Adaptation of Transportation Infrastructure to Climate Change from a Risk Based Policy Perspective

Mr. Tom Wall, Georgia Institute of Technology

Wednesday, 19 January 2011 - 16:00

Location: Room 610, Skempton (Civil Eng.) Bldg, Imperial College London

Abstract
Thomas Wall will discuss the need to adapt transportation infrastructure to meet the potential threats of climate change. This seminar will focus on the background motivation for adaptation, as well as general strategies to adapt to the potential impacts of climate change in light of current infrastructure management practices. Exemplary strategies discussed will include those developed in the UK, as well as those currently under development in the US.

Biography
Thomas Wall is a doctoral student in civil engineering at the Georgia Institute of Technology studying climate change adaptation as applied to transportation planning and infrastructure management. He holds an M.S. in civil engineering from Georgia Tech, as well as a B.S. in civil engineering from Oregon State University. Recently, Mr. Wall was awarded a Fulbright Scholarship to conduct climate change adaptation research at Imperial College London and the University of Amsterdam during the 2010-2011 academic year.
Climate Change and Risk: Adapting Transport Infrastructure to Future Climate Conditions

Thomas Wall
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January 19, 2011
Overview

- Climate change impacts to transport infrastructure
- Response options
- General guidance for adaptation and decision frameworks – the case for risk management
  - IPCC
  - United Kingdom - UKCIP & Highways Agency
  - Australia/NZ
- Work in development at Georgia Tech
  - Adaptation framework
  - Prioritization of adaptations
- Key questions/moving forward
Climate Change Types and Magnitude

• Observed *changes* in climate:
  – Increased average surface temperature
  – Increased average sea level
  – Decreased Arctic/polar ice

• Observed *effects* of climate change:
  – Increase in frequency of hot days
  – Decrease in frequency of cold days
  – Increase in frequency of heat waves over most land areas
  – Increased frequency of high intensity storms/rainfall
Impacts on transportation infrastructure, 1

- Inland flooding and increased storm water runoff
  - Atlanta flooding, USGS: greater intensity than 500 year storm

Source: AJC, 2009
Impacts on transportation infrastructure, 2

- Coastal flooding and extreme high sea-level
  - Hurricane Katrina (2005)
- Increased average surface temperatures
  - Permafrost melt in Alaska

Source: SUNY-Buffalo (MCEER), 2010
Source: University of Idaho, 2009
Responses to Climate Change Impacts

- **Mitigation**

- **Adaptation**
  
  “Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects.” (IPCC, 2007)
General Guidance for Adaptation, 1

- Intergovernmental Panel on Climate Change (IPCC)
  - 1992 (IPCC, supplement to AR1) – Scenario-driven impact assessment, “adaptive policies”
  - 1994 (IPCC, supplement to AR1) – Scenario-drive impact assessment, evaluation of “adaptation strategies”
    - Defining goals and objectives
    - Specifying important climate impacts
    - Identifying adaptation options
    - Examine constraints of identified options
    - Quantify measures and formulate alternative strategies
    - Weight objectives and evaluate trade-offs
    - Recommend adaptation measures
  - 1995 (IPCC, AR2) - Introduces risk analysis for socio-economic and biophysical impact analysis
General Guidance for Adaptation, 2

• Intergovernmental Panel on Climate Change (IPCC)
  – 2001 (IPCC, AR3) – Introduces risk management in response to:
    • Attitude of risk aversion and loss-mitigation in infrastructure management community – top down vs. bottom up approaches.
    • Uncertainty associated with climate change
      – Climate change projections
      – Actual effects of climate change
      – System vulnerabilities
      – Adaptive capacity of systems
      – Ability to implement adaptation
      – Adaptation costs
  • Offers no formal framework for risk management approach
General Guidance for Adaptation, 3

- UK Climate Impacts Programme
  - 2000 (UKCIP) – Impacts assessment, stakeholder involvement

**Figure 1.1b** Co-ordination of activities and roles within the UK Climate Impacts Programme

Source: UKCIP, 2000
General Guidance for Adaptation, 4

- UK Climate Impacts Programme (UKCIP)
  - 2003 technical report – Adaptation framework to address risk and uncertainty*

Figure 1: A framework to support good decision-making in the face of climate change risk

Source: UKCIP, 2003
Australia & New Zealand introduce joint standard for risk management,

- 2004 - AS/NZS 4360

Source: Standards Australia and Standards New Zealand, 2004
General Guidance for Adaptation, 5

• Intergovernmental Panel on Climate Change (IPCC)
  – 2007 (AR4) – “the certainty that some climate change will occur is driving adaptation assessment beyond the limits of what scenario-driven methods can provide.” (IPCC, 2007)

  – Introduces a generalized risk management framework:
    • A scoping exercise, Establish context of overall assessment is approach to be used.
    • Risk identification, climate and non-climate sources of risk, acceptable risk levels.
    • Risk analysis, Determines and analyzes impact likelihood and consequences.
    • Risk evaluation, Prioritization of adaptation and/or mitigation measures.
    • Risk treatment, Application and monitoring of selected adaptation and/or mitigation
UK Highways Agency: Transportation Specific Adaptation Frameworks

- UK Highways Agency
  - 2008 - *Climate Change Adaptation Strategy*

![Diagram](Figure 2.1: Highways Agency Adaptation Strategy Model)

Source:
Primary criteria for risk appraisal and prioritization
(Highways Agency, 2008)

- Uncertainty
  - Climate change predictions
  - Effects of impacts

- Rate of climate change
  - Time horizon of climate change vs. expected life of asset/activity

- Extent of disruption
  - Number of network disruptions
  - Extent to which users are affected by disruptions

- Severity of disruption
  - Recovery time/recoverability
UK Highways Agency: Transportation Specific Adaptation Frameworks

Primary criteria for risk appraisal

- Uncertainty
  - Climate change predictions
  - Effects of impacts

<table>
<thead>
<tr>
<th>Uncertainty level - climate change predictions</th>
<th>Uncertainty level - effects of climate change on asset/activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Medium</td>
<td>H</td>
</tr>
<tr>
<td>Low</td>
<td>M</td>
</tr>
</tbody>
</table>

Table 4.4: Uncertainty matrix

Primary criteria for risk appraisal

- Rate of climate change
  - Time horizon of climate change vs. expected life of asset/activity

**Table 4.5: Rate of climate change matrix**

<table>
<thead>
<tr>
<th>Time horizon for climate change effects to become material</th>
<th>Asset life / activity time horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-term (up to 2020)</td>
<td>High (H)</td>
</tr>
<tr>
<td>Mid-to-longer term (between 2020 and 2080)</td>
<td>Medium (M)</td>
</tr>
<tr>
<td>Longer-term (beyond 2080)</td>
<td>Low (L)</td>
</tr>
</tbody>
</table>

Primary criteria for risk appraisal

- Extent of disruption
  - Number of network disruptions
  - Extent to which users are affected by disruptions

<table>
<thead>
<tr>
<th>Score</th>
<th>Criterion: Extent of Network Affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>&gt;80% of network / users affected, or any specific highly strategic routes/locations</td>
</tr>
<tr>
<td>Medium</td>
<td>20-80% of network / users affected</td>
</tr>
<tr>
<td>Low</td>
<td>&lt;20% of network / users affected</td>
</tr>
</tbody>
</table>

*Table 4.6: Extent of disruption matrix*

*Source: Highways Agency, 2008*
UK Highways Agency: Transportation Specific Adaptation Frameworks

Primary criteria for risk appraisal

- Severity of disruption
  - Recovery time/recoverability

<table>
<thead>
<tr>
<th>Criterion: Severity of Disruption</th>
<th>High</th>
<th>Disruption time &gt; 1 week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium</td>
<td>Disruption time 1 day-1 week</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>Disruption time &lt;1 day</td>
<td></td>
</tr>
</tbody>
</table>

*Table 4.7: Severity of disruption matrix*

UK Highways Agency: Transportation Specific Adaptation Frameworks

Prioritization:

- Highly disruptive, time-critical with high confidence

\[
\text{Priority} = \frac{\text{Rate of climate change} \times \text{Extent of disruption} \times \text{Severity of disruption} \times (4 - \text{Uncertainty})}{81}
\]

<table>
<thead>
<tr>
<th>Qualitative Score</th>
<th>Numerical Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>3</td>
</tr>
<tr>
<td>Medium</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td>1</td>
</tr>
</tbody>
</table>

*Table 4.8: Scoring conversion*

Transportation Specific Adaptation Frameworks - Work at Georgia Tech, 1

- Identify critical performance measures
- Identify critical assets in the network
- Identify predominant climate change trends and factors for region
- Identify impact of these changes on local environmental conditions
- Identify vulnerabilities of highway system to these changing conditions
- Conduct risk appraisal of vulnerabilities and environmental changes
- Identify trigger levels
- Assess feasibility and cost effectiveness of adaptation strategies

Climate Adaptation Planning

Network Functions
- Asset A
- Asset B
- Asset C
- Asset X

Identify affected highway agency functions
- Change design standards
- Change operating strategies
- Change maintenance practices
- Change construction practices
- Etc.
Transportation Specific Adaptation Frameworks - Work at Georgia Tech, 2

1. Identify critical performance measures
2. Identify critical assets in the network
3. Identify predominant climate change trends and factors for region
4. Identify impact of these changes on local environmental conditions
5. Identify vulnerabilities of highway system to these changing conditions
6. Conduct risk appraisal of vulnerabilities and environmental changes
7. Identify trigger levels
8. Assess feasibility and cost effectiveness of adaptation strategies
9. Identify affected highway agency functions
10. Identify critical performance measures

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Transportation Specific Adaptation Frameworks - Work at Georgia Tech, 2

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Climate Adaptation Planning

- Assess feasibility and cost effectiveness of adaptation strategies
- Identify affected highway agency functions
- Network Functions
- Asset A, Asset B, Asset C, Asset X

- Change design standards
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- Etc.
Prioritization Schemes

National Research Council (NRC, 2010)

- Methods for comparing and ranking adaptations
  - Cost-effectiveness analysis
  - Benefit-cost analysis
  - Risk management
  - Decision analysis
  - Multi-criteria analysis

- Issue of uncertainty
  - Risk management “gaining traction as complementary analytic tool”
  - Several general strategies available
  - Alternate approaches
Risk-Based Prioritization, 1

Probability of critical event
- Probability of regional climate variation
- Probability of critical event
- Probability of asset adversely impacted by critical event
  - $f(x)$ of vulnerability (asset age, condition, type, location, adaptive capacity, etc.)

Examples of probability models
- Earthquake engineering
- FHWA’s HYRISK – bridge scour model using NBI
- Dr. Laurie Garrow, Dr. Matt Higgins (Georgia Tech) – NBI-based simulation model, trigger points
Consequences

- Cost/feasibility of asset repair/replacement
- System/network disruption –
  - User disruption (e.g., HYRISK – bypass length, ADT, ADT-truck)
  - Impacts to local economies
  - National defense
  - Emergency evacuation
- Strata of consequence – Primary, Secondary, Tertiary...

Integration into decision-making framework

- Benefit-cost analysis
- Multi-criteria analysis
- Cost-effectiveness analysis
Key questions moving forward

- How to better integrate *uncertainty* into prioritization and analysis framework?
  - Hallegatte, 2008
    - No-regrets strategies
    - Reversible strategies
    - Safety margin
    - Soft strategies
    - Strategies that reduce decision-making time horizons
  - Potential others
    - Risk management
    - Iterative/periodic analysis
- Which decision-making analysis method(s) are most appropriate?
- What socio-economic variables to include?
- Where do you draw the line with consequences?
- Threshold of actionability?
Questions & References, 1

Questions?

References:

References (con’t):

   http://www.lowcarboneconomy.com/community_content/_low_carbon_blog/3630/sewage_plant_gets_first_wind_turbine