

Modeling the Impact of Complex, Multi-Vector Disruptions to the Marine Transportation System (MCAT): FINAL REPORT

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Executive Summary:

The Marine Transportation System (MTS) is a vital part of the nation’s supply chain. While the MTS can generally overcome any single disruption with limited cascading impacts, the impact of multiple disruptions can overwhelm it. Most recently, COVID, the Ukraine War, low water levels in the Panama Canal and other disruptions resulted in larger and more persistent supply-chain impacts than many stakeholders expected. To date, most research and contingency planning has focused on single-event disruptions – such as an oil spill, natural disaster, or security incident. There has been little analysis of the cascading impacts of multiple disruptions that build on each other in complex ways. This suggests that modeling the impact of multiple vector disruptions and multiple MTS targets can help policy makers, business leaders, and others anticipate, plan for, mitigate, and rapidly recover from future disruptions. This is especially important as Coast Guard and DHS leadership seek to manage risks to an MTS with congestion and capacity challenges and that is increasingly reliant on complex technology and skilled labor, while remaining vulnerable to a multitude of threats, from cyber security to atmospheric conditions shifting.

We are working with a team of government and private sector stakeholders to better understand the immediate and cascading consequences of multiple disruptions, to investigate pre- and post-incident mitigation and resilience strategies through analysis and economic modeling, and to develop a user-friendly decision-support tool, “MCAT,” for use by the Coast Guard and others to improve risk management at the local, regional, and national level, and apply the results to understand current supply-chain crises such as those involving congestion in ports, vessel accidents, terrorist attacks, power outages, labor strikes, and impacts of geopolitical events such as the Russia-Ukraine War. The MCAT tool research is an extension of the successful “reduced-form” approach to transforming sophisticated complex models into decision-support tools in the development of CREATE’s Economic Consequence Analysis Tool, E-CAT, and its extensions, which use a computable general equilibrium model to estimate the total economic impacts of individual and complex disruptions stemming from a variety of threats.

Project Goal and Objectives

We seek to develop new tools for understanding and measuring the economic (and other) impacts of complex, interacting disruptions of the MTS, including real-world situations of contemporary policy interest to DHS, and to deliver tools and recommendations for the Coast Guard and other stakeholders as to potentially concerning scenarios and countermeasures that might minimize those impacts.

Methodology (please provide a brief summary of the methodology used in the research):

The project follows these seven components:

Component 1: SME Engagement: Extensive discussions with stakeholders, including a distinguished Advisory Board consisting of practitioners with relevant expertise, including numerous active or retired Coast Guard officers; leaders of port security on the West, East, and Gulf coasts and the Great Lakes; and leaders of companies working on all aspects of the MTS.

Component 2: Scenario Development: Development of complex disruption scenarios involving identified disruptions, guided by SMEs, stakeholders and literature, and vetted as plausible by SMEs and stakeholders.

Component 3: Continued Development of the MCAT Modeling Tool. While the MCAT tool is already quite mature as a result of our work in earlier years, we aim for continuous improvement. By using it in analyzing specific MTS disruption scenarios and countermeasures, we incorporate input from a broad range of stakeholders that should be included in planning and post-incident decision-making about disruptions.

Component 4: Economic Impact Analysis. Analysis of complex and cascading economic impacts of detailed scenarios, using computable general equilibrium (CGE) analysis, the results of which are being used to enhance the MCAT tool.

Component 5: SME Involvement in Identification of Pre-disruption Mitigations and Post-Disruption Resilience Strategies: Dialogue with stakeholders leading to identification of mitigations and resilience strategies for detailed scenarios.

Component 6: Analysis of the Reduction of the Impact of Disruptions under Mitigation and Resilience Strategies: Analysis of the reduction in economic impacts of selected mitigations and resilience strategies applied to detailed scenarios, using the MCAT tool.

Component 7: Extensive Stakeholder Engagement with Results of the Project: Presentations of project results to government and industry groups as well as stakeholders identified in advance of the project or during stakeholder engagement.

Final Summary Abstract:

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Component 7: Extensive Stakeholder Engagement with Results of the Project: Presentations of project results to government and industry groups as well as stakeholders identified in advance of the project or during stakeholder engagement. Involvement of key people in an active Advisory Board that meets bi-monthly and whose members often participate in project update meetings and interviews.

Benefit to DHS:

According to the U.S Coast Guard Command Instruction, the USCG is designated as the Sector Specific Agency (SSA) for the maritime mode of transportation, pursuant to the National Infrastructure Protection Plan (NIPP). The complexities of the MTS necessitate the development of strategies, plans, and standard processes and procedures that can be rapidly implemented. Thus, it is important to provide Coast Guard leadership with tools to understand potential disruptions and their potential impact, as well as potentially important countermeasures, so as to do strategic planning and resource allocation to prepare for such disruptions. Such tools will also be useful to other DHS components that work closely with the Coast Guard during disruptions to the MTS, for example, FEMA.

The benefit to DHS is reflected in dramatic stakeholder engagement. Involvement of the USCG Sector New York and District 1, Sector Los Angeles-Long Beach, Port Authority of NY/NJ, and security team at Port of Long Beach in development of our Kill van Kull and Western scenarios, and in their own parallel activities, has been an important factor in the success of our project. Involvement of USCG, US Army Corps of Engineers, MARAD, and other agencies and the private sector has been an important role in development of our work on low water in inland rivers. This continues in the present project year with interactions and invitations from USCG District 9 and the US Committee on the MTS (CMTS) (run by Dept. of Transportation, with DHS representation) to participate in Great Lakes exercises and hot washes, and involvement of D-9 and other government agencies and the private sector in planning and analyzing scenarios involving the Great Lakes and smart ports. The number of meetings with stakeholders shows the interest in our project. Numerous Coast Guard leaders, active or retired, are members of the project Advisory Board. In earlier years, in addition to briefing numerous USCG officers and groups, we have briefed the Manager of Borders & Maritime Safety and Security at DHS and were invited to brief CMTS in a webinar; the ESF-1 Working Group of the FEMA Region X

Regional Interagency Steering Committee (RISC); and the CISA Resilience Services Branch. We also briefed the MTRSU in the Port of New York/New Jersey at the invitation of USCG Sector New York. We briefed the CISA group leading the government-wide Committee on the Continuity of the Economy and later were asked to provide input to their report. In addition, we briefed interagency working groups and task groups including DHS representation, including the Interagency Committee on the Supply Chain and the Interagency Task Group on Cyber-Physical Systems (co-led by CISA), which then invited us to become regular meeting participants. We were invited to plan, participate in, and contribute to a hotwash in a tabletop exercise in Baltimore Harbor organized by an interagency committee including DHS components TSA, USCG, and CISA. Ironically, this exercise featured the collapse of the Key Bridge, which, unfortunately, actually occurred in March 2024. We were also invited to participate in a USCG cyber exercise in the Port of New York/New Jersey and to join in the hotwash afterwards. As we developed new examples of complex disruptions, we got involved with USCG District 9 (Great Lakes) and USCG Sector Corpus Christi (related to offshore ports and spillover after the Panama Canal low water events). Involvement with the private sector continued with new partners such as Maher Terminals, Vitol, and Maersk, to name a few. These private sector partners help us to understand how cutting-edge technology and market forces are impacting marine transportation and ensure that our work has a foundation of practical, real world, activities. This involvement with stakeholders has continued to drive our work this year and is outlined in this report.

General overview of progress:

1. USCG Interactions: Continued regular and detailed interaction with primary stakeholder, US Coast Guard.
 - (a) One highlight of this period was an invitation to brief the USCG Board of Inquiry convened in November 2024 after the Baltimore Bridge collapse in March 2024. Such a Board of Inquiry hasn't been called since 1993, and this one is concerned with evaluating multiple aspects of waterway safety.
 - (b) A second highlight was our involvement in planning for, participating in, and working on the after-action report in an exercise held in October 2024 at the Port of Cleveland; this was organized by the Committee on the Marine Transportation System, which includes the USCG and other agencies.
 - (c) We were also invited to brief USCG Waterways Management in October 2024.
 - (d) We continued to be involved with USCG District 9 in planning two exercises on the Great Lakes and interacted with USCG D-9 to get feedback on our Great Lakes scenarios.
 - (e) We held numerous discussions about our New York scenario with USCG Sector New York and two members of USCG Sector NY joined our project Advisory Board in August 2024.
 - (f) We had a very useful discussion about our Great Lakes scenarios with the Branch Chief of the Bridges Branch of USCG District 9, since many of the key Great Lakes scenarios involve bridge outages or collapses.

(g) Our Advisory Board has numerous USCG representatives as well as retired USCG officers, it continues to meet bi-monthly with robust discussions, and Board members also regularly participate in project update meetings.

We feel that this is a strong record of communication with a primary sponsor and the continued interest in the results of our work demonstrates the practicality and usefulness the key stakeholder sees in it.

2. Other Government and Private Sector Interactions: We continued to have regular and detailed interaction with numerous stakeholders from government and the private sector.

(a) This included an invitation by the Port Authority of NY NJ and the CBP to tour the Port of New York New Jersey in September 2024.

(b) We met on numerous occasions with representatives of the Port Authority of NY NJ, New York Shipping Association, and Maher Terminals about our New York scenario.

(c) We discussed smart ports issues with leadership of two of the world's top smart ports, Hamburg and Antwerp-Bruges, with a representative of the Electrification Coalition, and with an advisor to the Port of Halifax.

(d) We discussed Great Lakes issues with the St. Lawrence Seaway GLS Administrator Adam Tindall-Schlicht and his team.

These and other similar interactions help us to understand how cutting-edge technology and market forces are impacting marine transportation and ensure that our work has a foundation of practical, real world, activities and in turn has open and interested customers. Numerous representatives of the private sector belong to our Advisory Board and participate regularly in Board meetings and project update meetings.

3, Development of Database of Complex Scenarios to the MTS: With the help of SME interviews, interaction with stakeholders from the Coast Guard and other government agencies, and the private sector, we continued to build a database of plausible examples of complex disruptions to the MTS, reaching over 40 scenarios. This includes over 12 in intermediate level of detail and four (described below) that were developed extensively. All four have been analyzed using the developing version of the MCAT tool, with the last one nearing complete analysis. Close interaction with USCG and other practitioners from government and the private sector has been crucial in the development of the scenarios, setting key parameters for the scenarios, providing examples of plausible countermeasures, and identifying usable impact estimates for the different countermeasures.

4. **Development of Complex Disruption Scenarios.** The four detailed scenarios developed in Years 1-3 have continued to be developed during year 4, with papers submitted and revised as well as analysis continuing.

- 1) *Ukraine War*: Disruption of grain and metal exports from Russia & Ukraine. (This one is based on actual events, not a hypothetical scenario.) We have also developed a

detailed report on MTS impacts of the War: This includes analysis of impacts on seafarers and port workers; navigation, regional trade, and ports; energy, including Russian oil exports to China and India, U.S. crude oil exports, natural gas and the Nordstream pipeline, and European diversification away from natural gas; deceptive shipping practices; food and grain; ports and shipping. While the report was concluded and delivered to DHS earlier we continued to collect examples of impacts during Year 4.

- 2) *Fertilizer Scenario*: Hot, dry summer leaves Mississippi River levels very low, affecting fertilizer traffic by barge; then lock/dam failure makes things worse; import disruption adds to the disruption.
- 3) *“New York State of Mind”*: Container ship fire in Kill van Kull (KVK) blocks the channel; cyber-attack on a terminal makes things worse. (Part of this scenario was actually realized in a Port of Newark ship fire in July 2023 and a USCG cyber exercise in October 2023 reflected the second part.)
- 4) *“West Coast Whammy”*: Labor disputes lead to cargo diversions and container spot rates much higher than usual. Wildfires lead to power outage at port of LA/LB; then an explosion on a vessel in LA/LB leads to MARSEC Level 2 throughout the West Coast.

5. Great Lakes and Smart Ports Scenarios Databases: This year, while continuing to prepare and modify our work on the key scenarios developed in earlier years, has turned to the understanding of issues facing the Great Lakes and issues facing smart ports. We have gained much useful information about these issues through the interactions described above and that has allowed us to compile significant databases of plausible complex, multi-vector disruptions involving the Great Lakes and smart ports. Our Great Lakes database of scenarios was reviewed by a representative of USCG District 9, who provided very useful feedback that we used to add, modify, and prioritize scenarios. She also forwarded the database to others in District 9. Our smart ports database was reviewed by members of the project Advisory Board who, as with the Great Lakes case, provided useful feedback. Both databases now include numerous examples of scenarios, and the feedback we received led us to select several scenarios for detailed development.

6. Smart Ports Disruptions Components, Uses, Disruptions Summary: Based on a literature review and extensive interviews, we have created a summary document that describes relevant components of smart ports, their use in maritime transportation, relevant vulnerabilities they introduce, and potential disruptions related to that component. The draft summary document has been shared with selected stakeholders.

7. Great Lakes Disruption Factors Summary: Based on a literature review, extensive interviews, and participation in an exercise, we have created a draft table of key factors affecting the MTS and the supply chain in the Great Lakes, factors such as dependence on international cooperation, narrow waterways between lakes and along the St. Lawrence Seaway, variable and

unpredictable ice seasons, old infrastructure, invasive species, numerous vulnerable rail crossings, limited salvage and fire-fighting and ice-breaking capability. The Coast Guard has told us this is very valuable.

8. “West Coast Scenario”: We finalized a case study analysis for the “West Coast Whammy Scenario,” which is a combination of a labor strike, power outage caused by a wildfire, and terrorist incident involving a radiologic device in a shipping container. The analysis advances the state-of-the-art threat analysis of the overlap and timing of three threats. We gained insights on resilience from expert interviews, reflected that in a simulation of several resilience tactics, and improved the methodology of linking ship-rerouting to the CGE model. A paper about this work was submitted during this period to *Transportation Research Part D*, following constructive feedback from a primary screening by the journal’s section editor. A paper for the trade journal *Pacific Maritime* was prepared and has now appeared. Presentations about this work were presented during this period to the Annual Meeting of the International Society for Integrated Disaster Risk Management (IDRiM) in August 2024 and to the Annual Meeting of the North American Regional Science Council, New Orleans, LA, in November 2024.

9. Low Water on the Mississippi. Our work on this scenario was completed in the previous year and has now been accepted for publication in the journal *Risk Analysis*. It was also presented at a meeting of the European Association of Environmental and Resource Economists in July 2024.

10. New York Scenario. There continues to be great interest in the New York scenario, which is a combination of port congestion, shipping accident, and malware attack. Of particular note is the interest in the scenario on the part of the USCG Sector New York, Port Authority of New York New Jersey, the Shipping Association of New York, and the private sector including Maher Terminals. This has led to numerous discussions and meetings to help us modify and refine the scenario to make it more complex but also more relevant. We have made significant progress on the scenario in this reporting period. The scenario has been specified in much greater detail than we originally thought necessary, thanks to detailed discussions with SMEs and stakeholders, the necessary commodity trade data has been obtained, and expert interviews on resilience completed. Analysis using the MCAT tool was well underway when the project was terminated. A research paper discussing the scenario has been drafted.

11. MCAT Tool: The MCAT tool was virtually fully programmed and ready for delivery at the end of Year 3, but we continued to develop it during Year 4, through applications to specific scenarios that the project continued to work on. MCAT aims to develop a rapid estimation capability for the economic consequences of maritime threats, including cyber threats. The research is an extension of the successful “reduced form” approach to transforming sophisticated complex models into accessible decision-support tools in the development of CREATE’s Economic Consequence Analysis Tool, or E-CAT. Unlike the E-CAT modules that

are only intended to provide ballpark estimates, the MCAT tool is able to provide accurate estimates based on a variety of threats and responses since it is based on more extensive sets of data and more intensive stakeholder input. It is also especially well-suited to addressing supply-chain issues. The model takes uncertainties into account, thereby providing confidence intervals over a range of estimates. The tool is intended to help high-level decision-makers in the MTS domain assess the severity of various threats and make evidence-based decisions. It is intended to serve as a valuable tool for risk-benefit analysis, as the benefits of reducing threats are essentially the averted negative consequences. The tool is intended to reveal qualitative and quantitative differences in preparedness, response, and MTS recovery activities that existing models and policies overlook. The tool's robust economic consequence modeling incorporates input from a broad range of stakeholders that should be included in planning and post-incident decision-making. Since effective response to complex disruptions will likely require a greater scope of authorities and capabilities than other events, the tool provides a way to bring the needed agencies and organizations into the process and help them plan for complex disruptions. As a result, resource allocation decisions will be more evidence-based than otherwise would be. Development of the tool has required extensive use of computable general equilibrium (CGE) modeling infrastructure procedures; evaluation of alternative methods to incorporate constraints in the model relating to export disruptions by suppliers and input disruptions to customers; development of a "looping" algorithm to be able to generate in a facile way hundreds of simulations automatically combining Monte Carlo methods and CGE solution algorithms; and sensitivity analyses of key parameters (primarily inputted import substitution possibilities). A software disclosure filing USC 2023-144 for the MCAT tool was initiated at the University of Southern California.

12. Publications: We recently had a refereed paper accepted in the journal *Risk Analysis* (Chen, et al., 2025) and appear in *Pacific Maritime* (Tucci, et al., 2025). We have had refereed articles in *Coast Guard Proceedings* (Tucci, et al., 2023), *Ports & Harbors* (Vijayagopal, et al., 2022), *Port Technology* (Roberts, Tucci, and Vijayagopal, 2022), *Proceedings of the IEEE International Conference on Technologies for Homeland Security* (Egan, et al., 2022, which won a best paper award), *Applied Economic Policy and Perspectives* (Rose, Chen, and Wei, 2023), *Proceedings of Western Decision Sciences Conference* (Baveja, et al., 2024), *Social Science Research Network* (Chen, et al., 2024A). Chen, et al. (2024B) is under review at *Transportation Research D*.

13. Presentations: In addition to presentations to government committees as described earlier, presentations have been made at the Western Economic Association Meetings (July 2022), the Society for Risk Analysis Meetings (Dec. 2022), the Allied Social Science Association Meetings (Jan. 2023), Annual Global Trade Analysis Project (GTAP) Conference (June 2023), Annual Conference of the International Society for Integrated Disaster Risk Management (Sept. 2023), Annual Meeting of the North American Regional Science Association (Nov. 2023) Western Decision Sciences Conference (2024) and the European Association of Environmental and Resource Economists (July 2024).

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