

A Resilience Assessment Framework for Infrastructure and Economic Systems:

Quantitative and Qualitative Resilience Analysis of Petrochemical Supply Chains to a Hurricane

Eric Vugrin, Drake Warren, and Mark Ehlen
Sandia National Laboratories

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U.S. Department of Homeland Security
Science and Technology Directorate



Critical Infrastructure Systems Face an Array of Threats

- “...protection, in isolation, is a brittle strategy”
- The nation needs to prepare for disruptive events
- Stakeholders need to understand how critical systems absorb, adapt, and recover from disruptive events
- Resilience analysis is critical to the nation’s preparation for disruptive events



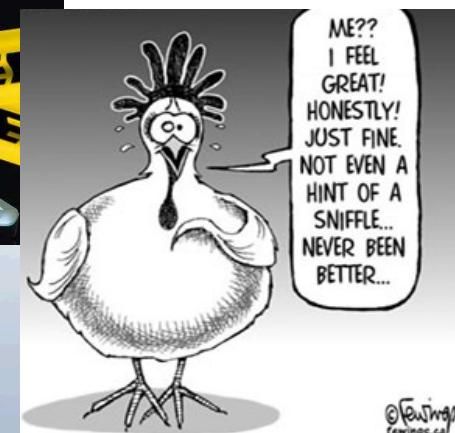
Hurricane Flooding



Terrorist Attacks



Cyber Attacks



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Pandemic Flu



Challenges in Critical Infrastructure Resilience Assessment

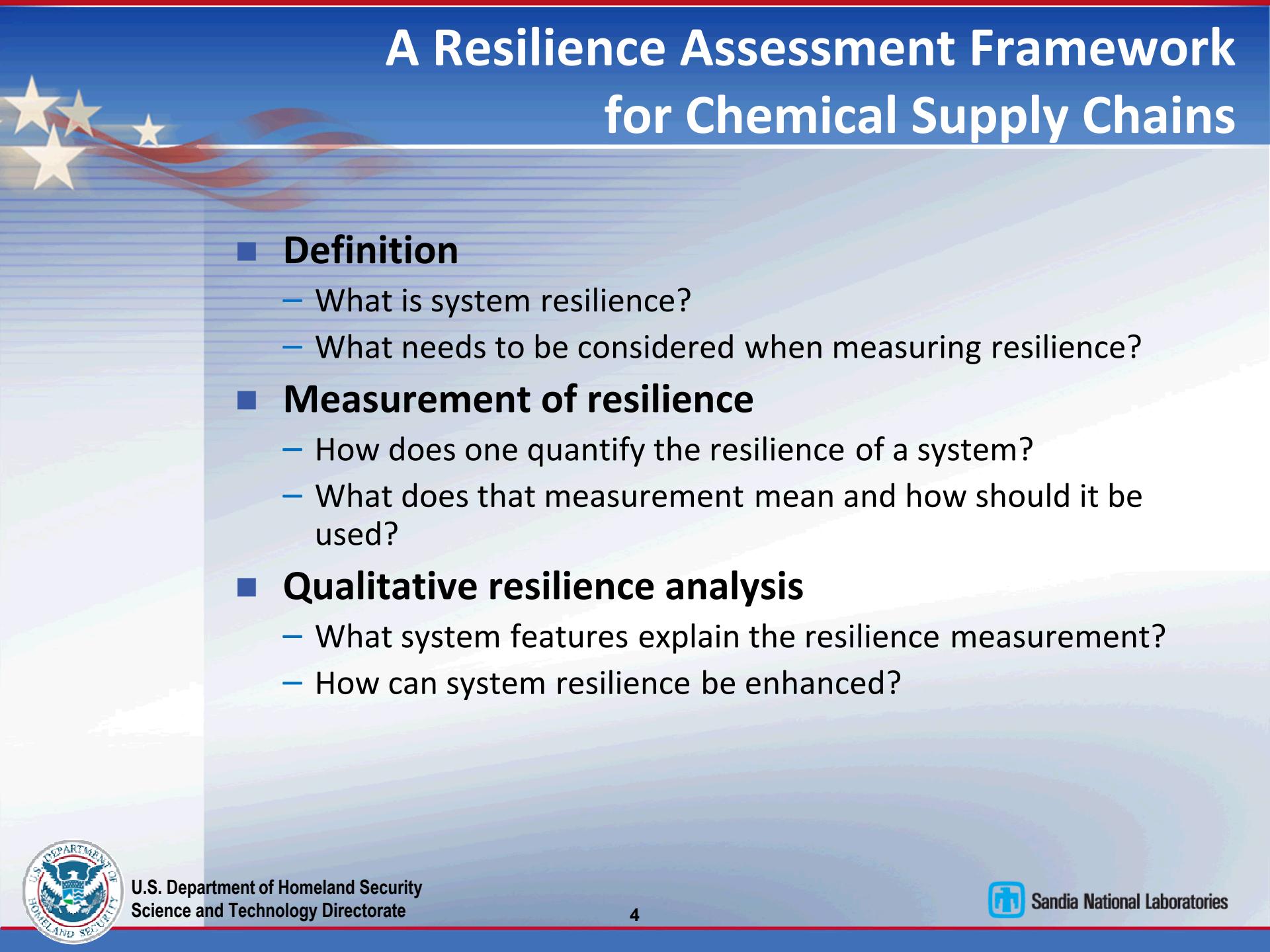
- Critical infrastructure resilience (CIR) policy^{jaj1} is a national priority, but several obstacles must be overcome before it can be widely enacted
 - There is no single widely-accepted definition of resilience
 - There is a lack of generally applicable analysis methods
 - Only impacts to system productivity, and not recovery costs, are generally considered in current approaches

Sandia National Laboratories, under funding from the Department of Homeland Security Science and Technology Directorate, has developed a resilience assessment methodology that addresses these challenges.



Slide 3

jaj1 Needed another word here. Will this one work?
jajone, 3/3/2010



A Resilience Assessment Framework for Chemical Supply Chains

■ **Definition**

- What is system resilience?
- What needs to be considered when measuring resilience?

■ **Measurement of resilience**

- How does one quantify the resilience of a system?
- What does that measurement mean and how should it be used?

■ **Qualitative resilience analysis**

- What system features explain the resilience measurement?
- How can system resilience be enhanced?



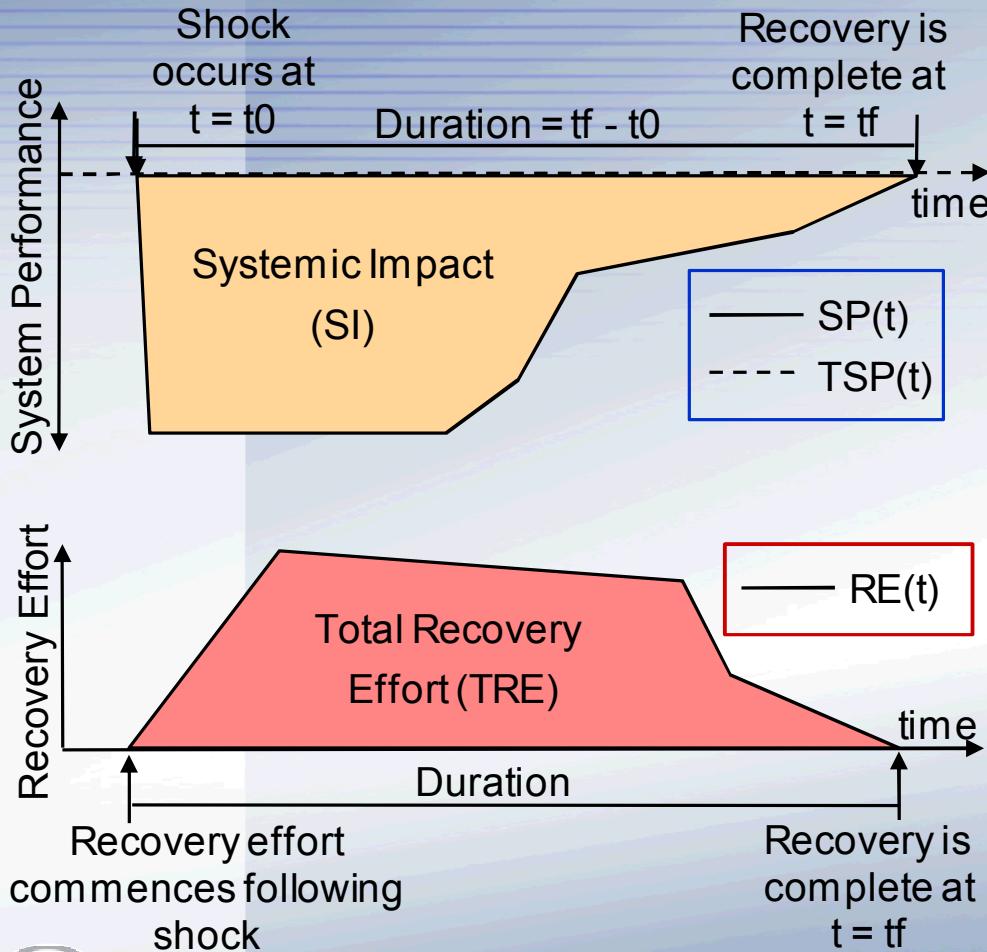
A Proposed Definition for Resilience

- “Given the occurrence of a *particular, disruptive event* (or set of events), the resilience of a system to that event (or events) is the ability to *efficiently reduce* both the *magnitude* and *duration* of the *deviation from targeted system performance* levels.”
 - Need to consider resilience in the context of a particular event
 - Efficiency refers to the costs associated with absorbing, adapting, and/or recovering from disruptions
 - System performance losses and costs are determined by the magnitude of impacts and their duration
 - “Targeted” system performance levels may be very different from pre-event performance levels; that is, a different state may be more desirable.

This definition is specifically created for the measurement and design of critical infrastructure resilience.



Calculation of Resilience Costs



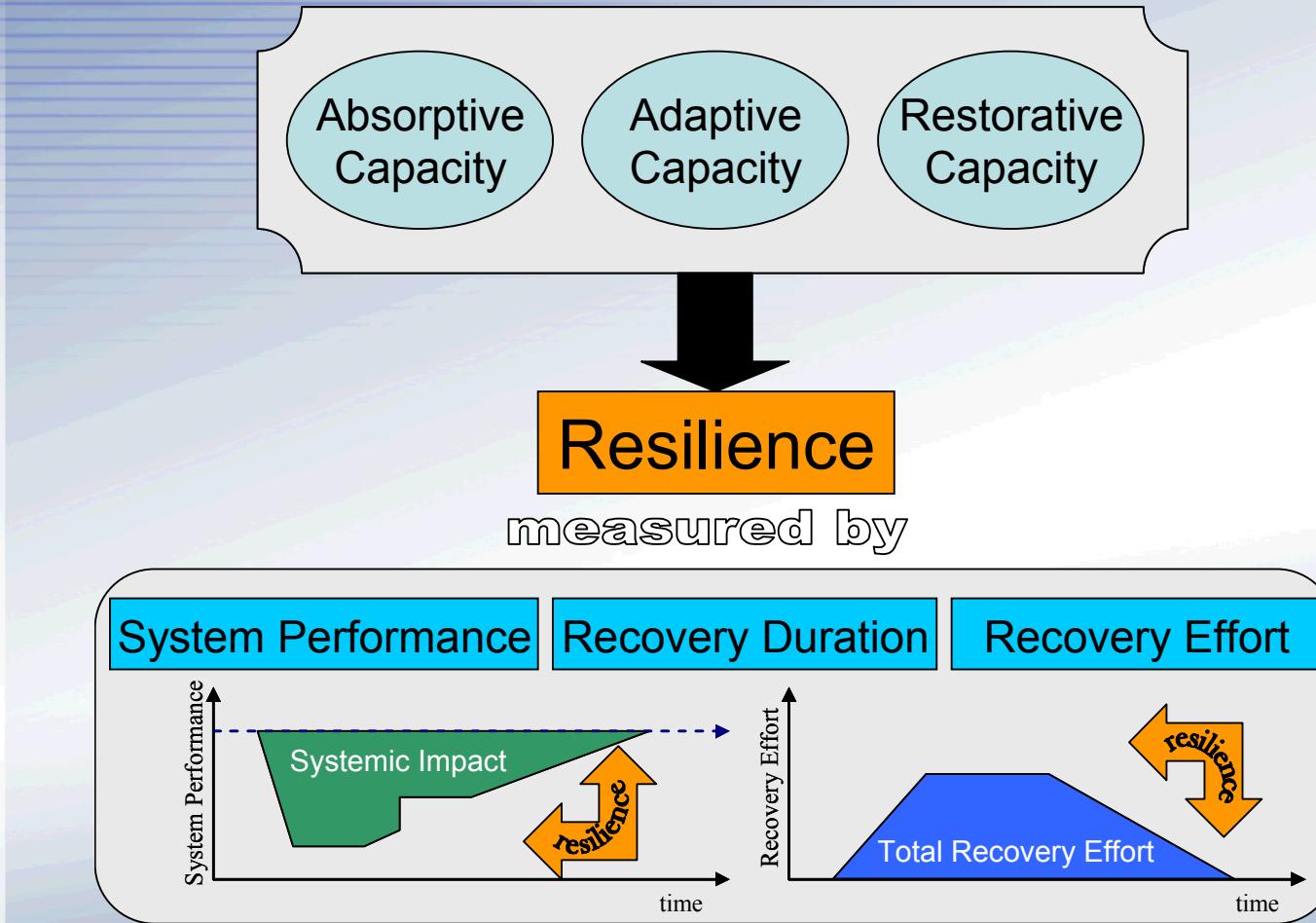
Resilience Costs

=

$$\frac{SI + \alpha \times TRE}{\int_{t_0}^{t_f} |TSP(t)| dt}$$



A System has Fundamental Characteristics that Determine its Resilience



Impacts to the National Petrochemical Supply Chain

- Compare resilience under two hurricane scenarios
- Affected facilities shut down 25 days
 - No production or demand at these facilities
- Systemic impact measured in terms of market value of chemical production
 - “Street value of chemicals”
- Recovery costs include
 - Increased marketing
 - Increased transportation costs
- Agent-based supply chain model studies impacts and recovery efforts

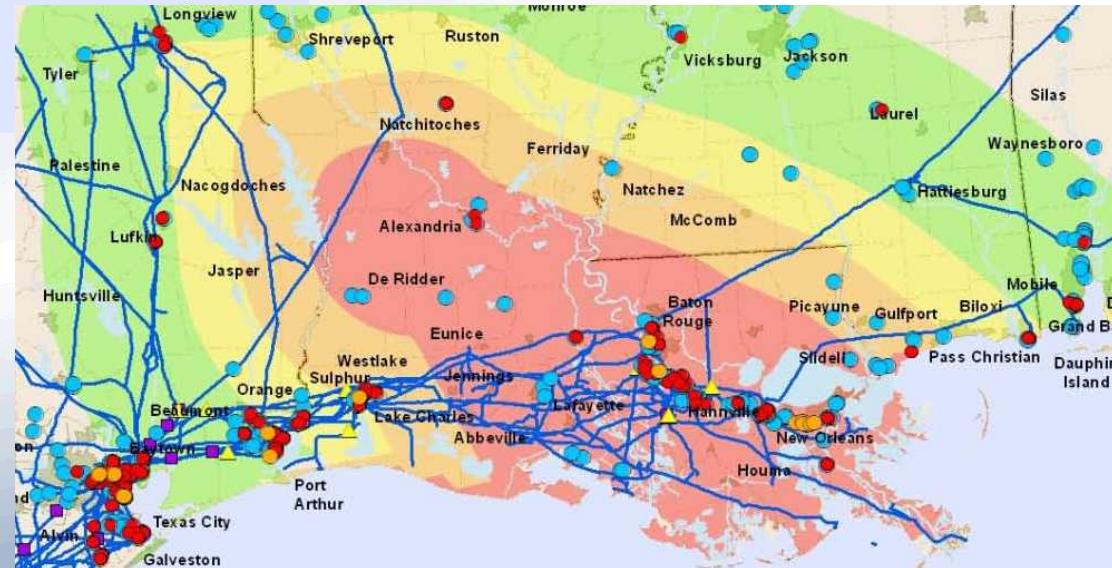


Test Case: Scenario Power Outage Contours



New Orleans Scenario

- 886 chemical firms
- 68 % of production capacity
- 75% of demand capacity

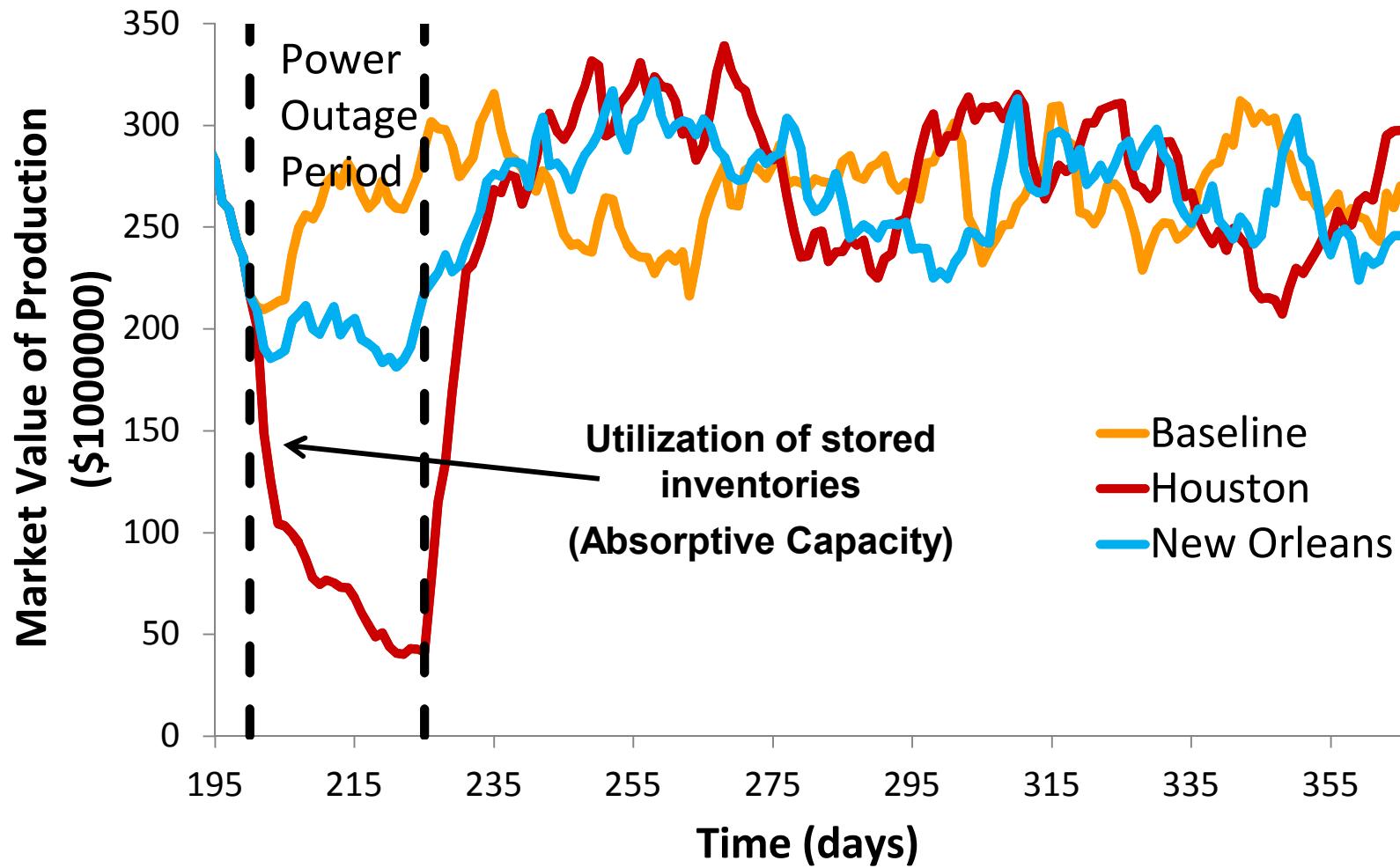


Houston Scenario

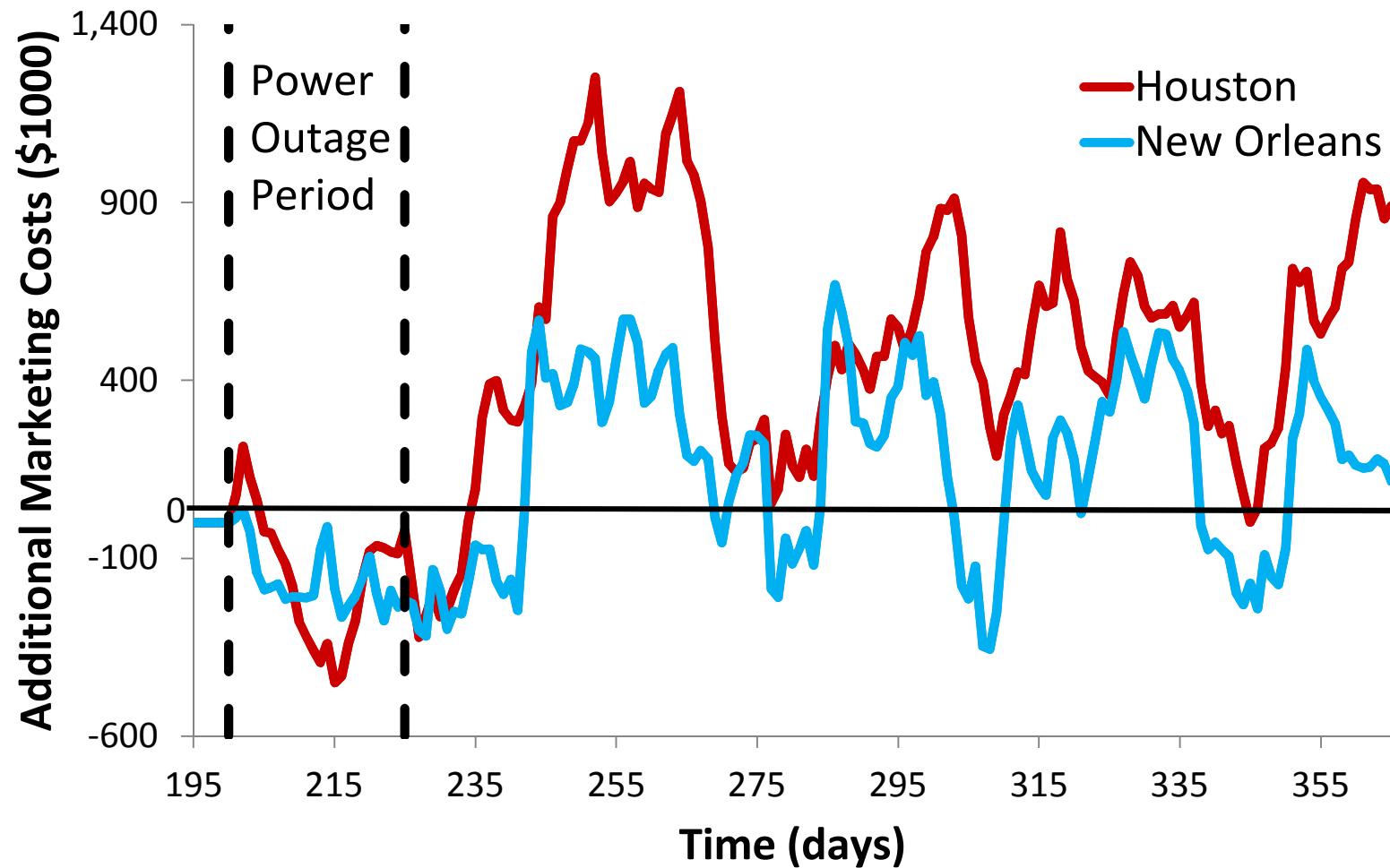
- 1,390 chemical firms
- 81 % of production capacity
- 53% of demand capacity



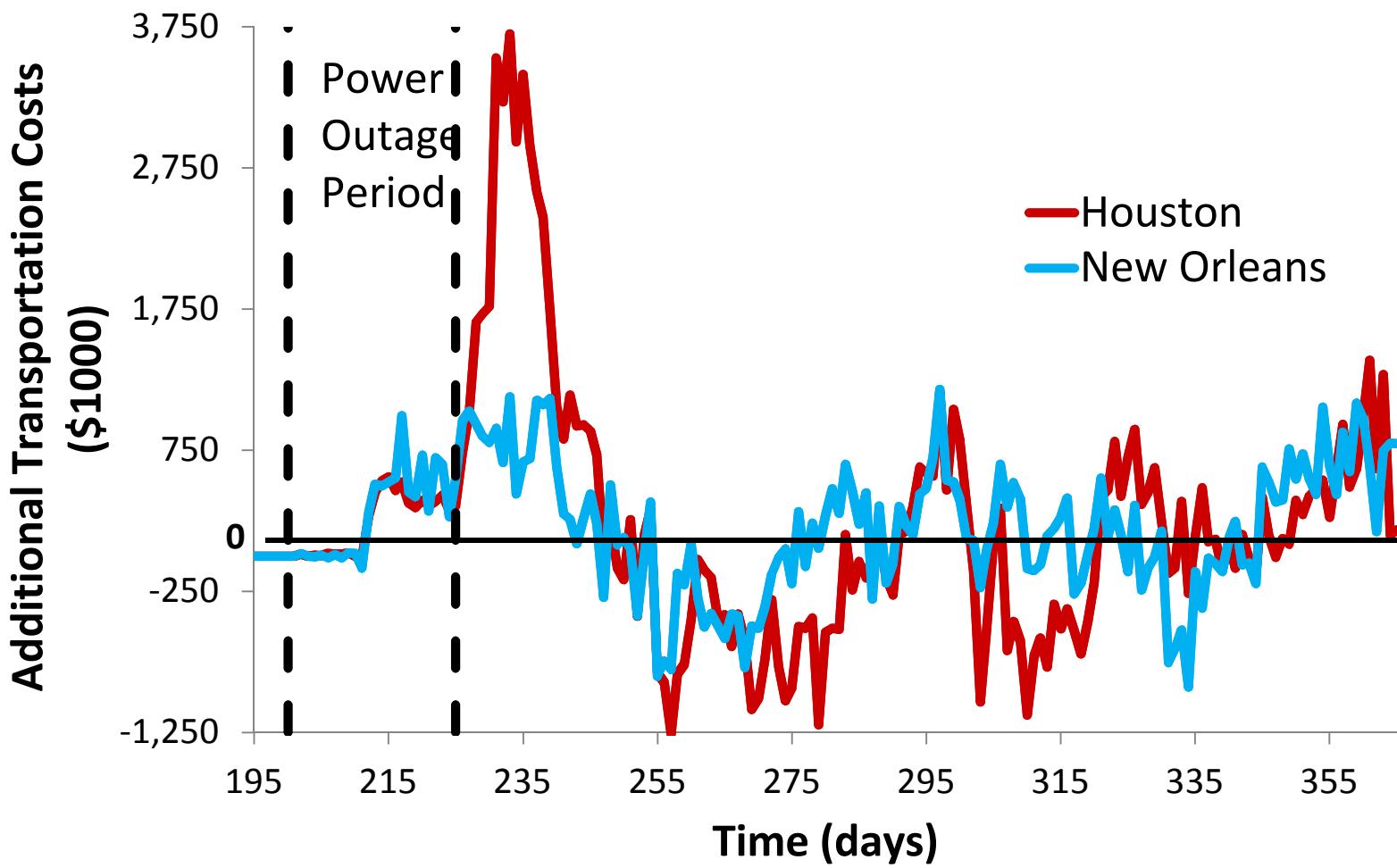
Test Case: Systemic Impact



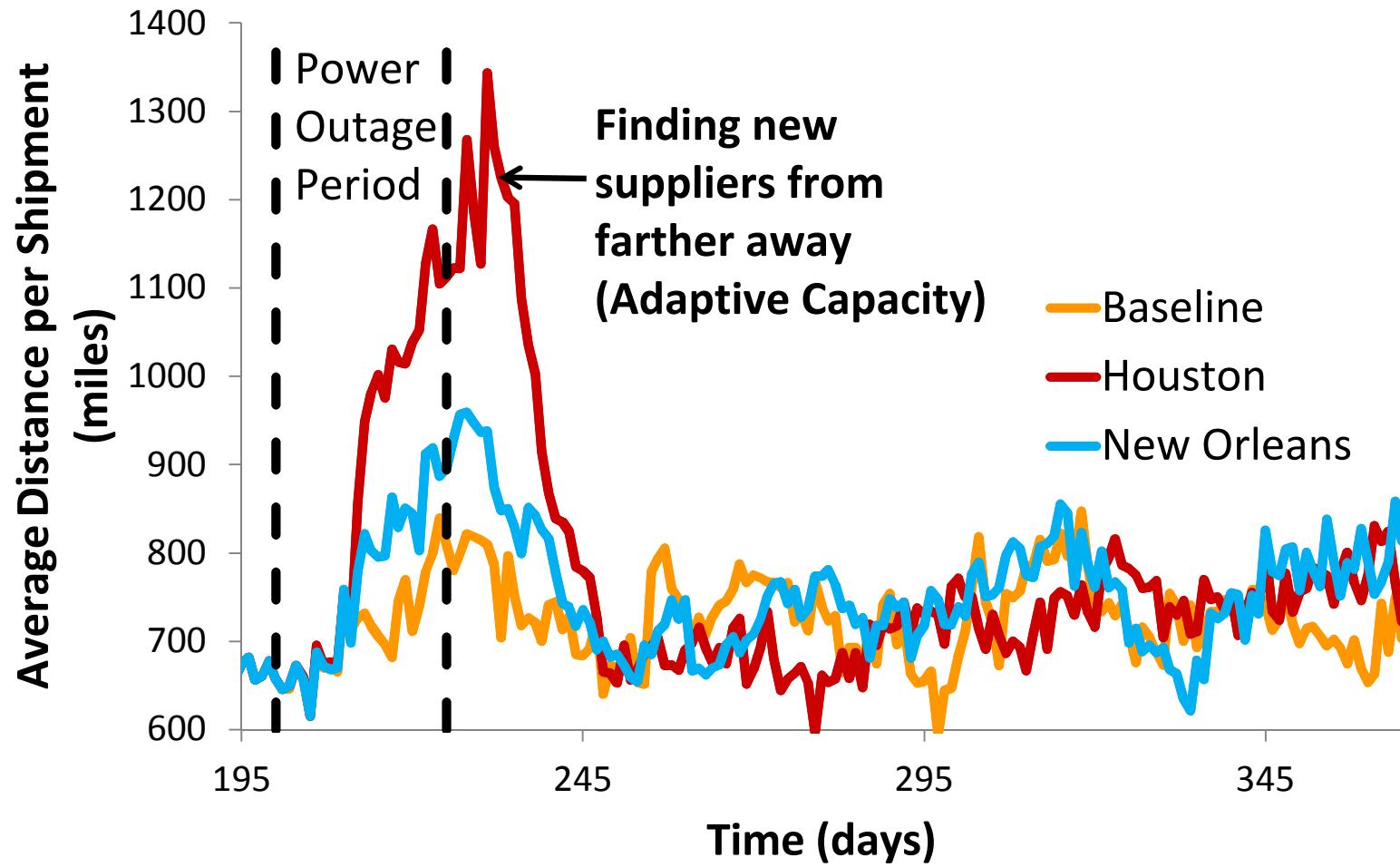
Test Case: Marketing Costs



Test Case: Transportation Costs



Test Case: Shipping Distances



Test Case: Resilience Costs Calculations

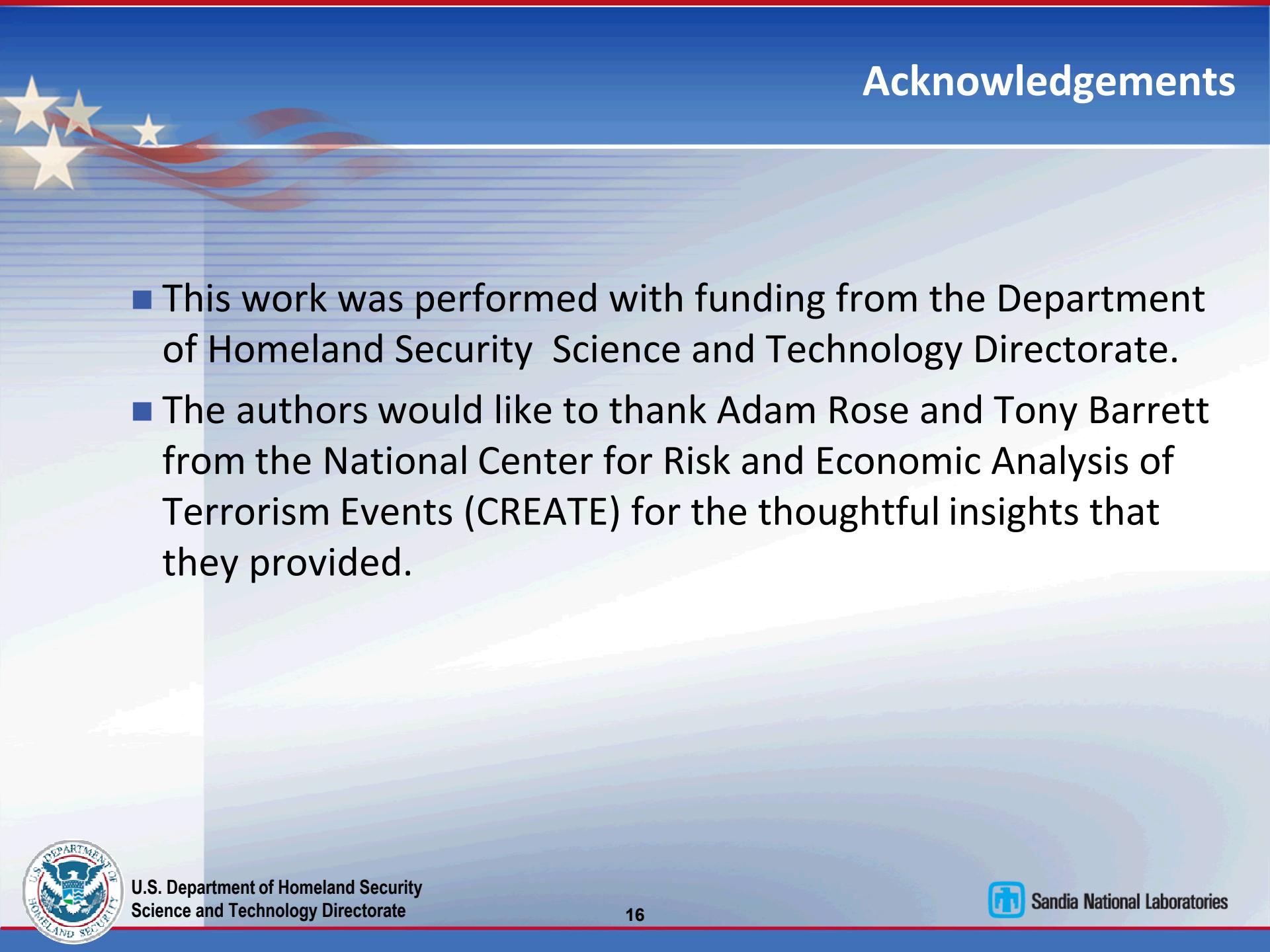
Measure	Houston Hurricane	New Orleans Hurricane
Target Market Value of Production (\$M)	20,000	20,000
Systemic Impact (\$M)	3,600	600
Recovery Effort: Market (\$M)	23	3.9
Recovery Effort: Transportation (\$M)	32	14
Resilience Cost	0.19	0.03

- All Houston scenario cost categories exceed New Orleans cost categories
- Systemic impact dominates recovery costs in both scenarios
- Lower resilience costs imply the petrochemical sector is more resilient to the New Orleans hurricane



- **The development of uniform infrastructure resilience analysis tools and methodologies is critical to improving resilience**
- **This project has made progress towards this goal, but feedback from the chemical sector will facilitate its applicability by**
 - Identifying metrics the sector considers important for measuring system impacts
 - Identifying processes the sector uses to recover and a means for estimating the costs of those processes
 - Suggesting datasets to validate models and analyses
 - Providing general insights on what makes the chemical sector more/less resilient





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