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Transportation Asset Exposure, Adaptation Alternatives, and Infrastructure Resilience: Steering Committee Project Appraisal

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The Economic Impacts of Sea-Level Rise in Hampton Roads: Transportation Asset Exposure, Adaptation Alternatives, and Infrastructure Resilience

Steering Committee Project Appraisal

Bahar Barami, Ph.D., May 18, 2016
USDOT/Volpe Overall Scope and Timeline

- **Quantifying** scale/scope of climate change risks
- **Inventory** data sources and baseline conditions
  - Estimates the value of the transportation infrastructure assets at risk of damage from sea-level-rise (SLR) and flooding;
- **Evaluating** conventional models and tools
  - Regional economic impacts of SLR and flooding
- **Identifying** infrastructure adaptation measures
  - Cost-effective reduction of SLR/flooding vulnerabilities, and ultimately climate-change resilience;

Task 1a Scoping Paper (distributed to stakeholders outside USDOT and available for others):
- Existing transportation asset information, including condition, gaps, vulnerabilities, geographic attributes, resistance to climate stressors, exposure to damage and overall system impacts
Approach

Analyzes Infrastructure Resilience as a function of a region’s ability to:

- **Identify vulnerabilities** to climate risks and prepare to **mitigate** them;
- **Quantify the economic impacts** of SLR and flooding;
- **Chart alternative pathways for adapting** to the risks;
- **Implement** effective and cost-beneficial **adaptation actions**;

Informative Models:

- NOAA and VIMS regional hydrological climate models;
- FEMA’s HAZUS-MH database for a GIS-based inventory of the potential scale of direct loss of asset value;
- Damage-cost data from SHELDUS database on county-level property damage from flooding, hurricane, coastal surges, and severe storms, 1960-2014;
- NOAA historical weather-related data on county-level property damage;
- Economic impact estimates from Input-Output (I-O) models (e.g., REMI, RIMS !!, IMPLAN; CGE), regional planning agencies (HRPDC, HRTPO), and Sandia’s REAcct I-O model.
Climate Risk Components

Risk = \( f(\text{Hazard Frequency}_{\text{event probability}} \times \text{Asset Exposure}_{\text{assets at risk of loss}} \times \text{Vulnerability}_{\text{asset sensitivity}} \times \text{Consequences}_{\text{value of losses/severity}}) \)

Measured as a function of three key metrics:

- **Sea-Level Rise (centennial SLR of 1.5 ft.; VIMS: a potential SLR of 1.5 ft. between 2032 and 2065);**
- **Storm Surge and Flooding (recurrent flooding due to low-lying topography);** and
- **Land Subsidence.**

These hazards create a greater likelihood of flooded roadways, rail tracks, transit stations; damaged bridges/piers/airport runways; curtailed rail/air/barge/highway operations; and slope failure.

Proximity to the sea, high-density urban development, and lack of protective structures increase exposure to hazard; Norfolk’s exposure is among highest in HR, with over 10% of its infrastructure assets, valued $1.3B-$2.2B, at risk of damage from SLR and flooding.

Region-wide vulnerabilities, measured as a function of asset concentration; sensitivity to damage; the number of tunnels and bridges; and reliance on port commerce.

Magnitude of damage as a function of the scale and costs of physical infrastructure destruction, business interruption costs, and loss of access to jobs and transport.
Norfolk Transportation Network

Primary Focus: Norfolk and Pretty Lake

- **Roads and Bridges**
  - >1,000 miles of roads; 173 highway bridges; and 5 rail bridges;

- **Five major tunnels**
  - HR Bridge-Tunnel, Monitor-Merrimack Bridge Tunnel, Downtown Tunnel, Midtown Tunnel, & Chesapeake Bay Bridge-Tunnel—connecting peninsula to Norfolk and Southside

- **Norfolk International Terminals**
  - POV’s largest terminal with 1.4 million TEUs

- **Norfolk’s ORF Airport**
  - One of the region’s two primary mid-sized airports, with 1.6M annual enplanements;

- **Mass Transit**
  - The Tide Light Rail Transit, freight and commuter rail service, bus and ferry service, and the VNG natural gas pipeline provide the city with a full range of transport services.
Key Features of Norfolk’s Network

Bridges, Tunnels, and Major Highways Dominate the Norfolk Transportation Network

Norfolk’s I-64 Intersections, Tunnels, and Bridges are Major Chokepoints in the Region
## Actual and Potential Weather Damage* Estimates in Norfolk

- **SHELDUS**: $117M, or $2.2M per year
  - Over 54 years, 1960-2014
- **HAZUS-MH**: $1.4B
  - For 172 miles of highway, rail bridges and tunnels
  - $321,000 for 5 rail bridges, and $628M for 173 highway bridges; (generally considered very low estimates)
- **60% of Norfolk’s flood-prone assets in fully developed parcels**
  - SLR risk greater than more other Hampton Roads cities
  - HRPDC: 1m SLR + midlevel storm surges $1.3B-$2.2B (10% of parcel’s improvement value)
  - HRPDC: 7% of HR’s improvement value ($9B-$16.5B) carries damage risk
- **Other vulnerabilities**
  - Recurrent flooding + uncompensated business interruption loss
  - Lack of adequate private insurance protection

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*Flooding, hurricanes, coastal surges, and storm damages*
Dominant Sectors in Norfolk Economy: Potential Sources of Instability

Norfolk’s high concentration of military- and port-infrastructure assets represents potential vulnerabilities to cascading economic downturns:

- Military accounts for over 32% of civilian jobs in Norfolk; the sector’s economic impact on regional GDP is $16.6B, with $10.9B of it in local earnings;
- Ports/Transportation—with POV’s total economic impacts of $10B—and Public Administration jobs together account for another 30% of Norfolk’s employment;
- With two thirds of its jobs in three climate-sensitive sectors, Norfolk is vulnerable to severe downturns in its regional GDP, as indicated by the recent job losses and declining income levels;
Tools for Economic Impacts Analysis and Decision-Making

- **BCA models**
  - Commonly used for making funding decisions for transport improvement projects
  - Challenges with BCA: limited applications for longer-term regional planning: it fails to account for extensive spillover impacts of SLR damages, and positive regional co-benefits from investment in adaptation

- **I-O models**
  - Generates useful estimates of the economic impacts of climate disruption
  - Examples: REMI, RIMS-II, and IMPLAN, and EIA tools such as Sandia’s Regional Economic Accounting (REAcct) tool have generated useful estimates of the economic impacts of climate disruption

- **DOT Asset-Management tool, TAM**

- **IIA I-O model**

- **Multi-Criteria Decision-Making (MCDA) tools**
  - Developed for the FHWA Gulf- Coast Pilot;

- **NCHRP CAPTA tool**
  - Determines Consequence Thresholds and selecting countermeasures for adverse climate events are among potentially effective decision-making tools.
I-O Model Estimates of the Direct and Indirect Impacts of Climate-Related Disruption

Costs of Damaged Infrastructure *do not Fully Capture* the Total Economic Losses from Climate Disruption

A 2015 study by Sandia Laboratories estimated the potential range of direct economic losses from a 4-day storm-related disruption, modeled for three SLR scenario in Norfolk:

- Norfolk’s losses ranged between $26M and $56M, depending on the storm-severity scenario; these direct costs accounted for only 38% of the total losses;
- Adding the indirect costs of losses from business interruption and loss of the means of livelihood/access to jobs would raise the total losses from direct and indirect damages by a factor of 2.6, to a range of $70M to $144.6M.

### Sandia’s REAcct Tool Estimates of SLR Disruption in Norfolk

<table>
<thead>
<tr>
<th></th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annual Direct Losses</strong></td>
<td>$26.92 M</td>
<td>$39.71 M</td>
<td>$55.60 M</td>
</tr>
<tr>
<td><strong>Annual Indirect Losses</strong></td>
<td>$43.08 M</td>
<td>$63.49 M</td>
<td>$89.00 M</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$70.0 M</td>
<td>$103.2 M</td>
<td>$144.60 M</td>
</tr>
</tbody>
</table>
Frequent Flooding ➔ Rising Social Vulnerabilities

Severe climate disruption costs

**Direct damages:**
- Property losses, traffic disruptions, and destroyed transportation assets

**Indirect losses:**
- Business interruption; loss of earnings; loss of insurance protection due to frequency of disruption, and amplified effects of poverty

**Contributing Factors:**
- Frequent inundation and “nuisance flooding” (major contributor to rising economic costs of SLR).

<table>
<thead>
<tr>
<th>HR City</th>
<th># of Repetitive Loss Properties</th>
<th>Average Cost of Mitigation (000)</th>
<th>Total Cost of Mitigation (000)</th>
<th>Average FEMA Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chesapeake</td>
<td>409</td>
<td>$250</td>
<td>$102,250</td>
<td>$757K</td>
</tr>
<tr>
<td>Hampton</td>
<td>863</td>
<td>$75*</td>
<td>$64,725</td>
<td>$833K</td>
</tr>
<tr>
<td>Norfolk</td>
<td>900</td>
<td>$162.5</td>
<td>$146,250</td>
<td>$778K</td>
</tr>
<tr>
<td>Portsmouth</td>
<td>186</td>
<td>$75</td>
<td>$13,950</td>
<td>$NA</td>
</tr>
<tr>
<td>Virginia Beach</td>
<td>561</td>
<td>$185</td>
<td>$103,785</td>
<td>$725K</td>
</tr>
<tr>
<td>Total HR</td>
<td>2,979</td>
<td>NA</td>
<td>$430,900</td>
<td>NA</td>
</tr>
</tbody>
</table>

NOAA has developed a Social Vulnerability Index (SoVI)

- Norfolk, 2009: 280 “frequently flooded” or “repetitive-loss properties”¹
- Norfolk 2014: 900 structures (3x 2009)
- 2,979 repetitive property losses which were not compensated by private insurance or NFIP
- $431M in uncompensated costs, creating a large gap between what FEMA paid and what was needed for flood mitigation improvements.

1. Defined by NFIP as “properties that have experienced at least two paid flood losses of >$1000 each in any 10-year period since 1978;”
Adaptation: Scope and Scale of the Path to Alternative Solution

Adaptation\(^1\): Integrated and iterative process of accommodation, engineering protection, and retreat

- **Accommodation measures:**
  - Elevated structures (cost range: $2,000-$30,000);
  - Floatable developments (cost range: $2,000-$30,000);
  - Drainage improvements;
  - Flood Proofing existing structures;
  - Beach Nourishment (costs: $300-$1,000/ft.)

- **Engineered Protection:**
  - Storm-Surge Barriers;
  - Closure dam or movable gates/barriers: $0.7M to $3.5M per meter (plus annual maintenance);
  - Seawalls: $150-$4,000 per linear ft;
  - Levees or Dikes, at $100-$1500 per linear foot;

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1. Intergovernmental Panel on Climate Change (IPCC)
Adaptation Planning Tools: MCDA Process for Priority Setting

Multi-Criteria Decision-Making (MCDA) planning tool & IIA I-O Risk Filtering model:\(^1\):

- Assists regional planners to conduct vulnerability assessments
- Calculates scores for each candidate improvement project across several scenarios,
- Helps planners to develop a priority ranking of the LRTP projects
- Four Criteria for Prioritization
  - existing facility plans;
  - proposed LRTP and Capital Investment Plan (CIP) projects;
  - TAZ location of significant segments of the region; and
  - funding-agency multimodal policies;

### Steps MCDA Assessment Components Output

<table>
<thead>
<tr>
<th>Steps</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td>Define the criteria and assign max score (relative importance) for each [e.g., for each asset (highway, bridge, rail, transit, airport) aligning criteria: congestion system condition, cost effectiveness ($/VMT) safety/security;</td>
<td>Assigned scores and measures of criticality;</td>
</tr>
<tr>
<td>Step 2</td>
<td>Define the list of projects to be prioritized;</td>
<td>Regional CIP or equivalent project lists;</td>
</tr>
<tr>
<td>Step 3</td>
<td>Assign baseline ratings to projects defined in Step 2 according to criteria define in Step 1</td>
<td>Automatically generated ratings;</td>
</tr>
<tr>
<td>Step 4</td>
<td>Calculate the aggregated score of each project via built-in MCA criteria value function based on inputs from Step 1-3</td>
<td>Baseline project ranking</td>
</tr>
<tr>
<td>Step 5</td>
<td>Develop up to 5 default climate and non-climate scenario-conditions:</td>
<td>Conduct Scenario-based analysis based on the matrix of project scores and priorities in the corresponding check box (as in following matrix;</td>
</tr>
<tr>
<td></td>
<td>Scenario 1: Increase in SLR+ storm surge; Scenario 2: SLR + Storm Surge + economic recession; Scenario 3: SLR + Storm Surge + increased wear &amp; tear on public infrastructure; Scenario 4: SLR + Storm Surge + ecologic damage/species loss/infectious diseases; Scenario 5: SLR + Storm Surge + increased traffic density + population + tourism growth;</td>
<td></td>
</tr>
</tbody>
</table>

1. FHWA Gulf-Coast Pilots
Adaptation Planning Tools: CAPTool*

Asset management system for identifying critical or high-cost assets, appropriate countermeasures for their protection.

- 6-Step adaptation planning process
- Consequence Threshold → Countermeasure Opportunities

- **Threshold** beyond which the asset owner/operator/system-user would consider investments in countermeasures justified, in order to prevent losses or mitigate the consequences.

- For each asset, this step determines what level of risk to the *population, property or service/mission* can be addressed in the agency’s current operations;

- Determines which assets are deemed critical and require further attention:
  - *Potentially Exposed Population (PEP)*
  - *Property Loss*
  - *Mission Importance*

- Range of adaptation options that are embedded in the tool’s dictionary;
  - Prediction
  - Intelligence gathering
  - Detection
  - Interdiction
  - Response
  - Preparedness
  - Design
  - Engineering structures
    - e.g., storm barriers, seawalls, berms, retrofits, easement, asset redundancy.

- For each countermeasure, relevant costs are determined by reference to a cost estimating manual, RSMeans.

*NCHRP tool – Cost Asset Protection for Transport Agencies*
Challenge of Quantifying the Benefits of Adaptation Projects

- **Hague Flood Wall, $60M**
  - Protect against rainfall runoffs
  - Pump station to remove rainfall runoff when gate is closed
  - New storm culvert beneath the Navy berms
  - Peripheral wall when land surface is low around creek, street elevation, and other improvements;

- **Pretty Lake Flood Wall, $50M**
  - Tide gage
  - Pump station
  - Structure elevation
  - Flood wall

- **Mason Creek Pump Station, $30M**

### Adaptation Measure Examples (Norfolk)

<table>
<thead>
<tr>
<th>City of Norfolk Neighborhood</th>
<th>Proposed Adaptation and Mitigation Projects</th>
<th>Assessed Property Value in the Watershed</th>
<th>Estimated cost</th>
<th>Project Cost as a % of Property Value ($5B total assessed value in watershed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Hague</td>
<td>Floodwall Tide gate</td>
<td>$1,624 M</td>
<td>$60 M</td>
<td>3.7%</td>
</tr>
<tr>
<td></td>
<td>Pump Station</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Berms/Closure walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretty Lake</td>
<td>Tide gate</td>
<td>$1,812 M</td>
<td>$50 M</td>
<td>2.8%</td>
</tr>
<tr>
<td></td>
<td>Pump Station</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Structure elevation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mason Creek</td>
<td>Pump Station</td>
<td>$1,604 M</td>
<td>$30 M</td>
<td>1.9%</td>
</tr>
<tr>
<td></td>
<td>New storm culvert</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Peripheral Berms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Structure elevation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>NA</td>
<td>$5,040 M</td>
<td>$140 M</td>
<td>2.8%</td>
</tr>
</tbody>
</table>
Next Steps: Resilience Analysis

Volpe Resilience Framework

Systematic process for improving climate change resilience due to economic, safety, security, and operational disruption:

- Prevent,
- Protect,
- Detect,
- Avoid,
- Monitor,
- Adapt, and
- Mitigate

Future Tasks:

- Expand the analysis beyond the baseline condition inventory to include a broader infrastructure resilience approach.
- Conduct a full scale analysis of the Pilot region’s transportation risks
- Develop proposal for cost-effective mitigation/adaptation measures
- Incorporating RM goals from NASA, DOD, DHS, USACE, EPA, Regional Planning Agencies is likely to generate significant regional benefit multiplier effects.
Next Steps: Close Data Gaps

- **Reducing the Siloes of Databases and Estimating Models.**
  - Abundant sources of data and modeling capabilities
  - Data sources view asset management, climate change, and regional economy in isolated analytical siloes
  - Fail to fully capture interconnections
  - More integrated use of EIA, TAM, and BCA tools to model regional climate resilience, and refinements to a regional CGE methodology to estimate the longer-term impact of preventive measures, and adaptation/mitigation actions

- **Integrating SLR Adaptation Approaches with Longer-Term Mitigation Solutions.**
  - NASA’s R&D projects on Earth Observing Satellites (EOS) Professor Nordhaus’ DICE-model estimates on carbon pricing and the impact of climate change on the GDP

- **Removing the Siloes of Transport Modes and Economic Security Strategies**
  - Recognize interlinkages between climate and disruption risks to the economy particularly in high poverty, high-exposure, frequently-flooded areas.
  - Recognize indirect impacts of frequent flooding on employment and income in
    - Transport-sensitive sectors such as tourism
    - Military,
    - Maritime commerce,
    - Technology-intensive sectors such as Profession/Scientific
    - Finance/Insurance
  - Recognize public/private regional freight and passenger railroads can enhance the region’s trade & supply-chain resilience
  - Assess asset/operational vulnerabilities in the private rail industry’s tracks and asset condition
  - Improve networks to provide alternate routes and modes when a particular asset is disrupted
Next Steps: Collaboration with USDOT/Volpe

- **Interagency Integration of Analytical and Estimating Tools and Models.**
  - In-depth focus on specific tools and capabilities as needed to support the Pilot and Pilot Working Groups
    - NCHRP CAPTA/CapTool; and Sandia’s REAcct tool
  - Employ more rigorous economic methods such as CGE
  - Examine economic impacts of specific scenarios on the regional economy and SLR resilience

- **Promoting OST’s Twinning Strategic Approach to Climate Resilience.**
  - US Air Force Office of Assistant Secretary for Installation, Energy, and Environment (SAF/IEE):
    - Promote energy efficiency & alternative aviation/installation fuel sources through micro-grid and solar PV;
  - NASA:
    - Climate change risk engagement
    - Research priorities and adaptation planning for DOD agencies that are directly at risk of SLR and flooding inundation in Hampton Roads.
    - CLARREO climate satellite mission
    - Climate Adaptation Science Investigator (CASI);
  - EPA:
    - CIRA climate impact tool
  - NOAA:
    - SoVI model to explore opportunities to mitigate social vulnerabilities outer

- **Collaboration with ODU and EIAC members on Economic Impact Assessment.**
  - Improve use of economic impact methodologies such as REMI, IMPLAN, and CGE to evaluate the long-term infrastructure investment options for preventive adaptation and risk mitigation
  - Build on the ODU 2015 State of Commonwealth Report findings on the DOD/Navy strategic shifts in Home Porting and the Pacific Pivot
  - Address social vulnerabilities that arise from fluctuations in GDP growth and rising rates of income inequality
  - More effectively assess regional trend impacts on climate change disruption and infrastructure resilience