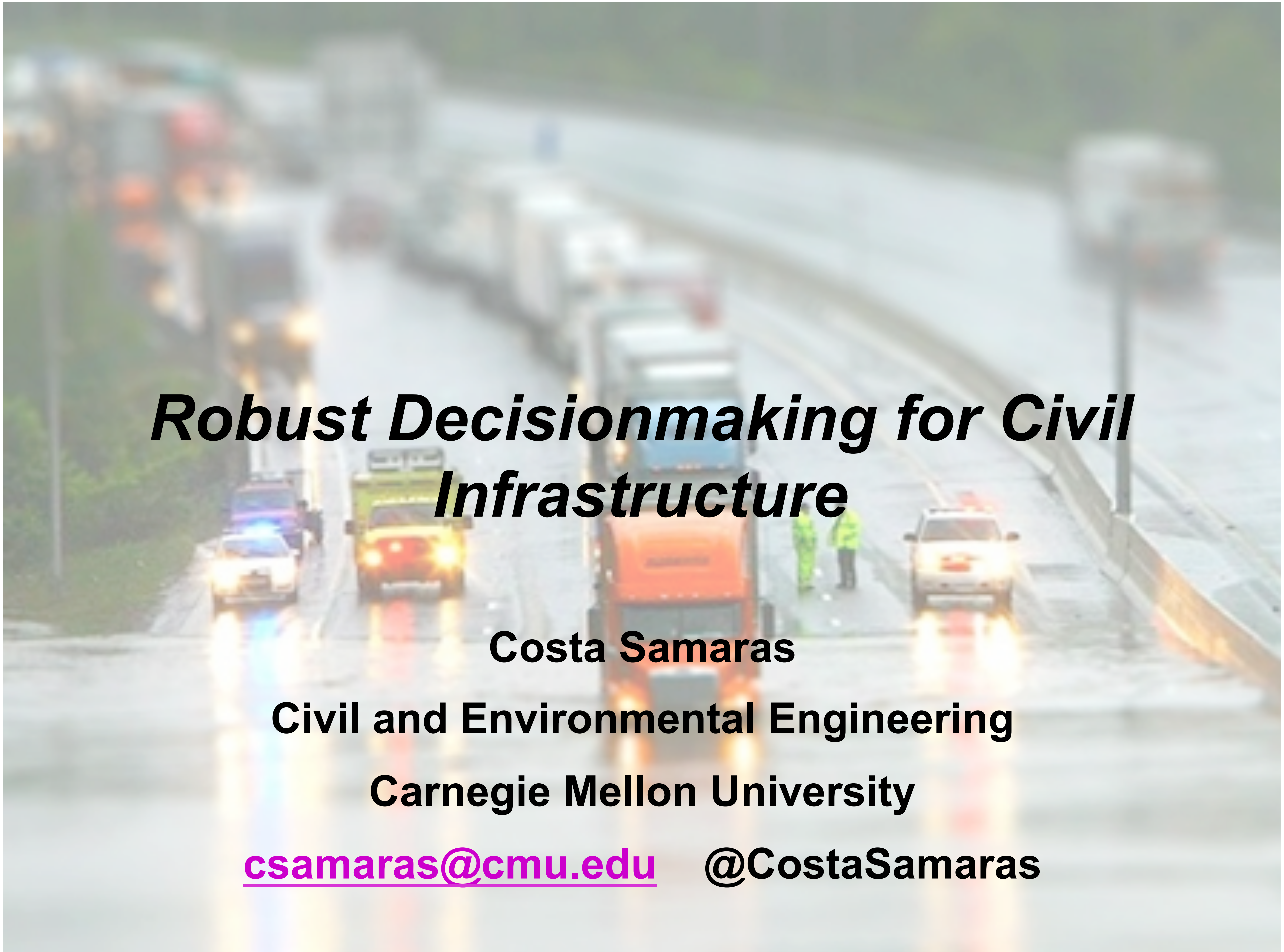

# *Robust Decisionmaking for Civil Infrastructure*

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# *Agenda*

- Introduction and Motivation
- Review of some existing approaches for modeling adaptation infrastructure
- Robust decisionmaking for civil infrastructure activities
- Feedback

# *Civil Engineering Sectors Affected by Climate Change Impacts*

- **Transportation** (highways, culverts, bridges, rail, airports, ports, navigation, pipelines)
- **Water Resources** (dams, levees, irrigation, reservoir management, flood risk management, drought management)
- **Urban Water Systems** (storm water management, municipal water supply and wastewater)
- **Coastal Management** (erosion, seawalls, groins, dredging)
- **Buildings and other structures** (buildings of all types and structural aspects of other infrastructure)
- **Energy supply** (power generation: hydropower, energy infrastructure design, wind engineering, thermal plant cooling, fuel supply)
- **Cold Regions** (freeze-thaw cycling, changes to the permafrost environment, snow accumulation and distribution)

Source: ASCE, 2013

# *Range of Projected Regional Indicators from the National Climate Assessment*

| Key Indicator | Mean Annual Temperature (2071-2099 vs. 1971-2000) | Summer Precipitation (2071-2099 vs. 1971-2000) | Sea level Rise (2100) | Number of Days > 95 °F (2041-2070 vs. 1971-2000) | Number of Days < 10 °F (2041-2070 vs. 1971-2000) |
|---|---|---|---|---|---|
| Northeast | +4°F to 9°F | -5% to +6% | 1.6 – 3.9 feet (0.5 – 1.2 m) | +10 days | -12 days |
| Southeast | +3°F to 8°F | -22% to +10% | | +23 days | -2 days |
| Midwest | +4°F to 10°F | -22% to +7% | | +14 days | -14 days |
| Great Plains | +3°F to 9°F | -27% to +5% | | +22 days | -4 days |
| Southwest | +4°F to 9°F | -13% to 3% | | +20 days | -3 days |
| Northwest | +3°F to 8°F | -34% to -4% | | +5 days | -7 days |

Adapted from (Dell et al., 2014), Tables 4.1 and 4.3, Pgs. 117 and 122. Excludes extreme weather events. Sea level rise will vary by geography and does not apply to the Midwest. Alaska, Hawaii and Pacific Islands not studied.

# *A Range of Climate Phenomena Will Affect Transportation Infrastructure and Operations*

- **Change in extreme maximum temperature**
  - **Asphalt softening and traffic-related rutting**
  - **Thermal expansion bridge in bridge joints**
  - **Reduced construction hours**

- **Change in range of maximum and minimum temperatures**
  - **Reduced snow and ice season but perhaps more intense**
  - **More freeze/thaw damage in northern states**
  - **Longer construction season but maybe more load restrictions**

Source: Adapted from NCHRP, 2014

# *A Range of Climate Phenomena Will Affect Transportation Infrastructure and Operations*

- **Change in amounts and intensity of precipitation**
  - **Deterioration of slope and structural stability**
  - **Inadequate drainage infrastructure**

- **Sea-level rise and storm surge**
  - **More frequent and severe flooding**
  - **Damage from saltwater intrusion**

- **Change in storm and wind intensity**
  - **Damage from wave and wind loads to infrastructure and systems**

Source: Adapted from NCHRP, 2014

# *The Need for Decision Support Appears to Precede the Broad Availability of Decision Support*

- **2013 Executive Order on resilience and climate change directs federal infrastructure investment decisions to analyze resiliency to climate change impacts**

- **$1 Billion climate resilience fund proposed in the fiscal year 2015 federal budget**

- **About $44B per year from Federal sources and $56B per year from State and Local Sources for highway capital expenditures**

Source: Preparing the United States for the Impacts of Climate Change. Executive Order 13653. November 1, 2013; FHWA, 2013

# *Choice is Between Generate Scenarios or Analyze Specific Actions*

- Engineering community initial attempts include adding single probability of failure to infrastructure benefit/cost analyses
- "Well-characterized distributions for climate variables are not available and probabilistic projections of socioeconomic factors may be even more unreliable" (Keller et al. 2008; Lempert et al 2012, etc.)
- RDM analysis:
  - Defines proposed policy
  - Identifies where policy fails to meet goals
  - Identifies response to these vulnerabilities
  - Organizes scenarios to support decisionmaker actions

Source: Preparing the United States for the Impacts of Climate Change. Executive Order 13653. November 1, 2013; FHWA, 2013; Lempert et al., 2012

# *Top-Down Modeling Identified Tradeoffs Between Adaptation Types and Mitigation*

- **Felgenhauer and Webster propose analyzing**
  - **Short-lived ''flow'' adaptation**
  - **Committed ''stock'' adaptation, and**
  - **Lower capacity ''option'' stock adaptation with the capability of future upgrading**
  - **Mitigation investment**

- **Identified that the ratio between these investments depends on substitutability between adaptation types, and if there are physical limits on damage mitigation from flow adaptation investments**

Source: Felgenhauer and Webster (2013a and 2013b)

# *Bottom-Up Modeling Provided Robust Decisionmaking Support for a Case Study*

- **Research question:**
  - **Should the Port of Los Angeles harden its container ship terminals against future sea level rise during the next major upgrades of those terminals?**


- **Study used Robust Decisionmaking methods and climate information with varying levels of uncertainty**

Source: Lempert, Sriver and Keller, 2012

# *Defining Future Conditions for Upgrades with RDM Using Four Steps*

- **Estimating present value savings due to infrastructure hardening over deeply uncertain parameters and many cases**

- **Summarizing common factors among cases that contribute to positive cost-benefit test**

- **Estimate probability threshold that would justify hardening**

- **Benchmark likelihood of cases by evaluating scientific lines of evidence**

Source: Lempert, Sriver and Keller, 2012

# *Lempert, Sriver and Keller Evaluated Decision to Harden Across Deeply Uncertain Parameters*

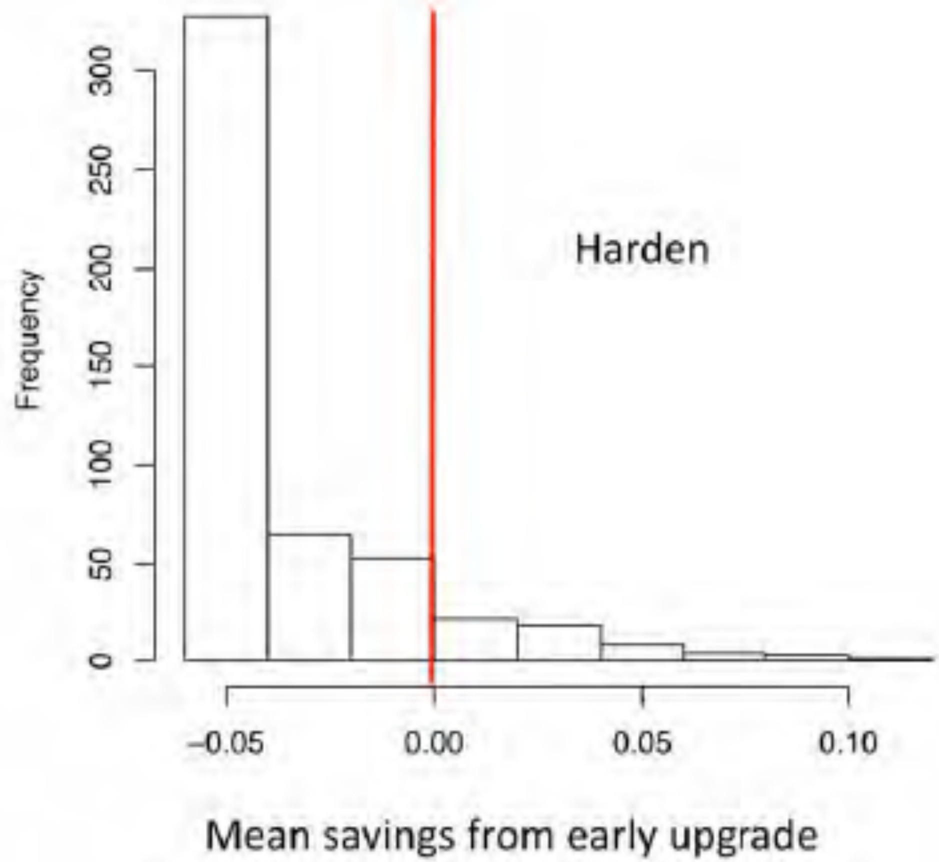



**Figure 5: Histogram of Model Results Generated with 500-point Latin Hypercube Sample over Deeply Uncertain Parameters in Table 1. Positive values indicate cases in which hardening at next upgrade passes a cost-benefit test.**

Source: Lempert, Sriver and Keller, 2012

# *Probabilistic and RDM Analyses Provide Different Information to Decisionmakers*

- **Probabilistic analysis**
  - **Begins with the best scientific estimates** and provides decision makers with the expected savings from an investment to harden.

- **RDM analysis**
  - **Begins by describing the conditions where such an investment would pass a cost-benefit test**, estimates the probability such a scenario would have to have to justify making the investment, and then assembles the scientific evidence that can help a decision maker judge whether or not the investment is worthwhile.

Source: Lempert, Sriver and Keller, 2012

# *The Need for Decision Support Appears to Precede the Broad Availability of Decision Support*

- **Robust Decision Making recommended as a possible method for infrastructure adaptation in:**
  - **DoD Adaptation Plan**
  - **2014 National Climate Assessment**
  - **ASCE Draft Guidance to Engineers**
  - **Many others**

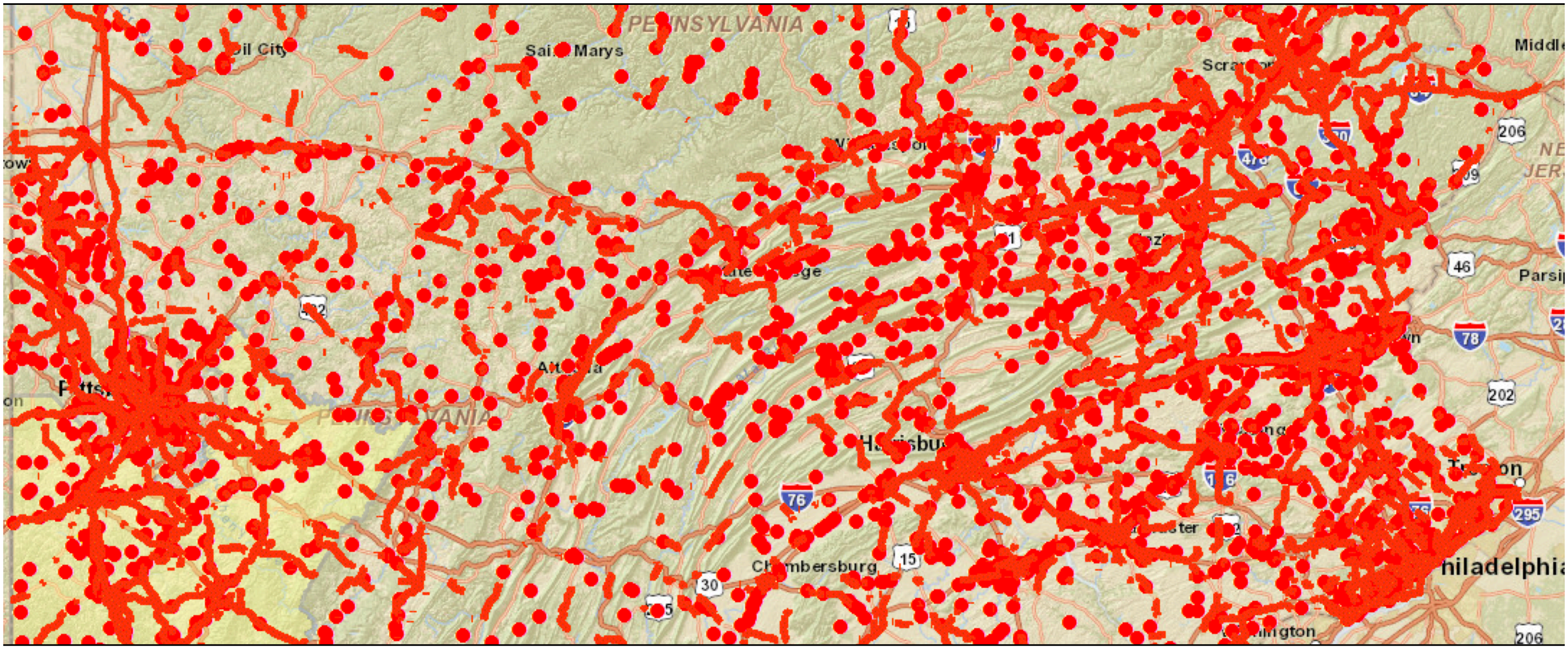
- **CEDM is developing methods for incorporating climate change adaptation decisions into traditional infrastructure management models**

# *Analysis on Applying RDM to Institutional Infrastructure Decisionmaking*

- **Risk of federal and state transportation infrastructure investment exposure to climate impacts**
  - **Initial focus on Pennsylvania highways and bridges**

- **$5.5B Pennsylvania highway & bridge program 2013-2016**
  - **$1.4B from federal**
  - **$3.8B from state**
  - **$0.2B from other**

# *Projects in PA Highway and Bridge Three-Year Capital Plan*



# *Analysis on Applying RDM to Institutional Infrastructure Decisionmaking*

- **Using capital cost, stated/realized useful life distributions, and existing asset management models**
  - **Define conditions over infrastructure estimated useful life where not hardening during upgrades would be regretted**
  - **Create inputs for cost/benefit analyses of transportation infrastructure under climate uncertainty**

# *Broader Impacts and Leverages*

- **Incorporating RDM and capabilities-based planning into cost-benefit analysis of Pacific infrastructure**

# *Broader Impacts and Leverages*

- **American Society of Civil Engineers developing guidance document for climate adaptation and engineering decisionmaking**

- **Three Carnegie Mellon adaptation graduate courses developed by CEDM personnel**
  - **Climate Change Adaptation (Fall 2014 Mini 1)**
  - **International Climate Change Adaptation (Fall 2014 Mini 2)**
  - **Climate Change, Impacts, and Adaptation (Spring 2015)**

# *Thank You*

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