COMPASS Education Series: Risk and Resiliency

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1. Intro and Overview
Agenda

1. Introductions/Overview
2. Definitions and terminology
3. Purpose and context
4. Idaho projections
5. Resilience and risk implementation frameworks, examples
6. Risk register exercise
7. Break
8. Beyond the risk register
9. Benefit-cost exercise
10. Adaptation benefit-cost analysis tool
11. Helpful resources
12. Open Q&A
Workshop Purpose

• What, why, and how of risk and resilience in context of transportation

• Help you think about risk and resilience in your activities – planning, operations, etc.

• Input welcome
2. Definitions and Terminology
Definitions and Terminology

• Risk
  • Potential of gaining or losing something of value
  • Probability of Threat Occurrence x Probability of Failure x Cost of Failure
  • Exposure x Sensitivity x Cost of Failure
  • Likelihood x Consequence
  • Effect of Uncertainty on objectives
  • Different levels and types

• Uncertainty
  • Degree to which a value is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable.

• Resilience
  • Ability to respond and recover from adversity
  • Amount of change a system can undergo without changing state

• Adaptive Capacity
  • Ability to adjust to/moderate/cope with a threat
  • Similar to Resilience
Definitions and Terminology

• Vulnerability
  • The degree to which a system is susceptible to, or unable to cope with, adverse effects
  • Function of Exposure, Sensitivity, and Adaptive Capacity

• Adaptation
  • Action to reduce Vulnerability or increase Resilience

• Criticality
  • Relative importance of an asset

• Risk Management
  • Coordinated activities to direct and control an organization with regard to risk

• Weather vs. Climate
  • Weather refers to conditions of atmosphere over short period of time
  • Climate refers to how atmosphere behaves over long period of time (includes averages, variability, and extremes)
  • Climate change refers to shifts in global or regional climate patterns
3. Purpose and Context
Why Focus on Risk and Resilience

• Create awareness
• Systematic approach to uncertainty
• Consider range of adaptations
• Prioritization of projects, activities
• Enhance existing decisions
• Cost effectiveness
Regulatory Framework

• MAP-21 and FAST Act – Asset Management Final Rule (2016)
  • States “shall develop a risk-based asset management plan that describes how the NHS will be managed to achieve system performance effectiveness and State DOT targets for asset condition, while managing the risks, in a financially responsible manner, at a minimum practicable cost over the life cycle of its assets.”
  • Life-cycle planning for asset classes should consider “future changes in demand; information on current and future environmental conditions including extreme weather events, climate change, and seismic activity; and other factors that could impact whole of life costs of assets.”
Regulatory Framework

• MAP-21 and FAST Act – Asset Management Final Rule (2016) (continued)
  • State DOTs “shall establish a process for developing a risk management plan”. Should include
    • Risk identification
    • Risk assessment – likelihood and consequence
    • Risk evaluation and prioritization
    • Mitigation plan for top priority risks
    • A summary of the evaluations of facilities repeatedly damaged by emergency events
  • State DOTs “shall conduct statewide evaluations to determine if there are reasonable alternatives to roads, highways, and bridges that have required repair and reconstruction activities on two or more occasions due to emergency events.”
Regulatory Framework

• MAP-21 and FAST Act – Planning Final Rule (2016)
  • Adds “takes into consideration resiliency needs” to purposes of statewide, nonmetropolitan, and metropolitan planning processes

• FHWA Order 5520 (2014)
  • “It is FHWA's policy to strive to identify the risks of climate change and extreme weather events to current and planned transportation systems. The FHWA will work to integrate consideration of these risks into its planning, operations, policies and programs in order to promote preparedness and resilience; safeguard Federal investments; and ensure the safety, reliability, and sustainability of the Nation’s transportation systems.”
In what areas is risk or resiliency planning reflected in decision making?

- Project Funding: 11%
- Performance: 26%
- Project Selection: 30%
- Project Design: 37%
- Operations: 52%
- Asset Management: 52%
- Maintenance: 59%
- Long-Term Planning: 67%
NCHRP Snapshot – Risk and Resiliency Planning – State DOTs

At what level is your agency assessing risk and/or resiliency?

- Corridor or Site Specific: 57%
- Project: 37%
- Network (e.g. Evacuation or Freight Route): 37%
- Agency or Enterprise: 37%
- Program (e.g. Asset Management, Operations): 34%
- Region: 29%
- State: 6%
NCHRP Snapshot – Risk and Resiliency Planning – State DOTs

What critical risks has your agency identified?

- Short-term extreme weather events: 81%
- Finance and revenue changes: 69%
- Agency capability or workforce: 50%
- Long-term climate change: 44%
- Autonomous and connected vehicles: 41%
- Need for redundant routes: 41%
- Political climate: 38%
- Disruptive technology: 34%
- Changing freight movements: 28%
- Shifts in travel patterns: 25%
- Changing agency mission: 22%
- Other: 9%
What types of transportation infrastructure are most vulnerable to extreme weather and sea level rise in your state or region?

<table>
<thead>
<tr>
<th>Infrastructure Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other (Ferry, Tunnels, Utilities)</td>
<td>8%</td>
</tr>
<tr>
<td>Transit</td>
<td>31%</td>
</tr>
<tr>
<td>Seaports</td>
<td>33%</td>
</tr>
<tr>
<td>Airports</td>
<td>33%</td>
</tr>
<tr>
<td>Walkways, Sidewalks, Paved/Gravel Trails</td>
<td>36%</td>
</tr>
<tr>
<td>Freight and Passenger Rail</td>
<td>44%</td>
</tr>
<tr>
<td>Bridges</td>
<td>89%</td>
</tr>
<tr>
<td>Culverts or Other Drainage Systems</td>
<td>94%</td>
</tr>
<tr>
<td>Roads</td>
<td>97%</td>
</tr>
</tbody>
</table>
If your agency is planning for risk or resiliency, have you developed tools or methods to:

- Assess Vulnerability: 51%
- Prioritize Investment Decisions: 34%
- Develop Adaptation Strategies: 26%
4. Idaho Climate Projections
Idaho Climate Observations and Projections

• “Temperatures increased across the region from 1895 to 2011, with a regionally averaged warming of about 1.3°F”

• “An increase in average annual temperature of 3.3°F to 9.7°F is projected by 2070 to 2099…The increases are projected to be largest in summer.”

• “While precipitation has generally increased, trends are small as compared to natural variability”

• “Change in annual average precipitation in the Northwest is projected to be within a range of an 11% decrease to a 12% increase for 2030 to 2059 and a 10% decrease to an 18% increase for 2070 to 2099” with decrease in summer precipitation under several scenarios

• The largest hydrologic responses “are expected to occur in basins with significant snow accumulation, where warming increases winter flows and advances the timing of spring melt. By 2050, snowmelt is projected to shift three to four weeks earlier than the 20th century average, and summer flows are projected to be substantially lower”

Source: National Climate Assessment
Idaho Climate Observations and Projections

• “Changes in river-related flood risk depends on many factors, but warming is projected to increase flood risk the most in mixed basins (those with both winter rainfall and late spring snowmelt-related runoff peaks) and remain largely unchanged in snow-dominant basins.”

• “Regional climate models project increases of 0% to 20% in extreme daily precipitation, depending on location and definition of “extreme” (for example, annual wettest day).”

Source: National Climate Assessment
5. Resilience and Risk Management Frameworks and Examples
FHWA Vulnerability Assessment Process
Asset-Level Adaptation Assessment Process

1. Define climate impacts
   a) Sensitivity screening to identify stressors
   b) Establish current and projected scenarios

2. Assess vulnerability
   a) Analyze exposure
   b) Analyze sensitivity
   c) Evaluate adaptive capacity
   d) Summarize results

3. Assess risk
   a) Identify likelihood
   b) Identify consequences
   c) Establish integrated risk

4. Formulate Adaptation
   a) Develop strategy shortlist
   b) Conduct brief benefit-cost analysis
   c) Identify priority adaptation strategy or package of strategies
Arizona DOT Extreme Weather Vulnerability Assessment

- Interstates connecting Nogales, Tucson, Phoenix, and Flagstaff (I-19, I-10, and I-17)
  - 4 sub regions (Districts)
- Variety of:
  - Climates
  - Elevations
  - Landscape Contexts
    - E.g., Biotic Communities
  - Climate stressors
Extreme Weather Potential Effects on Transportation System in Study Area

- Shortened pavement life (heat, freeze-thaw, snow plowing)
- Culverts - design capacity, maintenance frequency
- Bridges - design capacity, maintenance frequency
- Roadside erosion
- Road closures from flooding/fire/rockfall/dust/low water crossings
- Shifting periods for paving operations
- Storm drain design
- Other
US 89 Landslide
Lessons Learned

• Work with scientific stakeholders – climate, ecology, etc. – regarding exposure
• Climate projections – data processing challenge given relatively large and geographically diverse study area and high spatial resolution
• Inherent uncertainty of climate projections, particularly pertaining to extreme precipitation
• Secondary stressors, such as wildfire and flooding, influenced by a variety of climate and non-climate factors, compound that uncertainty for localized analyses
• Work with transportation operations and maintenance staff regarding sensitivity and consequence
• Rather than attempting to assign definitive vulnerabilities, study team aimed to characterize current extreme weather vulnerabilities and highlight potential future changes in key risk factors
FHWA Post Hurricane Sandy Transportation Resilience Study (Ongoing)

- Collaboration between FHWA, FTA, State DOTs, MPOs, Port Authority of New York & New Jersey, local transit agencies

- Enhance the tri-state region’s resiliency to climate change and extreme weather in the longer term, while informing the ongoing Hurricane Sandy recovery process

- Identify feasible, cost-effective strategies to reduce and manage extreme weather vulnerabilities amid the uncertainties of a changing climate

- Advance the state of knowledge and develop methods to assist agencies in the tri-state region—and nationwide—that are seeking to plan and invest for long-term climate resilience
Post-Sandy Study Tasks

- Multi-modal damage/disruption assessment based on recent storms
- Region-wide vulnerability assessment
- “Mesoscopic” assessments of three subareas
- Adaptation analysis
- Engineering-based adaptation assessment of ten assets
- Process refinement
- Coordination and collaboration
Mesoscopic Vulnerability Assessments
<table>
<thead>
<tr>
<th>Strategy</th>
<th>Parent Strategy</th>
<th>Strategy Scale</th>
<th>Asset Type (for Asset Specific)</th>
<th>Type</th>
<th>Cost</th>
<th>Stressors Addressed</th>
<th>Primary Climate Risk Impact Type (Likelihood, Consequence, or Better Risk Information)</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidelines (water barriers)</td>
<td>Water barriers</td>
<td>General</td>
<td>Waterway Management</td>
<td>Engineering</td>
<td>$$$$</td>
<td>Flood, Erosion</td>
<td>Likelihood</td>
<td>Longer term</td>
</tr>
<tr>
<td>Levees (longitudinal naturally occurring ridge or artificially constructed wall)</td>
<td>Water barriers</td>
<td>General</td>
<td>Natural or Nature-based</td>
<td>$$$</td>
<td></td>
<td>Flood, Waves</td>
<td>Likelihood</td>
<td>Longer term</td>
</tr>
<tr>
<td>Widening/Channelization of waterways</td>
<td>Waterway modification</td>
<td>General</td>
<td>Waterway Management</td>
<td>Engineering</td>
<td>$$$$</td>
<td>Flood, Erosion</td>
<td>Likelihood</td>
<td>Longer term</td>
</tr>
</tbody>
</table>

Enhanced ITS Infrastructure allowing for increased capacity on alternate roadways and demand management by giving up-to-date information to travelers, coordinating access to auxiliary lanes/shoulders, planning/communicating time of day restrictions/incentives. ITS can better inform event response systems.

Enhance ITS system: System: Operational: $\$\$\$\$: All: Consequence: Shorter term

Increase roadway capacity on alternate/priority routes to create redundancy.

Parallel transportation capacity: System: Engineering: $\$\$\$: All: Consequence: Mid term

Improve transit capacity to compliment physical strategies.

Parallel transportation capacity: System: Engineering: $\$\$\$: All: Consequence: Mid term

Ferry and barge systems for movement.
<table>
<thead>
<tr>
<th>Shorter Term</th>
<th>Longer Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Update and maintain event notification and response system for</td>
<td>- Implement flood prevention measures for most vulnerable sections of</td>
</tr>
<tr>
<td>roadways, including evacuation routes. Make explicit operational plans for</td>
<td>GSP (Matawan Creek, Laurence Harbor).</td>
</tr>
<tr>
<td>sections of GSP in two highest vulnerability areas.</td>
<td>- Concrete sealant/surface treatment for surfaces not previously</td>
</tr>
<tr>
<td>- Transit coordination and contingency plan for flooding and high-wind</td>
<td>inundated.</td>
</tr>
<tr>
<td>events on North Jersey Coast Line and ferry terminals. Should leverage</td>
<td>- Cathodic protection for metal elements.</td>
</tr>
<tr>
<td>bus lines. Should be flexible enough to address different flooding</td>
<td>- Raise or relocate vulnerable electrical/communications assets (related to</td>
</tr>
<tr>
<td>scenarios.</td>
<td>roadway or transit systems).</td>
</tr>
<tr>
<td>- Regularly coordinate with USACE and other stakeholders to ensure</td>
<td>- Erosion control aimed at surface protection (e.g., vegetative cover,</td>
</tr>
<tr>
<td>complementary adaptation strategies and identify gaps.</td>
<td>mats/blankets) for areas that flood regularly.</td>
</tr>
<tr>
<td>- Better tracking of disruption and damage information to inform planning.</td>
<td>- Revise rail speed guidance given effects of extreme heat on tracks.</td>
</tr>
<tr>
<td>- Use resilience best practices and incorporate SLR projections for new</td>
<td>- Consider capacity enhancements for bus transit and road network.</td>
</tr>
<tr>
<td>infrastructure projects/updates that are already planned - work this into</td>
<td>- More frequent inspection of infrastructure vulnerable to heat (e.g., rail</td>
</tr>
<tr>
<td>existing process.</td>
<td>buckling, catenary systems).</td>
</tr>
<tr>
<td>- Prune branches and other vegetation susceptible to wind.</td>
<td>- Increase regular maintenance of drainage ways.</td>
</tr>
<tr>
<td>- Floodproof South Amboy Substation.</td>
<td>- More aggressive floodproofing for South Amboy Substation; consider</td>
</tr>
<tr>
<td></td>
<td>raising or relocating.</td>
</tr>
</tbody>
</table>

**Adaptation Matrices**

**Higher Risk Tolerance/Lower Investment**

- Strategies included above for higher risk tolerance/lower investment in shorter term (transit contingency plan, event response, etc.).
- Investigate and implement flood prevention measures (e.g., watertight barriers on roadside, added culverts) for most vulnerable sections of GSP (Matawan Creek, Laurence Harbor).
- If NBI info outdated, conduct scour criticality assessment for bridges. Prioritize bridges over Raritan River given their high flooding consequence.
- Investigate and implement flood prevention measures (e.g., adding more culverts or widening culvert) for Route 36 at Many Mind Creek given its relatively high flooding likelihood.
- Enhanced ITS infrastructure allowing for increased capacity on alternate roadways and demand management by giving up-to-date information to travelers. ITS can better inform event response system.
- Enhance capacity on N-S evacuation routes leading away from NHS facilities and North Jersey Coast Line in study area.
- More aggressive floodproofing for South Amboy Substation; consider raising or relocating.

**Lower Risk Tolerance/Agressive Investment**

- Strategies included above for higher risk tolerance/lower investment in longer term.
- Coordinate with stakeholders to add general coastal protection measures (e.g., floodwalls, levees, beach nourishment) in vulnerable areas that have not already have them.
- For coastal bridges in areas of frequent flooding, consider superstructures that can resist lateral flow and wave forces.
- Berms and other measures in places on roads and North Jersey Cost Line with frequent flooding.
- More aggressive erosion control strategies.
- Further enhance capacity on N-S evacuation routes.
- Improve bus transit capacity.
- Enhance electricity infrastructure so that it remains functioning in extreme events and continues to power transit, traffic signals, ITS.
- Strengthen mooring/berthing fixtures at docks, ferry terminals, Earle.
- Fender or dolphin systems to protect vulnerable piers and other infrastructure from vessel impact.
- Flood prone land acquisition / incentivized relocation.
General Risk Management Steps (mostly from ISO 31000 Guidebook)

1. Identify the organization’s goals and objectives
2. Identify risks to reaching those goals and objectives
3. Score or rank/prioritize risks
4. Consider mitigation methods, strategies
5. Manage each type of risk
6. Communicate risks, and management strategies
7. Monitor results and update accordingly
8. Improve the process
Equation for Calculating Risk

Risk (Cost) = Probability of Event Occurrence X Impact (Cost) of the Event Occurring

Example: a certain large rock has a 1% chance of falling onto westbound Interstate 70 in Glenwood Canyon each year, with expected damage of $1,000,000.

This represents a $10,000 annualized “risk cost”
Risk Impacts in Transportation

• Safety – crashes, injuries, fatalities, property damage
• Mobility and trip time reliability
• Costs of fixing the damage
• Other economic costs – lack of access, interrupted commerce
• Performance costs – not delivering projects as intended, and/or not hitting targets
### Risk Register Excerpt

<table>
<thead>
<tr>
<th>Risk Level</th>
<th>Asset Class</th>
<th>Event/Occurrence</th>
<th>Prob</th>
<th>Safety</th>
<th>Mobility</th>
<th>Asset Damage</th>
<th>Other Financial Impact</th>
<th>Risk Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project</td>
<td>All</td>
<td>Flooding (or any inclement weather event) (resulting in long term impacts -- damage to assets, requiring replacement)</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>20.0</td>
</tr>
<tr>
<td>Agency</td>
<td>ALL</td>
<td>Uncertainties that affect reaching performance targets; including revenue, costs, processes, etc.</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>12.0</td>
</tr>
<tr>
<td>Project</td>
<td>Traffic</td>
<td>Wind damage to high-mast lighting, signals, overhead signs, VMS</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>8.0</td>
</tr>
<tr>
<td>Program</td>
<td>ALL</td>
<td>Uncertainties that affect the ability to deliver projects as intended, and on time, within budget</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>12.5</td>
</tr>
</tbody>
</table>
## Risk Scoring Matrix

<table>
<thead>
<tr>
<th>Likelyhood</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level</td>
<td>Negligible</td>
<td>Minor</td>
<td>Major</td>
<td>Critical</td>
<td>Catastrophic</td>
</tr>
<tr>
<td>1</td>
<td>Low</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Medium Low</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>Medium</td>
<td>3</td>
<td>6</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>Medium High</td>
<td>4</td>
<td>8</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>High*</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Level</td>
<td>Risk ID</td>
<td>Voted</td>
<td>Priority</td>
<td>Event / Occurrence</td>
<td>Likelihood</td>
</tr>
<tr>
<td>-------</td>
<td>---------</td>
<td>-------</td>
<td>----------</td>
<td>-------------------</td>
<td>------------</td>
</tr>
<tr>
<td>Project 3b</td>
<td>10</td>
<td>4</td>
<td>Flooding (resulting in long term impacts -- damage to assets, requiring replacement)</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Project 3g</td>
<td>12</td>
<td>5</td>
<td>Burn area - post-fire debris flows, blocked culverts -- loss of service</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Project 3l</td>
<td>11</td>
<td>5</td>
<td>Scour Critical Bridges are vulnerable to a storm event of sufficient size results in road loss</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Project 3e</td>
<td>10</td>
<td>5</td>
<td>Rockfall incident with loss of function/mobility (several days) or fatality</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Project 3j</td>
<td>11</td>
<td>5</td>
<td>Rockfall incident requiring maintenance, but no or minimal mobility impact</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Project 3d</td>
<td>9</td>
<td>5</td>
<td>Culverts less than 48 inch diameter (failing and closing road - not managed currently)</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Project 3a</td>
<td>11</td>
<td>5</td>
<td>Project delay due to environmental, utility, RR, or right-of-way issues, or land owner claims</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Agency 1l</td>
<td>6</td>
<td>5</td>
<td>Return of commodity price volatility</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Project 3e</td>
<td>10</td>
<td>5</td>
<td>Rockfall incident requiring maintenance, but no or minimal mobility impact</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Project 3l</td>
<td>11</td>
<td>5</td>
<td>Landslide - maintenance required</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Agency 1l</td>
<td>6</td>
<td>5</td>
<td>Return of commodity price volatility</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Project 3m</td>
<td>9</td>
<td>5</td>
<td>Retaining walls (failing and impacting traffic)</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Agency 1d</td>
<td>9</td>
<td>5</td>
<td>Revenue variations/uncertainties -- inability to predict/project total funds</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Consequence Score: 24.0
Other Considerations: None
Top Ten Risk Scores (24.0 to 15.8)

1. Flooding (resulting in long term impacts -- damage to assets, requiring replacement)
2. Burn area - post-fire debris flows, blocked culverts -- loss of service
3. Bridge Strike (Highest frequency) -- clearance less than 16 ft
4. Not having enough funds to meet targets
5. Rockfall incident with loss of function/mobility (several days) or fatality
6. Roadway washout from pipe failure (structural) e.g. Vail Pass -- Road failure
7. Fiber optic backbone severed, resulting in loss of communication
8. Impacts/crashes of traffic with fleet vehicles
9. Hazardous materials -- spill, e.g. Hwy 6
10. Essential repairs (Bridge) -- Major cost/risk
Second Ten Risk Scores (15.8 to 12.9)

11. Parts availability limiting number of vehicles in use
12. ITS devices impacted by vehicles (VMS signs, signals, etc.)
13. Local control of NHS segments
14. Unfunded maintenance requirements -- e.g. regulatory
15. Changing functional needs for the buildings, regarding the needs in an existing location
16. Landslide causing loss of road and long term mobility impacts/delay
17. Subsurface utilities impacts by others in ROW and below roadways
18. Retirement of key people, loss or turn-over of staff, resulting in loss of knowledge (Maintenance Program specifically)
19. No internal buy-in on the asset management philosophies re: implementation; thus compromising condition goals
20. Load-restricted bridges -- uncertainty of ability to support loads
Overall Risk Scores by Asset Class – From the Risk Register
Fully Develop the Risk Register

1. Risk event types – considering the “extremes”
   a) Rare, catastrophic events
   b) More frequent, but less impacting events
2. Scoring – making sure “extremes” are properly evaluated
3. Strategy Identification – considering multiple options for each risk
   a) “Tolerate, Treat, Transfer, Terminate”, etc.
4. Benefits – estimating reduction in “Risk Score” (or annualized costs) with each strategy
5. Costs – estimating the cost of implementing the strategy
## Extended Risk Register

<table>
<thead>
<tr>
<th>Level</th>
<th>Event/Occurrence</th>
<th>Likelihood</th>
<th>Safety</th>
<th>Mobility</th>
<th>Asset Damage</th>
<th>Other Financial Impact</th>
<th>Funding</th>
<th>Insurance</th>
<th>Regulatory</th>
<th>Political</th>
<th>Reputation</th>
<th>Risk Score</th>
<th>Mitigation Strategy</th>
<th>Benefit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agency</td>
<td>Not communicating to and getting buy-in at the appropriate levels in CDOT how the RB AMP works*</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>x</td>
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<td>Agency</td>
<td>Not having enough funds to meet</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>2</td>
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<td>10.5</td>
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<td>Agency</td>
<td>Local control of NHS segments --</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>x</td>
<td>x</td>
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<td>x</td>
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<td>15.0</td>
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<tr>
<td>Agency</td>
<td>Revenue variations/uncertainties</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>10.5</td>
<td></td>
<td></td>
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<td>Agency</td>
<td>Public perception of CDOT (Negative)</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>6.3</td>
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<tr>
<td>Agency</td>
<td>Politics -- COMBINE WITH LEADERSHIP</td>
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<td>3</td>
<td>x</td>
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<td>Underestimating the impact of Dri</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
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<td>x</td>
<td>5.2</td>
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<tr>
<td>Agency</td>
<td>Contractors cannot handle drama</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>2</td>
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<td>Agency</td>
<td>Lack of appropriate project cost controls</td>
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<td>Agency</td>
<td>Return of commodity price volatility</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>x</td>
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<td>8.1</td>
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<tr>
<td>Agency</td>
<td>Financial collapse of a privately-owned project</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>x</td>
<td>x</td>
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<td>x</td>
<td>x</td>
<td>2.8</td>
<td></td>
<td></td>
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<tr>
<td>Program</td>
<td>Retirement of key people, loss of skilled personnel, etc., etc.</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<td>11.0</td>
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<tr>
<td>Program</td>
<td>Project delivery risks due to organ barrier blockage</td>
<td>3</td>
<td>2</td>
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<td>x</td>
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<td>x</td>
<td>x</td>
<td>7.2</td>
<td></td>
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<tr>
<td>Program</td>
<td>Construction cost variations</td>
<td>3</td>
<td>1</td>
<td>1</td>
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<td>4</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>6.9</td>
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<tr>
<td>Program</td>
<td>Data management (that impacts CDOT)</td>
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<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>11.0</td>
<td></td>
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</tr>
<tr>
<td>Program</td>
<td>Will I-70 viaduct pull funding from another program</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>x</td>
<td>x</td>
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<td>x</td>
<td>12.0</td>
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<tr>
<td>Program</td>
<td>Unfunded maintenance requirements</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>15.8</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Project</td>
<td>Project delay due to environment</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>8.3</td>
<td></td>
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<tr>
<td>Project</td>
<td>Flooding (resulting in long term impacts)</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>x</td>
<td>x</td>
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<td>x</td>
<td>x</td>
<td>24.0</td>
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<tr>
<td>Project</td>
<td>Culverts less than 48 inch diameter</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>x</td>
<td>x</td>
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<td>x</td>
<td>x</td>
<td>9.5</td>
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<tr>
<td>Project</td>
<td>Bridge failure -- structural, other</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>10.8</td>
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<tr>
<td>Project</td>
<td>Rockfall incident requiring maintenance</td>
<td>5</td>
<td>2</td>
<td>1</td>
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<td>1</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>7.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project</td>
<td>Rockfall incident with loss of function</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>x</td>
<td>x</td>
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<td>18.0</td>
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<td>Project</td>
<td>Crash with fire occurs inside a tunnel</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>13.5</td>
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<tr>
<td>Project</td>
<td>Burn area - post-fire debris flows, etc.</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>21.0</td>
<td></td>
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</tr>
</tbody>
</table>
Investment Tradeoffs and Target-Setting for Traditional Performance-Based Assets/Programs
Risk Classes Can Be Analyzed and Traded Off in the Same Manner as Asset (Performance) Classes
SUMMARY - Steps to Addressing “Risk” in Your TAM Plan

1. Identify risk event types, levels, etc.
2. Build a “Risk Register” – quantify probabilities and consequences for each event type
3. Identify risk mitigation strategies – and define their costs and benefits
4. Determine how to “package” risk mgmt efforts
5. Evaluate and prioritize candidate solutions
6. Include risk opportunities in overall asset management investment tradeoff analysis
## Risk Register Excerpt

<table>
<thead>
<tr>
<th>Risk Level</th>
<th>Asset Class</th>
<th>Event/Occurrence</th>
<th>Prob</th>
<th>Safety</th>
<th>Mobility</th>
<th>Asset Damage</th>
<th>Other Financial Impact</th>
<th>Risk Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project</td>
<td>All</td>
<td>Flooding (or any inclement weather event) (resulting in long term impacts -- damage to assets, requiring replacement)</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>20.0</td>
</tr>
<tr>
<td>Agency</td>
<td>ALL</td>
<td>Uncertainties that affect reaching performance targets; including revenue, costs, processes, etc.</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>12.0</td>
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<tr>
<td>Project</td>
<td>Traffic</td>
<td>Wind damage to high-mast lighting, signals, overhead signs, VMS</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>8.0</td>
</tr>
<tr>
<td>Program</td>
<td>ALL</td>
<td>Uncertainties that affect the ability to deliver projects as intended, and on time, within budget</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>12.5</td>
</tr>
</tbody>
</table>
6. Risk Register Exercise
7. Beyond the Risk Register
A Completed Register – *But... “Where do we go from here?”*

- Corridor-based risks
  - Risks that have a location (geospatial) component
  - Examples -- rock fall, culvert failure, ITS/signs, etc.

- Risks to infrastructure or agency performance
  - Uncertainties regarding the achievement of performance goals (costs, revenue, modeling, project formulation processes)

- Project Delivery risks
  - Programmatic/systemic issues -- chronic delays, splits, overruns, & not delivering projects as intended
  - Project-specific risks to cost and schedule
What information is needed to do more in-depth risk assessments?
Ultimate Site-Specific Analysis
Approaches to modeling risk

- **Hazard/Risk Index (top down)**
  - Pros: fast, low data requirements, output easy to understand
  - Cons: Low resolution, subjective

- **Historical Scenario (mix of top down and bottoms up)**
  - Pros: based on event-specific data, good for frequent hazards
  - Cons: misses extreme events, and site-specific risk event outcomes

- **Probabilistic (bottoms up)**
  - Pros: accounts for both frequent/low-impact and rare/extreme events, for each site
  - Cons: high data/expertise requirements, need to ensure outputs can be understood

Increasing Effort & Complexity

Redd Engineering
Total Risk Score per Mile for Each Corridor Type

- Mtn Rural
- Interstates
- Other H.T.
- Mtn Urban Other
- Plains Urban I/S
- Rolling Urban I/S
- Plains Rural I/S
- Rolling Rural I/S
Risk per Mile for Each Asset Class
(two corridor types shown here)
Bridge Risk Scores by Corridor
What other types of risk are there?
Pavement Performance versus Funding --
Bridge Performance versus Funding

![Graph showing the relationship between annual budget and percent deck area on bridges classified as structurally deficient from 2013 to 2033. The graph includes lines for different annual budgets: $115M, $140M, $168M, $175M, and $200M.]

- **Annual Budgets:**
  - $115M
  - $140M
  - $168M
  - $175M
  - $200M

- **Years:**
  - 2013
  - 2018
  - 2023
  - 2028
  - 2033

- **Y-axis:** Percent Deck Area on Bridges Classified as Structurally Deficient
- **X-axis:** Annual Budget
Performance Uncertainties - *Variability, Volatility of Parameters*

- **Project Costs**
- **Available Revenue**
- **Project Formulation Processes**
- **Modeling Uncertainties**
Cost Estimates – Medium Size

Inaccuracy of Estimates - %

Years From Project Delivery

% Difference from Let Year Amount

-80 -60 -40 -20 0 20 40 60

0 2 4 6 8 10 12 14 16
Performance Risks and Process Improvement -- 
Leading and Lagging Indicators

“Plan”

- Planning Analysis
  - Mgmt System runs
  - Program Tradeoffs
  - Project Optimization
  - District input

“Act”

- Adjust Strategic Goals
  - Long-range planning
  - Balanced Scorecard
  - Performance Targets

“Check”

- Work Gets Done
  - Projects completed
  - Conditions monitored
  - Plan vs. Actual Results
  - Feedback to Decision Makers

“Do”

- Programming
  - 10 yr horizon
  - Fiscally constrained
  - Funding uncertainties
  - 6-yr STIP
8. Benefit-to-Cost Exercise
Summary and Other Thoughts
Goals in Overall Results

• Ability to analyze risks by location (geospatially), along with performance-based opportunities

• Processes and tools to formulate projects, considering both performance and risk-based opportunities

• Ability to include risk in overall investment and resource allocation decisions

• Ability to consider performance-related uncertainties in planning, target-setting, and project delivery processes
  • Gap analysis of projected (planned) performance versus actual
  • Making improvements in planning and project scoping processes
  • Reducing losses due to chronic project delivery issues
So, that’s all there is, correct?

• We have the definition of risk
  • “Uncertainties in reaching your goals”
• We know the steps (see ISO 31000)
• What could possibly be missing?
• Sometimes the best cookbooks are no substitute...
• There are some rules of thumb and lessons learned regarding risk management that are worth knowing
  • For discovering and evaluating various risk opportunities
  • For selecting and packaging solutions to reduce risk
What about the synergies and compromises between traditional asset management efforts and resilience efforts?
Risk & Resilience Tradeoffs
Canyon “A” and Resilience

<table>
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<tr>
<th>Frequency of Flood</th>
<th>Light Rehab</th>
<th>Medium Rehab</th>
<th>Heavy Rehab</th>
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<tbody>
<tr>
<td>500 year</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>100 year</td>
<td>X</td>
<td>X</td>
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</tr>
<tr>
<td>50 year</td>
<td>X</td>
<td>OK</td>
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</tr>
<tr>
<td>25 year</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
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</table>
Lessons Learned...
Anecdotes, Lessons Learned

• 500 yr event – “not gonna happen again in my lifetime...” (are you sure?)
• ‘We have thousands of culverts, let’s analyze the “average” one...’ – NOTE: in order to properly assess risks, extremes matter, and there is no “average culvert”. Rare, high-impact events are important

• Some things are not risk items, but are management decisions:
  • Whether to buy or lease equipment
  • Pavement management, bridge management (??)
Discoveries re: Good Risk Analysis

• “Extremes matter!”
  • Consider full range of frequent vs. “rare” occurrences
  • There is no “average culvert”
  • “The Black Swan”, by Nassim Taleb

• Consider a full range of strategies, such as:
  • “Tolerate, treat (mitigate), transfer,...” etc.
  • How much to invest in a strategy? Are there tradeoffs?
  • Packaging of risk-based solutions
    • Site-specific
    • Corridor-based
    • State-wide or regional/district-based programs/projects

Redd Engineering
Key Discoveries (cont.)

• It *is* lucrative to manage risk opportunities --
  • Thorough analysis can identify the best opportunities, e.g.:
    • Geohazards “risk costs” in the tens of $millions (CDOT)
    • Performance and project delivery uncertainties can cost up to 5% in losses (WYDOT)

• “*Hey, we can fix that*”, with good management strategies:
  • Using new and innovative methods and tools
  • Lower the impact, transfer the risk, lessen the uncertainty, fix your processes, etc.
  • Lead time on risk analysis can be long, so get started
### Inputs (Please enable Macros)

#### Summary Results

<table>
<thead>
<tr>
<th>Event</th>
<th>Scenario</th>
<th>IRR</th>
<th>BCR</th>
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<tbody>
<tr>
<td>SLR/Surge</td>
<td>USACE Low</td>
<td>7%</td>
<td>2.71</td>
</tr>
<tr>
<td>SLR/Surge</td>
<td>USACE Intermediate</td>
<td>7%</td>
<td>2.71</td>
</tr>
<tr>
<td>SLR/Surge</td>
<td>USACE High</td>
<td>6%</td>
<td>1.95</td>
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<tr>
<td>SLR/Surge</td>
<td>NOAA High</td>
<td>5%</td>
<td>1.67</td>
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</table>

#### Name | Value | Units | Notes & Sources

<table>
<thead>
<tr>
<th>Sea Level Rise/Surge</th>
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</thead>
</table>

#### Failure Threshold Details

- No Build Failure Threshold (feet) - NAVD88: 15 feet
- Build Failure Threshold (feet) - NAVD88: 18 feet
- Tidal Datum: MSL
- Tidal Datum name: "" (choose Mean Sea Level (MSL) or other)
- Tidal Datum, difference from NAVD88 (feet): "" (given tidal datum name, if "Other" tidal datum selected, input name)
- Zone Type: VE
- Elevation Type: Flood Elevation

Surge elevation at which asset fails without improvement. Given in NAVD88 vertical datum. User should override placeholder values. See FEMA website for guidance: https://www.fema.gov/flood-zones

#### Sea Level Rise Projection Information (Please enable Macros)
Adaptation BCA Tool Purpose and Basics

• Perform benefit-cost analysis for climate adaptation investments in transportation infrastructure

• Incorporate climate projections and associated risks for:
  • Sea level rise/storm surge
  • Precipitation

• Planning level

• Spreadsheet-based
BCA Inputs

• Project and Asset Information
  • Construction cost, completion year, etc.
  • Project lifecycle and repair cost
  • No-Build repair cost
  • Discount rate
  • Disruption closure length
  • Detour length and time

• Transportation
  • Annual Average Daily Traffic with % breakdowns between auto/truck/bus and business/personal travel
  • Fuel cost and economy
  • Value of time
  • Vehicle occupancy
BCA Inputs

• Climate
  • Sea Level Rise/Storm Surge
    • Build and No-Build failure elevations
    • Sea level rise projections by gauge location
    • Tidal datum shift for gauge locations
    • 10-year, 50-year, 100-year, and 500-year event elevations
      • User specifies elevation type (flood, stillwater, etc.) and VE versus AE
      • FEMA supporting info on elevations
  • Precipitation
    • Exceedance event (i.e., 50-year event) with projected return intervals by projection
    • Probability of withstanding event for Build and No-Build
Benefits and Costs

• Benefits incorporate (1) the difference between probabilities of asset failure in No-Build and Build and (2) the difference between costs of asset failure in No-Build and Build
  • Can be interpreted as avoided costs under Build vs. No-Build

• Benefits
  • Avoided asset repair costs
  • Avoided delay costs for autos, buses, and trucks
  • Avoided fuel costs for autos, buses, and trucks

• Costs
  • Capital cost
  • Construction asset closure cost
## BCA Results Format

- **Metrics**
  - Net Present Value (NPV): Discounted Benefits – Discounted Costs
  - Benefit Cost Ratio (BCR): Discounted Benefits / Discounted Costs
  - Internal Rate of Return (IRR): Rate of return that makes NPV equal to 0, or the rate at which an investment breaks even

- Results provided for each Sea Level Rise or Precipitation projection

### RESULTS SUMMARY

**Sandy Vulnerability Assessment Scenario**

<table>
<thead>
<tr>
<th>Costs</th>
<th>USACE Low</th>
<th>USACE Intermediate</th>
<th>USACE High</th>
<th>NOAA High</th>
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<tbody>
<tr>
<td>w ith adaption</td>
<td>$5,730,459</td>
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<tr>
<td>Discounted</td>
<td>$5,563,553</td>
<td>$5,563,553</td>
<td>$5,563,553</td>
<td>$5,563,553</td>
</tr>
<tr>
<td>Benefits (Avoided Losses)</td>
<td>$2,355,376</td>
<td>$2,355,376</td>
<td>$5,146,450</td>
<td>$6,775,355</td>
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<tr>
<td>NPV</td>
<td>-$3,208,177</td>
<td>-$3,208,177</td>
<td>-$417,103</td>
<td>$1,211,803</td>
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<tr>
<td>IRR</td>
<td>-5%</td>
<td>-5%</td>
<td>0%</td>
<td>1%</td>
</tr>
<tr>
<td>BCR</td>
<td>0.42</td>
<td>0.42</td>
<td>0.93</td>
<td>1.22</td>
</tr>
</tbody>
</table>
Findings and Implications

• Economic performance depends heavily on a number of variables, including roadway volume, project cost, closure length, disruption cost per day (including productivity losses and detour time), build and no build failure thresholds, and recurring damage costs.

• If projects or activities are already planned, consider marginal costs and benefits of adapting them to climate risks – start with activities, projects that are happening anyway.

• Early notification, effective evacuation, and enhancing productivity of evacuees can help reduce the larger disruption costs and allow practitioners to delay or forego massive disruption prevention projects such as raised roadways.
Findings and Implications

• Allowing infrastructure to flood can be an option provided that individuals are safe and disruption costs are relatively low (e.g., individuals not having to spend days in evacuation shelters due to failed transportation infrastructure alone)
  • Under this and other strategies, practitioners should investigate how to minimize recurring damages that need to be repaired after every inundation event

• When individuals are cut off from their homes for substantial periods due to transportation infrastructure failure alone, larger projects that prevent this disruption can be more feasible

• In cases where larger construction projects can be economical but construction delays are substantial, it might be more cost-effective to begin construction after a storm event when the asset is already closed
Findings and Implications

• Parallel adaptation efforts can affect the economics of a particular project substantially; coordination is key

• Status of non-transportation assets (e.g., households, workplaces, electrical infrastructure, water infrastructure, power infrastructure) is important to consider.
  • E.g., roadway flood prevention project can be less cost effective if the homes and infrastructure it leads are going to be damaged or disrupted anyway. The transportation network’s benefits rely on the value of the origins and destinations that it connects

• Practitioners should conduct sensitivity testing and ground truthing when using BCA and related analyses
10. Helpful Resources
Helpful Resources


• FHWA Resilience website (https://www.fhwa.dot.gov/environment/sustainability/resilience/)

Helpful Resources

• NCHRP Integrating Extreme Weather Into Asset Management Plans (http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP25-25(94)_FR.pdf)
• NCHRP Managing Risk Across the Enterprise (http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP08-93_FullGuide.pdf)
• ISO 31000 Risk Management (https://www.iso.org/iso-31000-risk-management.html)
• Intergovernmental Panel on Climate Change (IPCC) Assessments (http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml)
• EPA Climate Resilience Evaluation and Awareness Tool (CREAT) 3.0 (https://www.epa.gov/crwu/build-resilience-your-utility)
• NOAA Climate.gov (https://www.climate.gov/)
Helpful Resources

• Downscaled Climate and Hydrology Projections (http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html)
• Climate Corps Sea Level Change Curve Calculator (http://www.corpsclimate.us/ccaceslcurves.cfm)
• USGS StreamStats Tool (https://water.usgs.gov/osw/streamstats/)
• Georgetown Climate Center Clearinghouse (http://www.adaptationclearinghouse.org/)
• California DOT - Addressing Climate Change Adaptation in Regional Transportation Plans (http://www.dot.ca.gov/hq/tpp/offices/orip/climate_change/documents/FR3_CA_Climate Change_Adaptation_Guide_2013-02-26_.pdf)
• Thinking, Fast and Slow – Daniel Kahneman
11. Questions