EVERYTHING’S CONNECTED
All the different services we depend on every day also depend on each other. To keep a service running smoothly means keeping other services running smoothly too - which can be tricky...

KEY TO ARROWS
A connects 2 things by having a direct impact on the product. B connects 2 things by having an indirect impact on the product and is used to indicate that an indirect impact can be made.

CLIMATE CHANGE
- Increase in temperature
- More severe weather patterns
- Extreme weather events

HEAVY SNOW
- Road closures
- Power outages
- Infrastructure damage

HIGH WINDS
- Damage to infrastructure
- Power outages
- Transportation disruptions

FLOODS
- Infrastructure damage
- Power outages
- Transportation disruptions

HEAT WAVES
- Increased energy demand
- Power outages
- Transportation disruptions

WIND
- Power generation
- Transportation

GAS
- Energy supply
- Transportation

WATER
- Water supply
- Food production
- Hydroelectric power

SEWAGE
- Waste management
- Water supply

AIR
- Transportation

ROADS
- Transportation

ELECTRICITY
- Energy supply
- Transportation

WASTE
- Recycling
- Energy supply

HEAT WAVES
- Increased energy demand
- Power outages

DINORWIG
- Hydropower generation
- Increased electricity demand

CO-LOCATION of different services
- Increased risk of disruption
- Interdependencies

AND FINALLY
- Continued monitoring
- Further disruption

SCIENCE: David Alderson
DIAGRAM: Terry Wiley

UNIVERSITY OF CAMBRIDGE
Judge Business School
Centre for Risk Studies
Growing Interdependency

- **Water & Wastewater**
- **Waste**
- **Transport**
- **Energy**
- **Digital Communications / ICT Systems**

- Energy supply
- Energy supply potential
- Energy demand management
‘The Internet of Things’ (IOT)
‘Smart... Everything’
UK Infrastructure Transitions Research Consortium

Modelling and Analysis of UK Infrastructure Transitions
Energy | Transport | Water | Waste | ICT

- 7 UK Universities
- 12 Government agencies & LAs
- 11 Engineering consultancies
- 10 Utility companies
- 2 Engineering societies
- 2 Research organisations & data providers
- 2 NGOs
- 1 Insurer
- 5 Contractors and sub-contractors

Consortium Leader – Professor Jim Hall
- Support from EPSRC - £4.7 million
- University contributions - £1 million
- Industry contributions £1.6 million
Outcomes from the ITRC – An Overview
National Infrastructure Model – Long-term Planning

- Visualisation Reports
- Central Database
- Integrated code-base
- Single User Interface
National Infrastructure Model – Risk & Vulnerability
The Future of National Infrastructure

A System-of-Systems Approach

Edited by Jim W. Hall, Martino Tran, Adrian J. Hickford and Robert J. Nicholls
MISTRAL: Multi-scale InfraSTRucture systems AnaLytics

Modelling and Analysis of UK and Global Infrastructure Transitions
Energy | Transport | Digital Communications | Water | Waste

Consortium Leader – Professor Jim Hall (Oxford)
- Support from EPSRC ~ £5 million
- University contributions ~ £1 million
- Industry contributions ~ £2 million
A generalised representation of interdependent infrastructure performance
Multi-scale Infrastructure Systems Analytics (MISTRAL)
Cambridge Group

Dr David Cleevely CBE FREng

Dr Edward Oughton

Professor Peter Tyler
National Needs Assessment

Sir John Armitt
President of the ICE
National Infrastructure Commission

Chancellor of the Exchequer

Led by Lord Adonis

Infrastructure Commissioners:

- Lord Heseltine
- Sir John Armitt
- Professor Tim Besley
- Dr Demis Hassabis
- Sadie Morgan
- Bridget Rosewell
- Sir Paul Ruddock
Integrated Infrastructure: Cyber Resiliency in Society

Insight into Systemic Technological Risk
Examples of CRS Recent Work

- Estimating the direct impact on industrial production systems
Examples of CRS Recent Work

- Estimating the direct impact on industrial production systems
- Quantifying the indirect impact on supply chains
Examples of CRS Recent Work

- Estimating the direct impact on industrial production systems
- Quantifying the indirect impact on supply chains
- Valuing the total cost to the UK economy
Ukraine – 23rd December 2015
Scenario Modelling Process

- DNO cyber attack scenarios
- Run Infrastructure Network Vulnerability Assessment Model: Estimate customers disruptions
- Shock UK IO model: Estimate direct and indirect economic losses by industry
- Produce simulations using OEM model: Estimate 5 year GDP@RISK
A System-of-Systems Approach to Infrastructure Interdependencies

- Systems model
- High resolution
- Multi-scale
- Interdependencies

Slide credit: Scott Thacker of ITRC
Electricity Customers Disrupted

Peak electricity customers disrupted (by decile)

0
1 - 81431
81432 - 98757
89758 - 98363
98364 - 110661
110662 - 132120
132121 - 169142
169143 - 232928
232929 - 284500
284501 - 400910

Ports
Cities / towns
Airports
London outline

London
Bristol
Birmingham
Manchester
Liverpool
Edinburgh
Glasgow

UNIVERSITY OF CAMBRIDGE
Judge Business School
Centre for Risk Studies
ITRC
Critical Infrastructure Customers Disrupted

Peak digital communications customers disrupted (by decile)

- 0
- 1 - 11941
- 11842 - 34838
- 34835 - 44791
- 44792 - 79226
- 79227 - 97523
- 97524 - 130359
- 130359 - 164651
- 164652 - 328126
- 328127 - 638574

Peak fresh water customers disrupted (by decile)

- 0
- 1 - 19889
- 19890 - 45815
- 45816 - 55360
- 55361 - 105389
- 105370 - 125209
- 126210 - 178102
- 178103 - 266523
- 266527 - 475558
- 475558 - 947529

Peak waste water customers disrupted (by decile)

- 0
- 1 - 19042
- 19043 - 32395
- 32396 - 68512
- 68513 - 90984
- 90985 - 104526
- 104527 - 127591
- 127592 - 149264
- 149265 - 1168482
- 1168483 - 2142004

[Map images showing distribution of disrupted customers across different categories]
Railway Customers Disrupted
### Direct and Indirect Economic Losses by Industry

<table>
<thead>
<tr>
<th>Industry</th>
<th>S1 Direct</th>
<th>S1 Indirect</th>
<th>S2 Direct</th>
<th>S2 Indirect</th>
<th>X1 Direct</th>
<th>X1 Indirect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial Services</td>
<td>897</td>
<td>419</td>
<td>2,175</td>
<td>1,039</td>
<td>5,325</td>
<td>2,870</td>
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<tr>
<td>Wholesale and Retail trade</td>
<td>770</td>
<td>505</td>
<td>1,950</td>
<td>1,263</td>
<td>6,126</td>
<td>3,710</td>
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<td>Real Estate Activities</td>
<td>820</td>
<td>388</td>
<td>2,063</td>
<td>956</td>
<td>6,295</td>
<td>2,601</td>
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<tr>
<td>Professional Services</td>
<td>700</td>
<td>335</td>
<td>1,736</td>
<td>834</td>
<td>4,857</td>
<td>2,369</td>
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<tr>
<td>Construction</td>
<td>428</td>
<td>406</td>
<td>1,088</td>
<td>1,020</td>
<td>3,574</td>
<td>3,123</td>
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<tr>
<td>Manufacturing</td>
<td>354</td>
<td>379</td>
<td>922</td>
<td>953</td>
<td>3,442</td>
<td>2,922</td>
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<tr>
<td>Health</td>
<td>402</td>
<td>255</td>
<td>1,013</td>
<td>638</td>
<td>3,101</td>
<td>1,900</td>
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<tr>
<td>Administrative Services</td>
<td>362</td>
<td>211</td>
<td>902</td>
<td>524</td>
<td>2,613</td>
<td>1,489</td>
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<tr>
<td>Transportation</td>
<td>304</td>
<td>252</td>
<td>762</td>
<td>628</td>
<td>2,317</td>
<td>1,822</td>
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<tr>
<td>Education</td>
<td>441</td>
<td>114</td>
<td>1,113</td>
<td>286</td>
<td>3,451</td>
<td>858</td>
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<tr>
<td>Information Technologies</td>
<td>440</td>
<td>96</td>
<td>1,085</td>
<td>239</td>
<td>2,776</td>
<td>672</td>
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<tr>
<td>Government And Emergency Services</td>
<td>318</td>
<td>206</td>
<td>797</td>
<td>515</td>
<td>2,407</td>
<td>1,511</td>
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<tr>
<td>Other Services Activities</td>
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<td>42</td>
<td>900</td>
<td>104</td>
<td>2,550</td>
<td>296</td>
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<tr>
<td>Accommodation and Food Service Activities</td>
<td>205</td>
<td>135</td>
<td>511</td>
<td>338</td>
<td>1,473</td>
<td>1,006</td>
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<tr>
<td>Communications</td>
<td>82</td>
<td>139</td>
<td>205</td>
<td>345</td>
<td>578</td>
<td>983</td>
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<tr>
<td>Food</td>
<td>63</td>
<td>135</td>
<td>162</td>
<td>341</td>
<td>589</td>
<td>1,079</td>
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<tr>
<td>Arts, Entertainment and Recreation</td>
<td>120</td>
<td>64</td>
<td>300</td>
<td>159</td>
<td>901</td>
<td>457</td>
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<tr>
<td>Water Supply and Waste Management</td>
<td>62</td>
<td>54</td>
<td>160</td>
<td>135</td>
<td>529</td>
<td>402</td>
</tr>
<tr>
<td>Energy (Oil and Gas)</td>
<td>12</td>
<td>74</td>
<td>30</td>
<td>184</td>
<td>80</td>
<td>529</td>
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<tr>
<td>Electricity</td>
<td>17</td>
<td>64</td>
<td>44</td>
<td>160</td>
<td>133</td>
<td>467</td>
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<tr>
<td>Defence Manufacturing</td>
<td>22</td>
<td>55</td>
<td>57</td>
<td>139</td>
<td>186</td>
<td>412</td>
</tr>
<tr>
<td>Agriculture, Forestry and Fishing</td>
<td>28</td>
<td>37</td>
<td>75</td>
<td>94</td>
<td>318</td>
<td>294</td>
</tr>
<tr>
<td>Mining</td>
<td>2</td>
<td>9</td>
<td>6</td>
<td>23</td>
<td>21</td>
<td>68</td>
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</tbody>
</table>
## Estimation of Economic Loss

<table>
<thead>
<tr>
<th>Scenario Variants</th>
<th>Lost Power (TWh)</th>
<th>Direct Industrial Production Losses (1 Yr) £ billion (from IO modelling)</th>
<th>Indirect Losses to Supply Chains (1 Yr) £ billion (from IO modelling)</th>
<th>GDP@Risk (5 Yr) £ billion (from macroeconomic modelling)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>10.3</td>
<td>7.2</td>
<td>4.4</td>
<td>49</td>
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<tr>
<td>S2</td>
<td>19.8</td>
<td>18.0</td>
<td>10.9</td>
<td>129</td>
</tr>
<tr>
<td>X1</td>
<td>39.6</td>
<td>53.6</td>
<td>31.8</td>
<td>442</td>
</tr>
</tbody>
</table>

**Domestic UK GDP@Risk under each scenario variant**

![Graph showing Domestic UK GDP@Risk over years 2016 to 2021 for different scenario variants.]

- **Baseline**
- **S1**
- **S2**
- **X1**
Helios Solar Storm Scenario

- Explores the potential economic impact of extreme space weather.
- Develops an open-source risk matrix.
- Undertakes sectoral analysis of global supply chain linkages and total macroeconomic losses.
- Estimates insurance portfolio losses.
US Dependent on Global Supply Chain

Annual Average LPT Imports, 2011-2013:
491 Units or $735 Million

Note: This analysis includes LPTs with capacity greater than or equal to 100 MVA.

(DOE, 2014)
Methodology

Scenario Variants

- S1
- S2
- X1

Method 1
State-level Multi-criteria Risk Matrix

Method 2
Calculation of Direct Costs to Economic Sectors

Method 3
Estimation of Indirect Costs to Domestic and International Supply Chains

Method 4
Economic Simulation of the GDP@Risk

Graph showing the timeline from 2005 to 2013 with data points indicating an upward trend.
Direct Economic Impacts by Industrial Sector
International Supply Chain Impacts

![Bar chart showing indirect shock to country GDP ($bn) for various countries: China, Canada, Mexico, UK, Japan, Germany, South Korea, France, Brazil, Russia, India. The chart distinguishes between indirect shock from downstream US imports and upstream US exports.](chart)
In Summary

- Critical infrastructure and technological catastrophe:
  - In context
  - Expertise
  - Recent achievements
  - Ongoing real world impact

- Research highlights:
  - Integrated Infrastructure
  - Helios Solar Storm
Conclusion

- Infrastructure systems are becoming more and more interconnected:
  - Proliferation of digital technologies in a rapidly changing environment;
  - Ramifications for risk, vulnerability and resilience;
- New models needed to understand technological risks in order to provide genuine insight for industry and government:
  - Uniquely placed to do this thanks to our methodological expertise;
  - Our perspective recognises the complexity of the international business landscape.