INSTITUTE FOR HOMELAND SECURITY

SUPPLY CHAIN MAPPING FOR

EMERGENCY MANAGEMENT DECISION MAKING

Institute for Homeland Security

Sam Houston State University

Mark Scott

Technical Paper: Supply Chain Mapping for Emergency Management Decision-Making

Mark Scott, Critical Infrastructure Consultant

Abstract: Supply chain issues are a growing concern for public sector emergency managers because communities rely on these privately-owned and operated systems to deliver goods needed for daily life and survival. Recent events have highlighted the many ways supply chains can be disrupted. Knowing how these systems are configured and how they operate is essential to making more effective operational decisions during emergencies and to support supply chain owners/operators restore flow following a disruption. Mapping the supply chain is a proven private sector practice for gaining visibility into these systems that may have application in the public sector. This paper describes why mapping helps improve emergency preparedness, how mapping has been done, and two case studies of its application for lifeline commodity supply chains in the National Capital Region. The paper concludes with a path forward for emergency managers seeking to use mapping to strengthen supply chain resilience in their communities, regardless of scale.

Keywords: supply chain; mapping; emergency managers; resilience

Author Biography:

Mark Scott's career spans over 40 years in risk management in the public, private, and nonprofit sectors. His experience includes professional engagement in critical infrastructure security and resilience, environmental and health & safety regulation, and hazardous materials risk management.

Most recently Mark managed critical infrastructure programs and initiatives for the District of Columbia's Homeland Security and Emergency Management Agency. In that role he designed and managed projects to assess the resilience of the food, water, fuel and healthcare supply chains serving the National Capital Region. Mark has also advised FEMA on supply chain resilience issues and training programs for local emergency managers, and has presented on supply chain resilience at multiple national forums.

Mark has lived and worked in the Washington D.C. area since 2008, having previously resided in Charleston, West Virginia and Pittsburgh, Pennsylvania. He holds a master's degree in urban and regional planning from the University of Pittsburgh. Mark also has served as member and past Vice-Chair of the Department of Homeland Security's State, Local, Tribal, and Territorial Government Coordinating Council.

Disclosure: The author reports there are no competing interests to declare.

Introduction

Supply chains are critical to community security and resilience.

Supply chains are systems or networks that encompass the entire process of making and delivering commercial goods. They include every stage from the supply of materials and the manufacture and packaging of the goods through to their distribution and sale. Supply chains are comprised of geographically dispersed and distinct private sector entities. No one business owns a supply chain, although dominant players are usually present.[1]

Supply chains include systems that provide lifeline commodities -- such as food, water, fuel, and healthcare supplies -- that communities need for everyday life and survival. While private sector entities own and operate supply chains, the public depends on their continued operation and their ability to recover quickly if disrupted.

Supply chain disruptions are increasing

Supply chains need to be flexible enough to absorb any shocks that may disrupt system operations. Yet events in recent years have shown that supply chains can and do get disrupted, sometimes violently, and these disruptions will likely increase due to climate change impacts, geopolitical conflicts, cyberattacks, future public health emergencies, and the likelihood of compounding and cascading events.

McKinsey[2] has classified supply chain shocks into four different types, based on their impact, lead time, and frequency of occurrence. For public sector officials and emergency managers, these shocks can be seen as the following events:

- *Unanticipated catastrophes.* These are historically remarkable events that can't be anticipated and lead to trillions of dollars in losses. Examples include extreme terrorism, large scale pandemics, and a systemic cyberattack.
- *Foreseeable catastrophes.* Similar magnitude to an unanticipated catastrophe but differs in that larger patterns and probabilities can guide general preparedness. Examples include large scale natural hazards and geopolitical conflicts.
- *Unanticipated disruptions.* These are serious and costly events but are on a smaller scale than catastrophes. Examples include localized natural disasters, civil unrest, and industrial accidents.
- *Foreseeable disruptions.* Some disruptions can be spotted in advance of their arrival. Examples include transportation labor disputes and global shortages of essential commodities.

There is a growing awareness of the need for supply chain visibility

Before a community can identify risks to these critical systems, it needs to understand what the supply chain looks like and how it works. Since the Covid-19 pandemic, there has been increasing

[1] MacCarthy, Bat L., Wafaa A.H. Ahmed, and Guven Demirel. "Mapping the supply chain: Why, what, and how?", *International Journal of Production Economics*, Volume 250, August 2022, 108688. https://doi.org/10.1016/j.ijpe.2022.108688

[2] McKinsey. "What is supply chain?" https://www.mckinsey.com/featured-insights/mckinsey-explainers/what-is-supply-chain?cid=other-eml-onp-mip-mck&hlkid=7e01943f8c914cbd829fcac2d4f31d28&hctky=12203888&hdpid=8f9d71d3-7318-471b-93b2-7e073406d67a

attention by policy makers, regulators, industry bodies and governments to how contemporary supply chains are configured, operated, and controlled. Along with this has come heightened interest in active surveillance of supply chains as they operate in real time. These interests require accurate information-based maps to facilitate risk analysis, monitoring, surveillance, and early detection of supply problems. Supply chain mapping is the key to gaining this visibility into the system.

Who the paper is directed to, and why it matters

This paper is written from a public sector perspective for officials and emergency managers working at the state, regional tribal, and local levels. These leaders share a common mission of protecting public health and safety, and one key to mission success is ensuring availability of commodities essential for daily life and survival. Recognizing and mitigating vulnerabilities that can lead to supply disruption is essential for community protection and resilience.

The paper identifies opportunities for building stronger public-private partnerships and adapting business mapping practices where appropriate. Private sector owners/operators can also benefit by gaining awareness of how emergency managers may pursue mapping to support the shared mission of supply chain resilience.

What this paper will discuss:

- How mapping provides visibility into the supply chain
- How mapping can be used to strengthen community preparedness
- Challenges and limitations to mapping
- Examples of how mapping has been used
- Lessons learned from the private sector that may have value for public sector managers
- A recommended way forward for the emergency management community

Mapping Provides Visibility into Supply Chains

Supply chain mapping is part of the larger process of supply chain risk management. The purpose of mapping is to gain a comprehensive view of the entire supply chain, including all the key supply and demand components and their linkages. This visibility provides insights into where the supply chain is most vulnerable, and that helps target investments and other actions that will have the biggest impact in improving resilience.

From a network science perspective, supply chains are primarily made up of **supply nodes** (where commodities originate), **demand nodes** (where consumers go to get those commodities) and **supply-demand links** (how commodities get from supply nodes to demand nodes). For emergency managers, getting visibility into supply chain operations can be most effectively done by examining these components within the three major dimensions of the system: upstream, midstream, and downstream.

When creating a supply chain map, several elements are typically considered:

1. Suppliers: sources of raw materials, components, or services that are essential for the production process.
2. Processors: facilities or entities responsible for transforming raw materials into finished goods.
3. Distribution Centers/Warehouses: locations where inventory is stored, managed, and distributed within the supply chain.

4. Transportation: routes and modes used to move goods between different locations, including shipping, road transportation, airfreight, etc.
5. Retailers/Distributors: entities responsible for distributing and selling the finished products to the end consumers.
6. Consumers: the end consumers and their demand patterns, which helps in aligning the supply chain to meet customer requirements effectively.

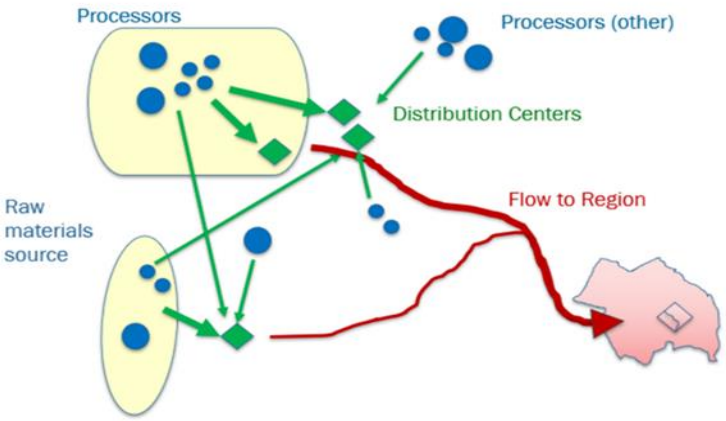


Figure 1: Generic depiction of supply chain mapping

Mapping is particularly useful in documenting the factors that help determine the overall resilience of the system:

- *Geographic distance between supply and demand* – In terms of supply chain performance, shorter paths ensure lower cost and product delivery time and facilitate the delivery of commodities from supply to demand nodes along the network.[3] For system resilience, shorter distances between supply and demand nodes reduces exposure to hazards that can disrupt the flow of goods.

- *Relative diversity of supply nodes, demand nodes, and routing options* – System resilience is also influenced by the relative diversity of suppliers, shipping options, and locations for consumers to receive goods. Increasing the diversity of supply locally has been shown to increase a community's resistance to supply chain shocks.[4]

[3] For an in-depth examination of resilience factors, see Sahlmueller, Till and Bernd Hellingrath. *Measuring the Resilience of Supply Chain Networks.* Proceedings of the 19th ISCRAM Conference – Tarbes, France May 2022. http://idl.iscram.org/files/tillsahlmueller/2022/2399_TillSahlmueller+BerndHellingrath2022.pdf

[4] Supply chain diversity provides adaptive options for a city to exploit when some of its supply chains suffer shock, thus boosting resilience to shock. For example, research has demonstrated that cities with a greater diversity of food suppliers have a lower probability of suffering a food supply shock for any reason. Boosting a city's food supply chain diversity increases the resistance of a city to food shocks of mild to moderate severity by up to 15 percent. (Michael Gomez, Alfonso Mejia, Benjamin L. Ruddell & Richard R. Rushforth (October 2020). *Supply chain diversity buffers cities against food shocks*. https://doi.org/10.1038/s41586-021-03621-0)

- *Concentration of production, processing, and distribution capabilities* -- It is common for a large percentage of key goods and services serving a densely populated area to depend on small number of distribution centers. These concentrations are fundamental to efficiency, cost-savings, and timely fulfillment of demand. But they can also become chokepoints that seriously complicate and impede flows during extended disruption or destruction of the system.[5]

Since no map can include everything, supply chain mapping requires making choices, and the map's content will depend on what is being analyzed and what data is available. Given the constantly evolving nature of supply chains and the extensive reach of upstream suppliers, it is most practical for emergency managers to acknowledge upstream suppliers but to focus their attention on the midstream and downstream components of the system.

It is also not reasonable or necessary to identify all nodes within a supply chain; the sheer size of many supply chains and the limited visibility into deeper sub-tier supply network structures present significant challenges in capturing the essential data for mapping. Emergency managers should instead focus on identifying first-tier suppliers that serve a large proportion of demand, including points of concentration of supply.[6]

Here are steps that public sector managers can take to conduct supply chain mapping[7]:

- *Identify the primary crucial suppliers for the local community*. This information may be obtained through online searches, local community knowledge, and local and regional economic reports. Strategic plans, emergency operations plans, and other guidance documents may also help identify previously identified supply locations.

- *Identify supply chain nodes within the scope of the review*. Supply chains serving urban areas extend into adjacent jurisdictions and regions, and are increasing global. Defining a manageable geographic boundary simplifies the mapping process and keeps the focus on those areas most likely to be influenced by emergency management actions. Boundaries to consider may include a state, a region, and/or focusing mainly on "last mile" delivery.

- *Identify the ultimate destinations of goods*. Each lifeline commodity will have its own distinct locations where end users acquire what they need. Knowing locations of destination sites and their characteristics improves understanding of demand patterns and helps set response priorities during a disaster.

- *Identify the infrastructure systems that provide critical support to supply chain operations*. Emergency managers should identify the infrastructure dependencies of key nodes, along with their physical locations. Electric power, petroleum fuel, natural gas, water and

[5] Palin, Philip J. Seven Steps to Counter Catastrophe. *Supply Chain Quarterly*, February 22, 2020. https://www.supplychainquarterly.com/articles/3152-seven-steps-to-counter-catastrophe

[6] FEMA suggests that because the goal of mapping is to develop a strategic understanding of the local/regional demand and supply network in order to identify key supply chain players with whom to engage, a detailed and comprehensive understanding of the global supply chain is not necessary. See Federal Emergency Management Agency (FEMA). *Supply Chain Resilience Guide*. April 2019. https://www.fema.gov/sites/default/files/2020-07/supply-chain-resilience-guide.pdf

[7] These steps are more fully explained in the FEMA *Supply Chain Resilience Guide* cited above.

wastewater, and communications are among the most critical infrastructure services needed to maintain and sustain supply chain operations.

- *Overlay key threats and hazards, and other stressors and disruptors, against the identified primary system nodes and links.* Hazard Mitigation Plans can help identify threats and hazards that may interrupt the flow of lifeline commodities. Flood inundation maps and evacuation routes overlaid on a supply chain map will highlight system components in high hazard areas or otherwise prone to disruption.

- *Create supply chain maps in a geographic information system (GIS) or with specialized supply chain risk management software.* This allows spatial depiction of important upstream, midstream, and downstream components and the overall flow of lifeline commodities, providing both situational awareness and a platform for evaluating alternate disruption scenarios.

Mapping Enhances Community Preparedness

Emergency management organizations that focus on understanding their lifeline commodity supply chains are better positioned to sense oncoming disruptions, visualize and analyze the impacts, run simulations that allow them to see a full range of options, and act based on the best available alternatives. Specifically, mapping allows emergency officials to:

- *Assess supply chain risks*: Mapping helps assess risks and overall system resilience by revealing locations of suppliers, distribution centers, transportation routes, points of distribution to consumers, and the interactions between them. This allows officials to understand the diversity and concentration of suppliers, determine if key facilities are in high hazard areas, and identify transportation chokepoints and other system vulnerabilities that could limit the flow of commodities during an emergency.

- *Strengthen preparedness*: Knowing the various components and dependencies within their supply network helps identify critical resources, design mitigation strategies, and develop or refine emergency response and recovery plans. This could include stockpiling essential resources; establishing mutual aid agreements with neighboring jurisdictions or private sector partners; and targeting mitigation funding to reduce hazards that could disrupt supply chain operations and to shore up critical infrastructure (such as transportation assets) that are essential to continued operation supply chain operation. Identifying supply diversity helps guide actions to increase that diversity, which will increase resilience.

- *Improve timely response to emergencies*: Having a mapped supply chain lets emergency managers quickly identify sources of supplies to meet immediate community needs and determine the most critical routes for their delivery. The information also helps pre-position response resources along key transportation routes; guides debris removal; and facilitates private sector access and re-entry to restore flow of goods. These actions can significantly speed up response times and ensure that lifeline commodities continue to be available with minimal interruption.

- *Enhance engagement with private sector owners/operators*: Supply chains involve multiple private sector organizations including suppliers, distributors, and logistics providers. Mapping identifies the primary stakeholders that support the supply chain, so officials can work with

them during steady state to understand their operations and how best to coordinate and share information during emergencies.

- *Promote inter-jurisdictional coordination*: By their nature, supply chains extend beyond jurisdictional boundaries to areas outside the jurisdiction's control or influence. This creates dependencies because maintaining vital transportation routes is often the responsibility of other local or state governments. Multiple jurisdictions may also rely on the same commodity distribution centers, potentially creating shared shortages during a disaster or catastrophic event. Knowing these dependencies helps determine how to better coordinate preparedness and response and share information during disruptive events.

Challenges and Limitations of Mapping

While supply chain visibility is an increasingly important focus for emergency managers, mapping a supply chain from the public sector perspective presents several challenges:

- *Lack of data*: Good quality data is crucial to create a true picture of system operations. Comprehensive data about every link in the supply chain will often be incomplete, outdated, or unavailable. Inaccurate information can lead to misleading conclusions and flawed decision-making. Maintaining data accuracy requires ongoing monitoring and verification.

- *Subjectivity and scope*: Mapping involves making choices about what information to include and how to represent it. For emergency managers, resource availability and bandwidth limitations makes it difficult to gain visibility into upstream components of more complex supply chains. In particular, lack of visibility beyond first-tier suppliers increases the risk of overlooking potential vulnerabilities, since supply chain disruptions may originate with a supplier's supplier, or even further up the supplier chain.

- *Dynamic nature of supply chains*: Supply chains are dynamic systems that change over time. New suppliers, technologies, market conditions, or adaptations made following a disruption can alter the existing supply chain structure, such that mapping the system at a particular point in time will not fully capture its evolving nature. Mapping needs to be regularly updated and adjusted to reflect changes in suppliers, processes, locations, and risks.

- *Reluctance to share information*: Supply chains are made up of multiple private sector entities that together support system operations, and data from them is crucial for successful mapping. However, some may be hesitant to disclose detailed information about their operations due to concerns about revealing sensitive or proprietary information, concerns about competition, or lack of trust in government.

Recent Applications of Mapping

Supply chain mapping has been undertaken in recent years within several large urban areas across the United States to highlight supply chain vulnerabilities, inform operational decision-making during emergencies, and identify resilience enhancement options. The following are recent examples:

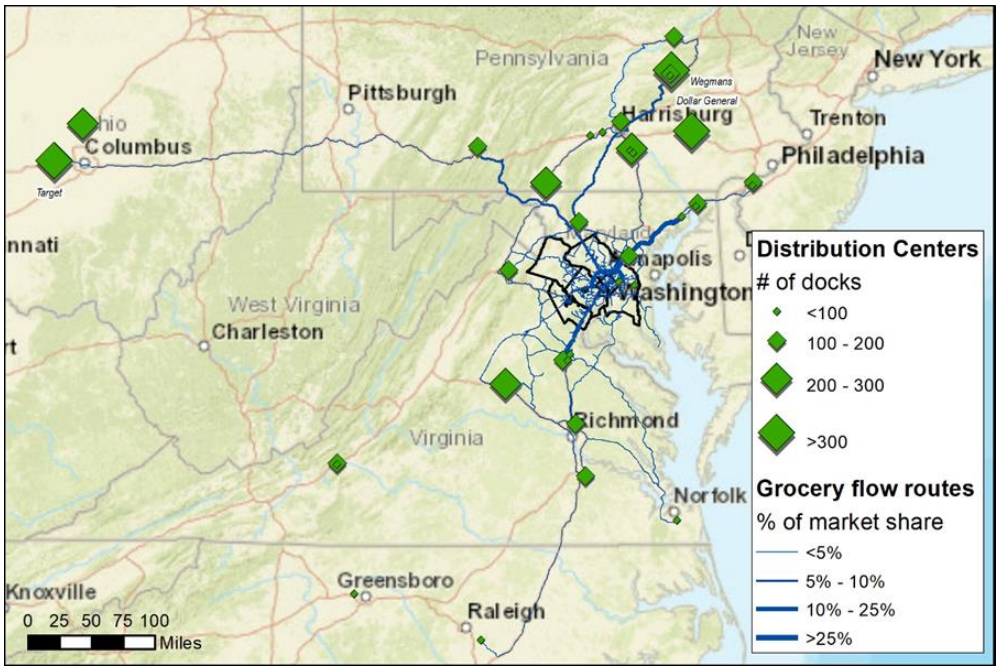
Case studies from the Washington DC area

Case study #1: Food supply for National Capital Region (NCR) communities[8]

Purpose: Characterize the food supply chain serving the NCR during steady state; identify what shocks could disrupt that supply chain; assess the potential impact of such events on supply chain operations and the affected communities; and identify opportunities to strengthen local and regional capability to prepare for, respond to, and recover from a food supply chain disruption.

Methodology: The foundational step for improving the region's capability for a food disruption was mapping the food supply chain to gain visibility into the various components of the system and understand how the factors of distance, diversity, and concentration affected the relative reliance of the system to a disruption. Mapping of **upstream** components of the system was done using data from the FHWA Freight Analysis Framework to show agricultural commodity flow from around the country into the NCR, and from various USDA databases to show agricultural production and food processing serving the region. For **midstream** components, USDA data and a variety of business databases were used to identify wholesaler locations, locate distribution centers for major grocery providers, and determine relative market share of these providers. This data was overlaid on mapping of regional freight routes identified by Metropolitan Washington Council of Governments (MWCOG), and used to model flow of groceries from distribution centers to retail locations using routing (by least trucking time) as shown below, in order to determine which routes carry the most flow. Mapping of the **downstream** components used multiple databases from USDA, local government, and food assistance organizations to characterize the relative importance of food for home use and food consumed away from home.

The following map shows distribution center locations and flow routes for the major grocery providers based on percentage of market share:



[8] This project was conducted by the District of Columbia Homeland Security and Emergency Management, with data collected and analyzed by CNA Corporation. Funding was provided by the FEMA Regional Catastrophic Preparedness Grant Program.

Application of study findings: The mapping done through this project has already proved beneficial to regional emergency preparedness:

- In January 2022 two major snowstorms passed through the Mid-Atlantic region, including parts of eastern Pennsylvania where mapping showed several food distribution centers supplying the NCR. The severity of the first storm led the Commonwealth of Pennsylvania to close roadways in affected parts of the state to commercial traffic for 24 hours, halting shipments from these centers and resulting in short-term shortages of food on grocery store shelves in the NCR. In advance of a second storm two weeks later, the District of Columbia's emergency management agency overlaid National Weather Service snowfall projections on the agency's food supply chain map and determined that additional impacts to the eastern PA food distribution centers could be expected. This information was shared with NCR emergency managers to help them better prepare for potential disruptions of food supplies for their communities. It also led to improved information-sharing between HSEMA and the Pennsylvania Emergency Management Agency for future events.
- During the March 2022 trucker convoy protest in the Washington DC area, information showing commodity flows over important freight routes was shared with local emergency managers across the NCR. In addition to providing situational awareness, this informed the deployment of local law enforcement and Department of Transportation assets to important locations across the freight network to minimize disruption of the flow of food and other essential commodities using these routes. The potential for disruption from this action also facilitated greater sharing of threat information between emergency managers and the region's major grocery providers for this and future events.
- Results of this mapping showed that Washington, DC, Baltimore MD, and Philadelphia PA share many of the same major commercial food providers. This has led to creation of a Mid-Atlantic Coordination Group to coordinate efforts between jurisdictions and the grocery industry in preparation for future emergency events with regional impact.

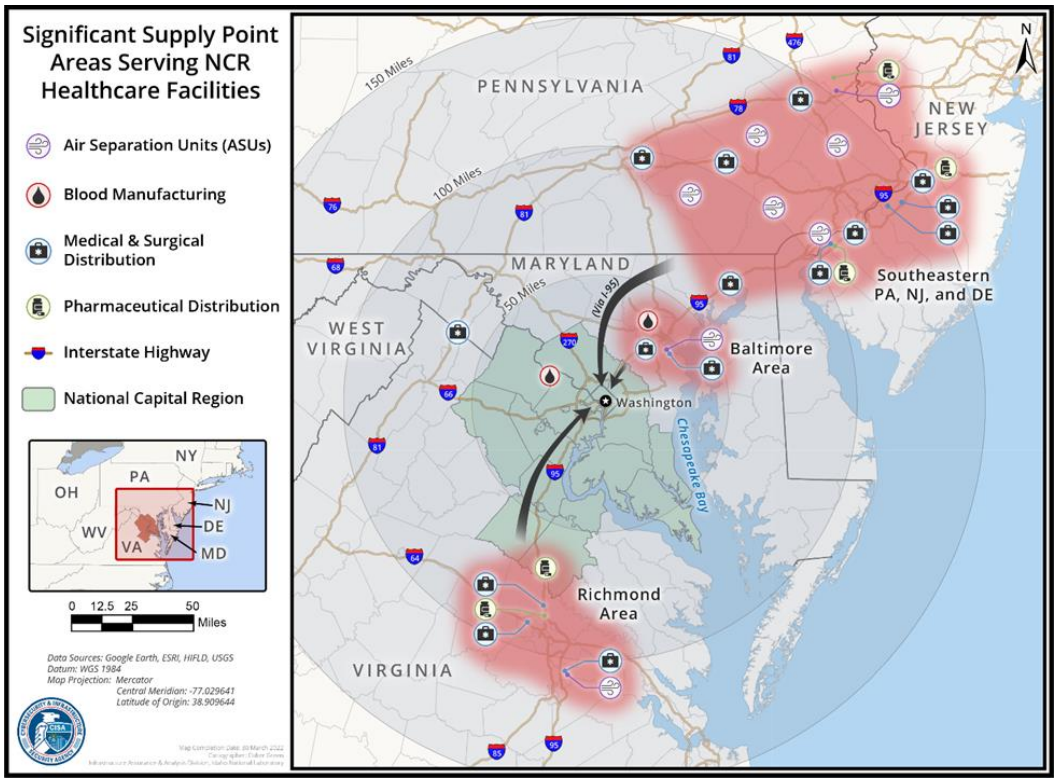
Case Study #2: Medical supplies for National Capital Region (NCR) healthcare facilities[9]

Purpose: Identify and map the key suppliers of critical commodities for healthcare facilities in the NCR; identify critical infrastructure dependencies for those facilities; and develop options for enhancing the resilience of the supply chains and infrastructure services.

Methodology: The three Health & Medical Coalitions operating in the NCR identified four essential commodities of concern: blood products, medical gases, medical and surgical equipment, and pharmaceuticals. Using key vendor analyses conducted by the three Coalitions, the project team developed an initial list of these product suppliers and then interviewed hospitals and other healthcare facilities in the region to identify their specific vendors, commodity management practices, and supply vulnerabilities. The team also conducted in-depth interviews with suppliers in each of the four categories to identify their supply management and delivery practices. Mapping of the supplier distribution centers serving the region was conducted as shown below, and resilience enhancement options developed for consideration by the three coalitions and the Council of Governments. A stakeholder workshop was used to share study findings and discuss how healthcare

[9] This project was conducted by the District of Columbia's Homeland Security and Emergency Management Agency and Department of Health, through the Department of Homeland Security/Cybersecurity and Infrastructure Security Agency's Regional Resilience Assessment Program (RRAP)

facilities and suppliers can better coordinate efforts during a disaster or catastrophic event in the region.



Application of Findings: Study results were briefed to each Coalition and the regional RESF-8 Healthcare Committee for integration of findings and resilience enhancement options into their work plans. Findings from the mapping of facilities supported situational awareness for regional emergency managers and healthcare facilities following two recent events: (1) a snowstorm in January 2022 that closed the major freight transportation route from Richmond VA to Washington DC for over 24 hours, and (2) a tornado in July 2023 that severely damaged a North Carolina pharmaceutical manufacturing facility that provides products to the NCR and several other regions.

Supply Chain Mapping in Texas

City of Houston/Harris County

Houston and Harris County have pioneered several public-private engagement processes to coordinate with key critical infrastructure owners/operators across the city, county, and region.[10] This has included in-depth mapping of the region's fuel supply chain to identify potential chokepoints in the system and better prepare for impacts from future tropical storms, and maintaining regular dialogue between local government officials and supply chain partners.

Texas Electricity Map

In 2023 the Texas Electricity Supply Chain Security and Mapping Committee adopted an Electricity Supply Chain Map of critical infrastructure for use during disaster and emergency preparedness and

[10] https://cities-today.com/supply-chain-proves-central-to-houstons-resilience-efforts/

response. The map identifies critical infrastructure facilities that make up the state's electricity supply chain, including electric generation plants and the natural gas facilities that supply fuel to power the plants. It is expected that state emergency management officials will use the map during weather emergencies and disasters to pinpoint the location of critical electric and natural gas facilities and maintain contact with those key facilities. The map is scheduled be updated twice a year, or more often if necessary.[11]

Texas Private Sector Advisory Council

In January 2023 the SHSU Institute for Homeland Security submitted recommendations[12] to the Texas Private Sector Advisory Council on legislation and policy measures for building resilience into critical supply chain infrastructures in the state. The recommendations included encouraging organizations to map their supply chains to identify both first tier (direct suppliers/service providers) and second tier (supplier's suppliers) vendors. The objective is to identify the stakeholders, understand the different relationships, timings, and costs, and classify the different supply chain risks that exists. In addition, the map process should provide insight into the strengths and weaknesses of supply chain partners.

Supply Chain Mapping by FEMA

The Federal Emergency Management Agency has proactively addressed supply chain resilience through mapping:

- For several areas of the U.S. prone to catastrophic events, mapping has been used to assess potential impacts and response options, including (1) a proof-of-concept project in 2020 for supply chain resilience in the Puget Sound region, which explored strategies and techniques for facilitating supply chain response and recovery following a catastrophic earthquake; (2) an assessment of emergent supply chain issues in Florida associated with Tropical Storm Ian in 2022; and (3) as a component of the National Strategic Supply Chain Risk Analysis for the 2023 hurricane season.
- FEMA's Supply Chain Analysis Network (SCAN) Team has used mapping to help establish baselines for private sector supply chains of lifeline commodities. These baselines serve as a supply chain intelligence assessment that seeks to define "normal" conditions in order to assess post disaster supply chain questions conditions and determine appropriate federal courses of action.
- FEMA's Technical Assistance Program has also trained multiple jurisdictions across the U.S. on supply chain mapping techniques and application.

Lessons from the Private Sector

Since at least the 1980s, mapping has been an essential strategy for businesses looking to increase their supply chain performance.[13] Recent research shows that companies with more visibility across their supply chains perform better during periods of disruption. For example, a small minority of companies that invested in mapping their supply networks before the Covid-19 pandemic emerged

[11] Railroad Commission of Texas. Texas Adopts First-Ever Electricity Supply Chain Map. April 29, 2022. https://www.rrc.texas.gov/news/042922-joint-rrc-puc-map/

[12] SHSU Institute for Homeland Security. *Building Resilience into Critical Supply Chain Infrastructures*. January 31, 2023. Contact the Institute regarding report availability.

[13] Muhammad Shujaat Mubarik, Simonov Kusi-Sarpong, Kannan Govindan, Sharfuddin Ahmed Khan & Adegboyega Oyedijo (2023) "Supply chain mapping: a proposed construct", *International Journal of Production Research*, 61:8, 2653-2669, DOI: 10.1080/00207543.2021.1944390

from that event better prepared to manage disruptions because they had more complete understanding of their supply chains.[14]

Many supply chain owners/operators use a combination of structural and dynamic visibility to orchestrate their supply chains for greater efficiency. **Structural visibility** is about knowing what the supply chain looks like. It provides a snapshot of operations at a point in time and helps uncover hidden issues, and includes traditional activities like network mapping, risk assessment, network assessments, and modelling. **Dynamic visibility** is knowing what's happening across the supply chain in real time, enabling a company to monitor and respond to events quickly.[15]

For future emergency events, having structural and dynamic visibility means that instead of scrambling at the last minute, supply chain managers have a lot of information to make key operational decisions within minutes of a potential disruption. They know which suppliers, sites, parts, and products are at risk, which allows them to put themselves first in line to secure constrained inventory and capacity at alternate sites.

More recently, private sector supply chain managers have begun leveraging advanced technologies to enhance operational efficiency and decision-making, including increasing visibility through mapping. Artificial intelligence (AI) is playing an increasingly important role in enabling the rapid collection, updating, and integration of data that can be used to automate mapping and allow visualization of supply networks in almost real time. AI-based tools such as digital twins and control towers support the risk prediction and assessment, real-time monitoring, natural disaster and weather analysis, and scenario planning and simulation needed to enhance supply chain performance.[16]

Artificial Intelligence Tools Supporting Supply Chain Mapping

Digital twin is a virtual replica of a supply chain. A digital twin replicating the typical behavior of the supply chain can be used to simulate and scenario model the supply chain's performance. It allows managers to understand where suppliers and points of production are, what logistics routes are used for which products and customers, and the relationships across the supply chain network.

Supply chain control tower is a cloud-based solution that leverages advanced technologies – such as artificial intelligence (AI), machine learning, and the Internet of Things (IoT) – to proactively manage supply chains. It provides a connected, customized dashboard of data, key business metrics and events across the supply chain, and enables organizations to understand, prioritize and resolve critical issues in real time more fully.

Source: Accenture; SAP

Understanding how businesses conduct mapping and deploy advanced technologies to enhance supply chain efficiency may help public sector managers see opportunities to adapt similar technology and data-driven approaches into their emergency management processes. Potential use cases include enhanced risk prediction, real-time monitoring, demand forecasting, supplier risk evaluation, natural disaster analysis, predictive maintenance, scenario planning, and automated decision-making.

While the mission-drivers and resources available are significantly different for the private and public sectors, many of the proven practices of supply chain owners/operators may have value for public sector application. By studying and adapting these practices where appropriate, officials can enhance their preparedness, response, and recovery capabilities, leading to more effective emergency management outcomes.

[14] Ibid.
[15] https://www.accenture.com/us-en/blogs/high-tech/how-visibility-boosts-supply-chain-resilience
[16] Ibid.

A Way Forward

Here are three near-term actions public sector officials and emergency managers can take using supply chain visibility to strengthen community resilience:

1. *Cities and regions should prioritize mapping the supply chains for their lifeline commodities.*

   This step begins by identifying the commodities of greatest importance, and seeking out existing data sources and partners to assemble the information necessary to map out each supply chain in accordance with local needs and conditions. Where possible, mapping should include both structural visibility (how the system is now) and dynamic visibility (how the system operates in real time). This step is critical because it will show where the supply chain is most vulnerable, and where actions can be taken to reduce that vulnerability. Once completed, the maps should be made an integral part of the jurisdiction's preparedness framework.

2. *Emergency managers should build meaningful partnerships with private sector actors who make up and support the supply chain, and with neighboring jurisdictions who share components of the supply chain.*

   Following a supply chain disruption, the role of the impacted businesses is to restore flow, while government's role is to do all it can to facilitate that restoration. This requires mutually beneficial and sustained relationships established during steady state, so that disaster response is coordinated and effective. During and after mapping, emergency managers should work toward generating as many touch points with suppliers as possible, and with key infrastructure service providers who support the system. Since the mapping exercise will also identify the supply chain's reach into other jurisdictions and regions, managers can use that information to build or strengthen information sharing and operational coordination with those government entities who share the supply chain.

3. *Mapping should be used to conduct stress tests (exercises) with private sector participation around potential supply chain disruption scenarios.*

   Mapping results can best be operationalized by testing how well the jurisdiction can deal with an emergency event that disrupts the availability of one or more of the lifeline commodities. These scenarios should incorporate the findings from mapping results into an existing training and exercise program that evaluates existing plans and capabilities. Involvement of private sector owners/operators in these activities will be essential to success. Beyond identifying strengths and areas for improvement, conducting these "stress tests" will help build trust and strengthen relationships with key private sector partners.

Resources

Bingham, Darren R., Richard R. Rushforth, Bo Stevens, and Benjamin Ruddle. "Mapping local food self-sufficiency in the U.S. and the tradeoffs for food system diversity", *Applied Geography*, Volume 143, June 2022, 102687. https://doi.org/10.1016/j.apgeog.2022.102687

CNA Corporation. A Case Study in Supply Chain Resilience – Private-Public Collaboration to Facilitate Flows: The Experience of Puget Sound early in the Pandemic. May 2022.

https://www.cna.org/reports/2022/05/A-Case-Study-in-Supply-Chain-Resilience-Private-Public-Collaboration-To-Faciltate-Flows-The-Experience-of-Puget-Sound-early-in-the-Pandemic.pdf

Fabbe-Costes, N., Lechaptois, L. and Spring, M. (2020), ""The map is not the territory": a boundary objects perspective on supply chain mapping", *International Journal of Operations & Production Management*, Vol. 40 No. 9, pp. 1475-1497. https://doi.org/10.1108/IJOPM-12-2019-0828

Federal Emergency Management Agency (FEMA). Supply Chain Resilience Guide. April 2019. https://www.fema.gov/sites/default/files/2020-07/supply-chain-resilience-guide.pdf

Khan, Sharfuddin Ahmed et al. "Blockchain technologies as enablers of supply chain mapping for sustainable supply chains." *Business Strategy and the Environment*, 2022:31:3742-3756. https://doi.org/10.1002/bse.3029

Lin, Xiaowen, Paul J. Ruess, Landon Marston, and Megan Konar. "Food Flows Between Counties in the United States," *Environmental Research Letters*, July 26, 2019. https://doi.org/10.1088/1748-9326/ab29ae

MacCarthy, Bat L., Wafaa A.H. Ahmed, and Guven Demirel. "Mapping the supply chain: Why, what, and how?", *International Journal of Production Economics*, Volume 250, August 2022, 108688. https://doi.org/10.1016/j.ijpe.2022.108688

Muhammad Shujaat Mubarik, Simonov Kusi-Sarpong, Kannan Govindan, Sharfuddin Ahmed Khan & Adegboyega Oyedijo (2023) "Supply chain mapping: a proposed construct", *International Journal of Production Research*, 61:8, 2653-2669, DOI: 10.1080/00207543.2021.1944390

Palin, Philip J. "Food and Other Flows in Case of Catastrophe," *Journal of Critical Infrastructure Policy*, Volume 1, Number 1, Spring/Summer 2020.

Palin, Philip J. Seven Steps to Counter Catastrophe. *Supply Chain Quarterly*, February 22, 2020. https://www.supplychainquarterly.com/articles/3152-seven-steps-to-counter-catastrophe

Palin, Philip J. "Supply Chain Resilience: Push and Pull in Catastrophes", *Journal of Critical Infrastructure Policy*, Volume 1, Number 2, Fall /Winter 2020.

Railroad Commission of Texas. Texas Adopts First-Ever Electricity Supply Chain Map. April 29, 2022. https://www.rrc.texas.gov/news/042922-joint-rrc-puc-map/

Sahlmueller, Till and Bernd Hellingrath. *Measuring the Resilience of Supply Chain Networks.* Proceedings of the 19th ISCRAM Conference – Tarbes, France May 2022. http://idl.iscram.org/files/tillsahlmueller/2022/2399_TillSahlmueller+BerndHellingrath2022.pdf

Strengthening Post-Hurricane Supply Chain Resilience. The National Academies of Science, Engineering, and Medicine, 2020. https://www.nap.edu/catalog/25490/strengthening-post-hurricane-supply-chain-resilience-observations-from-hurricanes-harvey

SupplyChainDive. "AI opens new frontier in supply chain planning." May 23, 2023. ttp://www.supplychaindive.com/news/inventory-demand-forecasting-ai-machine-learning/650781/?%3A+2023-05-23+Supply+Chain+Dive%3A+Operations+%5Bissue%3A50745%5D=&%3A+Operations=

Xiaowen, Lin et al. Food flows between counties in the United States. 2019 *Environ. Res. Lett.* **14** 084011. https://doi.org/10.1088/1748-9326/ab29ae

Personal Interviews

Philip J. Palin, independent supply chain resilience SME supporting FEMA and CNA (conducted 6/14/2023)

Dr. Jason Riley, Sam Houston State University and the Institute for Homeland Security (conducted 5/22/2023)

Benjamin L. Ruddell, Ph.D., P.E., Professor, School of Informatics, Computing, and Cyber Systems (SICCS), Northern Arizona University (conducted 5/22/2023)

Eugene Shearer, Supply Chain Advisor, FEMA Logistics Management Directorate (conducted 6/8/2023)

INSTITUTE FOR HOMELAND SECURITY

Sam Houston State University

The Institute for Homeland Security at Sam Houston State University is focused on building strategic partnerships between public and private organizations through education and applied research ventures in the critical infrastructure sectors of Transportation, Energy, Chemical, Healthcare, and Public Health.

The Institute is a center for strategic thought with the goal of contributing to the security, resilience, and business continuity of these sectors from a Texas Homeland Security perspective. This is accomplished by facilitating collaboration activities, offering education programs, and conducting research to enhance the skills of practitioners specific to natural and human caused Homeland Security events.

Institute for Homeland Security
Sam Houston State University

Scott, M. (2023) Supply Chain Mapping for Emergency Management Decision-Making. (Report No. IHS/CR-2023-1027). The Sam Houston State University Institute for Homeland Security.
https://doi.org/10.17605/OSF.IO/T34EP