Complex Risk Factors and Cascading Consequences in the Maritime Supply Chain

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Diverse and complex, the global maritime supply chain is by far the largest single component of global trade. Most operational planning and academic research has focused on single disruptions such as oil spills, hurricanes, or security threats to this system, especially at the port level. While maritime trade has proven resilient, challenges over the past few years have revealed that, when multiple disruptions coincide, maritime supply chains can be unexpectedly strained leading to cascading consequences.

A greater understanding of how these various disruptions interact can improve risk analysis, resilience, and stakeholder engagement. Quantifying the economic impact can improve modeling and demonstrate the value of reliable maritime supply chains. This research can also help prepare for a future where climate change, digital transformation, emerging technology, workforce demographics, and new trading patterns all present dynamic maritime supply chain risks.

The MTS and Maritime Supply Chains

The Marine Transportation System (MTS) is composed of port and vessel operators, agencies, seafarers, stevedores, and service providers that see marine transportation as central to their purpose and responsibility. A somewhat U.S.-centric term, in plain language, the MTS is made up of the organizations that show up for local harbor safety and area maritime security committee meetings.

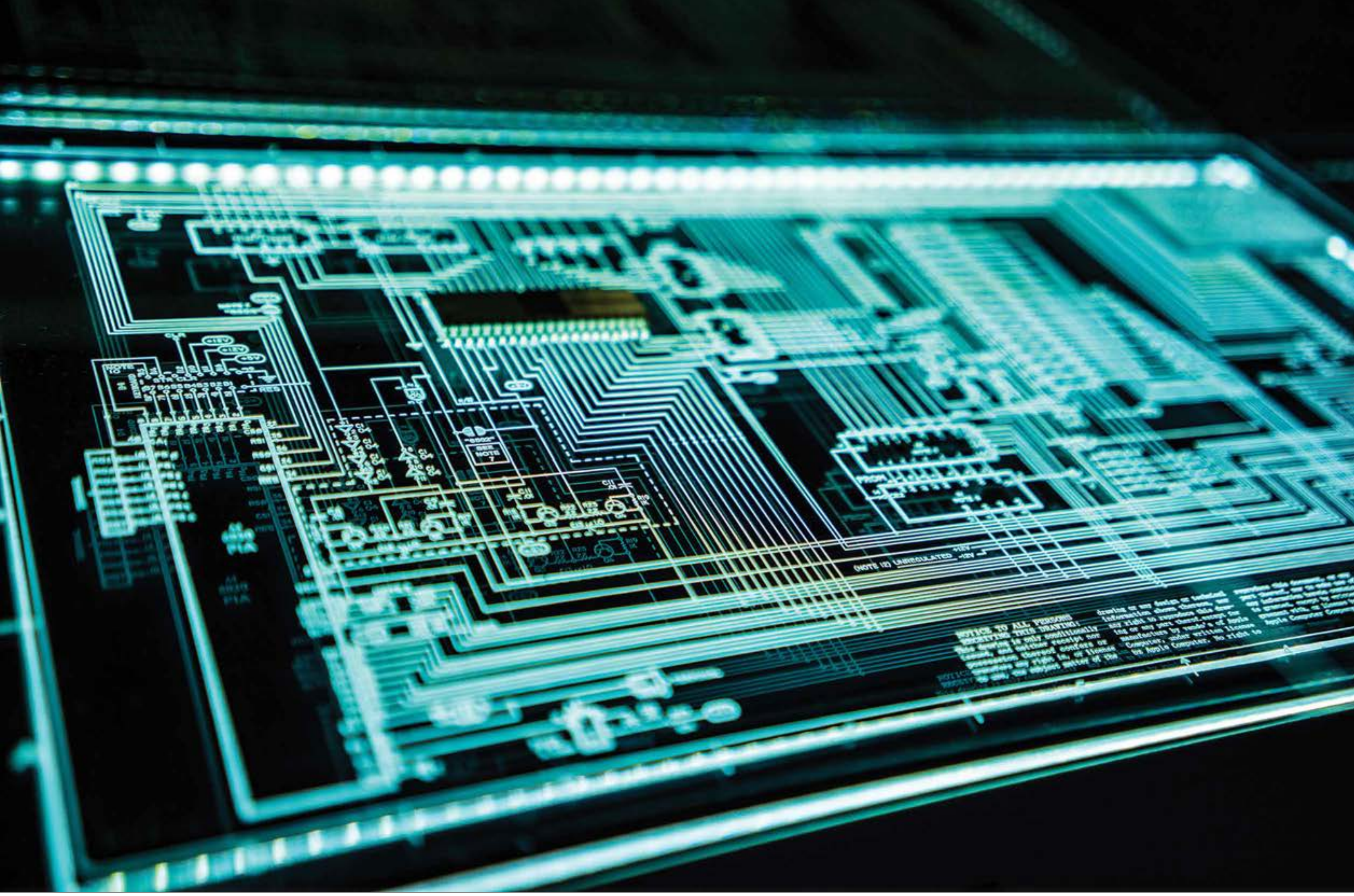
In this article, MTS and the term "maritime supply chain" are not interchangeable. The latter includes the MTS and extends to other players, including overseas shipping, upland warehousing, long haul rail and truck lines, and endpoints such as retailers and manufacturers. These additional players are equally important to enabling the maritime supply chain to serve the broader economy.

The most serious consequences of marine supply chain issues may fall on entities not represented in traditional MTS discussions. Accordingly, our research is focused on understanding "cascading consequences" to all of these components of maritime trade.

Background and Purpose

Since 2020, a diverse collection of disruptions has unexpectedly impacted maritime supply chains, as well as non-traditional stakeholders. The COVID-19 pandemic was, and remains, a significant driver in these disruptions. Still, other events, including the blockage of the Suez Canal, cyberattacks, changing trade patterns, and the Russian invasion of Ukraine, have impacted maritime supply chains. When multiple disruptions coincide, or a new disruption occurs when another one is already underway, the risks and impacts can be significantly harder to understand and quantify.

Consumers, manufacturers, MTS-related organizations, and government officials have all been impacted by these events, often in unanticipated ways. These cascading consequences continue to flow through our



As automation increases, so does the potential for cyber related disruptions. Adi Goldstein | Unsplash

economy and society. We seek to understand how these various disruptions interact; how one type can magnify the impact of another; and where hidden or disproportionate consequences may occur. Improved modeling of these complexities can help us prepare for future events.

In a project that is a joint effort, we are exploring complex, multivector disruptions to the MTS. The research includes an extension of Center for Risk and Economic Analysis of Threats and Emergencies' Economic Consequence Analysis Tool, or E-CAT, which has successfully addressed the economic consequences of supply chain issues.

Complex Disruptions: What Makes Them So Complicated?

All disruptions require some combination of capabilities, authorities, and skills to respond effectively. Resource limitations can aggravate responses if similar resources are needed to address multiple components of complex disruptions. For example, a vessel grounding and oil spill might both require work boats and crews to stabilize the vessel and deploy pollution equipment. But, this type of scenario also has its advantages in that the similarity of the events may make it relatively easy to prioritize needs and sequence the use of specific resources.

Another way a complex disruption can play out is if different resources must be brought to bear against different aspects of the situation. It might seem counterintuitive that this could make things worse since there is reduced competition for individual resources. However, coordinating the response and resuming normal marine supply chain activity could be challenging if different

Types of Disruptions

Hurricanes	Oil spill	Cyber attacks to ports/vessels	Tariffs/trade war
Earthquakes/tsunami	Vessel grounding/fire in port/channel	GPS/AIS disruptions	Labor/management dispute
Storm surge/sea level rise	Damage to bridges and port infrastructure	Sustained security threat/incident	Specialized marine fuel shortages
Infectious disease	Sustained power outages	Radiological risks (e.g., Fukushima scenario)	Truck, chassis, or container shortages

There are countless examples of maritime disruptions, and even more ways to organize them. At the risk of oversimplification, this table provides a short list of the many types of disruptions that maritime supply chains may experience and should be read vertically.

agencies and private sector organizations, each with their own priorities and cultures, must still coordinate actions.

For instance, imagine a vessel collision in a channel combined with a GPS/Automatic Identification System disruption. The collision requires tug boats, traditional marine casualty investigators, and salvage experts. The GPS disruption requires technical experts skilled in electronics, satellite, and radio transmissions. Coordination between the groups and communication to supply chain stakeholders about how and when the situation will be resolved will be challenging. If there is any suggestion that the GPS disruption was a deliberate event, and that it contributed to the vessel collision, then a third, law enforcement-focused, set of players will be involved.

Consider the above scenario from the perspective of a shipper, freight forwarder, pilot, or other maritime supply chain player. A blocked channel alone is unfortunate, but precision GPS might enable the use of alternate routes. Alternatively, GPS disruptions are a concern, but as long as ships can use established channels, marine traffic should continue at an acceptable, if not ideal, rate. However, when combined, commerce is seriously hampered. The GPS disruption might also affect terminal

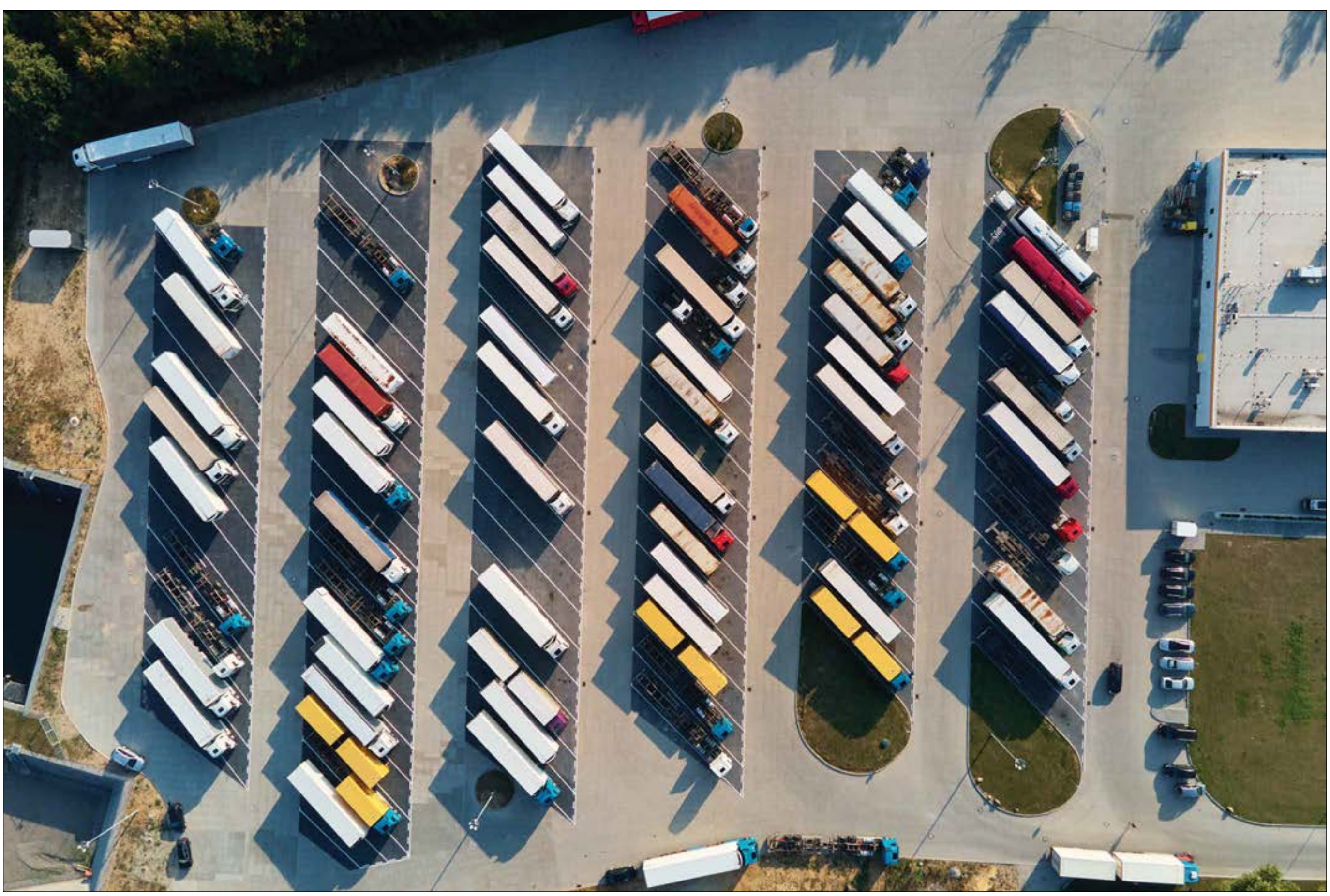
Maritime Supply Chain Study Partners

Study partners include three Department of Homeland Security (DHS) university centers of excellence:

- the Command, Control, and Interoperability Center for Advanced Data Analysis (CCICADA)[1] at Rutgers University,
- the Center for Risk and Economic Analysis of Threats and Emergencies (CREATE)[2] at the University of Southern California,
- and the Center for Accelerating Operational Efficiency[3] at Arizona State University.

Endnotes:

1. https://ccicada.org/
2. https://create.usc.edu/
3. https://caoe.asu.edu/



Ports are congested areas. Small disruptions can quickly have ripple effects. Lazy_Bear|Getty Images operations, further increasing the complexity of the event and its impact on maritime supply chains.

Furthermore, disruptions that are new, novel, or reliant upon skills, capabilities, and resources from outside the MTS community can also comprise complex supply chain issues. This is especially true if outside experts do not prioritize the maritime supply chain.

The novel coronavirus is an example where seafarers and port workers had no special skills or training to respond to the virus and public health experts had no understanding of maritime work environments. Therefore, the priorities were not aligned.

A similar situation could arise from widespread power outages impacting ports and other maritime supply chain players. The power generation and transmission organizations will be responding from different locations than the Coast Guard and potentially with different priorities. Meanwhile, freight forwarders and other logistics providers will struggle to track and reroute cargo while on emergency power. A power outage, combined with some other disruption, could certainly lead to significant cascading consequences.

How Do Maritime Supply Chains Work?

Despite these scenarios, maritime supply chains *do* work. Countless individual workers and businesses innovate, improvise, and overcome obstacles, working independently and on a business-to-business level. Government agencies find ways to use their authority and capabilities to allow a company to efficiently resume business. The hard work of all of these individuals has meant that, while the consequences of recent disruptions have been significant, they have been economic and transitory, not societal and persistent.

To help understand the impact of disruptions, the table on this page provides a highly simplified diagram of critical supply chain elements. If any of these elements is negatively impacted, the system is resilient enough to recover with minimal costs and impacts—if the disruption is small. When the severity, duration, geographic scale, or other factors are sufficiently large, cascading impacts occur.

In our model, people are the foundation of all maritime supply chain activity. Despite automation, computers, and other technology, we rely on skilled workers at every step. This is what has made COVID-19 so disruptive. COVID-19 did no physical or cyber damage, but its impact on people slowed every link in the supply chain.

The various non-human components are subject to damage and destruction, and MTS members, like other businesses, need to minimize costs, including replacement costs, which does not necessarily promote resilience. For example, gantry cranes at container terminals are vital for cargo operations, but no facility can afford to have an extra $35 million gantry crane sitting idle on standby just in case a working crane becomes damaged.

At the retail and manufacturing levels, the widely adopted "just in time" inventory system meant that businesses had little ability to absorb supply chain disruptions. While there is a great deal of discussion in the business community about revising this approach, the economic incentives for a lean inventory will likely prevail.

While economic incentives do not necessarily promote resilience, in some cases they may even aggravate disruptions. Such is the case when ocean carriers find it more profitable to leave empty containers in port, rather than wait for them to be filled and loaded back on ships. In other cases, the economic consequences of a disruption may be primarily borne by manufacturers and retailers, rather than by the maritime and port entities.

Finally, government agencies, classification societies, insurance companies, and similar organizations provide independent, expert risk oversight and governance functions. Their capacity is limited, and disruptions may push risk tolerances to uncomfortable levels.

The MTS is continuously evolving, however, and it is important to plan for its future. Will investment in systems allowing vessels to use new types of fuels lead to new infrastructure requirements and vulnerabilities? Will increasing automation lead to problems in the case of power outages? Will autonomous and semi-autonomous vessels on the water and trucks in the ports lead to new kinds of complex disruptions? We need to develop ways to address these kinds of questions.

Development of Complex Disruption Scenarios

The first phase of our research was to interview a variety of transportation experts on their experiences with disruptions. While all of the researchers have had some experience in this field, listening to these experts explain

Critical Supply Chain Elements

<table>
<tr><td colspan="3">Port authorities, government agencies, governance structures, insurance</td></tr>
<tr><th>Distant Navigation</th><th>Port Area</th><th>Upland</th></tr>
<tr><td>Vessels
Long range communications
Locks and dams
Canals and straits
Vessel navigation, routing and voyage planning systems
Bunkering & ship support</td><td>Port facilities and infrastructure
Tugs and other support vessels
Aids to navigation
Port and cargo technology
Cargo containers, chassis, and other cargo systems
Drayage</td><td>Customers
Suppliers
Long haul rail and truck
Warehousing
Power and utilities
Manufacturing
Specialized services</td></tr>
<tr><td colspan="3">People
Seafarers, port workers, technicians, truck and rail operators, agency personnel, others</td></tr>
</table>

how the systems work, how they sometimes fail, and "what keeps them up at night," was fascinating. Our initial round of interviews included port authorities, vessel operators, dry cargo and energy terminal representatives, Coast Guard personnel, academics, and even a representative from the air forwarders industry, for an outside perspective on supply chains.

These experts helped us identify plausible and potentially useful scenarios to examine in more detail—a key element of our research. It soon became apparent that disruptions do not happen in a vacuum or against a backdrop of "ideal" supply chain activity. Accordingly, we are including pre-existing conditions and other considerations in our test cases.

In our first scenario, a fire on a container ship leads to a blockage of the Kill van Kull Federal Channel. The account below is an abbreviated version of the scenario we are developing with the cooperation of Coast Guard Sector New York and the Port of New York and New Jersey, which is planning an exercise along these lines.

> ***Background Condition:*** A surge in port activity coincides with a shortage of trucks and some road and bridge repairs. The result is long lines at container terminals and greater than normal congestion. These conditions add cost but don't otherwise affect port activity.
>
> ***Initial Disruption:*** A fire breaks out in the cargo hold of a container vessel as it approaches a terminal in the Kill van Kull in New York Harbor. There are no deaths, but the intense heat and smoke, and concerns about a possible capsize, make moving the vessel risky. The channel is blocked for a week. Overhaul, salvage, and cargo transfer take an additional week, with much of the cargo and other vessels diverted to other nearby terminals.
>
> ***Secondary Disruption:*** A cyberattack corrupts the data and stops operations at two terminals for three days. Other terminals slow their cargo operations by 50 percent for two days, while both internal IT personnel and law enforcement agencies check data integrity. The combination of a suspicious fire and a cyber attack suggests that a coordinated, sophisticated attack on the port is in progress. The Coast Guard sets Maritime Security Level 2. This further slows the movement of cargo and vessels through the port area.
>
> ***Additional considerations:*** The source of the fire might have been illegal or improperly stored

Delayed or diverted cargo can have serious impact on businesses far from port areas. liorpt | Getty Images

Small, novel threats—like a lithium ion battery fire—can have big impacts. Photo courtesy of Tavo Romann

hazardous materials or sabotage. Uncertainty about what is in any given, and now fire-damaged, container, compounded by data integrity questions, will complicate the response. Large amounts of heavy black smoke in the middle of a densely populated area raises public health concerns in two states, including for ferry passengers. Various cargo owners may decide to sue each other or the vessel owner, further slowing cargo and vessel disposition. Longshore workers may refuse to work until air monitoring deems it safe.

Questions We Would Like to Answer

While this scenario poses a host of emergency response challenges, our research is focused on understanding and quantifying the supply chain impacts. How many vessels and how much cargo would this event affect? Would vessels and cargo divert to other ports? After the channel is clear, how long would it take for normal trade to recover, and would that happen in steps or all at once? Who outside the port area would be affected, and by how much? What actions would promote a fast economic recovery?

With the help of Sector Los Angles/Long Beach, the LA Port Authority, and security leads at the Port of Long Beach, we are developing a West Coast scenario involving a wildfire-caused power loss combined with more conventional port disruptions. As in New York, an already planned exercise provides the perfect opportunity to examine the cascading impacts of these scenarios. We are grateful to Coast Guard and port authority personnel for finding ways to dovetail their preparedness

The Kill Van Kull Federal Channel, a tidal strait between Staten Island, New York City, and Bayonne, New Jersey, is one of the most heavily travelled waterways in the Port of New York and New Jersey. The vast majority of containerized cargo bound for the port passes through the Kill Van Kull.

The majority of all containerized cargo destined for the Port of New York and New Jersey traverses the Kill Van Kull Federal Channel. Photo courtesy of Jim.henderson work with our research, as we are confident it will benefit all parties.

The goal of the research is to develop a model, useable by various stakeholders, to better understand multiple risks to maritime supply chains, including the likely economic consequences of such events.

Ukraine

A few short months after our initial research was approved, Russia invaded Ukraine. We quickly expanded the scope of our work to track the maritime disruptions of the invasion, and DHS has approved continued research on that topic.

While the direct impacts to the U.S. MTS have been small, there have been substantial impacts to other maritime stakeholders, from stranded seafarers to the superyachts of oligarchs. Energy, food, and commodity trading have been impacted, and smuggling and sanctions-evading activity have accelerated.

While much of the focus has been on food and energy trade, we are completing a study that describes the conflict's impact on grains and certain metals, including nickel, palladium, titanium, aluminum, copper, and uranium. Russia is an important source of these materials, and trade restrictions have led to skyrocketing commodity prices. This has various cascading impacts, including on European automotive production lines, and on the production of semiconductors and catalytic converters in the United States.

We will provide a much more detailed accounting of this significant disruption in the future. For now, we note that the war has weakened governance, shifted trade patterns and partners, strained ports, upended markets, and threatened the lives and livelihoods of people well beyond the combat areas.

Initial Observations

While our work is in no way complete, we have learned a tremendous amount from the various professional experts we have interviewed, as well as from ongoing reviews of industry publications, government data, and other sources. A few of those observations include:

- Cybersecurity remains a concern, and even the perception that data integrity may be in doubt could impact supply chain activity.
- Improperly labeled or packaged hazardous materials, including flammable items such as lithium ion batteries, is a growing concern.
- With much of the maritime community's focus on COVID-19 and technology issues in recent years, the ability of port communities to implement and sustain meaningful security requirements (e.g., maritime security) is uncertain.
- Maritime supply chain challenges caused many businesses to shift from a "just in time" to a "just in case" approach to their inventory and supply chain management practices. As supply chains stabilize, it is unclear if organizations will continue this practice or return to their former, cost-minimizing approach.

How You Can Help

If you have opinions, observations, or recommendations related to "complex disruptions" and how the industry can improve its resilience, please contact Dr. Fred Roberts, director of the Command, Control, and Interoperability Center for Advanced Data Analysis, at froberts@dimacs.rutgers.edu. We'd love to talk with you!

About the authors:

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Fred Roberts, Ph.D., is distinguished professor of mathematics at Rutgers University and director of the Command, Control and Interoperability Center for Advanced Data Analysis, a U.S. Department of Homeland Security university center of excellence. He has done extensive research on cyber and physical disruptions to the marine transportation system, much of it in collaboration with the U.S. Coast Guard.

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