Overview of Resilient Systems

2021 APRU Multi-Hazards Summer Lecture Series: Creating a Resilient Society against Multiple Hazards

28 July 2021

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Poll
Outline

- Recent extreme events in North America and Europe
- Worldwide trend of disasters
- Changes in global risk perception
- Risk analysis framework
- Rising protection gap and increasing risk
- What is resilience?
- Regime shifts
- Applications of the concept of resilience:
  - Critical infrastructure systems resilience
  - Food system resilience
  - Social resilience
  - Socio-technical resilience
- Smart cities and resilient systems
- Summary
What happened:
- High pressure area was sandwiched between two low pressure areas
- Anomalies relative to average daily temperatures (2014-2020) were up to 15°C higher for the same day

Losses:
- > 900 deaths, wildfires
- > USD 3 billion
2021 Western North America Heat Wave – Past Heat Wave Events in North America

Key observations:

- Likely amplified by climate change (Philip et al., 2021; Fischer et al., 2021)
- Potentially a ‘Grey Swan’ event – an event that would not be predicted based on history, but may be foreseeable using physical knowledge together with historical data (Lin et al, 2016).

2021 European Floods – Extreme Event

What happened:
- A storm complex moved from France to Germany and brought excessive amount of rainfall

Losses:
- > 200 deaths
- > USD 3 billion

Key observations:
- Intense rainfall was forecasted for affected areas
- Not a Grey or Black Swan event
Number of Disasters – Worldwide

Trend:

- Number of weather-related disasters stabilised during the last two decades

Source: EM-DAT, CRED, 2021
Global Risks in 2020

Experts from various sectors and disciplines provided their perception on the potential **likelihood** and **impact** of key risks for the global level.

Global Risks: Changes from 2005 to 2020

Key changes:
- Pandemics and extreme weather more likely to occur with similar intensity
- Increasing digitalisation and global interconnectedness leads to higher impacts in case of IT breakdown

From Risk to Resilience

Risk

Resilience
A few definitions…

Risk is typically defined as:
Risk = Hazard x Exposure x Vulnerability

Hazard: a potentially **destructive physical phenomenon** (e.g., an earthquake, a windstorm, a flood).

Exposure: the **location**, **attributes**, and **value of assets** that are important to communities (people, buildings, factories, farmland, etc.) and that could be affected by a hazard.

Vulnerability: the **likelihood** that assets will be damaged/destroyed/affected when exposed to a hazard

Source: https://understandrisk.org/vizrisk/what-is-risk/
Risk Analysis Framework – Drivers in the Context of Flood Hazards

- **Risk Exposure**
  - Climate change
  - Human-environmental coupling
  - Urbanisation

- **Vulnerability**
  - Flood hazard map from Ho Chi Minh City, FATHOM 2

- **Hazard**
  - Flood magnitude
  - Frequency

- **Exposure**
  - Soil condition
  - Unplanned development

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Unplanned development
Soil condition

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Human-environmental coupling

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Urbanisation

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Risk Assessment – Hazards & Disasters

Singapore, April 2021

New Orleans, August 2005


https://www.nationalgeographic.org/article/making-history-hurricane/
Increasing Damages from Natural Disasters – Rising Protection Gap

Source of data: Swiss Re, 2021
Risk Horizons

City planning horizon

Risk mitigation (reduction) and adaptation
High **uncertainty** on whether hazards become more severe in the future due to climate change and whether exposure and vulnerability remain stable or increase due to changes in land-use (e.g. urbanisation).
Disaster Risk Management – Extreme Events

Disaster risk management cycle

- Preparedness
- Mitigation
- Disaster
- Response
- Recovery

Extreme events require additional efforts or more resilience
What is Resilience?

**Definition** by United Nations Office for Disaster Risk Reduction:
The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.
Application of Concept or Resilience in Science

Source of data: Bielefeld Academic Search Engine

- Ecological Resilience: Holling, 1973
- Socio-ecological Resilience: Adger, 2000
- Community resilience: Bruneau et al., 2003
What is Resilience?

Credit: Hans R. Heinimann, 2019
Regime Shifts

5,000-6,000 years ago after a steady decline of terrigenous dust and vegetation cover, an abrupt collapse occurred in the Sahara creating the current desert.

Regime shifts are large, persistent, and usually unexpected changes in ecosystems and social-ecological systems” Biggs et al., 2018, Ecology and Society.

Scheffer and Carpenter, 2003
Warming of the ocean due to climate change can lead to death of coral reefs. Dying of coral reefs has severe impacts on marine habitats.

Impacted marine habitats change ocean biodiversity and available resources for humans.

Source: https://www.tropicalsnorkeling.com/live-vs-dead-coral.html#gallery/pageGallery/3/
Increased need to understand **intrinsic capabilities** of systems and how they interact with users (i.e. people)
Interdependencies in Critical Infrastructure Systems

Above surface:
- Buildings
- Roads

Above/below surface:
- Power lines
- Telecommunication

Below surface:
- Water
- Canalisation

Need to understand interdependencies
Cascading Effects of a Disruption in Critical Infrastructure Systems

Goal: to build resilience to manage disruptions
Workflow to Identify Critical Infrastructure Elements – Road Network

Based on network analysis identify **critical road links** for ensuring critical services, such as medical services and emergency response. Example: Ho Chi Minh City, Vietnam

Video from UR2020 presentation available: https://www.ur2020.org/agenda/session/440043
Critical Infrastructure Systems – Recovery of Power Supply


Method:
- Fitting of functions from the gamma family to estimate parameters of recovery of power supply for power utilities.

Findings:
- Absorptive (a), adaptive and restorative (b) capabilities are intrinsic to a system. Recovery time (c) may depend on actions taken.

Hurricane Sandy, 2012

Modelling of recovery process

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Food System Resilience – Tomatoes in Morocco

System Dynamics Model

Findings:
- System dynamics allows to model the various process of a system and determine critical thresholds (e.g. depletion of groundwater)


Temara groundwater for a) (in Rabat Salé Kénitra Region) and Chtouka groundwater for b) (in Souss Massa Region) dynamics. Relatif water volume compared to the initial time in 2008.
Social Resilience: Changes in Social Capital during COVID-19

Singapore:
- Social network: 48% somewhat/strongly disagree, 34% neutral, 18% somewhat/strongly agree
- Social support: 35% somewhat/strongly disagree, 38% neutral, 27% somewhat/strongly agree
- Social cohesion*: 13% somewhat/strongly disagree, 34% neutral, 53% somewhat/strongly agree

Switzerland:
- Social network: 51% somewhat/strongly disagree, 34% neutral, 15% somewhat/strongly agree
- Social support: 47% somewhat/strongly disagree, 22% neutral, 31% somewhat/strongly agree
- Social cohesion*: 36% somewhat/strongly disagree, 19% neutral, 45% somewhat/strongly agree

Method:
- Representative surveys (n=1500) conducted in mid-2020 in Singapore and Switzerland

Findings:
- Rather than collective action, people have to rely on their own abilities to cope with the pandemic. Collective action is less important.
- Need to monitor changes of social capital over time --> second survey.
- Need to analyse how social networks change due to increasing online and virtual interactions.

Behaviour-oriented Corruption in Power Systems during COVID-19

Impact of COVID-19 progression on the Singaporean residential electricity consumption

Method:

Findings:
- Peak aggregate household demand are strongly correlated with daily new and recovered COVID-19 case numbers, there is causality.
- Proactive response of Singaporeans to the pandemic even before Circuit Breaker was enforced.

Develop Smart Cities & Resilient Systems

- Take a system-of-systems approach by linking physical with cyber systems
- Optimise the use and availability of resources in densely populated areas
- Analyse sensor data from networks and people to identify cognitive patterns
Summary

- Extreme events are likely to become more frequent due to human-induced climate change.
- Urbanisation leads to a coupling of hazard exposure and vulnerability.
- Insurance may support risk management efforts, but are not sufficient. Planning needs to take into account changing risk exposure and possibility of complex crises.
- Risk management needs to be complemented with resilience management to better deal with unexpected, rare and high-impact events.
- Focus in resilience research is on understanding intrinsic capabilities of systems and how potential disturbances cascade.
- Digitalisation allows individuals to be directly connected to physical systems. Enormous research opportunities to better understand resilience of socio-technical systems.
FRS II (2020-2025): Programme Structure

Delivering novel solutions for resilience management through engineering, design and social research

- Distributed Cognition for Social Resilience
- Develop a SoS understanding
- Perspectives:
  - Design
  - Distributed control
  - Data networks
  - Digital twin

- High-Density Urban Systems
- Perspectives, link HDUS to:
  - Urban metabolism
  - Optimal pathways for the future
  - Climate change
  - Financial systems

- Cyber-Physical Systems
- Perspectives:
  - Mobile sensor platform
  - Soft sensors (social media)
  - Context-specific fusion of data
  - Social resilience
  - FinTech Behaviour

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Delivering novel solutions for resilience management through engineering, design and social research
Critical Infrastructure Systems Resilience

2021 APRU Multi-Hazards Summer Lecture Series: Creating a Resilient Society against Multiple Hazards

29 July 2021

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Outline

• **An introduction into critical infrastructure systems resilience**
  • What are critical infrastructures
  • Complex interdependencies
  • Defining critical Infrastructure resilience and its dimensions

• **Transportation systems resilience**
  • Global disaster risks exposure
  • How to achieve infrastructure resilience: Ho Chi Minh City case study
    • BRT Corridor project planning with ur-scape
    • Lifeline preparedness for flood risks

• **Summary**
Critical infrastructure

Assets, systems, and networks that provide essential services for the security of a nation, its economic prosperity, and the health and safety of its citizens.
Direct damages from disasters to the power generation and transport infrastructure are estimated at **US$18 billion** a year in low- and middle income countries globally.

But the estimated cost of the associated disruption to services (energy and transport) ranges from **US$391 billion to US$647 billion**, at least 20 times larger.
In February 2021, as a result of deadly winter storm and record low temperatures in Texas, USA, 4.5 million people were cut off from power.

A utility structure is encased in ice on Feb. 15, 2021 in Houston. Source: https://www.texastribune.org/2021/02/16/texas-power-outage-ercot/
Interdependence of Critical Infrastructure Systems

- A massive **electricity** generation failure, more than 4.5 million homes and businesses were left without power.
- **Water** service was disrupted for more than 12 million people due to pipes freezing and bursting.
- Intermodal **freight** network was shut down and train lengths were reduced for safety reasons.
- Water treatment facility lost power, forcing a city-wide boil water notice to be issued. Non-urgent surgeries were cancelled and patients were transferred due to the water shortage and impacted heating system.
- The **power** outages have also had a major impact on rail traffic that is critical for many supply chains, leading to impacts to manufacturing, warehousing and store operations.
  - Shut down semiconductor plants clustered around Austin, further disrupting a supply chain that has already been falling short of customer needs.
- Electricity prices on the state’s wholesale market soared by $47 billion. Some energy firms made billions in profits, while others went bankrupt.
Critical Infrastructure Resilience

The resilience “triangle” (Bruneau et al., 2003) - technical basis for resilience assessment

The ability of the system to

- reduce the chances of shocks
- absorb a shock if it occurs
- recover quickly after a shock

Critical Infrastructure Resilience

Towards a comprehensive modelling framework - high-level dimensions

- “TOSE” by Bruneau et al. (2003)

- US National Infrastructure Advisory Council (2010)
  - People and processes
  - Infrastructure and assets.

Please click on the location where you are at.
What is this type of hazard?

- Earthquakes
- Cyclones
- Surface flooding
- River flooding
- Coastal flooding
Transportation Infrastructures and disaster risks

Global dominant hazard exposure per region (Koks et al., 2019)

Public Critical Infrastructure Planning with Resilience-thinking

A research collaboration with the World Bank Group and Ho Chi Minh City, Vietnam

Future Resilience Systems: Dr. Jonas JOERIN, Dr. Yi WANG, Dr. Dr. Peter LUSTENBERGER
Future Cities Lab Global: Prof. Stephen CAIRNS, Michael Joos

ur-scape adapted to HCMC for a flooding with 100-year return period
Digital workflow

Hazard events
- FATHOM2 flood maps
  - Estimated water level for raster cell (~90m)
  - 10 RP, fluvial and pluvial

Exposure and disruption
- Functionality loss
  - Road closure due to "heavy flooding" (inundation depth > 0.3 m)
  - Highest cell value (water level)

Critical component Analysis
- Topological analysis
  - Network science indicators
  - Before/after a disruptive event

Road transport network
- OpenStreetMap data
  - Road orientation and class
  - Operational attributes (e.g., speed limit)

Critical Infrastructures Planning in ur-scape: BRT Corridor

- Catchment area analysis
  - Identify beneficiary/impacted communities
  - Assist travel demand planning

- Component level – “vulnerability”
  - Flood risks screening for critical infrastructures (e.g., stations and road segments)
Critical Infrastructures Planning in ur-scape: BRT Corridor
Critical Infrastructure Services

Road Transportation Network for Supporting Emergency Services

- **Network level - “criticality”**
  - Identification of “hotspots” based on network science: the lifeline under normal and flooded situations
  - Wider social costs consideration by incorporating human assets
Road criticality in the 10-min catchment network of District 4 Hospital
(No disruption)
Road criticality in the 10-min catchment network of District 4 Hospital
(disrupted by pluvial flooding with 20-yr return period)
Change of the edge betweenness centrality of road segments

<table>
<thead>
<tr>
<th>Flood depth (m)</th>
<th>Change</th>
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<tbody>
<tr>
<td>0.3</td>
<td>-517</td>
</tr>
<tr>
<td>0.5</td>
<td>-300</td>
</tr>
<tr>
<td>1</td>
<td>-100</td>
</tr>
<tr>
<td>1.5</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>300</td>
</tr>
<tr>
<td>10</td>
<td>991</td>
</tr>
</tbody>
</table>
Population density weighted OD-based edge betweenness centrality

Population density:

- 0 - 77042
- 77042 - 304534
- 304534 - 597409
- 597409 - 1248692
- 1248692 - 2027510

Population grid:

- 1 people/cell
- 91.58283 people/cell
- 182.16566 people/cell
- 272.74849 people/cell
- 363.33132 people/cell
- 453.91415 people/cell
- 544.49698 people/cell
- 628.1119 people/cell
- 697.791 people/cell
Summary

- **Both “economic” and ”societal”**: improve understanding of critical infrastructure and factors which may determine criticality
- **A “System-of-Systems” perspective**: the framework needs to consider the complete range of hazards and complex failure modes as a result of inter-related, upstream dependencies
- **The favourable investment in resilience**: undertake further economic and engineering research to better understand and quantify a suitable level of investment in technical resilience

Figure: Singapore Mass Rapid Transit trains travel along lines at the Jurong East interchange in Singapore by Roslan Rahman/AFP/Getty Images