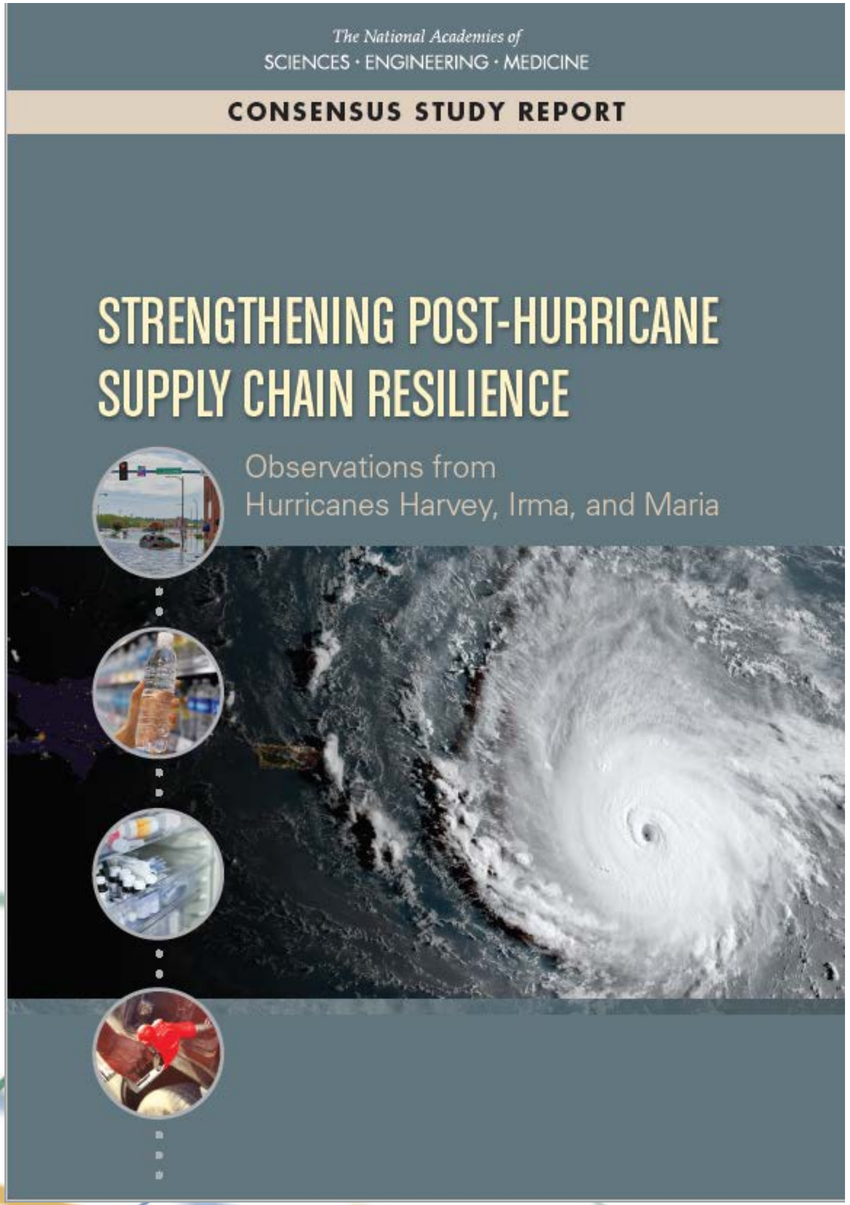
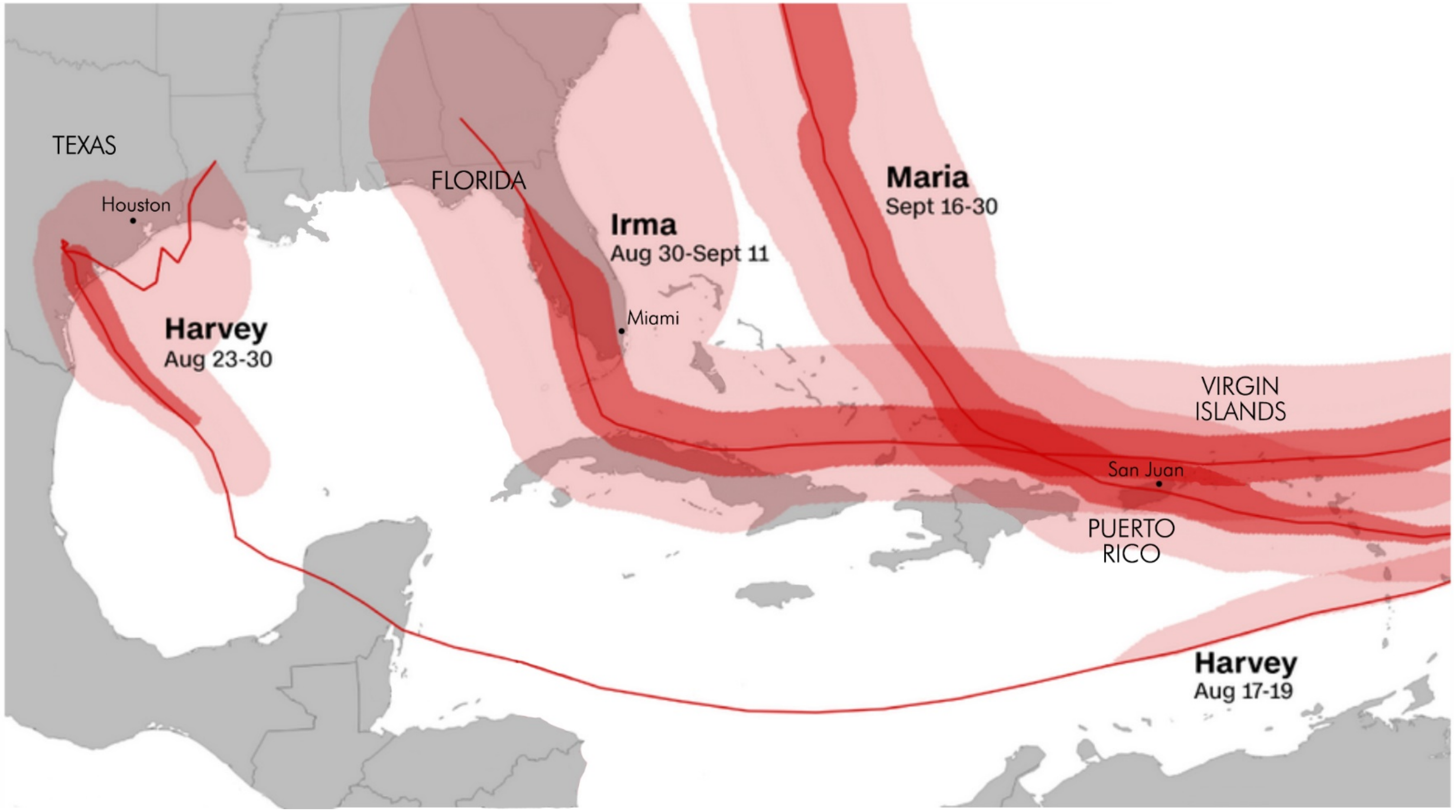
The National Academies of
SCIENCES · ENGINEERING · MEDICINE

Strengthening Post-Hurricane Supply Chain Resilience

Observations from Hurricanes Harvey, Irma, and Maria



Motivation: Why the current focus on supply chain resilience?



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 of current systems–thus providing some important lessons learned.

The Committee's Task

Study supply chain strengths and vulnerabilities

For key lessons learned and observations

In areas affected by 2017 Hurricanes

Provide options and recommendations for distribution of key commodities and restoration of utilities applicable to public and private sectors

A unique, three-pronged project

PHASE 1

Discovery

- Collect data
- Conduct interviews
- Develop case studies
- Preliminary insights and observations
- Public session meeting

CNA

PHASE 2

Report-Writing

- Produce consensus report: findings, conclusions, and recs for supply chain policy and strategy
- Public session meeting/workshop

NAS

PHASE 3

Advanced Analysis

- Produce report or tool
- Advanced analysis of supply chains affected by 2017 hurricanes
- Present options for strengthening national supply chain

MIT

The CNA Case Studies

1. **"Retail Resilience in Puerto Rico"** examines the surprising resilience of the retail sector supplying food and fuel after Hurricane Maria.
2. **"Static on the Relief Channel"** investigates how food deliveries from the federal government created both real and perceived impacts on the retail food sector in Puerto Rico and caused spillover effects into other supply chains.
3. **"Resupplying Metro Miami"** examines Florida during Hurricane Irma, specifically, how fuel availability affected the transportation of food and other goods before, during, and after the hurricane.
4. **"Harvey Turns On (and Then Turns Off) the Tap"** looks at how Hurricane Harvey affected water suppliers, and what hindered and helped their ability to recover.
5. **"Constraints in Optimized Networks"** looks at bottlenecks in supply chains in a variety of forms, using four examples from Florida and Puerto Rico.
6. **"External Factors—Debris and Donations"** examines of how post-storm debris management and unrequested donations can influence the resilience of lifeline supply chains by changing the response environment and imposing burdens on local resources needed for disaster response.

National Academies' Committee Membership

- **JAMES FEATHERSTONE** (*Chair*), Los Angeles Homeland Security Advisory Council
- **ÖZLEM ERGUN,** Northeastern University
- **KATHY FULTON,** American Logistics Aid Network
- **WALLACE HOPP,** University of Michigan
- **PINAR KESKINOCAK,** Georgia Institute of Technology
- **BRYAN KOON,** IEM
- **ALICE LIPPERT,** Energy Analyst / Independent Consultant
- **CRAIG PHILIP,** Vanderbilt University
- **KEVIN SMITH,** Sustainable Supply Chain Consulting
- **SAM MANNAN,** Texas A&M University *(passed, September 2018)*

Committee Meetings

Committee meetings were held in:

- **Washington DC**
- **San Juan, Puerto Rico**
- **Houston, Texas**
- **Miami, Florida**
- **St.Thomas, U.S. Virgin Islands**

Overall the committee gathered input from ~65 people (federal, state local government officials, private sector representatives, community leaders, researchers, others.

Basic Supply Chain Concepts

Supply chain management aims to match supply with demand in a responsive, accurate, cost-efficient manner. But this goal can be compromised by disruptive events such as hurricanes. Supply chain resilience aims to minimize impacts of such disruptions on an affected population.

Some key concepts:

- **Bottleneck:** the point in a supply chain that limits its flow *(determines the SC capacity)*
- **Lead time:** time from initiation of a request for a product to delivery *(determines SC responsiveness)*

Supply Chain disruptions can result from :

- **demand shifts** *(e.g., spike in demand for fuel)*
- **capacity reductions** *(e.g., a factory closed by storm damage)*
- **communication disruptions** *(e.g., loss of cell/internet service).*

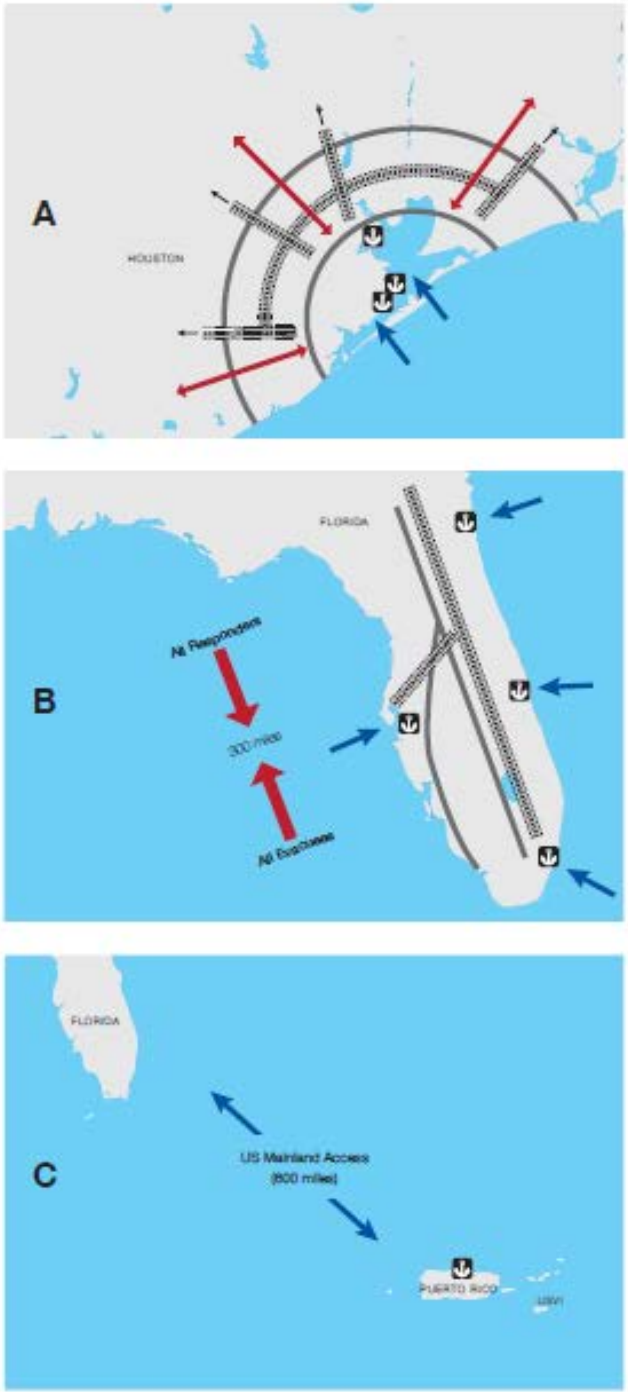
Supply Chain resilience depends on how bottlenecks and lead times are affected by such disruptions and what capabilities exist for swift restoration after a disruption.

Basic Supply Chain Concepts

Strategies for achieving supply chain resilience:

- **readiness** *(mitigation and preparedness actions to help a system avoid and withstand disruptions)*
- **response** *(emergency relief through the establishment of temporary replacement supply chains)*
- **recovery** *(the restoration of normal supply chain performance through repair of damaged infrastructure, nodes, links).*

Finding the right balance among these strategies, and foreseeing where bottlenecks are likely to emerge, requires understanding the **criticality** and **vulnerability** of supply chain links and nodes. *A node/link that is both critical and vulnerable is a major source of risk, and an opportunity to build resilience.*



Some key factors underlying supply chain disruption vulnerability

- defining geographical features
- configuration of the main supply chain links and corridors
- concentration of critical nodes and possible points of failure
- modal diversity available
- vulnerability of the critical infrastructure that supports supply chain continuity

Temporal and geographical interdependencies

- The rapid succession of hurricanes meant response resources were stretched very thin and had to shift rapidly among all the affected locations.
- Most goods are transported via: Florida→Puerto Rico→ St.Thomas →St.John and St.Croix. Disruptions to truck deliveries and marine carrier operations cascaded throughout this chain.

- Emergency managers faced complicated decisions about routing relief supplies among the affected locations. Supply chain recovery in one place was dependent upon recovery in another place.
- Illustrates the importance of understanding the operation of interdependent supply chains and geographical regions in emergency management planning and training.

Some notable impacts from the 2017 hurricanes

Houston area / Hurricane Harvey

- Record-shattering floods impeded almost every aspect of supply chain operations and emergency response.
- Flooded facilities included fuel and chemical plants with important (local, regional, national) supply chain implications.
- Despite the unprecedented challenges, many devastating problems were averted, due in part to rigorous systems for disaster preparedness and response, including strong links with key industrial sectors and organizations.

Some notable impacts from the 2017 hurricanes

Chapter 3

South Florida / Hurricane Irma

- Illustrated the benefits of robust disaster preparedness/response systems, with good relationships among EM officials and industry; and the benefits of investments in hardening/upgrading power systems.
- Yet some vulnerabilities were exposed. e.g., meeting fuel demand during a massive evacuation; maintaining sufficient inflow of supplies in the face of delivery bottlenecks; ensuring adequate coordination in moving trucks and supplies across state lines.

Some notable impacts from the 2017 hurricanes

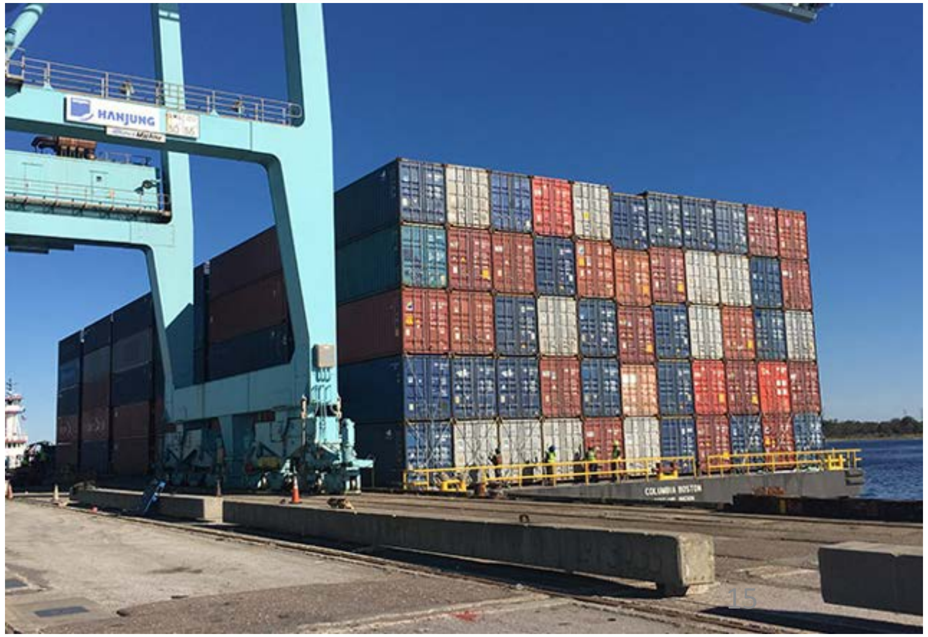
U.S. Virgin Islands / Hurricanes Irma & Maria

- Unique challenges of small islands: heavy dependence on ship imports for critical goods, difficulties disposing storm debris, lack of housing for relief workers, limited port space for processing relief shipments.
- Challenges prioritizing relief supplies (e.g., lack of re-building supplies, cement).
- Yet many commercial and relief supply chains operated relatively well, and signs of resilience among the population (e.g., local businesses re-opened quickly; most homes and facilities had working generators and fuel, and cisterns to collect water).

Some notable impacts from the 2017 hurricanes

Puerto Rico / Hurricanes Irma and Maria

- Limited coordination of emergency preparedness systems among federal and local agencies and the business community.
- Fragile, aging power and communications infrastructure were severely damaged, causing many cascading impacts.
- Port of San Juan was overwhelmed as relief shipments poured in while bottlenecks limited distribution of those goods.
- Some manufacturing plants critical to national supply chains were not prioritized for assistance.
- Yet many businesses across the island were resilient and ready to resume operations quickly (if not constrained by the power outages).



Some commonalities / lessons learned

- Post-hurricane bottlenecks and disruptions arise mostly at the distribution level– often because infrastructure damage impedes processing, delivery, selling of goods.
- Large companies have far more capacity than small businesses to invest in continuity planning, partnerships with government officials, employee assistance programs, hardening of critical systems.
- Investments to reduce vulnerability of critical infrastructure can minimize storm disruptions and speed the recovery of local economies.
- Emergency managers often lack a solid basis to prioritize allocation of relief supplies and to know when to stop the "push"—due to limited knowledge about vulnerable/critical supply chain nodes, information disruptions.
- Confusion often arises around rules for providing generators and fuel to parties needing assistance—especially private sector entities that are critical supply chain nodes.

Recommendation 1: Shift the focus from pushing relief supplies to ensuring that regular supply chains are restored as rapidly as possible through strategic interventions.

"Relief supply chains" can be life-saving following a disaster. But pouring relief supplies into an area for too long can have unintended effects that delay recovery, because:

- relief supply chains often contract the same resources that local businesses need to resume normal supply chains (e.g., drivers, trucks, ships, barges, port storage space)
- this approach doesn't address last-mile distribution problems (constraints from blocked roads, lack of fuel supplies, power outages, workers shortages).

Is hard to change this dynamic because:

- elected officials often continue to request relief supplies from FEMA even when there is no clear indication that such supplies are needed or can be distributed.
- most places lack systems / processes to gauge the conditions and capabilities of local supply chains, and thus cannot 'see' when to scale back emergency response.

Recommendation 1. Shift the focus from pushing relief supplies to helping ensure regular supply chains are restored as rapidly as possible through strategic interventions.

Augment the focus on delivering relief supplies with a focus on finding causes of unmet demand (i.e., supply chain bottlenecks, gaps, broken links)—and pursuing strategic interventions to help regular supply chains recover rapidly.

Some key strategies:

- Improve pre-disaster planning and communications, to foster insight about the resilience, capacities, and limitations of key stakeholders.
- Expand the scope of FEMA’s roles (a more active role aiding infrastructure repair? more latitude to prioritize support for critical private sector facilities?)
- To counter political pressures, change how FEMA is evaluated—not just the *amount* of relief supplies delivered, but also the speed/strength of recovery.

Recommendation 2. Build system-level understanding of supply chain dynamics as a foundation for effective decision support.

Wise prioritization of resources requires *system-scale understanding* of critical supply chains and their dependencies, including possible cascading impacts. Building this understanding requires a wide array of information, such as:

before the event ("blue skies"):

- the supply and demand forces driving flow of critical goods through a given area, and how disruptions can affect these flows
- the criticality and vulnerability of key supply chain nodes, links, infrastructure

during and after the event ("grey skies"):

- real-time impacts information (e.g., blocked roads, closed stores/factories)
- current capacity of local stakeholders to respond to these impacts.

Recommendation 2. **Build system-level understanding of supply chain dynamics as a foundation for effective decision support.**

Modeling and analytical frameworks are needed to integrate these complex data streams and extract practical decision-support information.

The benefits of investing in such systems:

- better understanding of supply chain vulnerabilities (for preparedness) and better visibility into demand/supply gaps (for response, recovery)
- emergency managers can more effectively prioritize the distribution of critical relief supplies and anticipate cascading effects of those decisions.
- enhanced capacity to focus on strategic restoration of broken supply chain links and infrastructure, thus helping normal activity rebound quickly.

Recommendation 3. **Support mechanisms for coordination, information sharing, and preparedness among supply chain stakeholders.**

Chapter 4

Examples of preparedness actions that build supply chain resilience:

- develop and regularly update emergency preparedness and continuity-of-operations plans; conduct training and worst-case-scenario drills
- test emergency communication protocols; identify workarounds for communications system failures
- develop plans to protect organizational personnel during hazardous events.

A critical need: clearly-defined processes for coordination and information sharing across levels of government, and across public and private sector silos.

Establishing relationships/trust takes time. Must begin before disasters occur.

Recommendation 3. Support mechanisms for coordination, information sharing, and preparedness among supply chain stakeholders.

There are existing mechanisms for emergency response officials to interact with industries that are critical to lifeline supply chains, e.g.:

- DHS Critical Infrastructure Threat Information Sharing Framework
- DHS Homeland Security Information Network
- Information Sharing and Analysis Centers
- Sectoral and Regional Consortium Coordinating Councils
- FEMA's National Business Emergency Operations Center

Each of these platforms provide valuable opportunities, but we must advance this collective "engagement ecosystem" in a way that minimizes the time burdens placed on individual participants.

Recommendation 3. Support mechanisms for coordination, information sharing, and preparedness among supply chain stakeholders.

Some examples of strategies:

- Strengthen industry/govt. coordination in identifying, pre-positioning, distributing resources.
- Put supply contracts in place ahead of time, in particular for fuel and generators.
- Develop plans to address the needs of workforce personnel and their families during disasters
- Strengthen mutual aid agreements within lifeline sectors (utilities, water, health, etc).
- Put private-sector liaisons in state/regional EM offices, to engage with businesses year-round.
- Encourage private sector entities to subscribe to HSIN for information, situational awareness
- Create partnerships with local NGOs that have established relationships serving vulnerable households/individuals.
- Plan relief aid points-of-distribution and arrangements for local organizations to staff them.
- Collect data on an area's disease/risk profiles, to aid planning about drugs to stockpile.
- Utilize internet and social media platforms for rapid dissemination of critical information.

Recommendation 4: Develop and administer training on supply chain dynamics and best practices for private-public partnerships

Those engaged in emergency response often have little or no private sector experience, or training to evaluate supply chain impacts of disasters and responses.

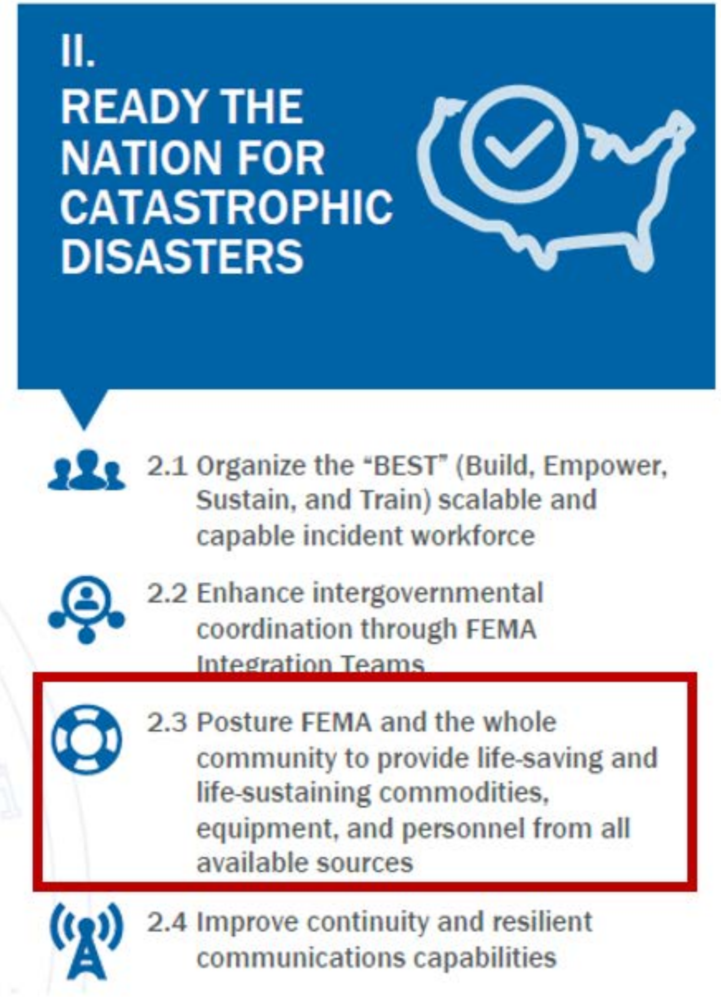
Emergency managers, and those in supporting roles, need training in topics such as:

- an overview of supply chains for key commodities and their interdependencies, and of the ways that disasters can impact local/regional economic dynamics
- understanding how critical infrastructure supports these supply chains
- how laws and regulations governing disaster operations can impact supply chains (e.g., when waivers can be beneficial)

Platforms for such training could include: courses in college emergency management programs; orientation training for new emergency managers and EOC staff; FEMA's in-person and online training classes.

Some Recent / Current Encouraging Developments

- FEMA 2018–2022 Strategic Plan
- Supply Chain Resilience Guide
- National Response Framework update, ESF14
- Disaster Recovery Reform Act / National Public Infrastructure Pre-Disaster Hazard Mitigation fund
- Emergency Management Performance Grants
- National Business Emergency Operations Center
- Supply Chain Analysis Network



FEMA

Critical Leadership Roles for FEMA

FEMA has unique capacity to provide leadership of these issues, assisting state and local emergency management across the country —especially for supply chain issues that cross state borders and that have national implications.

For instance, FEMA can provide technical assistance (e.g., for collecting data and mapping critical assets, linkages, and interdependencies), and can strengthen coordination with private sector and NGO stakeholders

While FEMA itself cannot be responsible for all these activities, it can provide leadership in *convening, coordinating, empowering* others—both through grant programs and hands-on capacity building guidance.

The Broader Policy Context

FEMA's ability to pursue some of these recommendations will be shaped and constrained by the Stafford Act and other existing legislative statues. "*Lawmakers may wish to consider whether such constraints need to be addressed*".

MIT research supporting the study

- Private sector organizations achieve supply chain visibility with enterprise resource systems. Achieving the same visibility across a sector of competing and decentralized private sector organizations will require a **shift in how the emergency management community approaches cooperation and data aggregation**.
- Models that leverage optimization and machine learning methods can provide emergency managers with **improved intuition** about supply chain systems and better tools for decision making. Improved intuition is the foundation for faster and better understanding of private sector supply chain disruptions and remedies during an urgent crisis.
- Models are also the foundation for development of **analysis and decision support tools** that complement current emergency management information sources and analytical capabilities.
- This report proposed a framework to connect pre-existing data feeds and collect information directly through creation of voluntary trusted spaces and mandatory reporting requirements.
- This report defined explanatory, predictive, and prescriptive models based on a generalized network framework that integrates interdependencies among multi-party supply chains and the essential resources of product, people, power, and communications.

Disaster Supply Chains: Moving from Situational Awareness to Actionable Analysis

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Center for Transportation and Logistics,
Massachusetts Institute of Technology

May 31, 2019

Table 1: Sentinel indicators for the fuel supply chain. Source: MIT analysis.

Data point	Collection		Aggregation		Current Emergency Management Uses		
	Yes/No	Party	Yes/No	Party	Situational Awareness	Forecasting	Actionable Interventions
Refinery count	Yes	Owner	Yes	EIA, CISA	Yes	No	Yes
Refinery status	Yes	Owner	Yes	EIA, CISA	Yes	No	Yes
Pipeline status	Yes	Owner	Yes	EIA, CISA	Yes	No	Yes
Pipeline inventory	Yes	Owner	Yes	EIA, CISA	Yes	No	Yes
Pipeline throughput	Yes	Owner	No	-	Yes	No	Yes
Terminal status - power	Unknown	-	No	-	Yes	No	Yes
Terminal status - personnel	No	-	No	-	No	No	No
Terminal status - inventory	Yes	Owner	Yes	EIA	Yes	No	Yes
Terminal racks - throughput	Yes	Owner	No	-	Yes	No	Yes
Terminal racks - count	Yes	Owner	No	-	No	No	No
Terminal racks - wait times	No	-	No	-	Yes	No	No
Fuel tanker fleet - operating %	Yes	Owner	No	-	Yes	No	Yes
Fuel tanker fleet - route choices	Yes	Owner	No	-	Yes	No	No
Retailer status - power	Yes	Owner	Yes	GasBuddy	Yes	No	Yes
Retailer status - personnel	Unknown	-	No	-	No	No	No
Retailer inventory - diesel	Yes	Owner	Yes	GasBuddy	Yes	No	No
Retailer inventory - regular	Yes	Owner	Yes	GasBuddy	Yes	No	No
Retailer sales - diesel	Yes	Owner	No	-	Yes	No	No
Retailer sales - regular	Yes	Owner	No	-	Yes	No	No
Retailer generator - connection	Yes	Owner	Partial	Unknown	Yes	No	Yes
Retailer generator - on site	Yes	Owner	No	-	Yes	No	Yes
Road, highway, bridge status	Partial	DOT	Partial	DOT	Yes	No	Yes

Table 4: PADD3 refinery utilization. Source: EIA.

PADD3 district	5-year average utilization (2012-2017)	September 2017 utilization
Texas Gulf Coast	90%	58%
Louisiana Gulf Coast	93%	99%
Texas Inland	94%	95%
Northern Louisiana/Arkansas	80%	86%
New Mexico	96%	112%

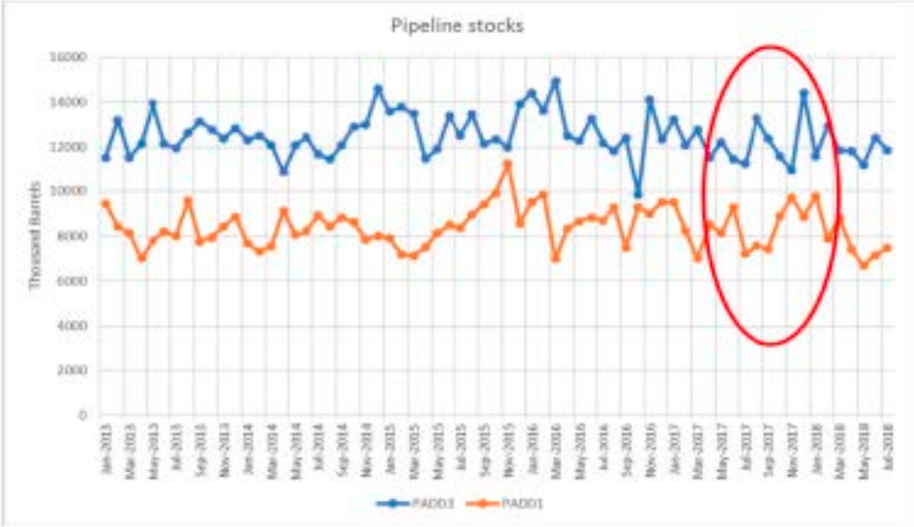


Figure 10: Aggregate pipeline stocks in PADD1 and PADD3. Source: EIA.

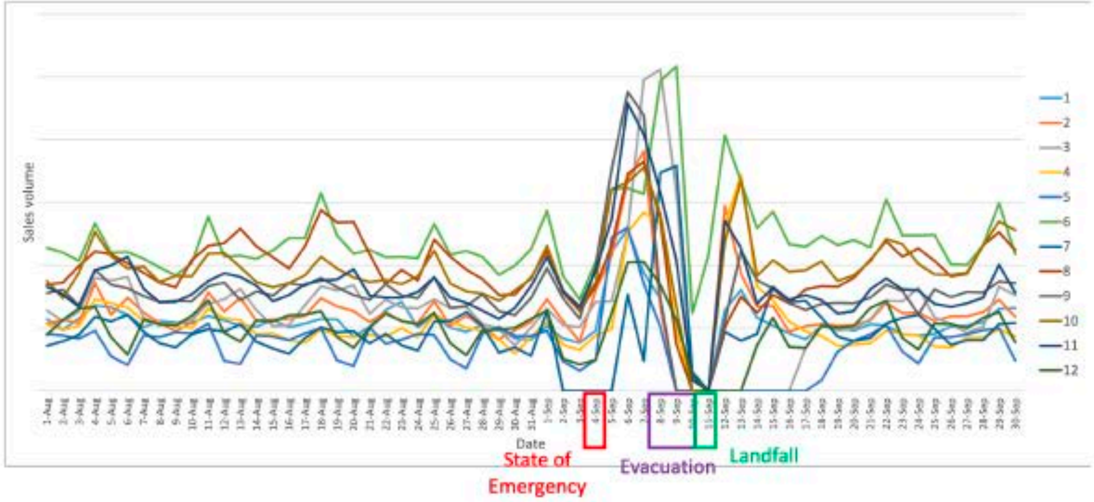


Figure 13: Regular fuel sales volume for 12 retailer locations in Florida during August and September 2017. Source: Retailer(s), MIT analysis.

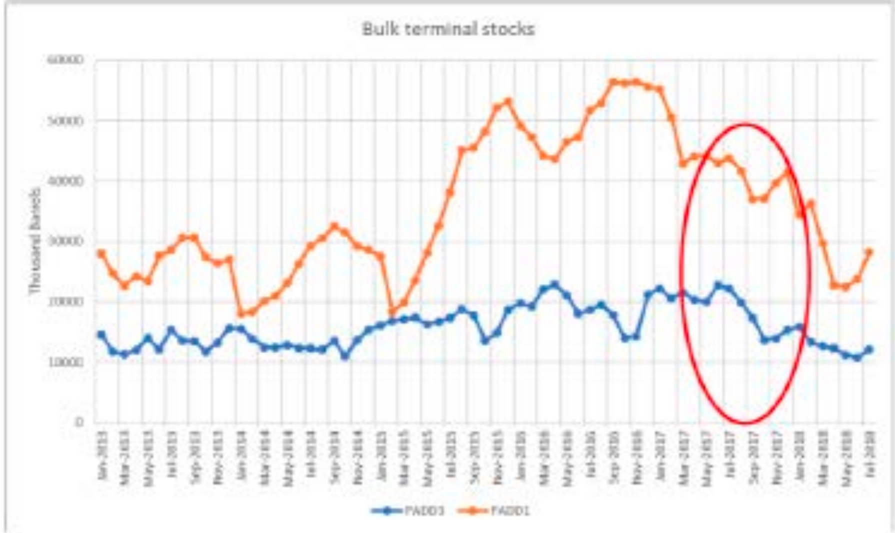


Figure 11: Aggregate bulk terminal stocks in PADD1 and PADD3. Source: EIA.

Source: The Florida Department of Transportation. (2018 January). *Hurricane Irma's Effect on Florida's Fuel Distribution System and Recommended Improvements*. Retrieve
from http://www.fdot.gov/info/CO/news/newsreleases/020118_FDOT-Fuel-Report.pc

Port Canaveral
@PortCanaveral

Follow

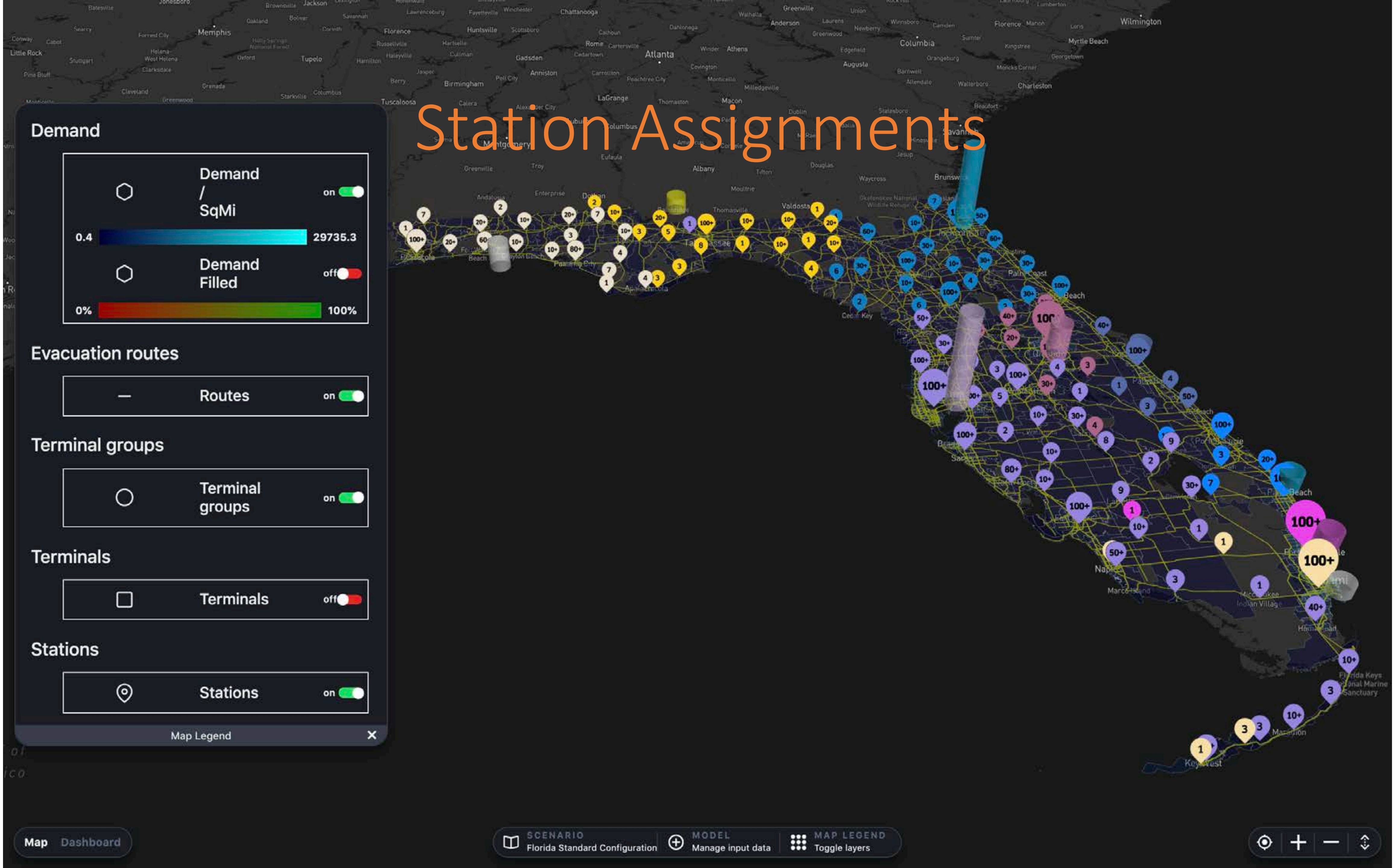
Over 750 tankers loaded and rolling with fuel across Florida from Seaport Canaveral in last 48 hours.

4:15 PM - 14 Sep 2017

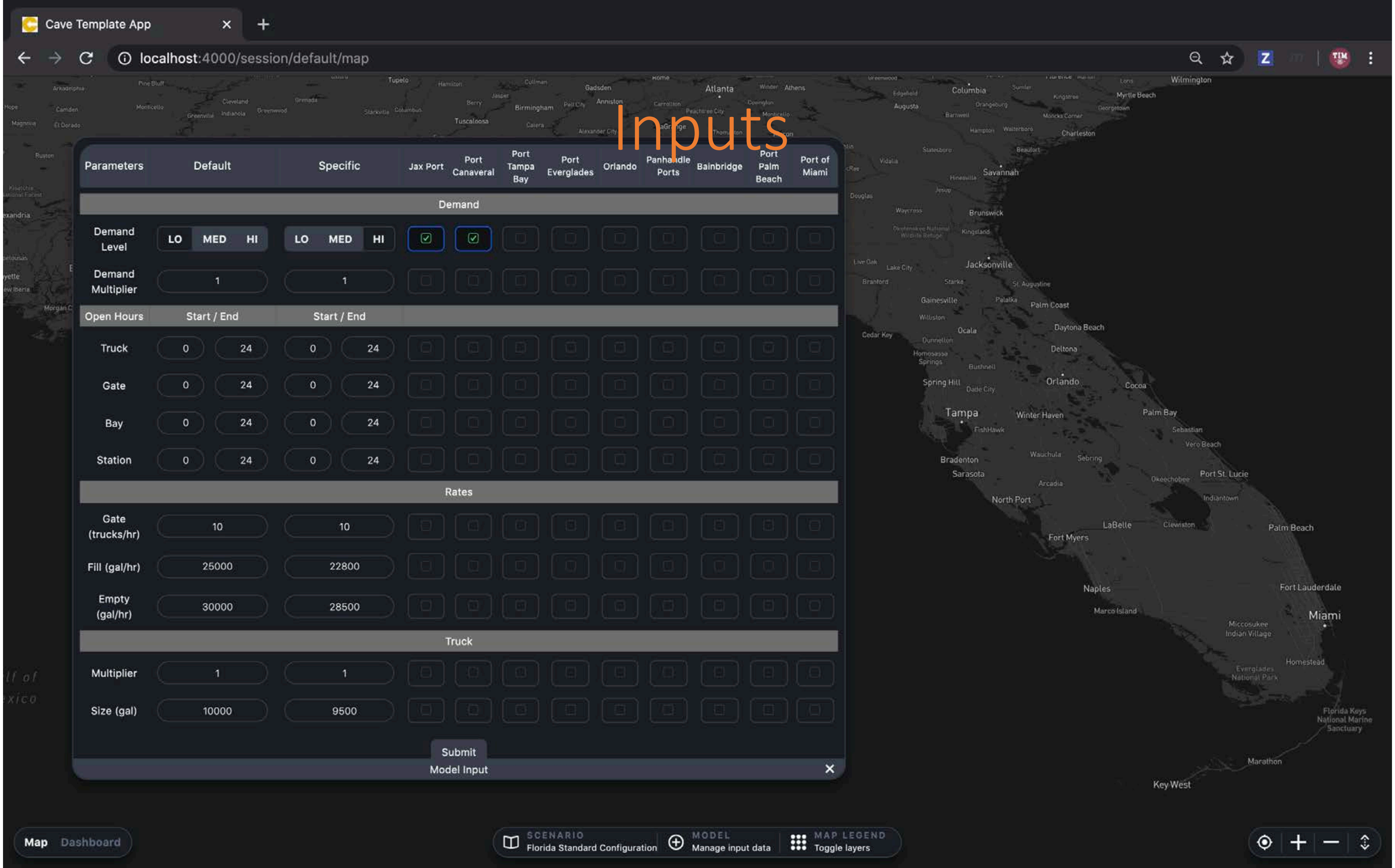
March 2020

Florida Fuel Distribution Model

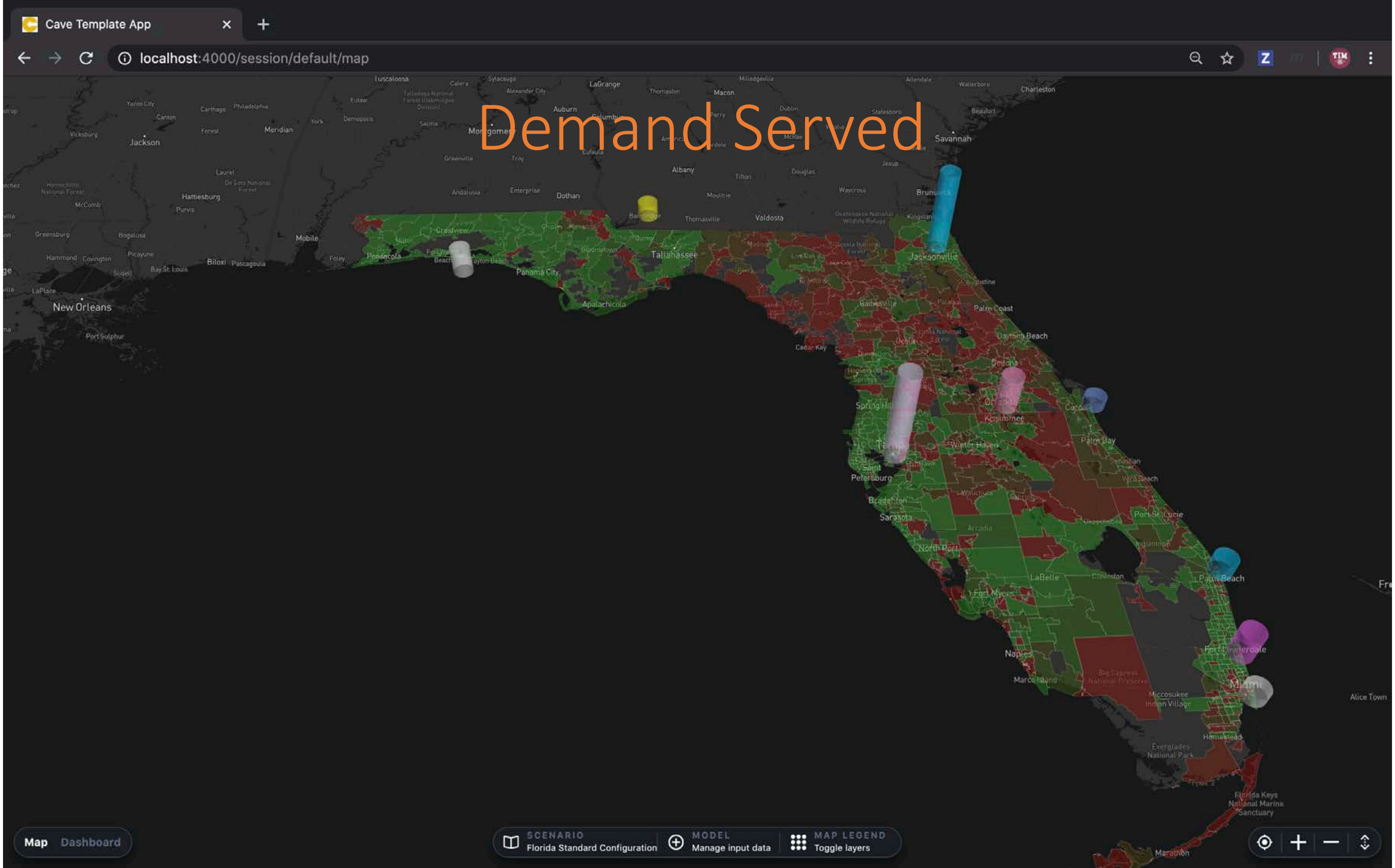
Station Assignments



Inputs


Cave Template App
localhost:4000/session/default/map
Parameters
Default
Specific
Jax Port
Port Canaveral
Port Tampa Bay
Port Everglades
Orlando
Panhandle Ports
Bainbridge
Port Palm Beach
Port of Miami
Demand
Demand Level
LO MED HI
LO MED HI
Demand Multiplier
1
1
Open Hours
Start / End
Start / End
Truck 0 24 0 24
Gate 0 24 0 24
Bay 0 24 0 24
Station 0 24 0 24
Rates
Gate (trucks/hr) 10 10
Fill (gal/hr) 25000 22800
Empty (gal/hr) 30000 28500
Truck
Multiplier 1 1
Size (gal) 10000 9500
Submit
Model Input
Map
Dashboard
SCENARIO
Florida Standard Configuration
MODEL
Manage input data
MAP LEGEND
Toggle layers

Demand Served



Dashboard

Demand per Area
Demand Filled
System Results
0.4
29735.3
Demand / SqMi
0%
100%
Demand Filled
Results
Available Trucks 837
Used Trucks 837
Avg. Fuel Delivered 45502
Total Fuel Delivered 18021879
LEGEND
Closed
Driving
Station
Terminal
Terminal - Waiting for Gate to Open
Terminal - In Gate Queue
Terminal - At Gate
Terminal - Waiting for Bay to Open
Terminal - In Bay Queue
Terminal - Filling Truck
LEGEND
Met
Unmet
System
Demand
0M
5M
10M
15M
20M
25M
Demand
Demand
LEGEND
Met
Unmet
0M
2M
4M
6M
Jax Port
Port Canaveral
Port Tampa Bay
Port Everglades
Orlando
Panhandle Ports
Bainbridge
Port Palm Beach
Port of Miami
Truck Use
Jax Port
Avail. Trucks 120
Used Trucks 120
Avg. Fuel Dlv. 54229
Tot. Fuel Dlv. 2717603
Port Canaveral
Avail. Trucks 30
Used Trucks 30
Avg. Fuel Dlv. 68717
Tot. Fuel Dlv. 741968
Port Tampa Bay
Avail. Trucks 252
Used Trucks 252
Avg. Fuel Dlv. 47123
Tot. Fuel Dlv. 5707386
Port Everglades
Avail. Trucks 90
Used Trucks 90
Avg. Fuel Dlv. 55839
Tot. Fuel Dlv. 2560141
Orlando
Avail. Trucks 110
Used Trucks 110
Avg. Fuel Dlv. 19173
Tot. Fuel Dlv. 1453577
Panhandle Ports
Avail. Trucks 42
Used Trucks 42
Avg. Fuel Dlv. 109024
Tot. Fuel Dlv. 1255017
Bainbridge
Avail. Trucks 22
Used Trucks 22
Avg. Fuel Dlv. 79023
Tot. Fuel Dlv. 544271
Port Palm Beach
Avail. Trucks 69
Used Trucks 69
Avg. Fuel Dlv. 30014
Tot. Fuel Dlv. 1359692
Port of Miami
Avail. Trucks 102
Used Trucks 102
Avg. Fuel Dlv. 20770
Tot. Fuel Dlv. 1682224
Dashboard