit the space of all possible outputs that the system can generate." [13] During the 2017 Hurricane Season, the real capacity of crucial networks was again and again reduced to what was happening—or too often *not* happening—at the neck of these perceived hourglass structures.

BJ'S WHOLESALE CLUB CROSS-DOCK

Five days a week, Joe drives up Pritchard Road through the wetlands and pines from which the Trout River forms. The BJ's Wholesale Club warehouse, cross-dock, and freight yard sit about 600 feet south of Pritchard, part of the 3,300-acre Westlake Park developed by Norfolk Southern.

BJ's Wholesale Club was founded in New England and followed its snow-bird customers to Florida. There are now 31 Clubs in Florida and five in Georgia. More are expected. The Jacksonville facility is usually called a distribution center, but it is arguably much more a cross-dock. Facing north is a 290,000-square-foot rectangular warehouse, and extending south is a long, thin 170,000-square-foot cross-dock (see Figure CS5-1). On one side, inbound product arrives from multiple vendors. On the other side, vans are allocated multiple products for specific retail locations. Like the waist of an hourglass? This is a configuration that not only facilitates high volumes, it practically enforces high velocity.

Figure CS5-1. BJ's Wholesale Club distribution center, 4500 Director Road, Jacksonville, Florida

Source: Google Maps

"Everything we do is designed to forward-deploy as fast as possible to our Clubs. That's where the products are needed, not anywhere else," says Trevor LaChapelle, BJ's Vice President of Global Transportation. "We want to receive and sell our products even before we've paid for them."

In addition to volume and velocity, BJ's Wholesale Club also competes on variety, claiming [14]:

> *Our approach to merchandising positions us between other warehouse clubs and grocery retailers. We sell a wide range of products, combining the bulk savings of a warehouse club with a broader assortment and selectively smaller pack sizes in perishable and grocery products than our club competitors. We have more stock keeping units (SKUs[3]) than other warehouse retailers (around 7,200 versus around 4,500), which allows us to offer a greater selection while still enabling us to manage our inventory more efficiently than supermarket and mass-market competitors (which can carry 40,000 or upwards of 100,000 SKUs, respectively).*

BJ's also claims to save its members 25 percent or more on grocery purchases compared to mainstream supermarkets. Competing on volume, velocity, variety, and value is only possible when supply chains can reliably discern what is needed where and when and can deliver on target. As BJ's explains to potential investors [14]:

> *We buy most of our merchandise from manufacturers for shipment either to a BJ's cross-dock facility or directly to our clubs. This eliminates many of the costs associated with traditional multiple-step distribution channels, including distributors' commissions and the costs of storing merchandise in central distribution facilities. We route the majority of our purchases through cross-dock facilities which break down truckload quantity shipments from manufacturers and reallocates these goods for shipment to individual clubs, generally within 24 hours. Our efficient distribution systems result in reduced freight expenses and lower handling costs compared to other retailers.*

As important to BJ's operations, especially in preparing for a fierce nor'easter or a major hurricane, is the freight yard surrounding their cross-dock and warehouse. Trevor LaChapelle explains:

> *At the end of week before Irma hit on Sunday, we were getting backed up on what could be delivered. Demand was off the charts. Transit times were doubled or more because of the evacuation....Most of the time, our Clubs are the relief valves in our supply chain. They are big enough to take almost anything we can get to them, and we push hard. [BJ's retail facilities range between 63,000 and 150,000 square feet.] But the whole week after Labor Day, inbound was*

[3] Stock Keeping Units or SKUs are popularly known as barcodes. These codes identify specific products and services and are widely used in inventory management.

delivering more volume than we could get off the property at Jacksonville. Obviously, we've got to keep the cross-dock flowing; any disruption in that flow would be its own disaster. So, when we see flow slowing between the cross-dock and the Clubs, we move product into parked vans. We keep a trailer pool on hand just for managing this risk. Our tractor-to-trailer ratio isn't efficient. In fact, it's awful, but this keeps the cross-dock flowing, which is most important. And with Irma we were able to create specific Hurricane Trailers pre-loaded with everything Clubs really need when the grid is down. So effectively adapting to the pre-storm problem actually helped us rebound more quickly post-storm.

BJ's and Cowan have consciously built into their high-volume, high-velocity, value, and variety optimized supply chain a relief valve to manage specifically unpredictable events. The neck of their hourglass can be expanded.

JACKSONVILLE AREA FUEL NETWORK

Joe usually fills up his tractor at the Travel Pilot Center near the intersection of I-295 and Pritchard. There's a Kangaroo Express across the street, but Pilot and Flying J give Cowan Systems a nationwide volume discount. The Cowan fleet carries twin 100-gallon fuel tanks. Trucks with two 150-gallon tanks are more common.

"Company-wide, our typical haul is about 200 miles," Joe says. "Fuel is heavy. The less fuel we carry, the more inventory we can haul. At typical speeds, our fuel tanks are good for about 2,000 miles. From Jacksonville, Miami is 700 miles roundtrip. Homestead is 760." Cowan Systems is serious about running lean. Their fleet of more than 1,700 tractors feature lighter-weight engines. Their trailers feature mostly aluminum flooring. Along with other intentional choices, a Cowan truck and trailer start about 5,000 pounds lighter than most of the competition.

Almost all of Jacksonville's fuel arrives by ocean barge, most of the time on Jones Act carriers from refineries near Houston. There are five active fuel terminals located near the convergence of the St. Johns River and the Broward River: Buckeye, TransMontaigne, MPLX, NuStar, and CenterPoint.

The Buckeye terminal is the local branch of one of the largest fuel operations on the planet. In the United States, the company operates 115 fuel terminals, with another 22 overseas. Buckeye has global storage capacity for more than 170 million barrels of fuel.[15] The Jacksonville terminal stores and sells gasoline and diesel from a six-bay fuel rack (see Figure CS5-2).

Figure CS5-2. Buckeye Terminals, LLC - Jacksonville 2617 Heckscher Drive

Source: Google Maps

There are about 400 fuel racks in the United States [16]. About 220 are attached to a pipeline. The others, like Buckeye in Jacksonville, depend on maritime vessels or tanker trucks for resupply or are located at a refinery. Racks are built to rapidly and safely fill tanker trucks. A tanker carrying 9,000 gallons can usually be filled in about 40 minutes. Many fuel stations have storage tanks with a capacity of roughly 9,000 gallons, often one for each grade or gasoline (or two for regular and one for premium if they use blending). But others, including the Pilot where Joe usually fills up, can have much larger storage capacities. The largest truck stops will often sell more than a million gallons of fuel per month. That means more than 25 rack visits per week just to keep one truck stop operating. According to a study conducted by the National Tank Truck Carriers, in 2013 tanker trucks accounted for 163,670 tractors (or 10.9 percent) of all the roughly 1.5 million over-the-road tractors in the United States.[17] Just about half of this fleet is committed to transporting petroleum products.

Buckeye has the largest rack in the Jacksonville area. But Pilot Travel Centers and other fuel retailers may, depending on price, availability, and bulk contracts, receive fuel from the Taft terminal near Orlando (150 miles), the Seaport Canaveral racks (160 miles), or even from the Colonial Pipeline racks at Bainbridge, Georgia (200 miles).

According to Genscape, a firm that monitors the energy market, "Total motor gasoline demand in Florida rose 62 percent between September 4–7 (2017) in preparation for Irma….Truck rack loadings on September 7 increased by 64 percent from one week prior, and

week-to-date (September 2–7) gasoline rack demand in the state was up 32 percent compared to the previous week (August 26–31).” [18]

The week before Irma hit, the demand for fuel was difficult to meet no matter where it was sourced. “A couple of million cars evacuating north tends to disrupt the best-laid plans,” Joe observes. On Saturday September 9, according to GasBuddy, about 36 percent of Jacksonville gas stations were dry. By Sunday local outages had climbed to 46 percent. [19] Joe recalls:

> *Diesel was sometimes still available when gas was out. Anyplace that still had gas had so many cars piled up that it was tough to get a truck through the crowd. I was able to top-off at the Pilot on Friday night, but it took a while. Anyway, after that, BJ’s reloaded the van for the first post-hurricane run. This set us up for a jump-start; it cleared the cross-dock and added weight to help the van resist winds. Nice trifecta. Then we parked real tight in the yard, more wind protection. Anyway, by Saturday morning the yard was packed tight as eggs in a carton.*

Jacksonville is more than 300 miles northeast of where Irma made second landfall on Sunday morning (September 10), but by Sunday night the city was feeling her full effect. Just over five inches of rain fell on Sunday, and about four and a half inches fell on Monday. [20] Wind gusts of over 86 miles per hour and sustained winds of 50 miles per hour were recorded.

Figure CS5-3. Buckeye Terminal faces flooding on Drummond Creek

Sunday night Jacksonville started losing power. About 12,000 customers were off the grid by 10:00 p.m. By Monday evening, over 230,000 customers (places not people) had lost power. [21] Eventually, 284,000 of more than 400,000 Jacksonville Electric Authority customers were without power for some period.

The Buckeye racks had emergency generators. The electrical outage did close several retail fuel stations. On Monday September 11, flooding was even more a problem. According to Weather Underground: “Waters along the St. Johns River in Jacksonville spiked dramatically on Monday morning, due in part to runoff from torrential overnight rains of 5”-15” across northeast Florida. At 1:06 p.m., the gauge at downtown Jacksonville’s Main Street Bridge showed a water height of 5.57’, smashing the previous modern-day record of 4.12’ observed during Hurricane Dora on Sept. 10, 1964.” [22] The Buckeye racks were 11’ above flood stage. But most tanker trucks stayed parked. Joe says:

> *I live just south of BJ's and could get in on Sunday without much problem. They wanted to send some trucks to Miami to see what's up. My wife went over to help with the grandkids. I decided to volunteer to make the run. Rain was really bad down on the Treasure Coast (Ft. Pierce, Vero Beach) but otherwise not much problem. The stores were open, and we could deliver. Not many others on I-95. But we noticed that everything was dark down and back, didn't see one truck stop open, and diesel was really tight in Jacksonville. I pulled back into the yard almost half empty.*

Florida's upstream fuel stocks were fine. Despite the loss of refining capability as a result of Hurricane Harvey, the US Department of Energy reported, "As of the August 25 Weekly Petroleum Status Report, stocks of gasoline in PADD 1 (East Coast) were near the top end of the 5-year range." [22]

The energy market adapted to the loss of supply from the Gulf Coast and the spike in Florida demand. *CityLab* reports [23]:

> *Barges that normally deliver from offline Gulf Coast refineries were rerouted to New York and Philadelphia to bring gas south. Tankers from Louisiana and Mississippi steamed eastward to reach Florida in time, having been delayed by Harvey's fearsome path. One oil trader redirected two European barges destined for Africa to Florida instead…the state took in some 570,00 barrels from Europe ahead of Irma in order to make up for supplies it had lost to Harvey.*

But no matter how much supply is available, the time and space required for distribution can be insufficient for sudden surge in demand. Joe observes, "Monday there were a whole bunch of empty gas stations. The number of fuel racks did not suddenly increase. Miles between racks and the gas stations stayed the same, and some were flooded. Most truckers stayed home, so even fewer tankers. Takes a while to make up the difference."

MARITIME TRANSPORT – CROWDING AT SAN JUAN PORT

More than a week before Irma's remnants hit Jacksonville, she had already impacted the city's docks. JAXPORT is the principal embarkation point for most mainland products shipped to and sold in Puerto Rico and the US Virgin Islands. TOTE, Trailer Bridge, and Crowley are all Jones Act Carriers[4] with significant operations at JAXPORT. Transit to San Juan typically requires three to six days depending on vessel, course, and speed.

[4] The Merchant Marine Act of 1920, also known as the Jones Act, requires that all goods moving between US ports be carried by US owned, built, and crewed vessels. As a result, US products consumed in Puerto Rico must be transported by so-called "Jones Act Carriers". The Jones Act does not restrict the import of foreign goods.

As Irma formed on August 30, there was scant time to expedite landings and cargo unloading at San Juan. The hurricane then delayed cargo movement while plowing through the northern Caribbean, hitting St. Thomas very hard and knocking out power to over a million Puerto Ricans. The Port of San Juan was closed September 5–7. [24] The Port of Jacksonville was closed September 9–13. When Maria hit Puerto Rico on September 20, shippers, stevedores, drayage drivers, and other port personnel were still working to make up for Irma's delays.

Joe's buddies still hauling to JAXPORT told him that as Maria closed in on Florida, CSX and Norfolk Southern embargoed cargo into Jacksonville, and lots of truckers were staying away, too. [25-26]

Demonstrating this delay—and the maritime system's adaptability—one of Trailer Bridge's vessels (*Chicago Bridge*) departed Jacksonville on September 1 arcing south of Cuba to avoid Irma's storm track. The vessel arrived at San Juan on September 12. The *JAX-San Juan Bridge* arrived at Jacksonville on September 5 and was held there until late on September 12. *Memphis Bridge* arrived from San Juan on September 7 and did not depart until September 15. Both vessels took the long way around Hispaniola to avoid Maria, arriving at San Juan on September 23. In early September, Trailer Bridge reactivated the vessel *Brooklyn Bridge* in anticipation of needing additional capacity to make up for these delays. [27] The vessel *JAX-San Juan Bridge* (see Figure CS5-4 below) was also sailing proximate sea lanes.

Figure CS5-4. The JAX-San Juan Bridge is a non-propelled barge, 223 meters x 32 meters

Source: TrailerBridge

In early September 2017, vessels operating between JAXPORT and San Juan included both self-propelled liners and tug barges. Crowley was sailing nine Roll-On, Roll-Off (RO-RO) barges. TOTE was serving San Juan with two LNG-powered Lift-On, Lift-Off (LO-LO) container ships. [28]

In 2015, JAXPORT had 2,200 vessel calls of all types, carrying more than 18.5 million short tons. That same year, the Port of San Juan had just over 1,500 vessel calls with more than 11 million short tons. About 7.3 percent of this throughput at San Juan consisted of groceries. [29] Both ports are key nodes connecting supply in the mainland US with demand in the Caribbean. The Port of San Juan is the most important entry point for goods coming into Puerto Rico and those continuing to smaller islands in the Caribbean. Both ports are "supernodes" because of their volume—and because their capacity to process goods has a profound impact on total throughput of dozens of supply chains for goods ranging from groceries to cars to concrete. All these goods pass through the same docks and are moved by the same cranes, whose overall capacity is more or less fixed.

Domestic shipments arriving on Jones Act carriers into the Port of San Juan are not liable for customs duties, but most items arriving at the port are liable for Puerto Rico sales and use taxes that are calculated and paid before the items leave port. Since 2014, these payments have been digitally facilitated using the Portal Integrado del Comerciante (PICO) system.

On Tuesday September 19, as Hurricane Maria tore through the eastern Caribbean, the Puerto Rico Department of the Treasury (widely referenced as Hacienda, reflecting the name of its colonial era headquarters) anticipated the PICO system could fail. It did in fact fail. But while communications systems were still operating, Hacienda conceived and distributed a temporary process to facilitate releasing certain "authorized merchandise," including food, medicines, raw material, animals, perishable goods, power plants, and goods received by bonded taxpayers. [30] The temporary procedure, also called "manual release," outlined the following requirements. The party receiving the goods must physically appear at the Office of Consumption Tax located in the Crowley facilities within the Isla Grande port zone (Crowley satellite office) and submit the following: a bill of landing, a manifesto, a copy of bonding documents, evidence of applicable payments, the name of the consignee, and the cost of merchandise.

On September 23, Trailer Bridge advised its customers in Puerto Rico [31]:

> *Department of Hacienda's electronic system remains down due to Hurricane Maria, since approximately 12 p.m. on Tuesday 9/19 no cargo has been able to be transmitted and no status has been able to be received by the carrier. Cargo that was not transmitted to Department of Hacienda prior to the system closure cannot be processed through normal electronic channels for release. We anticipate based on the devastating impact of Hurricane Maria it will be several days or longer before the electronic processes are back up and running.*

Given disrupted sailing schedules starting with Irma, many shippers used the window between the two hurricanes and after Maria's passing to surge what they could toward San Juan. When the port fully reopened on September 13, several staged fuel shipments immediately made delivery. [32] But many—even most—newly received commercial products were held at the port until taxes could be paid.

Figure CS5-5. Crowley maritime shipping lanes

There were myriad reasons why many shipments were not retrieved from the port in the first two weeks after Maria's passing, including the direct impact such a hard-hitting storm has on survivors. There are immediate issues of response and recovery that do not usually involve retrieving Bills of Landing. Given the island-wide grid loss, this would have been difficult even for those so inclined. But even with all the paperwork in hand, warehouse or retail locations could not receive goods from the port before clearing debris from the roads. With the grid (and refrigeration) non-operational, refrigerated vans were better for some products (fresh produce, for example) than hot tables or shelves. Many truckers faced a host of survivor priorities and felt uncertain about driving conditions and fuel availability.

For reasons ranging from new paperwork requirements to much more profound (and less arbitrary) impediments, congestion on the docks soon became a severe problem. More than a week after Maria's landfall, *Bloomberg* reported [33]:

> *Thousands of cargo containers bearing millions of emergency meals and other relief supplies have been piling up on San Juan's docks since Saturday. The mountains of material may not reach Hurricane Maria survivors for days. Distributors for big-box companies and smaller retailers are unloading 4,000 20-foot containers full of necessities like food, water, and soap this*

> *week at a dock in Puerto Rico's capital operated by Crowley Maritime Corp. In the past few days, Tote Maritime's terminal has taken the equivalent of almost 3,000. The two facilities have become choke points in the effort to aid survivors of Hurricane Maria. "There are plenty of ships and plenty of cargo to come into the island," said Mark Miller, a spokesman for Crowley, based in Jacksonville, Florida. "From there, that's where the supply chain breaks down—getting the goods from the port to the people on the island who need them."*

Others in Puerto Rico claimed that Hacienda officials at the port expedited FEMA freight and ignored commercial throughput, diverting trucking resources that usually served wholesalers and retailers. Movement out of the port was below normal for much of the first three weeks after landfall.

Between unclaimed containers piling up at the port and many removed containers not being returned, Jacksonville was on the edge of not having enough containers to make new loads. Jose Ayala, vice president for Crowley's Puerto Rico services, told the *Journal of Commerce* that Crowley had "added more than 5,000 containers and several hundred chassis to make up for slower equipment turn times." [28] Puerto Rico was eating up containers already in short supply globally since early in 2017 [34]. In June 2017 the *Journal of Commerce* reported [35]:

> *US exporters are scrambling to find containers, with some coming up empty handed. While some of the shortage is seasonal, some of it is because of new Chinese regulations slowing container production and pressure on carriers to get empties back to Asia for import loads. Kansas City has been hit particularly hard, according to individual carrier reports that have also highlighted Dallas, Denver, Memphis, and even Chicago.*

Because of Hurricanes Irma and Maria, maritime transport between JAXPORT and San Juan experienced delays. There were also several system disruptions. But there was never a fundamental shortage of supply. Rather, there was a significant surge in supply. The unevenness of flow, combined with this surge, created congestion at the port in San Juan. The surge in supply did not always match demand preferences, and there were several problems with surface transportation once products arrived at San Juan, which further increased congestion at the port.

Several months after the 2017 Hurricane Season, a shipping executive[5] walked along the docks at JAXPORT:

> *What happened in Puerto Rico post-Maria was probably the biggest Beer Game ever played," he said. "Think about it, the system that had been feeding 3.4 million people on September 19 was mostly still in place after landfall. All the food that was in the pre-existing pipeline was still*

[5] This interviewee spoke on the condition of personal anonymity and not identifying his employer

flowing, maybe flowing around Cuba instead of direct to San Juan, but nothing fundamental had happened at JAX or the San Juan port to change anything. People just got nervous. Grid's out. Communication's spotty. Lots of stores aren't open. Truckers are absent. So, yeah, folks got nervous. At the port and on the liners and on order into Jacksonville, they've got everything they need. But they started ordering more. Demand was erratic and anxiety-driven. New sources of demand – like FEMA, Commonwealth, and Mayors – ordered a lot more on top of the plus-up already flowing. So, we're trying to push a lot more down essentially the same pipe. Was there displacement? Hell, yes. Was there a need for much better distribution of stuff on the island? Absolutely. Was more stuff needed? Not really and handling all the unneeded stuff just complicated solving the distribution problem. As usual there was a real communication and distribution problem, misperceived as a supply problem.

The Beer Game[6] is a role-play activity often included in introductory supply chain management classes. It was originally developed at the MIT Sloan School of Management. In its most common form, the game typically exposes how small changes in the pattern of downstream demand can be amplified in terms of upstream supply. Inaccurate perceptions of demand—usually related to distorted communication of demand—can create production inefficiencies, excess inventory, disrupted distribution, and ineffective fulfillment of demand. These symptoms are often referred to as the "bullwhip effect."[7] Instead of decisions based on documented demand and actual supply, uncertainty drives behavior that floods the market. In the case of post-Maria Puerto Rico, was the pre-existing neck size closer to the right size than was realized at the time?

Not surprisingly, cargo receipts by weight for the Port of San Juan were about 20 percent below normal for September 2017. But October receipts were higher than October 2016. The weight of cargo received at San Juan in November 2017 was 40 percent higher than in November 2016, and it was the most delivered in November since 2012. December cargo was 18 percent higher than December 2016 and the highest in five years. [36]

INTRAVENOUS BAG MANUFACTURING IN PUERTO RICO

[6] The Beer Game

[7] Sloan Management Review, The Bullwhip Effect

Trailer Bridge was founded to provide single-carrier, highway-with-maritime transportation to and from the mainland and Puerto Rico. The company has its headquarters in Jacksonville and sails from the southwest tip of Blount Island.

Like all carriers operating between JAXPORT and Puerto Rico, its loads into San Juan are much heavier than those sailing outbound. Its inbound flow to San Juan is four-times larger than its flow on the return trip to JAXPORT. Most of the shipping containers sailing from San Juan are empties, needed at the mainland port and farther back to refill with supplies for Puerto Rico. There are comparatively fewer products moving into JAXPORT. Each year, Bacardi alone sends about 138 million pounds of rum to the mainland. But the highest value products embarked for the mainland are usually medical goods and pharmaceuticals.

Despite overall declines in pharmaceutical production in Puerto Rico, in recent years Trailer Bridge has seen outbound volume for specific categories of medical goods increase. [37]

Figure CS5-6. Baxter IV bag

Puerto Rico produces $40 billion per year in pharmaceuticals and medical goods. This is more than the value produced by California and Indiana combined (the next two top producers of US pharmaceuticals and medical goods). According to the Food and Drug Administration (FDA) [38]:

> *Puerto Rico manufactures thirty drug products and approximately ten biological devices/biologics that are of critical importance because Puerto Rico is a primary or sole manufacturing site and these drugs do not have clear therapeutic alternatives. All forty of these products are being carefully monitored by the FDA Drug Shortage Teams; fourteen of these drugs are sourced only in Puerto Rico.*

Since 2015—and Hurricane Maria—Trailer Bridge experienced specific increases in shipping volumes for intravenous bags. Baxter is the largest US producer of these products. There are two plants in Puerto Rico that produce over 40 percent of the intravenous bags used in US healthcare. [39] A global shortage of these products began in 2014. Since then Baxter has been pushing to fill the gap, hence the increase seen by Trailer Bridge. In this case, the production capacity constrains more than the transportation capacity.

According to the New England Journal of Medicine [40]:

> *Saline is an inexpensive product—it's simply salt water—but proper manufacturing practices are required to keep it sterile, pyrogen-free, and free from particulate matter. Production demands are challenging, since very large quantities are needed: more than 40 million bags per month. Saline is required for virtually all hospitalized patients, whether as a component of a medication infusion or as a hydration, resuscitation, or irrigation fluid. Unfortunately, shortages of saline have become commonplace in recent years. Most drug shortages occur with older, generic, injectable medications that are produced by a small number of suppliers—typically three or fewer. The United States gets its saline from just three companies: Baxter International, B. Braun Medical, and ICU Medical. Most shortages are caused by a quality or production problem at the manufacturing facility—causes that apply to the current saline shortage as well.[2,3] In addition, when one supplier experiences a shortage, other suppliers often have insufficient manufacturing capacity to make up the difference.*

US supplies were further reduced by an August 2017 decision by B. Braun Medical to exit the intravenous bag market [41]. The hourglass structure of the intravenous bag market tightened at the neck—the relatively few sites that account for much of the manufacturing.

The plants manufacturing intravenous bags are located at Guayama, about 30 miles from Maria's landfall, and at Jayuya in the central highlands, one of the hardest hit areas. As was the case across Puerto Rico, the electrical grid failed. Restoration of the grid to each of these locations was difficult and especially time consuming in Jayuya. At the beginning of March 2018, half of the residents of Jayuya were still off the grid. [42]

The manufacturing facilities had emergency generating units. But these were designed and fueled to maintain operations during short-term outages, not for months and months. Further, they were large units that consumed large amounts of diesel. About two weeks after Maria, Baxter was having particular difficulty being regularly refueled. They reached out to FEMA for fuel. A FEMA official explains:

> *It was, I think, my second day in Puerto Rico. I was at the JFO [Joint Field Office] and some guy generally explained the situation and asked for fuel support. Made sense to me, and I felt like we could get them what was needed. But as I understood regulations, for FEMA to provide this support to the private sector, I needed someone to officially tell FEMA that this is a critical national facility. I asked. I pushed for maybe two more days. No answer. Then I moved on to where I could make a difference. There were plenty of other problems where I was able to be more productive. You don't even have time or energy to be frustrated."*

As far as this FEMA official recalls, no one said anything about intravenous bags. There was no mention of 40-plus percent of national production.

> *It was a big pharmaceutical and medical goods maker. That was good enough for me. I probably didn't connect the dots until early January when I happened to hear about the saline shortage*

> *back on the mainland. But even if I had connected the dots at the beginning, I'm not sure we were, at least back then, leaning forward to engage these kinds of problems. We were plenty busy just trying to keep the hospitals running and the water on.*

Nine months after the fact, a more senior FEMA official offers:

> *Yeah, we're still not there yet. We're focused down-the-supply-chain to move heaven and earth to respond to a state request to fill a gap or an unmet need. It's the most used and straightforward way we exercise our Stafford Act authorities. But understanding the up-the-supply-chain issues where we, the operators/executors, don't know what we don't know about critical infrastructure or supply chains or maybe don't know what someone else or some plan knows, that's the issue. We need to have processes, systems and relationships that let us see these things coming. That said, and with all the benefit of hindsight, I sure wish we would have worked with Baxter to get the Commonwealth to request the refueling. That's the solution that is always fastest and most effective: get the issue in front of the Governor's team so they can ask for the help.*

There had been a shortage of this critical product since 2014. One of three US manufacturers exited the market in August 2017. The single largest US manufacturer lost production capability in late September. Then, the 2017–2018 flu season was one of the worst in years. [43] Did someone say "perfect storm"?

On October 13, Scott Gottlieb, the FDA Commissioner, issued a statement that included [44]:

> *The FDA has also taken many steps to help Baxter restore operations in its Puerto Rico facilities and move critical products onto and off the island. The FDA and Baxter will continue to keep in close consultation as we monitor the challenging situation on the island. The agency is also continuing its work with other manufacturers on steps to prevent or mitigate shortages of other types of critical medical products. Among the actions that the FDA is taking—in conjunction with other manufacturers and federal and local government partners—to help restore production in Puerto Rico and maintain operations on the island is helping facilities secure fuel and manufacturing supplies, and the logistical support to move critical products onto and off the island.*

In late December—about 90 days after the hurricanes hit—power was restored to the Baxter manufacturing plants. On January 4, 2018, the FDA Commissioner reported [44-45]:

> *All the other companies that manufacture products that were on our initial list of drugs that we considered critical and at risk of potential shortages—because the drugs were largely or entirely manufactured in Puerto Rico—are now on the power grid. Many of these companies report to us that their production is increasing. While there are still many challenges that remain—for instance, the commercial power grid remains unstable in places—these developments reduce the risk of any future shortages resulting from the impact of the storm on the island's manufacturing sector.*

In June 2018, Trailer Bridge was honored by New York's Seamen's Church—along with Crowley and TOTE—for what the carriers had delivered to Puerto Rico after the hurricane. [46] What they carried *out* of San Juan to Jacksonville was equally lifesaving.

PRELIMINARY ANALYSIS

To serve dense populations, volume (or more precisely, throughput) is necessary. High velocity can be conducive to moving volume. Efficiently moving volume at high velocity often facilitates delivery at a cost/price (value) that is affordable to a higher proportion of the population.[8] Networks often assume an hourglass structure in trying to improve velocity (speed in a specific direction).

To deliver volume at higher velocities, networks are organized and emerge. As greater volume at higher velocity is achieved (i.e., throughput or flow), spatial concentration is a recurring—perhaps innate—feature of networks. Spatial concentration, volume of flow, and velocity of flow are often mutually reinforcing. [47]

How and where concentration emerges in a network has important implications for robustness, resilience, and adaptability. How and where flow is generated can be equally important to the behavior and survivability of the network.

High volumes moving at high speed to specific destinations are needed for BJ's Wholesale Club to achieve its business goals and the expectations of its customers. For this purpose, BJ's has concentrated its capacity for receiving goods from suppliers and shipping to its Clubs at one location west of Jacksonville. This location was selected, designed, and is currently operated to maximize velocity of throughput. The cross-dock is a self-constraining choice. Warehouse or other longer-term storage is strictly limited in part to enforce velocity. Comparatively cheap vans are kept on hand to provide a seldom needed relief valve. Since there are no viable replacement facilities (a structural bottleneck in the supply chain), the relief valve ensures that the throughput of the cross-dock can be maintained.

Florida's fuel network is concentrated in six large nodes, specifically petroleum product terminals.[9] This concentration facilitates economies of scale involved in transporting and storing large quantities of fuel. Each of these nodes consists of its own sub-networks

[8] Variety of choice and the so-called veracity (visibility and integrity) of the supply chain may be a comparative advantage in attracting demand.

[9] Tampa Port, Taft Terminal, Port Everglades, Port Canaveral, Port of Jacksonville, and the Colonial Terminal at Bainbridge, Georgia

featuring a method of filling the terminal storage (pipeline or offloading ships), and one or more fuel racks to fill trucks that distribute the fuel. Enormous supply is distributed to enormous demand through a proportionally narrow discharge point. The number of fuel racks—and tanker bays available at each rack—reflect a network configuration that is arguably optimized as "just right" for currently perceived and anticipated demand.[10] The relief valve for fuel racks mostly involves operating for longer hours and, up to a point, serving additional tankers. But too many tankers at the same time can also reduce overall throughput. [48]

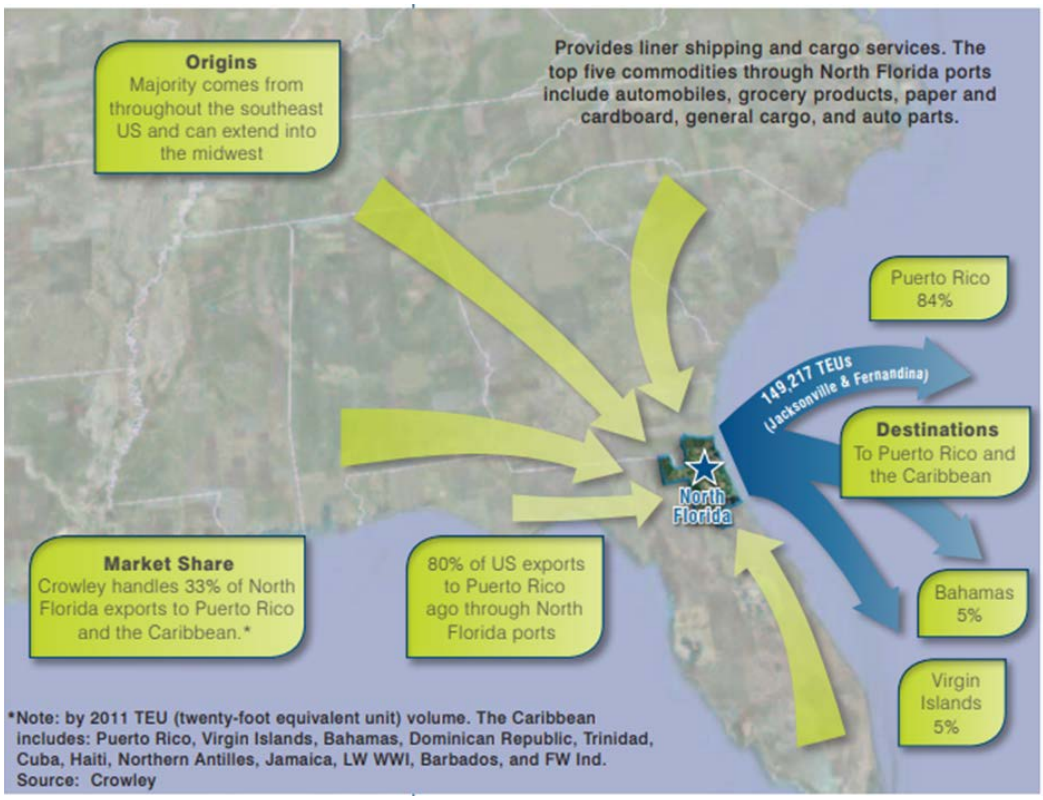
Puerto Rico's supply network is highly concentrated at the Port of Jacksonville [49] as well as at (and near[11]) the Port of San Juan with three carriers and a comparatively small number of vessels facilitating the vast majority of supply. The strong link between Jacksonville and Puerto Rico is shown in Figure CS5-7, a schematic of the Crowley maritime network's freight flows. As spatial concentration of volume has increased—and as regional carrier volumes have increased [50]—competition focused on velocity appears to be increasing. [51] Increasing shipping capacity is not easy or quick. Diversifying ports, origins, or entries can be even more complicated. These ports, and the supply chains for all the goods they handle, depend on the processing capacity of docks, cranes, and even bureaucrats.

Intravenous bags are needed in high volumes. Given low profit margins for the product, concentrating production is a reasonable network configuration choice. Velocity of supply from existing production has become more important as sources of volume have declined. When forty percent of volume usually serving US healthcare was suddenly shut off by the collapse of the grid in Puerto Rico, problems emerged with nearly every attempted relief valve. [52]

[10] For an interesting treatment on the role of constraints in configuration problems see: The Goldilocks Problem by Tudor Hulubei , Eugene C. Freuder and Richard J. Wallace.

[11] Outside the Port of San Juan, primarily in Bayamon, there is a parallel spatial concentration of storage and distribution capacity.

Figure CS5-7. Crowley maritime network



Source: North Florida Freight Logistics and Intermodal Framework [53]

Once concentrations of supply and demand are well-established and regular channels of movement (involving both time and space) have emerged, quick changes in a network can produce unpredictable effects. But awareness of concentrations and channels—including related risks and rewards—presents the opportunity to reduce excessive risks and develop response strategies for when risks are realized. Being able to find hourglass structures in regional and local demand and supply networks can provide helpful strategic and operational focus.

In the FEMA After-Action Report on the 2017 Hurricane Season, the agency concludes [54]:

> *The unparalleled scope and scale of the 2017 Hurricane Season underscored the need for, and identified several limitations in, implementing timely national response capabilities that are fully integrated with and supportive of private sector supply chain restoration. In 2017, public and private sector response and recovery efforts were too "stove-piped" to share timely information, too slow to consult, and as a result, often too late to synchronize stabilization efforts. The public and private sector are inextricably linked and must have shared situational awareness and the*

ability to synchronize their respective efforts to be successful. FEMA should work with its key partners to develop a more comprehensive understanding of local, regional, and national supply chains, as well as stronger relationships with critical private sector partners to support rapid restoration in response to catastrophic incidents.

Such a "comprehensive understanding of local, regional, and national supply chains" will include the role of network concentration and related constraints. In each of the four examples outlined above, significant concentration(s) of supply was connected to significant concentration(s) of demand by way of rather sparse points of discharge: cross-docks, fuel racks, and the JAXPORT to San Juan maritime shipping lane. These hourglass structures—usually sufficient to support supply and demand—can suddenly become life-threatening constraints. Recognizing the potential for such constraints and being prepared to preempt emerging constraints is an important means of synchronizing private-public stabilization efforts.

Hourglass structures are common features in hierarchical systems. They are observed both in natural and engineered contexts. Hourglass structures can assume fractal-like properties, appearing self-similar from micro-to-macro.[12] They are not always constraints. If and when the neck of an hourglass survives an extreme event, it may in fact be a crucial element in increasing system capacity.

For all these reasons, these hourglass structures can reward attention by individuals and organizations involved in disaster mitigation, preparedness, response, and recovery. Where are the hourglass structures? How can hourglass structures be pre-identified and anticipated

[12] From "The Hourglass Effect in Hierarchical Dependency Networks" by Kaeser M. Sabrin and Constantine Dovrolis*: It has been observed across several disciplines that hierarchically modular systems are often structured in a way that resembles a bow-tie or hourglass (depending on whether that structure is viewed horizontally or vertically). Informally, this means that the system generates many outputs from many inputs through a relatively small number of intermediate modules, referred to as the "knot" of the bow-tie or the "waist" of the hourglass. This "hourglass effect" has been observed in embryogenesis, in metabolism, in immunology, in signaling networks, in vision and cognition, in deep neural networks, in computer networking, in manufacturing, as well as in the context of general core-periphery complex networks. The few intermediate modules in the hourglass waist are critical for the operation of the entire system, and so they are also more conserved during the evolution of the system compared to modules that are closer to inputs or outputs. These observations have emerged in a wide range of natural, technological and information disciplines, and so it is interesting to investigate whether the so-called hourglass effect has deeper and more general roots that are largely domain independent…. If there is a change in the inputs (sources), the outputs do not need to be modified as long as the modules at the waist can still function properly. Similarly, if there is need for a new target, it may be much easier (or cheaper) to construct it reusing the modules at the waist rather than directly relying on sources. This is related to the notion of "constraints that de-constrain", introduced by Kirschner and Gerhart in the context of biological development and evolvability. At the same time however, the presence of these critical modules at the waist (the "constraints") limit the space of all possible outputs that the system can generate.*

in demand and supply networks? In the supply chain there are already analogues to streamflow gages from hydrology in place that could help us measure the volume and velocity of upstream to downstream flows. These views of volume and velocity can be used to determine where there are constraints, as well as when instead the neck is actually enhancing throughput. For example:

Demand Pull: Where are electronic transactions being made (with bank cards or electronic benefit cards)? Often more important, where are electronic transactions *not* being made?

Flow Volume and Velocity: What are traffic counts at key transportation intersections? What are traffic counts at fuel racks? How is the rack-rate for fuel behaving? What are regional (and wider) spot-market rates for trucking? What is the sailing schedule for vessels? How do the current numbers compare to recent counts and year-over-year? Where are the principal breaks in the transportation network?

Supply Potential: What are currently available fuel stocks? Did major distribution centers, warehouses, and cross-docks survive the event? Are these facilities still connected to transportation networks? Do they have key resources needed to operate (power, fuel, water, communications, personnel)?

Being able to monitor specific indicators of volume and velocity across demand and supply networks would enhance the ability of FEMA and others to effectively target disaster mitigation, preparedness, response, and recovery in case of disruption and destruction. In some cases, restoring supply potential by providing key resources or a relief valve for a glut in product that is constraining throughput can be more effective than surging a replacement supply chain.

This case study was developed by the Institute for Public Research at CNA, a not-for-profit research organization that serves the public interest by providing in-depth analysis and result-oriented solutions to help government leaders choose the best course of action in setting policy and managing operations.

Additional case studies related to issues of Supply Chain Resilience emerging from the 2017 Hurricane Season are available at: www.cna.org/supplychainresilience

References

[1] US Census Bureau. 1920. *Population of Counties, 1920 Census.* https://www2.census.gov/prod2/decennial/documents/41084484v1ch2.pdf.

[2] Jacksonville Port Authority. 2017. "JAXPORT Sets New Cargo Records In 2017." *JAXPORT Newsroom*. 23 Oct 2017http://www.jaxport.com/newsroom/news/jaxport-sets-new-cargo-records-in-2017.

[3] North Florida TPO. 2015. Spreadsheet. *Duval County State Roads Traffic Counts - 2015*. Portable Document Format. http://northfloridatpo.com/images/uploads/Duval_County_State_Roads_Report_-_2015.pdf.

[4] US Census Bureau. American Community Survey, 2012. *Occupation of Civilian Population*. https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=CF.

[5] NIFA. "Puerto Rico's Secretary of Agriculture visits NIFA, addresses food security issues." USDA National Institute of Food and Agriculture: Newsroom. 8 Oct 2015 https://nifa.usda.gov/announcement/puerto-rico%E2%80%99s-secretary-agriculture-visits-nifa-addresses-food-security-issues.

[6] EIA, and ICF International. 2016. *East Coast and Gulf Coast Transportation Fuels Markets.* U.S. Energy Information Administration, U.S. Department of Energy. February 2016.https://www.eia.gov/analysis/transportationfuels/padd1n3/pdf/transportation_fuels_padd1n3.pdf.

[7] Cluster Mapping, Harvard Business School, and US Economic Development Administration. 2016. "Jacksonville, FL Economic Area." Region Dashboard: Summary. http://www.clustermapping.us/region/economic/jacksonville_fl.

[8] Delgado, Mercedes, Richard Bryden, and Samantha Zyontz. 2010. *Categorization of Traded and Local Industries in the US Economy.* https://clustermapping.us/sites/default/files/files/page/Categorization%20of%20Traded%20and%20Local%20Industries%20in%20the%20US%20Economy.pdf.

[9] World Economic Forum. 2008. *Global Risks 2008: A Global Risk Network Report.* World Economic Forum. January 2008. http://unpan1.un.org/intradoc/groups/public/documents/apcity/unpan034800.pdf.

[10] Sheffi, Yossi. 2014. "Logistics Clusters: The Feedback Loop Leading to Economic Growth and Jobs." *European Business Review.* 20 Jan 2014 http://www.europeanbusinessreview.com/logistics-clusters-the-feedback-loop-leading-to-economic-growth-and-jobs/.

[11] Van Dyke Parunak, H., R. Savit, and R.L. Riolo. 1988. "Agent-Based Modeling vs. Equation-Based Modeling: A Case Study." In *Multi-Agent Systems and Agent-Based Simulation: First International Workshop*. Edited by Jaime S. Sichman, Rosaria Conte, and Nigel Gilbert. 10-25. Paris, France: Springer, https://books.google.com/books?id=rspsCQAAQBAJ&pg=PA12&lpg=PA12&dq=hourglass+supply+chain&source=bl&ots=fi6pEnWmbt&sig=XqaalzwqpxiE3rnaNPvtM_sdjF4&hl=en&sa=X&ved=0ahUKEwj9qODK3qDcAhXJg-AKHbP4A_MQ6AEIdDAO#v=onepage&q=hourglass%20supply%20chain&f=false.

[12] Walton, Christopher. 2007. *Agency and the Semantic Web*. Oxford, England: OUP Oxford. https://books.google.com/books?id=sqIVDAAAQBAJ&pg=PA80&lpg=PA80&dq=%22hourglass%22+supply+chain&source=bl&ots=CvwYaNr_43&sig=qdfxKp8g2NlGU5Eup7VhvYczuFs&hl=en&sa=X&ved=0ahUKEwirjJPA5KDcAhWLON8KHV2pB_cQ6AEIczAN#v=onepage&q=%22hourglass%22%20supply%20chain&f=false.

[13] Sabrin, Kaeser M., and Constantine Dovrolis. 2017. "The hourglass effect in hierarchical dependency networks." *Network Science* 5 (4): 490-528. doi: 10.1017/nws.2017.22. https://www.cambridge.org/core/journals/network-science/article/hourglass-effect-in-hierarchical-dependency-networks/DDBCA83D16CA74B827DAB66A98CC906A.

[14] US Securities and Exchange Commission Filing. *FORM S-1 REGISTRATION STATEMENT*. http://secfilings.nasdaq.com/filingFrameset.asp?FilingID=12817480&RcvdDate=6/18/2018&CoName=BJ%27S%20WHOLESALE%20CLUB%20HOLDINGS%2C%20INC.&FormType=S-1/A&View=orig.

[15] Buckeye Partners LP. 2017. *POSITIONED TO CAPITALIZE ON OPPORTUNITIES 2017 ANNUAL REPORT*. http://www.buckeye.com/LinkClick.aspx?fileticket=FyF3dJS9IQs%3d&tabid=84.

[16] Scott Berhang, and Oil Price Information Service. "Pricing 101 Part 3: Wholesale Rack Fuel Pricing Essentials." OPIS Blog. 12 Sep 2017 http://blog.opisnet.com/wholesale-rack-fuel-pricing-essentials.

[17] National Tank Truck Carriers Inc. 2017. *Tank Truck Industry Market Analysis* http://tanktruck.org/docs/default-source/default-document-library/market-analysis.pdf?sfvrsn=2.

[18] White, Dylan. "Florida Gasoline Demand Spikes Ahead of Hurricane Irma's Landfall." Genscape. 8 Sep 2017 https://www.genscape.com/blog/florida-gasoline-demand-spikes-ahead-hurricane-irmas-landfall.

[19] GasBuddy. "IRMA LIVE UPDATES: FUEL AVAILABILITY & STATION OUTAGES." 11 Sep 2017 https://business.gasbuddy.com/hurricane-irma-live-updates-fuel-availability-station-outages/.

[20] US Climate Data. 2018. "Climate Jacksonville Beach - Florida " US Climate Data. https://www.usclimatedata.com/climate/jacksonville-beach/florida/united-states/usfl0229/2017/9.

[21] First Coast News, and WTLV. 2017. "Power outages in Florida are skyrocketing due to Hurricane Irma." *First Coast News*. 11 Sep 2017https://www.firstcoastnews.com/article/weather/irma/power-outages-in-florida-are-skyrocketing-due-to-hurricane-irma/472897737.

[22] US Department of Energy. 2017. *Hurricane Irma & Hurricane Harvey Event Report.* Infrastructure Security and Energy Restoration, US Department of Energy. (Update #23), Sep 8, 2017. https://www.energy.gov/sites/prod/files/2017/10/f37/Hurricanes%20Irma%20and%20Harvey%20Event%20Summary%20%2323.pdf.

[23] Bliss, Laura. 2017. "Why Florida Ran Out of Gas." *CityLab*. 13 Sep 2017. https://www.citylab.com/transportation/2017/09/why-florida-ran-out-of-gas/539541/.

[24] Coast Guard News. "Coast Guard does damage assessment, announces port openings in Puerto Rico, the U.S. Virgin Islands." Coast Guard News. 7 Sep 2017 http://coastguardnews.com/coast-guard-does-damage-assessment-announces-port-openings-in-puerto-rico-the-u-s-virgin-islands/2017/09/07/.

[25] CSX. "CSX Customer Advisory - IRMA UPDATE: CSX Restores Service in GA, SC, AL and Jacksonville, FL." Service Bulletins, CSX. 13 Sep 2017 https://www.csx.com/index.cfm/customers/news/service-bulletins1/csx-customer-advisory-irma-update-csx-restores-service-in-ga-sc-al-and-jacksonville-fl/.

[26] Hutchins, Reynold. 2017. "US Southeast ports to reopen but cargo delays to last days." *Journal of Commerce*. 12 Sep 2017. https://www.joc.com/trucking-logistics/us-southeast-ports-reopen-cargo-delays-last-days_20170912.html.

[27] Trailer Bridge. "Hurricane Maria Update #1." Trade Notifications. 18 Sep 2017 http://www.trailerbridge.com/news/hurricane-maria-update/.

[28] Bonney, Josh. 2017. "Jones Act carriers add more Puerto Rico capacity." *Journal of Commerce*. 02 Nov 2017. https://www.joc.com/trucking-logistics/us-southeast-ports-reopen-cargo-delays-last-days_20170912.html.

[29] Bureau of Transportation Statistics. 2018. *Port Performance Freight Statistics Program: Annual Report To Congress 2017.* Bureau of Transportation Statistics, US Department of Transportation. https://www.bts.gov/sites/bts.dot.gov/files/docs/browse-statistical-products-and-data/port-performance/216906/port-performance-2017-revised-1-30-18-2.pdf.

[30] KPMG. "Puerto Rico: Tax authority's guidance on tax deadlines, following hurricanes." KPMG Insights. 2 Oct 2017. https://home.kpmg.com/us/en/home/insights/2017/10/tnf-puerto-rico-tax-authority-guidance-on-tax-deadlines-following-hurricanes.html.

[31] Trailer Bridge. "Hurricane Maria Update #7." Trade Notifications. 23 Sep 2017 http://www.trailerbridge.com/news/hurricane-maria-update-7/.

[32] Crowley Maritime Corp. "Crowley Jones Act Vessels Loaded with Fuel for Hurricane Stricken Locales - Over 135 Million Gallons Ready for Discharge." Crowley- News and Media. 24 Sep 2017. http://www.crowley.com/News-and-Media/Press-Releases/Crowley-Jones-Act-Vessels-Loaded-with-Fuel-for-Hurricane-Stricken-Locales-Over-135-Million-Gallons-Ready-for-Discharge.

[33] Bloomberg News. 2017. "Mountains of aid for Puerto Rico languish on docks in San Juan after Hurricane Maria." *The Times Picayune (NOLA.com)*. 28 Sep 2017. https://www.nola.com/hurricane/index.ssf/2017/09/puerto_rico_storm_aid_ports.html.

[34] Tirschwell, Peter. 2017. "Is there a container shortage brewing?" *Journal of Commerce*. 10 Feb 2017. https://www.joc.com/maritime-news/container-lines/there-container-shortage-brewing-market_20170210.html.

[35] Hutchins, Reynold. 2017. "US exporters struggling to find inland containers." *Journal of Commerce*. 14 Jun 2017. https://www.joc.com/maritime-news/container-lines/there-container-shortage-brewing-market_20170210.html.

[36] López, Jorge A. Miró. 2018. *2.5 - Transport, storage, communications and tourism statistics.* Office of Tariff Issues and Economic Studies, Government of Puerto Rico. https://estadisticas.pr/en/inventario-de-estadisticas/carga_pasajeros_aereos_maritimos.

[37] Abbott, Paul Scott. 2017. "Jacksonville-to-San Juan carriers displaying billion-dollar confidence in Puerto Rico trade." *American Journal of Transportation* (643). https://www.ajot.com/premium/ajot-jacksonville-to-san-juan-carriers-displaying-billion-dollar-confidence.

[38] FDA. 2017. *SECURING THE FUTURE FOR PUERTO RICO: RESTORING THE ISLAND'S ROBUST MEDICAL PRODUCT MANUFACTURING SECTOR* Food and Drug Adminstration. https://www.fda.gov/downloads/newsevents/newsroom/fdainbrief/ucm584030.pdf.

[39] CBS News. 2018. "Hospitals struggle to battle peak flu season amid widespread IV bag shortage." *CBS News*. 9 Jan 2018. https://www.cbsnews.com/news/flu-season-straining-resources-iv-bag-shortage-hurricane-maria-puerto-rico/?xid=PS_smithsonian.

[40] Mazer-Amirshahi, Maryann, and Erin R. Fox. "Saline Shortages — Many Causes, No Simple Solution." Perspective - New England Journal of Medicine. 21 Mar 2018 https://www.nejm.org/doi/full/10.1056/NEJMp1800347.

[41] Langreth, Robert, and Cynthia Koons. 2017. "U.S. Hospitals Face a Shortage of This Most Basic Necessity." *Bloomberg Businessweek*. 14 Nov 2017. https://www.bloomberg.com/news/articles/2017-11-14/this-simple-lifesaving-liquid-is-suddenly-in-short-supply.

[42] Thomsen, Jacqueline. 2018. "Puerto Rico as many remain without power." *The Hill*. 27 Feb 2018http://thehill.com/policy/energy-environment/375827-power-companies-pull-workers-from-puerto-rico-as-many-remain.

[43] CDC, G. Garten, and et al. 2018. "Update: Influenza Activity in the United States During the 2017–18 Season and Composition of the 2018–19 Influenza Vaccine." *Morbidity and Mortality Weekly Report - Center for Disease Control and Prevention*. 8 Jun 2018. https://www.cdc.gov/mmwr/volumes/67/wr/mm6722a4.htm.

[44] FDA. "Statement by FDA Commissioner Scott Gottlieb, M.D. on Baxter manufacturing recovery in Puerto Rico." Press Announcements, US Food and Drug Administration. 13 Oct 2017 https://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/ucm580290.htm.

[45] FDA. "Statement by FDA Commissioner Scott Gottlieb, M.D., update on recovery efforts in Puerto Rico, and continued efforts to mitigate IV saline and amino acid drug shortages." Press Announcements, US Food and Drug Administration. 4 Jan 2018. https://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/ucm591391.htm.

[46] Seamen's Church Institute. "41st Annual Silver Bell Awards Dinner." Special Events - Seamen's Church Institute. 10 Jun 2018. https://seamenschurch.org/article/41st-annual-silver-bell-awards-dinner.

[47] Tomer, Adie, and Joseph Kane. 2014. *Mapping Freight: The Highly Concentrated Nature of Goods Trade in the United States.* Global Cities Initiative, Brookings Institute, JPMorgan Chase. Nov 2014. https://www.brookings.edu/wp-content/uploads/2016/06/Srvy_GCIFreightNetworks_Oct24.pdf.

[48] Pas, Eric I., and Shari L. Principio. 1997. "Braess' paradox: Some new insights." *Transportation Research Part B: Methodological* 31 (3): 265-276. https://www.sciencedirect.com/science/article/pii/S0191261596000240.

[49] Chico, Ricardo Cortes. 2017. "Crisis in supplies became evident." *El Nuevo Dia*. 9 Dec 2017. https://www.elnuevodia.com/english/english/nota/crisisinsuppliesbecameevident-2381010/.

[50] Miller, Greg. 2016. "Caribbean rates fall as container lines fail to curb overcapacity." *Journal of Commerce*. 26 Aug 2016https://www.joc.com/maritime-news/container-lines/freight-rates-fall-liner-efforts-curb-caribbean-capacity-fall-short_20160826.html.

[51] Benecki, Paul. 2018. "PULLING TOGETHER: THE U.S. TUG-AND-BARGE INDUSTRY IS AN OVERLOOKED JONES ACT ASSET WITH MULTIPLE BENEFITS." *The Maritime Executive*. 9 Feb 2018https://www.maritime-executive.com/magazine/pulling-together#gs.=0KUTYc.

[52] Thomas, Katie. 2017. "U.S. Hospitals Wrestle With Shortages of Drug Supplies Made in Puerto Rico." *The New York Times*. 23 Oct 2017. https://www.nytimes.com/2017/10/23/health/puerto-rico-hurricane-maria-drug-shortage.html.

[53] North Florida TPO. 2012. *North Florida Freight, Logistics and Intermodal Framework Plan.* North Florida Transportation Planning Organization. December 2012. http://northfloridatpo.com/images/uploads/docs/Freight_Logisitics_Intermodal_Framework_Plan.pdf.

[54] FEMA. 2018. *2017 Hurricane Season After-Action Report.* Federal Emergency Management Agency. Department of Homeland Security. July 2018.