CASE STUDY:
CUMBERLAND/TENNESSEE RIVER INLAND WATERWAY RESILIENCE ANALYSIS
IN SUPPORT OF THE DHS/USACE PORT RESILIENCE GUIDE

Janey Camp, PI
Craig Philip, Co-PI
Miguel M. Moravec
STUDY REGION OVERVIEW

INLAND WATERWAYS SUPPORT TENNESSEE'S KEY INDUSTRIES

<table>
<thead>
<tr>
<th>Industry Sub-Category</th>
<th>Percent of Goods Shipped by Water (Tons)</th>
<th>Direct Tennessee Jobs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop production</td>
<td>34.2% of inbound</td>
<td>1,860*</td>
</tr>
<tr>
<td></td>
<td>15.0% of outbound</td>
<td></td>
</tr>
<tr>
<td>Utilities</td>
<td>12.0% of inbound</td>
<td>3,560</td>
</tr>
<tr>
<td>Transportation** &amp; Warehousing</td>
<td>8.3% of inbound</td>
<td>38,560</td>
</tr>
</tbody>
</table>

*Total for Agriculture, Forestry, Fishing, and Hunting sector (NAICS 11)
**Related to water transportation

TOP INLAND WATERWAYS COMMODITIES BY WEIGHT (comprising 62% of total tonnage)

- Sand, gravel, coal, clay, salt, and slag: 9.4 million tons
- Coal, flight, and coal coke: 6.2 million tons
- Petroleum products: 3.4 million tons

TOP INLAND WATERWAYS COMMODITIES BY VALUE (comprising 65% of total value)

- Gasoline: $1.3 billion
- Fuel Oils: $1.2 billion
- Transportation equipment, including motor vehicles and engines: $857.7 million

TENNESSEE'S INLAND WATERWAY ASSETS AT A GLANCE

- Tennessee, Mississippi, and Cumberland Rivers
- 5 public ports

In 2018, 30.8M tons of freight valued at $5.2 BILLION moved on Tennessee's inland waterways, which is equivalent to 770,000 TRUCKS. Avoided trucks translate into reduced congestion, emissions, and crashes, lessening impacts on highway infrastructure.
KEY RESEARCH QUESTIONS

• Can we ID Ports/Docks/Terminals that can transfer cargos to/from other modes to provide redundancy in the face of disruption and provide system redundancy?

• What are the impacts of natural hazard events on the IW System Operation and Delivery of Commodities?

• Can the Inland Waterway System ensure petroleum product supply to Middle & East Tenn if Colonial Pipeline is disrupted?
PROJECT ACTIVITIES/TASKS

1. Plan and Convene 2 Stakeholder Roundtable Sessions
2. Prepare summary of Priorities and Takeaways from the Stakeholder roundtables
3. Identify and secure necessary data to Characterize the System
4. Apply Guide methodology/approach and/or RRAP approaches to characterize/evaluate region
5. Identify and evaluate 3 disruption scenarios
6. Estimate impacts for each scenario on the case study area & the petroleum supply chain
7. Identify potential operational resilience strategies including operational variability and recovery time, etc.

Source: Forthcoming DHS Port Resilience Guide
Inland Waterway Case Study

**TIER 1**
- Seek to understand and prioritize the critical functions of the system
- **Outcomes** — quickly IDs critical functions, key sectors, stakeholders and any gaps or easy wins. If more information is needed to control for resilience, proceed to Tier 2.

**TIER 2**
- ID structure of the system including cascading events during disruption by utilizing both experts and observational data
- **Outcomes** — reveal structure of system and interrelated components to be able to compare project or investments.

**TIER 3**
- Analyze the system’s key functions and structure throughout disruptions and drops in function
- **Outcomes** — qualitative metrics and understanding of the recovery process in order to ID intervention opportunities and management plans.

Source: Forthcoming DHS Port Resilience Guide
CHARACTERIZING THE REGION

- Considering key assets and infrastructure
- Evaluating connectivity and opportunities for multi-modal transfers
- Reviewing historical commodity flows (including during times of disruption)
- Identifying disruptions and potential impacts
CHARACTERIZING THE REGION

Cheatham Lock Tonnages, Nashville Market

Pickwick Lock Tonnages, Chattanooga Market
STAKEHOLDER INVOLVEMENT - MTG 1

**Marine/Barge Carriers**
- AWO
- Tenn-Cumberland Waterways Council
- HF Lines
- Ingram Barge Company

**Shippers**
- TVA
- Pine Bluff Aggregates
- Waterways Council

**State Government**
- TDOT
- KY Transp. Cabinet
- TEMA
- KY EMA
- AL DOT

**Infrastructure Owners/Operators**
- US Army Corps of Engineers– Nashville District
- TVA
- Columbia Pipeline

**Terminal/Port Operators**
- Pine Bluff Aggregates
- HF Lines
- Grand Rivers Terminal (Watco)
- Port of Decatur
- Jasper Industrial Park

**NGO's**
- Cumberland River Compact
- TRVA

**Research**
- TRB Inland Waterway Committee
- TRB Resilience Section
- Marine Board

**Planning Agencies**
- Greater Nashville Regional Council
- Chattanooga TRHIVE

**Others**
- DHS CISA
- US Army Corps of Engineers - ERDC
- PHMSA
- US DOT / CMTS
STAKEHOLDER INVOLVEMENT – MTG 1

• Key Assets Identified
  • Port of Memphis Intermodal Hub
  • Barkley Canal
  • Tennessee–Tombigbee Waterway

• Disruptions Outlined
  • Seismic, Waterway Outage, and Pipeline Disruption
  • Lack of Redundancy in Petro and other supply chains
  • Resilience Actions
DISRUPTION SCENARIOS

1. Multimodal Impact Event
   • Colonial Pipeline Spur to Tennessee

2. Lock Outage
   • Cheatham Lock and Dam Maintenance

3. Waterway Navigability Impacted by Earthquake
   • New Madrid Fault Event Impacting
     Tennessee/Cumberland/Ohio River Confluence and Bridge Crossings
DISRUPTION SCENARIO:
COLONIAL PIPELINE SPUR TO TENNESSEE, SERVICE INTERRUPTION
CONTINGENCY PLANS, IMPACTS, LESSONS LEARNED, RECOVERY AND RESILIENCE

Miguel M. Moravec
PhD Student

VANDERBILT UNIVERSITY
HISTORICAL DISRUPTIONS OF COLONIAL PIPELINE

2021 Ransomware Cyberattack

- 2017 Hurricane Harvey Closure
- 2016 Explosion Closure

Photo courtesy of Bloomberg

VANDERBILT UNIVERSITY
SINCE 2012 RIVER DELIVERED REFINED PETROLEUM HAS SUPPLEMENTED THE COLONIAL PIPELINE INTO THE NASHVILLE MARKET
## Major SE Markets Served by the Colonial Pipeline

<table>
<thead>
<tr>
<th>City</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nashville, TN</td>
<td>692,587</td>
</tr>
<tr>
<td>Chattanooga, TN</td>
<td>179,690</td>
</tr>
<tr>
<td>Knoxville, TN</td>
<td>186,173</td>
</tr>
<tr>
<td>Raleigh, NC</td>
<td>464,485</td>
</tr>
<tr>
<td>Charlotte, NC</td>
<td>857,425</td>
</tr>
<tr>
<td>Asheville, NC</td>
<td>91,560</td>
</tr>
</tbody>
</table>

Source: New York Times
WHAT HAPPENED DURING LAST MONTH’S PIPELINE DISRUPTION?

• Source: GasBuddy
  • Quoted by NPR, WSJ, the Tennessean
  • Daily Gas Station Outages by city, daily
  • Largest gas price discovery platform in North America
  • Caveat: crowdsourced
GAS BUDDY DATA CAN MEASURE THE DISRUPTION IMPACT AT THE LOCAL LEVEL

<table>
<thead>
<tr>
<th>City</th>
<th>7th Day Station Outages (%)</th>
<th>12th Day Station Outages (%)</th>
<th>Annual Petro Flux (kt)</th>
<th>Population [43]</th>
<th>Per Capita Petro barge Volumes (kt/person)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nashville, TN</td>
<td>34.4</td>
<td>18.9</td>
<td>1715</td>
<td>692,587</td>
<td>0.002476</td>
</tr>
<tr>
<td>Chattanooga, TN</td>
<td>44.6</td>
<td>34.1</td>
<td>158</td>
<td>179,690</td>
<td>0.000879</td>
</tr>
<tr>
<td>Knoxville, TN</td>
<td>41.4</td>
<td>31.6</td>
<td>85.83</td>
<td>186,173</td>
<td>0.000461</td>
</tr>
<tr>
<td>Raleigh, NC</td>
<td>75.7</td>
<td>44.1</td>
<td>0</td>
<td>464,485</td>
<td>0</td>
</tr>
<tr>
<td>Charlotte, NC</td>
<td>66.4</td>
<td>41.6</td>
<td>0</td>
<td>857,425</td>
<td>0</td>
</tr>
<tr>
<td>Asheville, NC</td>
<td>73</td>
<td>60.1</td>
<td>0</td>
<td>91,560</td>
<td>0</td>
</tr>
</tbody>
</table>
WATERBORNE PETRO VOLUMES & GAS STATION OUTAGE ANALYSIS

7th Day Log Model

Per Capita Petro barge Volumes

Gas Station Outages (%)

12th Day Log Model

Per Capita Petro barge Volumes

<table>
<thead>
<tr>
<th>Statistical Metrics</th>
<th>7th Day Linear Model</th>
<th>7th Day Log Model</th>
<th>12th Day Linear Model</th>
<th>12th Day Log Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-Value</td>
<td>0.05409</td>
<td>0.03488</td>
<td>0.04407</td>
<td><strong>0.01105</strong></td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.5571</td>
<td>0.6391</td>
<td>0.5973</td>
<td><strong>0.7917</strong></td>
</tr>
<tr>
<td>Std. Error</td>
<td>.00001634</td>
<td>0.000788</td>
<td>.00001985</td>
<td>.0000507</td>
</tr>
</tbody>
</table>
Q: To what extent can the inland waterway system ensure supply of petroleum products to the Middle and East Tennessee regions during a disruption of the Colonial Pipeline?

A: Supply disruption in Nashville was much lower than reported in other markets.
RESILIENCE ENHANCEMENT OPTIONS (REOs) IDENTIFIED IN PREVIOUS DHS MARINE RELATED PROJECTS

• Compile and Document Information
  • Infrastructure vulnerabilities and priority list for repair
  • Critical infrastructure lists
  • Roles/responsibilities during disaster scenarios
  • Standard and alternate operating procedures

• Collaborate and Coordinate
  • Host a series of planning workshops to familiarize partners with risk
  • Inform public and private entities of relevant vulnerabilities to systems and provide support for enhancing resiliency
  • Work collaboratively with local, state, and federal emergency management organizations

• Improve existing infrastructure
  • Address aging infrastructure (bridges, locks, dams)
  • Undertake soil liquefaction mitigation efforts in earthquake prone areas
  • Share results of natural hazard modeling on facility specific basis to encourage owner/operator hazard mitigation planning

• Incorporate Additional Tools
  • Vessel Queue Prioritization and Sorting Tool (USCG)
  • Cyber Security Evaluation Tool (CSET) and Cyber Resilience Review (CRR)
EXAMPLES OF RESILIENCE ENHANCEMENT OPTIONS RELEVANT TO THE STUDY AREA

• Expand Chattanooga and Knoxville terminals to accept fuel barges
  • Theme: Improve existing infrastructure
  • Note: Colonial pipeline purchased one of the fuel terminals in Chattanooga, so when their services went offline it impacted that terminal as well

• Increase Traffic on Tombigbee River
  • Theme: Collaborate and Coordinate
  • Scenarios: Earthquake impacting Mississippi river, shutdown of colonial pipeline
  • Note: TennTom much narrower than Cumberland, Tennessee rivers

• Update Building Codes
  • Theme: Improve existing infrastructure
  • Scenarios: All
  • Proactive building codes are among best mitigation techniques
STAKEHOLDER MEETING 2

Disruption Scenario 1 – Multimodal Impacts

- Colonial Pipeline Spur to Tennessee, Service Interruption
  - Megan Simpson – USACE Nashville District
  - Ben Bolton – TDEC Office of Energy Program's (OEP)
  - Barry Gipson - James Companies, former Pipeline Company Executive
  - Moderator: Miguel Moravec – Vanderbilt University

Takeaways

- Develop additional liquid bulk waterway terminal capacity
- Identify mothballed terminals, especially near multimodal assets
- Continue strong industry / government collaboration
Disruption Scenario 2 – Lock Outage

- Cheatham Lock and Dam Maintenance
  - Megan Simpson – USACE Nashville District
  - Gene Whelan - Pine Bluff Materials, Operator of Largest Multicommodity Marine Terminal on the Cumberland River
  - Steve Southern - Ingram Barge Company, Activation of Waterway Action Plans to Improve Stakeholder Coordination
  - Moderator: Craig Philip – Vanderbilt University

Takeaways:

- Update Building Codes
- Continue strong industry / government collaboration
STAKEHOLDER MEETING 2

Disruption Scenario 3 – Waterway Navigability Impacted by Earthquake

- New Madrid Fault Event Impacting Tennessee/Cumberland/Ohio River Confluence and Bridge Crossings
  - James M. Wilkinson, Jr. – Executive Director, CUSEC (Central US Earthquake Consortium)
  - Ben Bolton – TDEC Office of Energy Program's (OEP)
  - Moderator: Janey Camp - Vanderbilt University

Takeaways:

- Increase Traffic on Tombigbee River
- Update Building Codes
- Rely on resilient, alternate energy sources / vehicles
PROJECT ACTIVITIES/TASKS

1. Plan and Convene 2 Stakeholder Roundtable Sessions
2. Prepare summary of Priorities and Takeaways from the Stakeholder roundtables
3. Identify and secure necessary data to Characterize the System
4. Apply Guide methodology/approach and/or RRAP approaches to characterize/evaluate region
5. Identify and evaluate 3 disruption scenarios
6. Estimate impacts for each scenario on the case study area & the petroleum supply chain
7. Identify potential operational resilience strategies including operational variability and recovery time, etc.
VANDERBILT CENTER FOR TRANSPORTATION AND OPERATIONAL RESILIENCY (VECTOR)

For information, contact:
Craig Philip – craig.e.Philip@vanderbilt.edu, or
Janey Camp – janey.camp@vanderbilt.edu, or
Miguel Moravec – miguel.moravec@vanderbilt.edu

https://www.vanderbilt.edu/vector/