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Critical Infrastructures – Interdependencies and consequences from a vulnerability perspective

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Critical Infrastructures (CIs)?

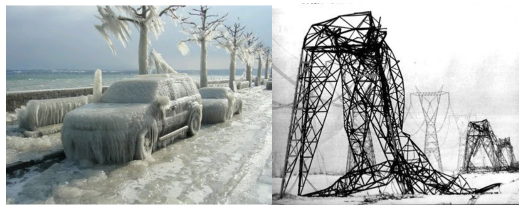
- *"…those assets or parts thereof which are essential for the maintenance of critical societal functions, including the supply chain, health, safety, security, economic or social well-being of people"* (EPCIP – COM, 2006)
- Brief history – From sector regulations towards holistic infrastructure protection
  - Starting point for the field; Executive Order 13010 (Executive Order, 1996), creating PCCIP in the USA.
  - 9/11 in 2001 and Hurricane Katrina in 2005 illuminated the importance and vulnerability of critical infrastructure. Creation of DHS and intensified work. From terrorism towards all-hazard approaches.
  - In Europe, the EPCIP program was initiated in 2006.
  - Today most countries around the world have programs focused towards CIP, i.e. moving from earlier "sector-divided" approaches towards more holistic infrastructure protection approaches.
  - A response to the interconnectedness of todays infrastructures – the backbone of society!

Rationale

- Society heavily dependent on the services of critical infrastructures, widespread disruption entails large-scale societal impacts.
- Hence:
  - Proactive risk and vulnerability approaches and long term planning fundamental
  - Of essence is to increase our understanding CIs limits, their interdependencies and societal dependence on the services these provide
- However, there exist several research, policy, and practical challenges for a holistic understanding and a fundamental need for development of approaches and methods in this field.

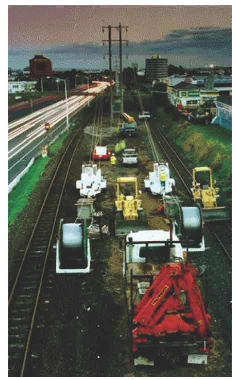
Hurricane Gudrun, Sweden 2005

Ice storm, Canada 1998



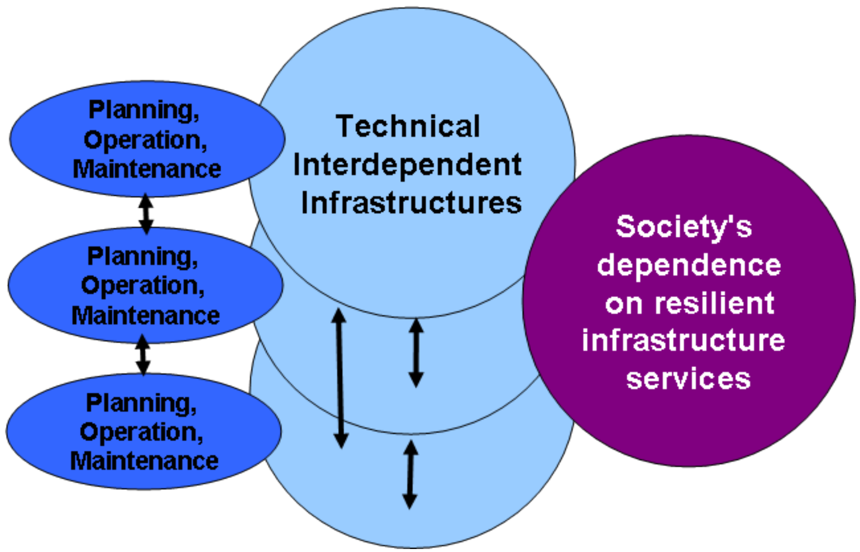
Blackout, USA 2003

Auckland 1998



Six challenges and examples of research at LU

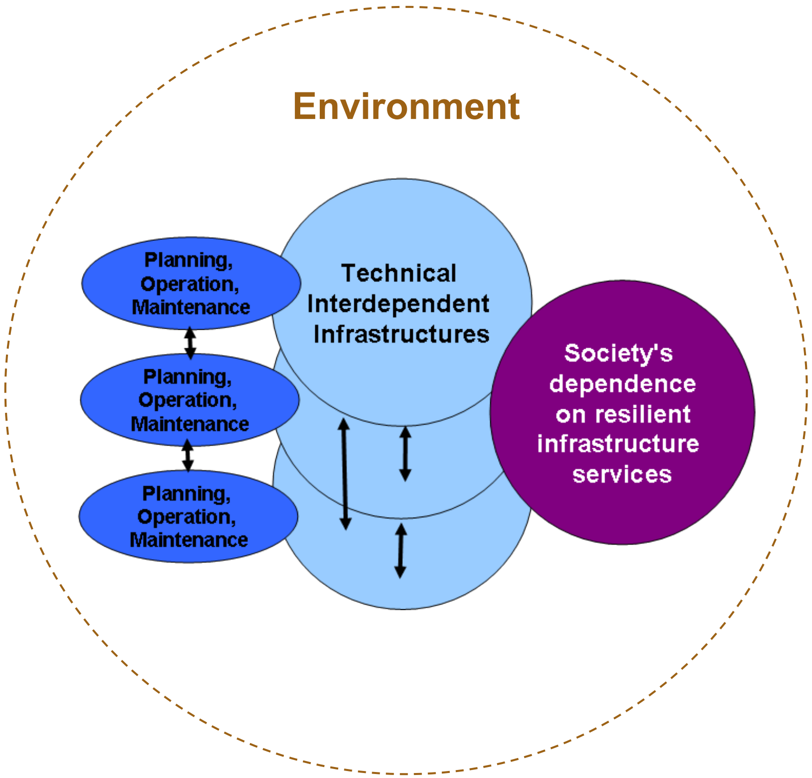
I. Addressing high impact and low probability events
II. Empirical data for cascading effects in critical infrastructures
III. Modelling and simulation of interdependent technical critical infrastructures
IV. Recovery and resilience of technical critical infrastructures
V. Interdependencies between societal functions and dependence on technical infrastructures
VI. Risk governance of critical infrastructures



Challenge 1

Addressing high impact and low probability events

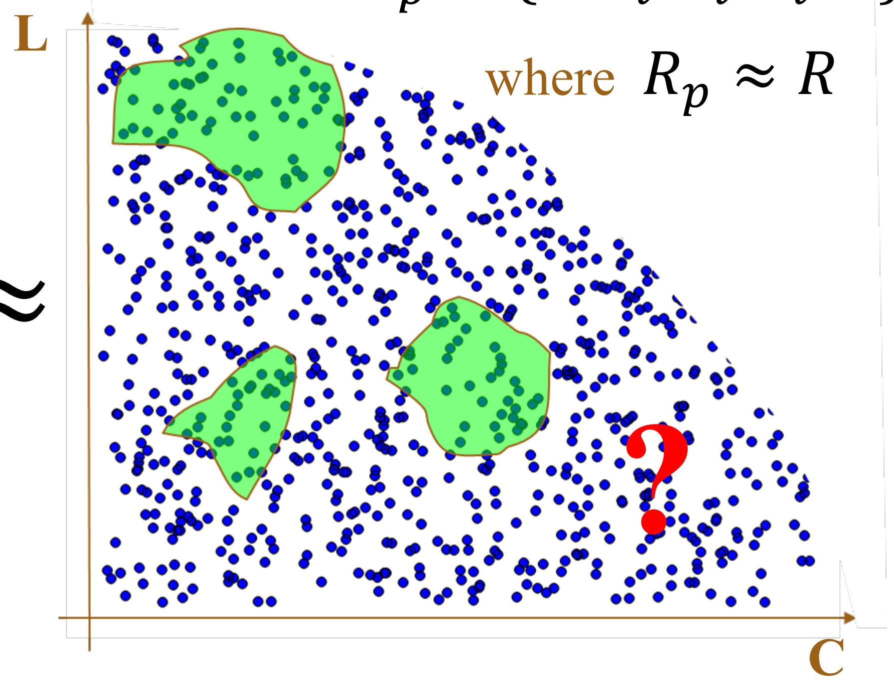
- Due to the complexities of national critical infrastructures; the services they provide, the operation of them, and the environment in which they operate → To address HILP use **vulnerability** as a **complement** to **risk (?)**



$\approx$

$$R_p = \{< S_i, L_i, C_i >\}_p$$

where $R_p \approx R$



Challenge 1

Addressing high impact and low probability events

***Likelihood** that an event/scenario affect the system, i.e. forcing it into a specific state*

*The **consequences** associated with a specific state of the system*

Risk = f(Hazard/Threat, Susceptibility, System State, Consequence)

***Likelihood** of an Hazard/Threat occurring*

***Likelihood** of an Hazard/Threat affecting the system*

Vulnerability *seen as a property of to the system states and the consequences associated with these states*

Models:
E.g. Aging models, Climate models, Terrorism models…

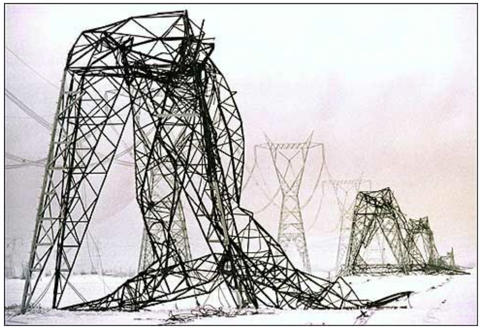
Models:
E.g. Fragility curves

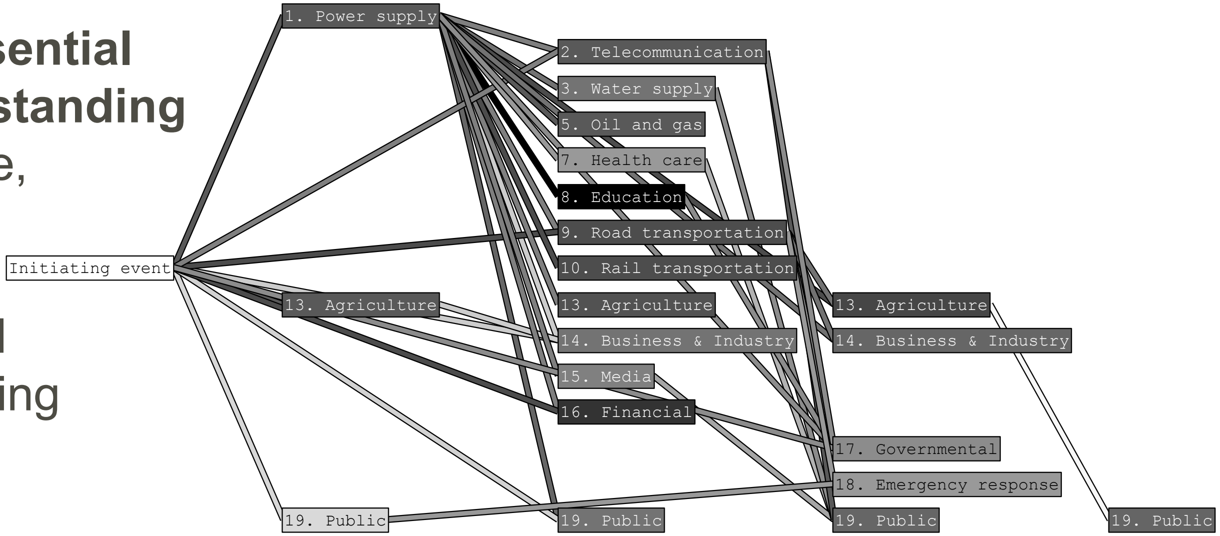
Models:
E.g. Power flow AC/DC
Pressure models
Traffic flow models
Cascading models
Stability models
Input-output models

Challenge 2

Empirical data for cascading effects between critical infrastructures

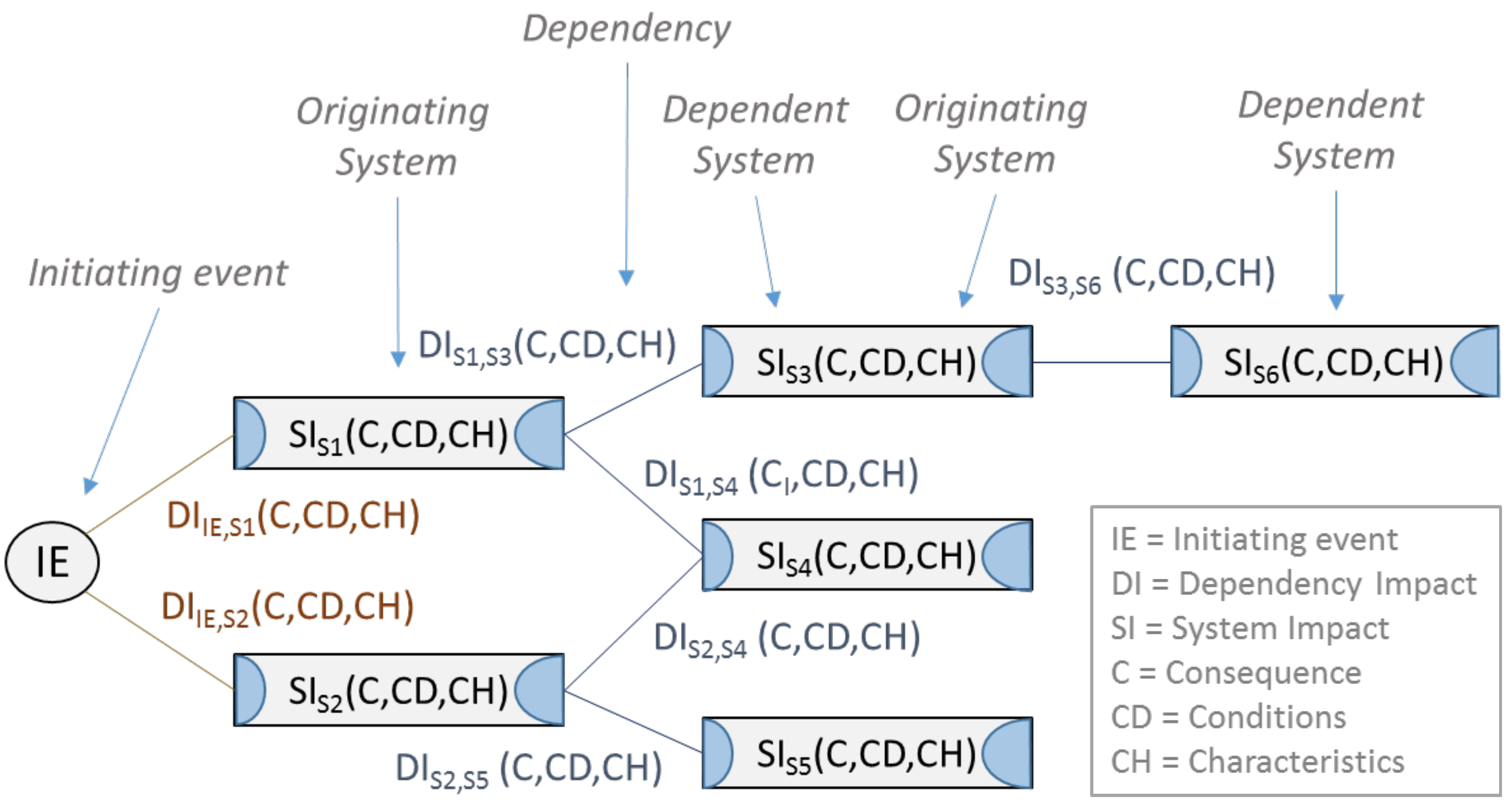
- To **support the research** in the field of critical infrastructures, one important aspect is the **access to empirical data**.
- In general, **good quality data** with respect to the **cascading effects** that arise when infrastructure collapses are **lacking**. For example traditional accident investigation methods do not focus on interdependencies.
- This type of **data is essential** to **increase our understanding** of society's dependence, how this picture has changed and the mechanisms behind interdependencies leading to cascading effects.





Challenge 2

Empirical data for cascading effects between critical infrastructures



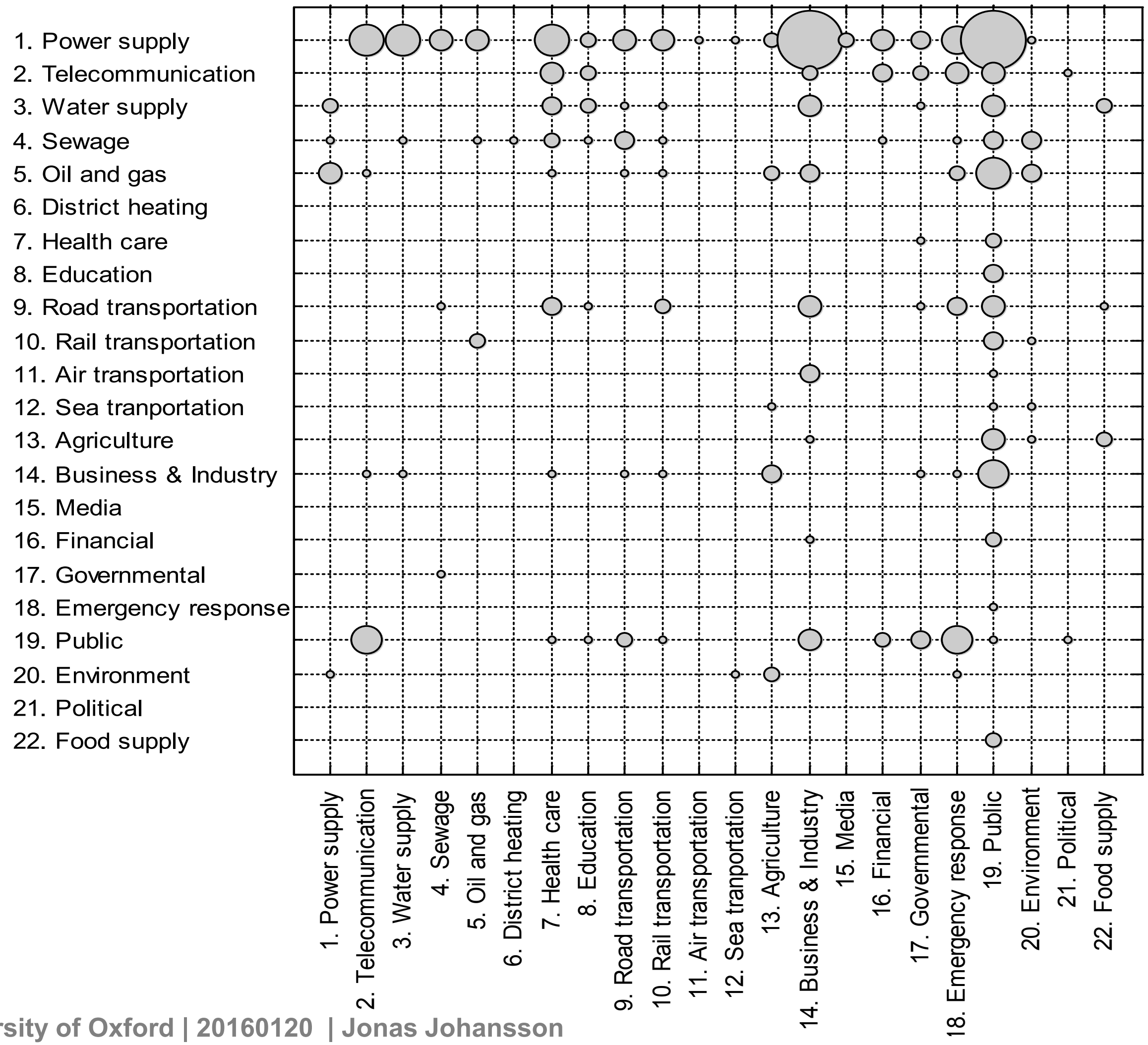
Challenge 2

Empirical data for cascading effects between critical infrastructures

	Event	Location	Year	IE type	Total # Systems	Casc. order	Event duration
1	Auckland	New Zealand	1998	Power outage	11	5	2m5d
2	Tieto	Sweden	2011	IT-event	7	4	2m
3	UK floods	UK	2007	Flooding	13	3	6m3d
4	Enschede	Netherlands	2000	Explosion	6	3	3y7m
5	London bombing	UK	2005	Terrorism	8	3	1y11m
6	Mont Blanc	Switz. France	1999	Fire	4	2	3y3m
7	Sandy	N. America	2012	Hurricane	18	5	2m1w
8	Eyjafjallagökull	Island	2010	Volcano eruption	5	2	1m1w
9	Malmö floods	Sweden	2014	Flooding	12	3	1d12h
10	Myyrmanni	Finland	2002	Terrorism	4	3	2w4d
11	Kista blackout	Sweden	2001	Power outage	9	3	1d16h
12	Östersund	Sweden	2010	Contam. water	7	3	5m4w
13	Baltimore	USA	2001	Tunnel Fire	10	4	2w2d
14	L'Aquila	Italy	2009	Earthquake	11	2	5y
15	European blackout	Europe	2006	Power outage	4	2	2h
16	Ice storm	N. America	1998	Ice storm	15	4	1m1d
…40							

Challenge 2

Empirical data for cascading effects between critical infrastructures



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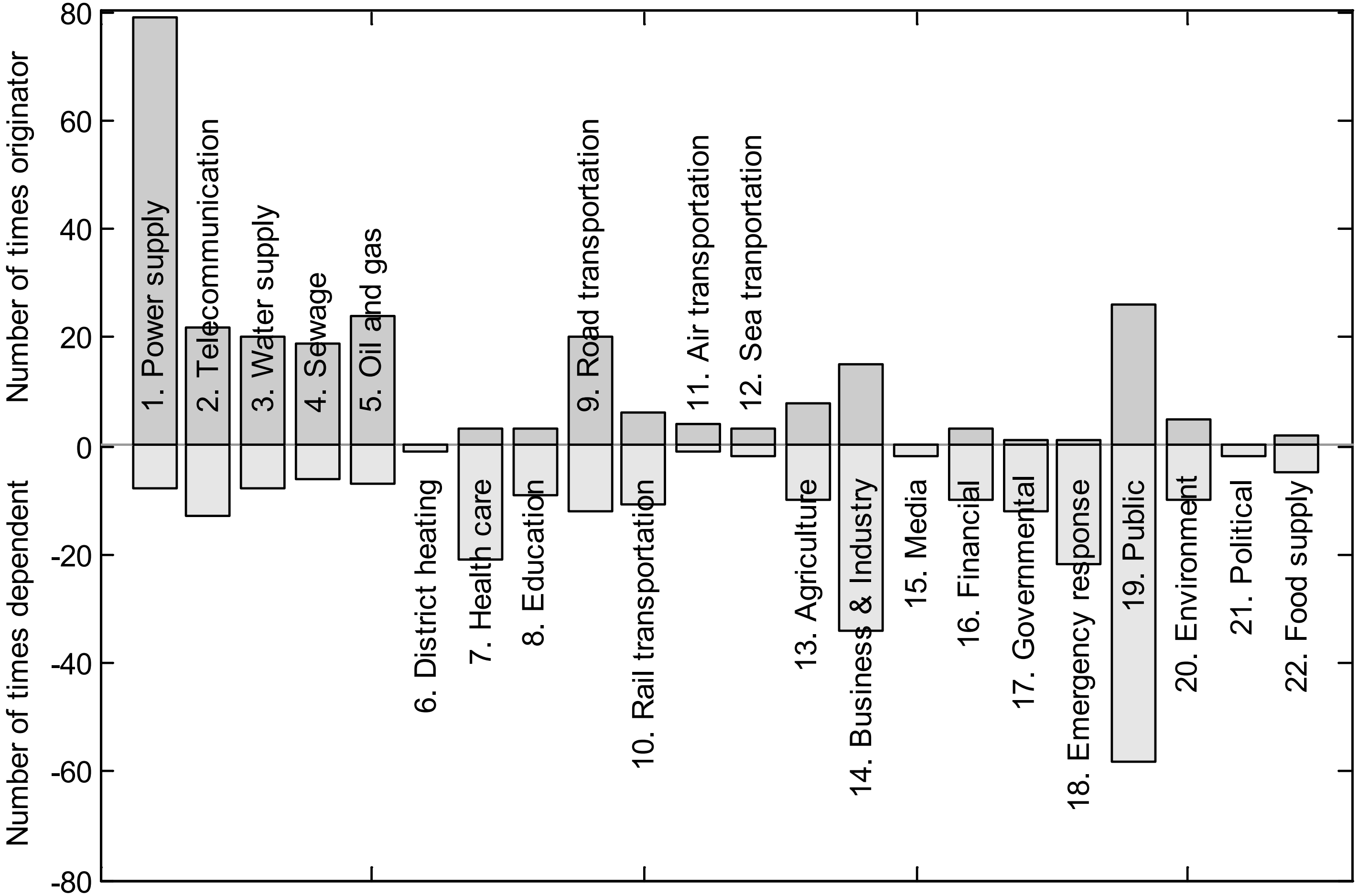

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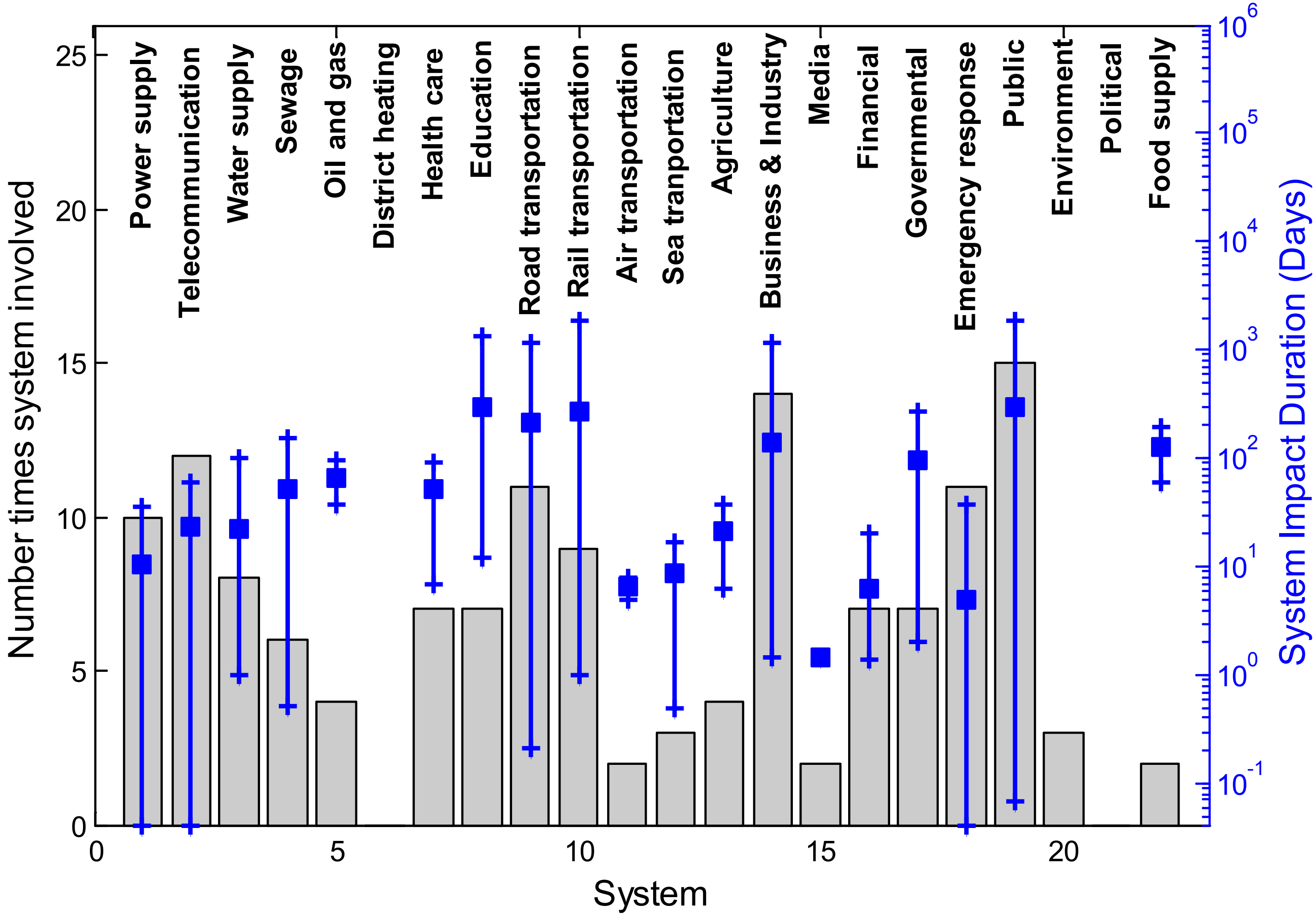

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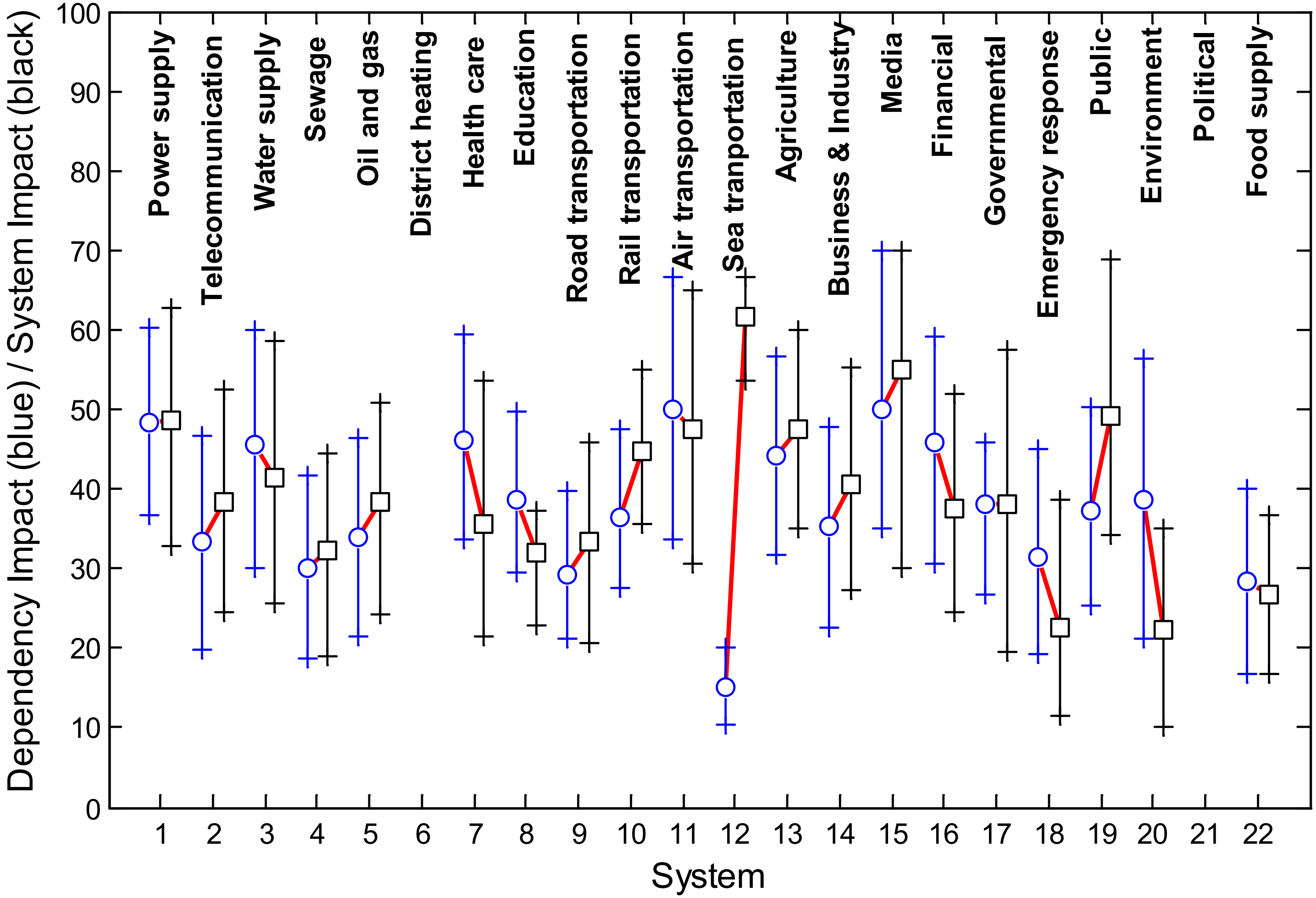

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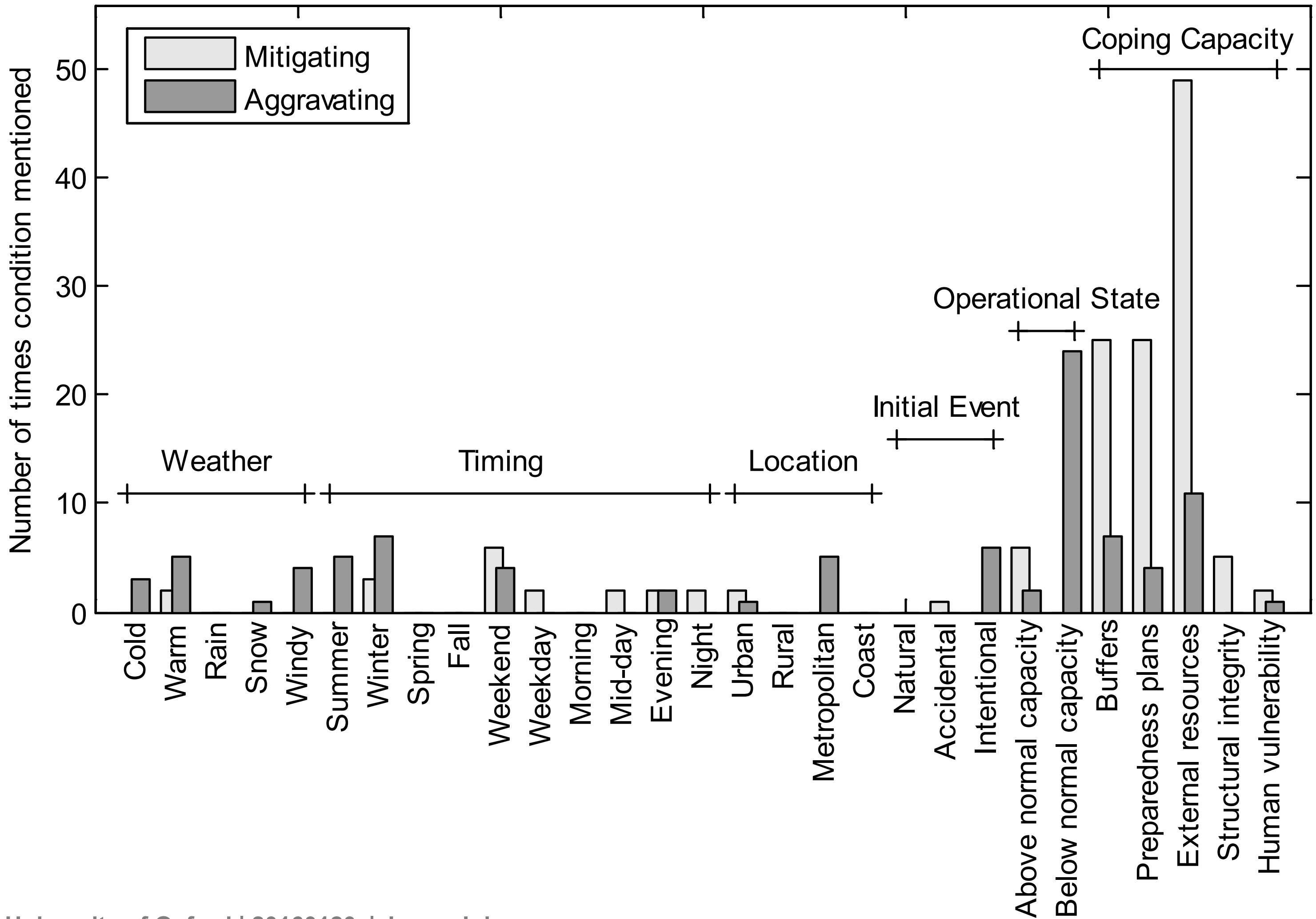
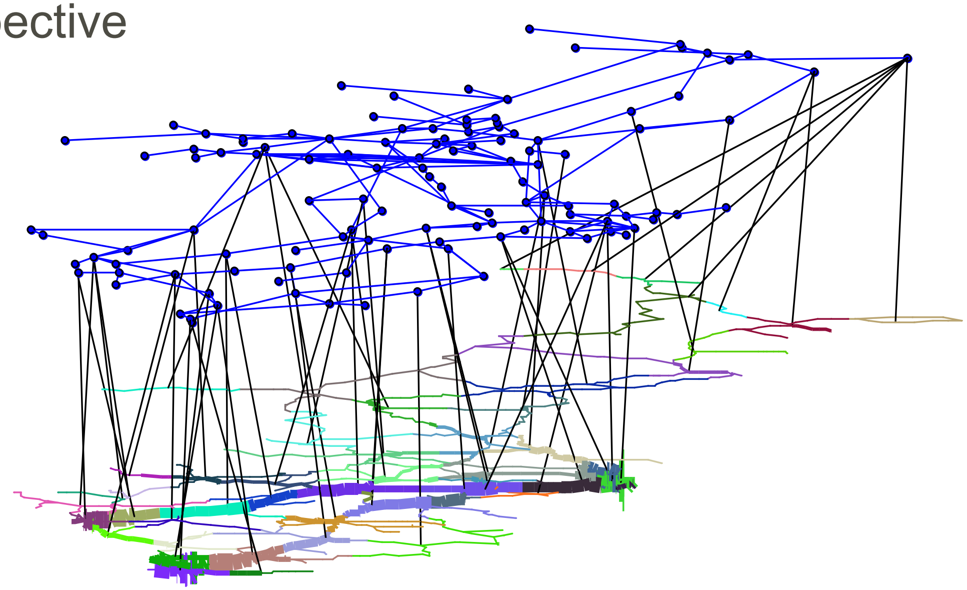


Challenge 3

Modelling and simulation of interdependent critical infrastructures

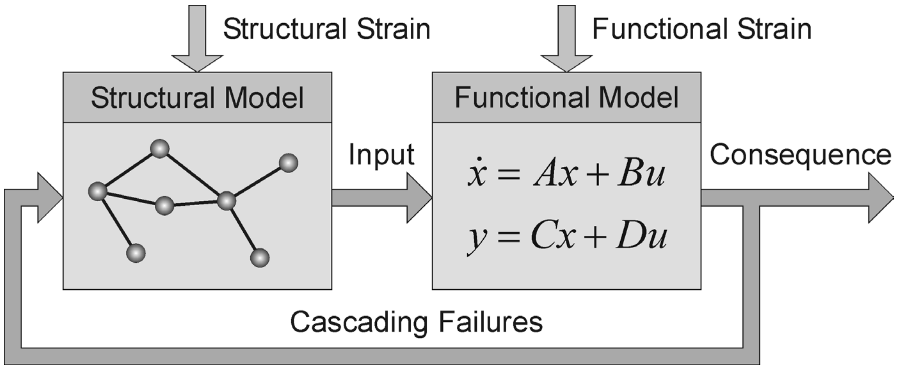
- **Technical infrastructures**, such as power systems, railways, air transportation and telecommunication, form a **subpart of critical infrastructures**.
- Here data of individual systems exist to some extent, however **data** of their **interdependencies and models of** accounting for the **"system-of-system"** behaviour of interdependent technical infrastructures **lacking**.
- From a Swedish governance perspective adequate mechanisms for managing risk and vulnerabilities from "system-of-system" perspective lacking.
- **Efforts needed** to develop models and simulation methods **to inform decisions from a more holistic perspective.**

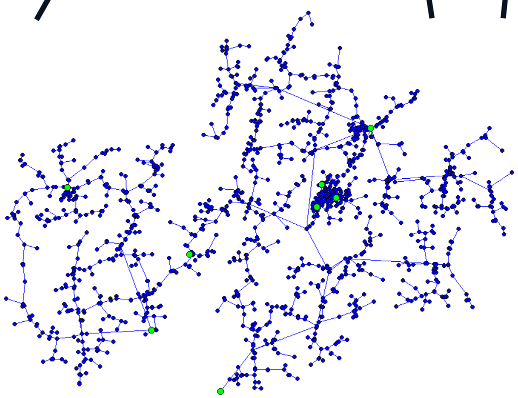


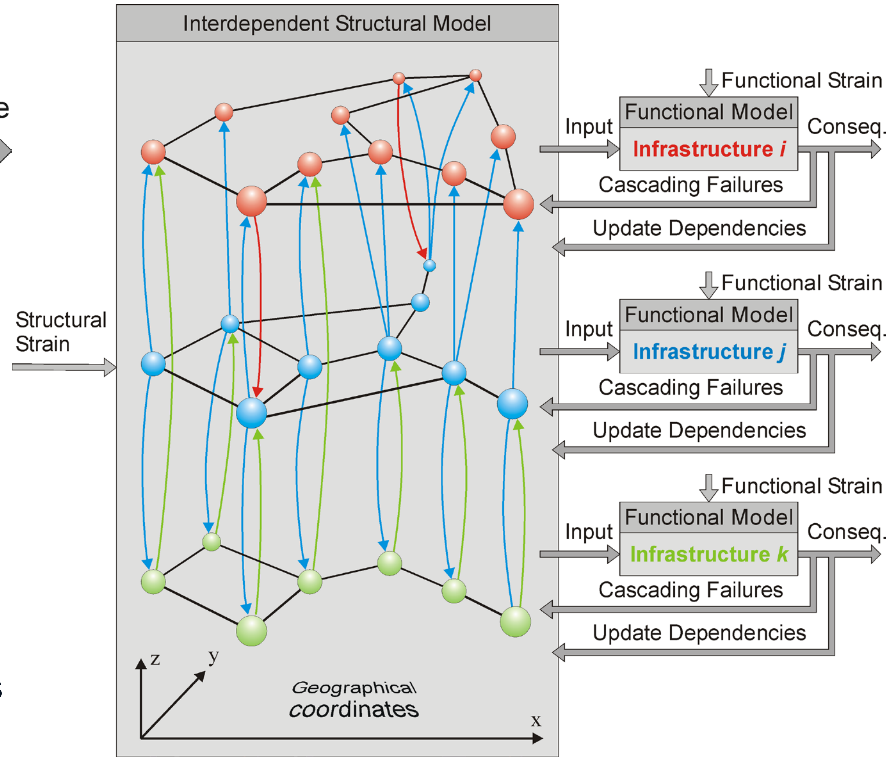
Challenge 3

Modelling and simulation of interdependent critical infrastructures

Singel system representation → **”System-of-system” representation**







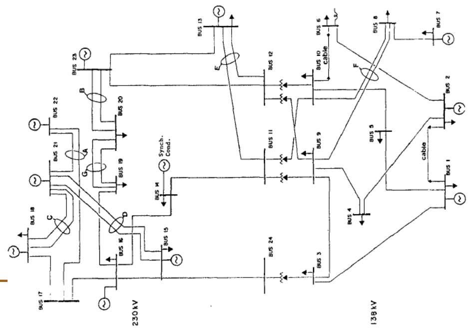
Computational effort vs fidelity:

1. Topological properties
2. Search algorithms
3. Flow Models
4. Dynamic simulation

Challenge 3

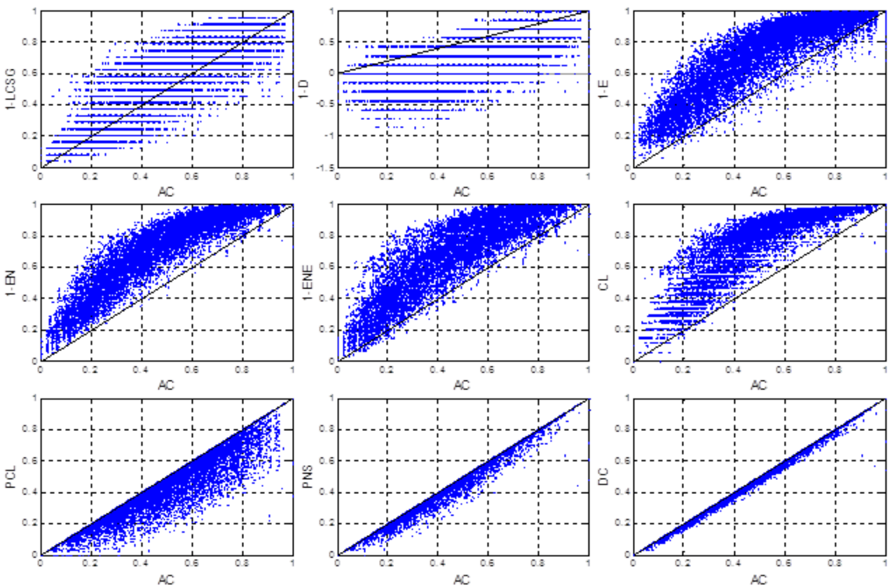
Modelling and simulation of interdependent CIs

IEEE RTS96

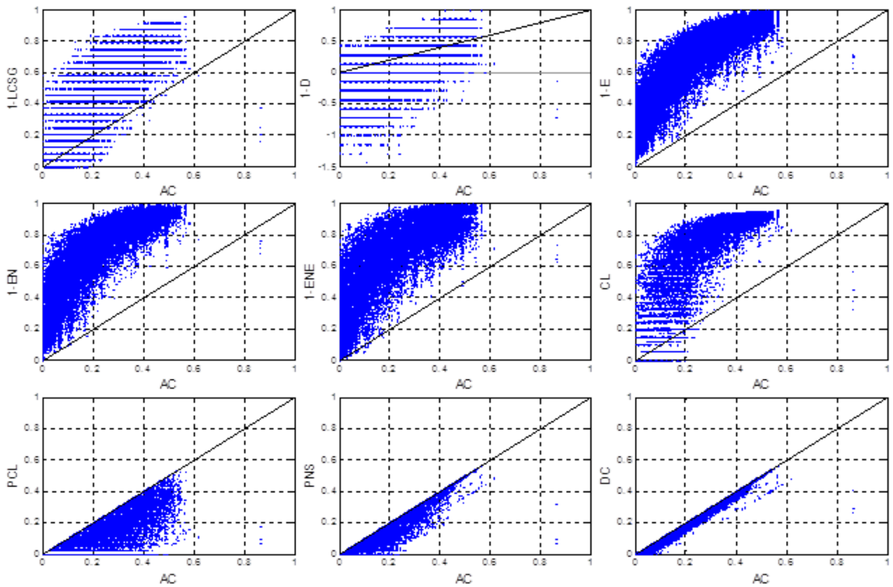


Functional model	Performance/consequence measures[1]	Label
Topological static – components are not differentiated	Largest connected subgraph (Holme and Kim, 2002)	LCSG
	Diameter (Newman, 2003)	D
	Average efficiency (average inverse geodesic length) (Newman, 2003; Crucitti et al, 2004)	E
Topological static – components are differentiated	Average efficiency only considering pairs of in-feed and load nodes	EN
	Average efficiency only considering pairs of in-feed and load nodes and electrical distance	ENE
	Connectivity loss (Albert et al., 2004)	CL
	Power connection loss (Johansson et al., 2007)	PCL
Simplistic capacity model	Power not supplied (Jönsson et al., 2008)	PNS
Physical flow models	DC load flow – power not supplied	DC
	AC load flow – power not supplied	AC

Random Node Removal



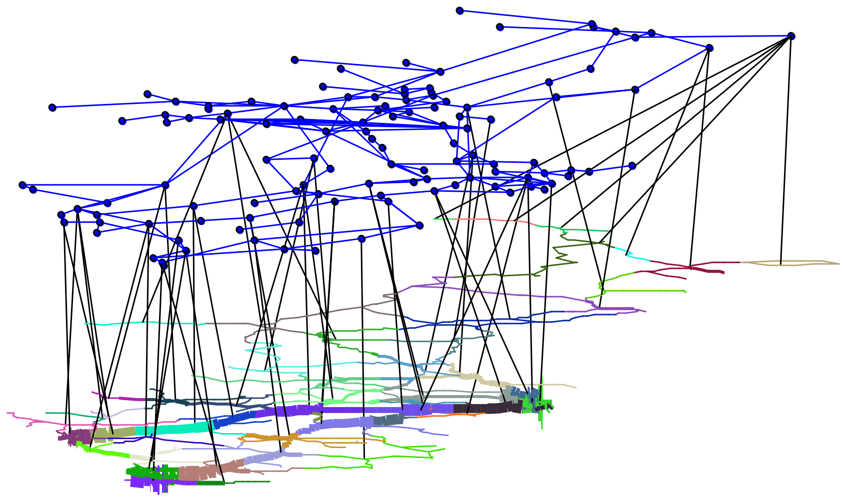
Random Edge Removal

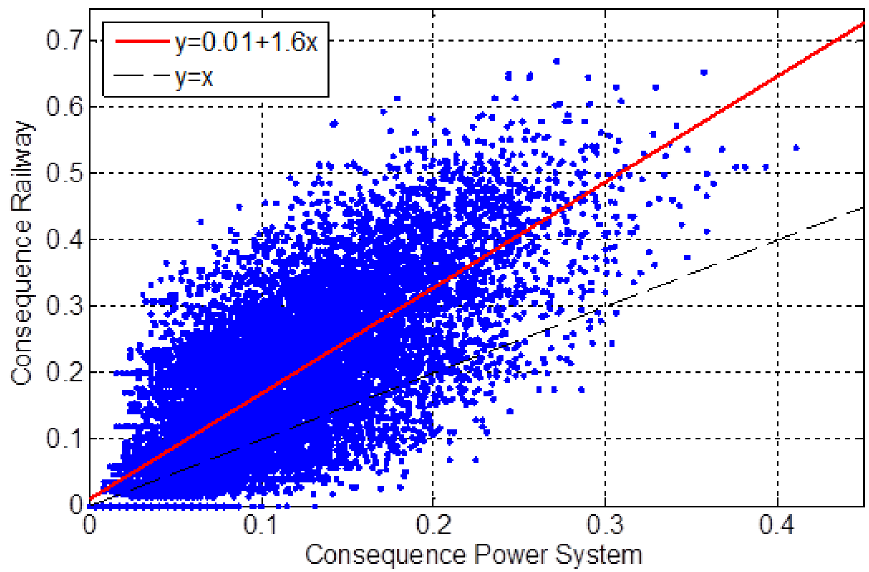


Challenge 3

Modelling and simulation of interdependent critical infrastructures

- Full scale models of Swedish
  - Transmission (DC load flow)
  - Railway (tracks & trains)
  - Their interdependencies (geographical and functional)
- Vulnerability analyses from three perspectives:
  - Global vulnerability (stress beyond “normal”)
  - Critical components (important assets to protect)
  - Geographical vulnerability (co-locations, hotspots)





Challenge 4

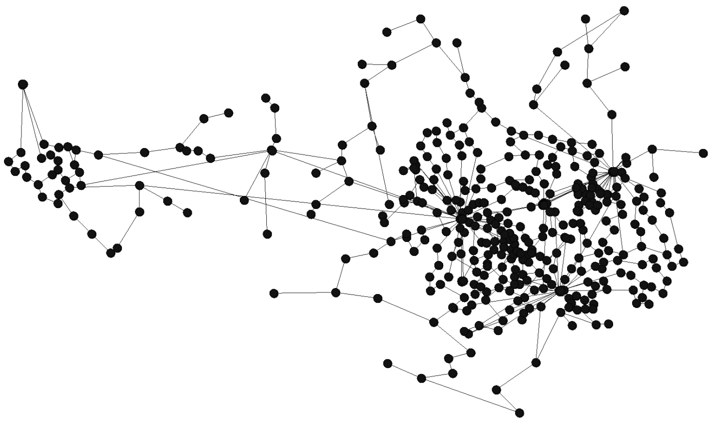
Recovery and resilience of critical infrastructures

- Technical infrastructures are inherently socio-technical by nature - they are designed, operated, maintained and restored by humans.
- In general, **research** in this field tends to **focus rather narrowly** on **“everyday” incidents** (based on historical data) and **technical aspects**.
- To better grasp the **resilience of infrastructures** more work is necessary of **their limits towards large-scale disruptions**, e.g. their ability to recover functionality.
- Approaches needs to **merge** the pure **technical parts** of the infrastructures with models able to capture the capacity of the **organisation in responding** to disruptions beyond normal.

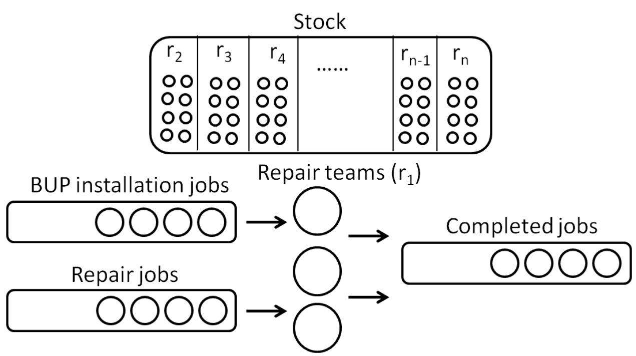
Challenge 4

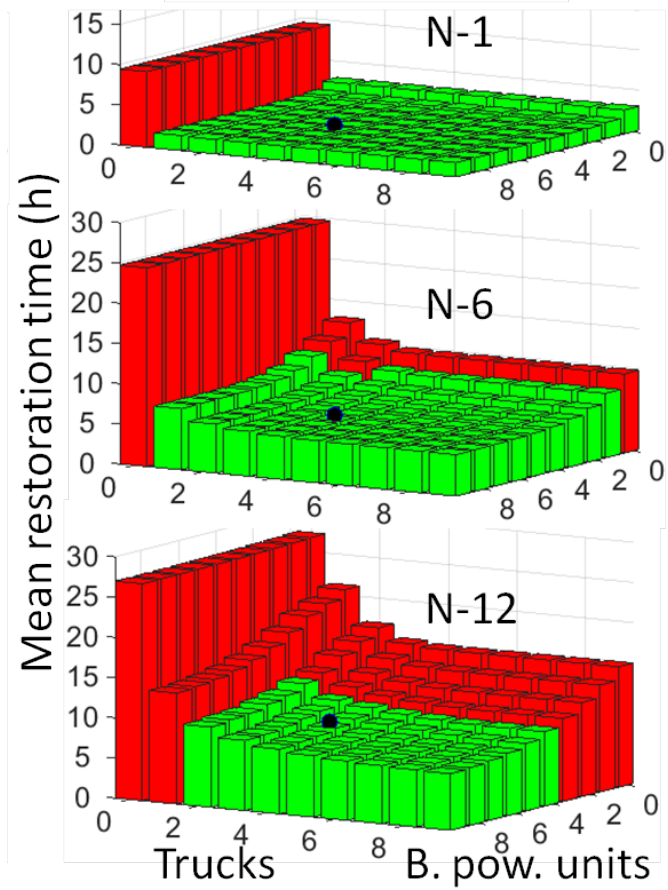
Recovery and resilience of critical infrastructures

Electric distribution system



Restoration system

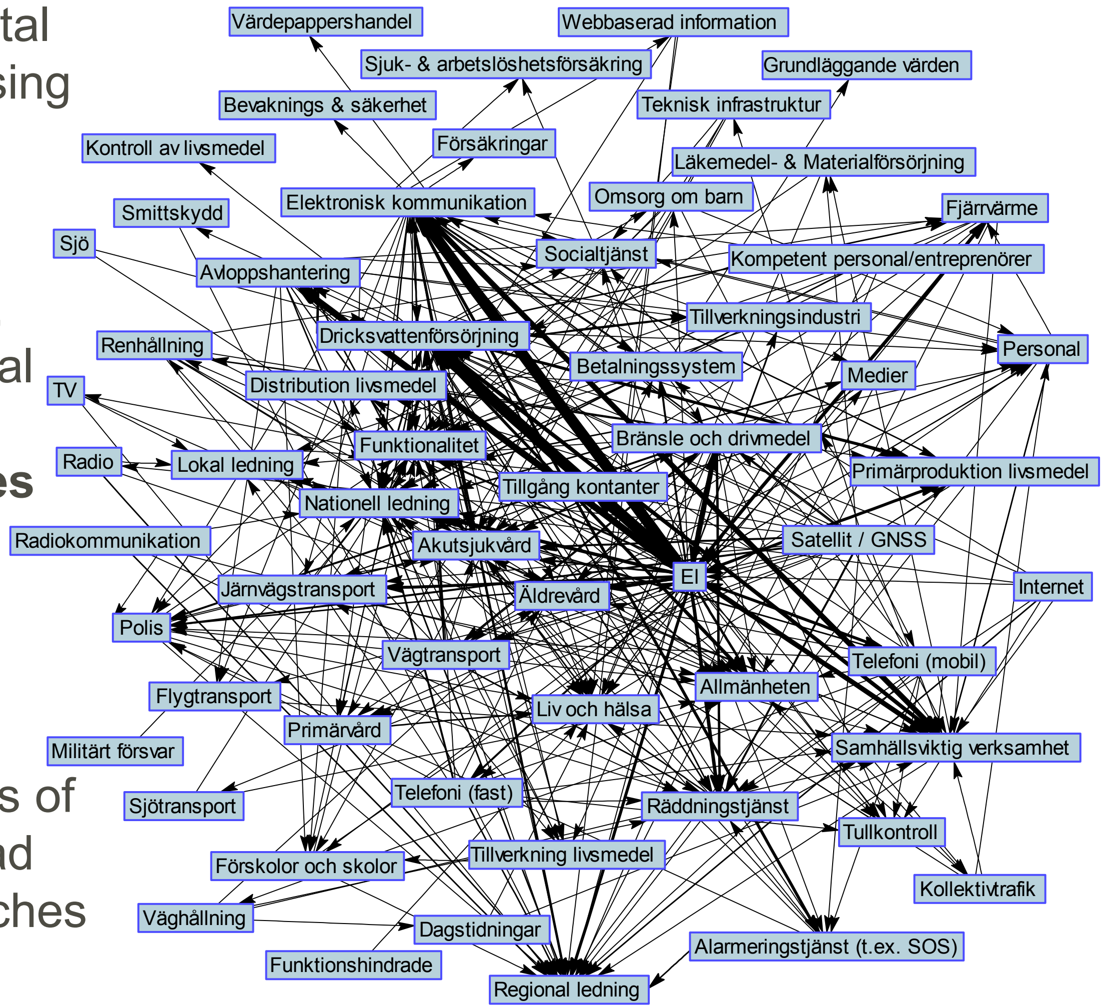




Challenge 5

Capturing interdependencies between societal functions

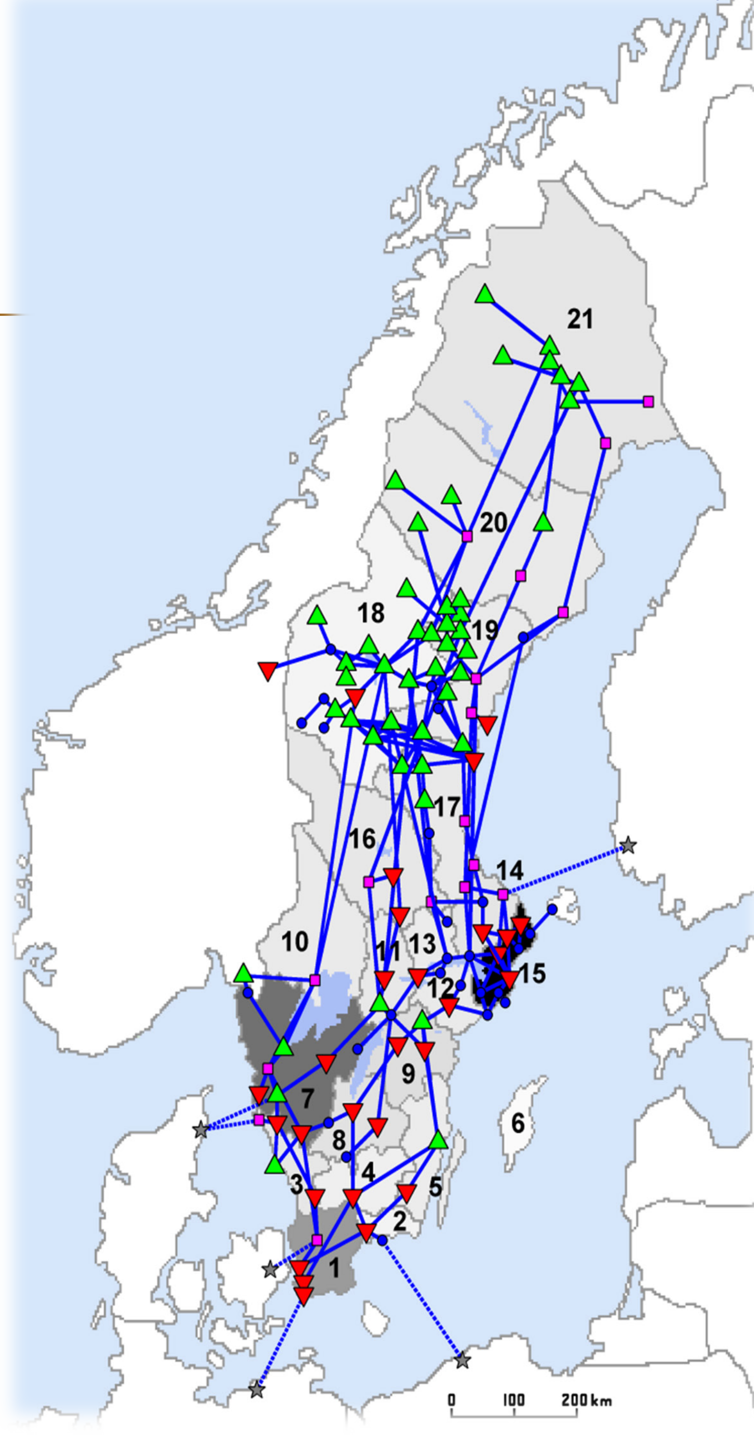
- Dependencies between societal functions seems to be increasing
- The overall “societal system” more tightly interconnected
- **Trends** such as globalisation, urbanisation, and technological development **drivers for efficiency** but also **introduces new vulnerabilities** and changes the risk picture.
- The understanding of the interconnectedness of these functions and the mechanisms of how consequences can spread limited. Need for new approaches and empirical data.



Challenge 5

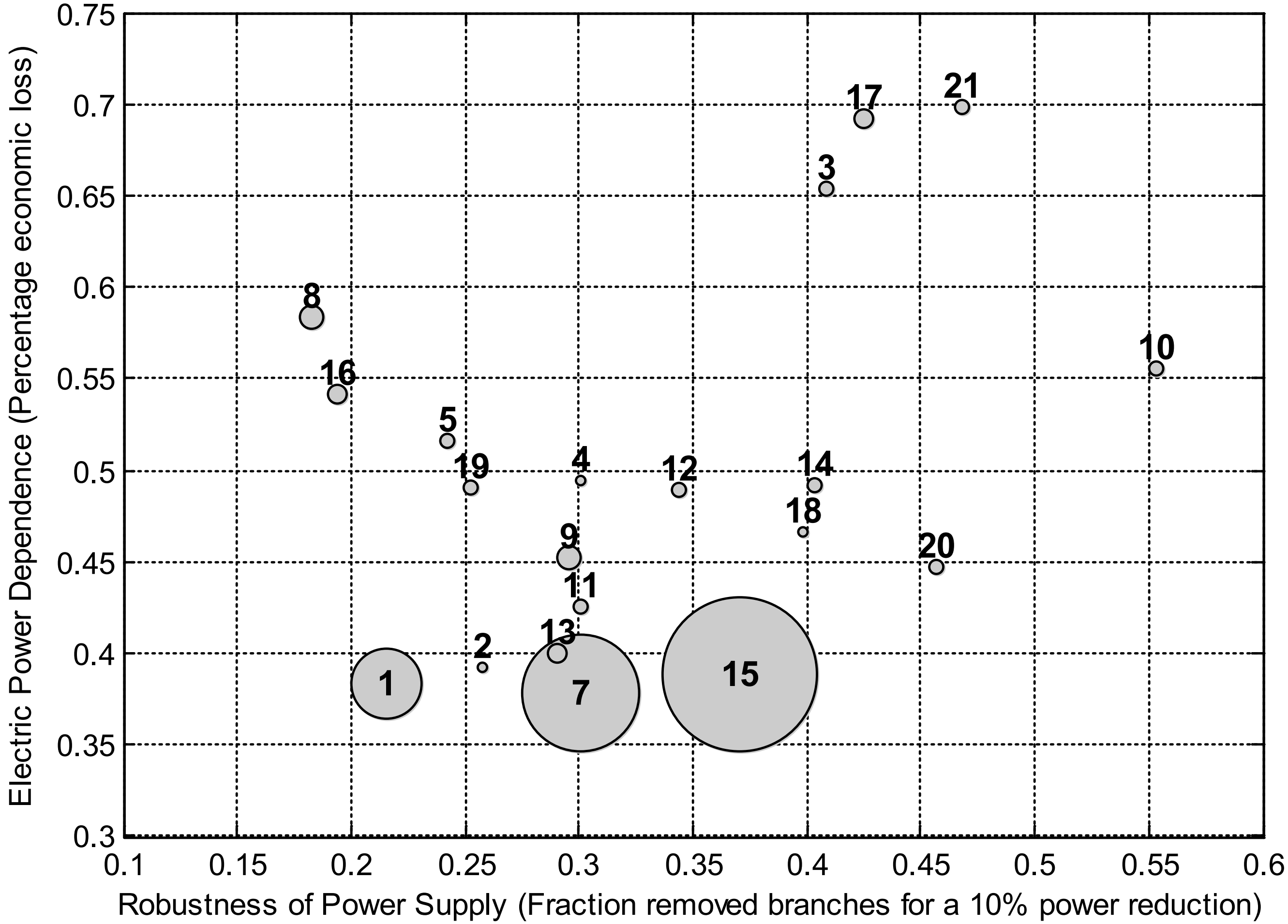
Capturing interdependencies between societal functions

- Question?
  - How does the vulnerability of the Swedish transmission system correlate to regional societal consequence of power outages?
- Power system
  - Representative DC-model of the Swedish Transmission system
  - Configuration in accordance with 23rd of September blackout in 2003
- Societal consequences
  - Economical Inoperability Input-Output model (IIM) – a linear model with its deficiencies
  - National economical data of 55 sectors make/use dependencies
  - Broken down to 21 regions (län)
  - Skåne, V.Götaland, Stockholm: 57% of GRP



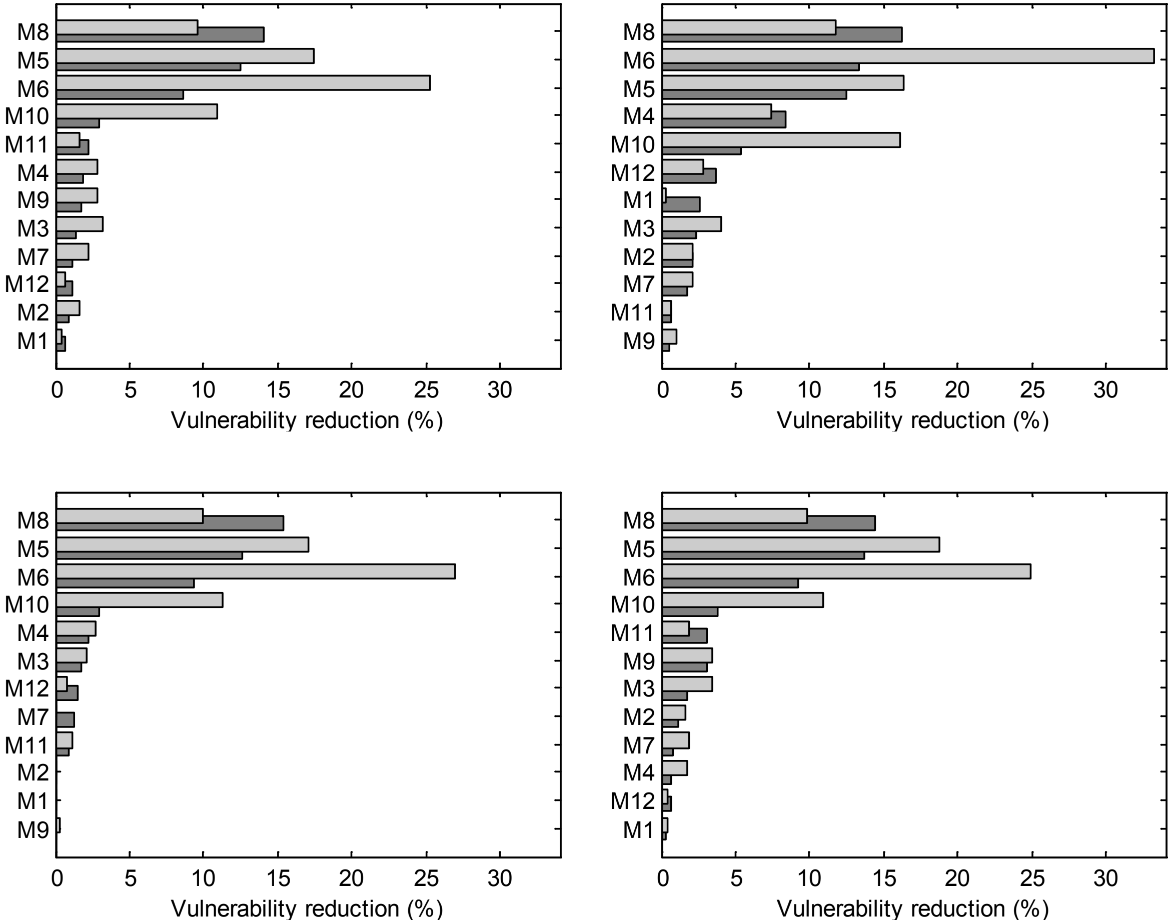
Challenge 5

Capturing interdependencies between societal functions

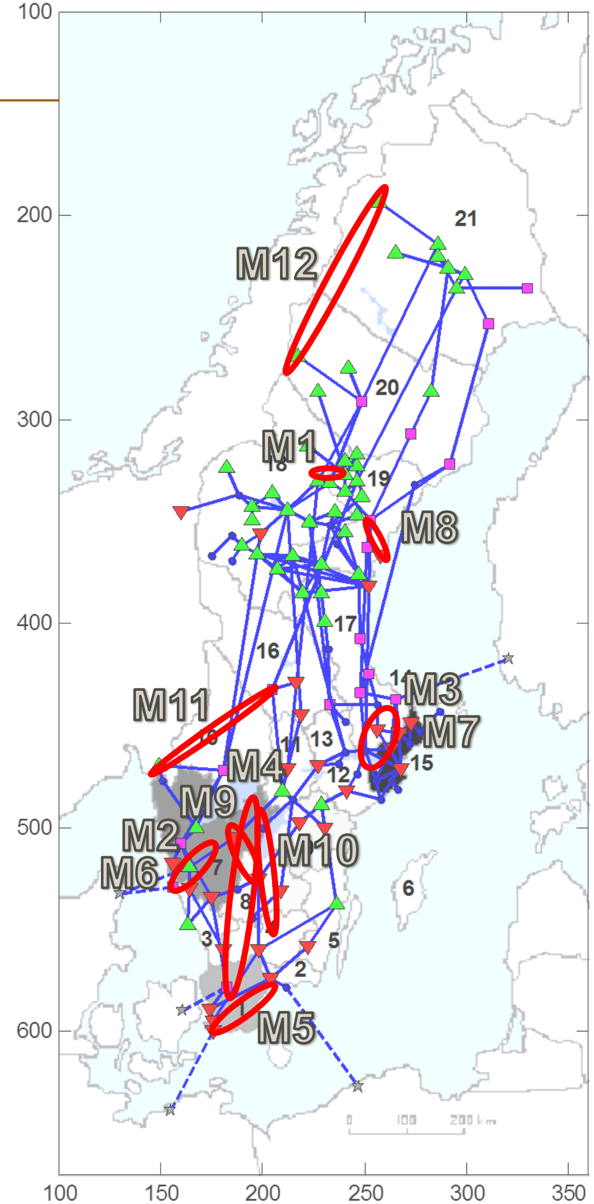


Challenge 5

Capturing interdependencies between societal functions



Dark grey = Power supply improvement   Light grey = Economical improvement



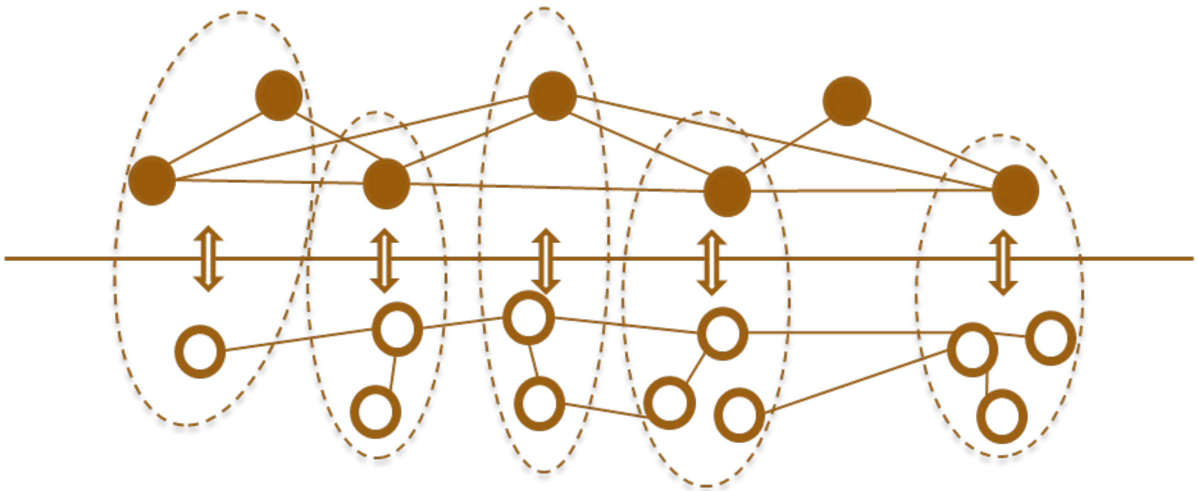
Challenge 6

Risk governance of critical infrastructures

- The operation and management of many critical infrastructures has become divided between a larger set of stakeholders, resulting in a dispersion of responsibility.
- In this institutionally fragmented setting, traditional risk management tools are not always suitable to deal with risks in a feasible manner.
- No single stakeholder has the superior authority or overview to make and implement holistic risk-reducing decisions.
- Research needs are related to stakeholders' diverse framings of risk, communication challenges, sub-contracting and cross-scale interactions.

Centre for Critical Infrastructure Protection Research (CenCIP)

- Newly formed centre of excellence at Lund University, 2015-2020.
  (8 seniors, 1 Postdoc, 2 PhD-students, 20 MSEK)
- Descriptive and normative research within three areas:
  - Interdependencies and societal consequences
  - A holistic view on terms, concepts and methods
  - Governance, measuring, monitoring, and learning



www.cencip.lu.se

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International Scientific Journals (peer-reviewed)

1. LaRocca, S., Johansson, J., Hassel, H., Guikema, S., (2014). Topological Performance Measures as Surrogates for Physical Flow Models for Risk and Vulnerability Analysis for Electric Power Systems, *Risk Analysis,* doi: 10.1111/risa.12281.
2. Johansson, J., Hassel, H., Zio, E., (2013). Reliability and vulnerability analyses of critical infrastructures: Comparing two approaches in the context of power systems, *Reliability Engineering and System Safety,* Vol. 120, pp. 27-38.
3. Johansson, J., Hassel, H., Cedergren, A., (2011). Vulnerability analysis of interdependent critical infrastructures: case study of the Swedish railway system, *International Journal of Critical Infrastructures*, Vol. 7, No. 4, pp. 289-315.
4. Johansson, J., Hassel, H., (2010). An Approach for Modelling Interdependent Infrastructures in the Context of Vulnerability Analysis, *Reliability Engineering and System Safety*, Vol. 95, pp. 1335-1344.
5. Jönsson, H., Johansson, J., Johansson, H., (2008). Identifying Critical Components in Technical Infrastructure Networks, *Journal of Risk and Reliability*, Vol. 222, No. 2, pp. 235-243.
6. Johansson, J., Jönsson, H., Johansson, H., (2007). Analysing the Vulnerability of Electric Distribution Systems: A Step Towards Incorporating the Societal Consequences of Disruptions, *Int. J. Emergency Management*, Vol. 4, No. 1, pp.4–17.

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7. Johansson, J., Hassel, H., Cedergren, A., Svegrup, L., Arvidsson, B., (2015). Method for describing and analysing cascading effects in past events: Initial conclusions and findings, *ESREL 2015*, Zürich, Switzerland, September 7-10.
8. Svegrup, L., Johansson, J., (2015). Vulnerability Analyses of Interdependent Critical Infrastructures: Case study of the Swedish National Power transmission and Railway system, *ESREL 2015*, Zürich, Switzerland, September 7-10.
9. Arvidsson, B., Johansson, J., Hassel, H., Cedergren, A., (2015). Investigation method for cascading effects between critical infrastructures, *ESREL 2015*, Zürich, Switzerland, September 7-10.
10. Cedergren, A., Johansson, J., Svegrup, L, Hassel, H., (2015). Local Success, Global Failure: Challenges Facing the Recovery Operations of Critical Infrastructure Breakdowns, *ESREL 2015*, Zürich, Switzerland, September 7-10.
11. Hassel, H., Cedergren, A., Svegrup, L., Johansson, J., (2014). A method for identifying cascading effects in past events as an input to a decision support tool, *ESREL 2014*, Wroclaw, Poland, September 14-18.
12. Landegren, F., Johansson, J., Samuelsson, O., (2014). Comparing Societal Consequence: Measures of Outages in Electrical Distribution Systems, *ESREL 2014*, Wroclaw, Poland, September 14-18.
13. Johansson, J., Svegrup, L., Hassel, H., (2014). Contrasting vulnerability reduction measures for critical infrastructures: using power system and regional inoperability input-output models, *PSAM 12*, Honolulu, Hawaii, USA, June 22-27.
14. Johansson, J., Hassel, H., (2014). Impact of Functional Models in a Decision Context of Critical Infrastructure Vulnerability, *ASCE ICVRAM&ISUMA 2014*, Liverpool, UK, July 13-16.
15. Johansson, J., Svegrup, L., Hassel, H., (2013). Societal consequences of critical infrastructure vulnerabilities: integrating power system and regional inoperability input-output models, *ESREL2013*, Amsterdam, Netherlands, September 29 - October 2, 2013.
16. Landegren, F., Johansson, J., Samuelsson, O., (2013). Review of Computer Based Methods for Modeling and Simulating Critical infrastructures as Socio-Technical Systems, *ESREL2013*, Amsterdam, Netherlands, September 29 - October 2, 2013.
17. Johansson, J., LaRocca, S., Hassel, H., Guikema, S., (2012). Comparing Topological Performance Measures and Physical Flow Models for Vulnerability Analysis of Power Systems. *PSAM11 & ESREL2012*, Helsinki, Finland, June 25-29, 2012.
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20. Wilhelmsson, A., Johansson, J., (2009). Assessing Response System Capabilities of Socio-Technical Systems, *TIEMS2009* Istanbul, Turkey, June 9-11.
21. Johansson, J., Jönsson, J., (2008). A Model for Vulnerability Analysis of Interdependent Infrastructure Networks, *ESREL2008 & SRA 17th*, Valencia, Spain, September 22-25.
22. Jönsson, H., Johansson, J., Johansson, H., (2007). Identifying Critical Components in Electric Power Systems: A Network Analytic Approach, *ESREL2007*, Stavanger, Norway, June 25-27.
23. Johansson, J., Lindahl, S., Samuelsson, O., Ottosson, H., (2006). The Storm Gudrun a Seven-Weeks Power Outage in Sweden, *CRIS2006*, Alexandria, VA, USA, September 25-27.
24. Johansson, J., Jönsson, J., Johansson, H., (2006). Analysing Societal Vulnerability to Perturbations in Electrical Distribution Systems. *CNIP06*, Rome, Italy, March 28-29.
25. Johansson, J., (2014). Discussion of a framework for interdependent critical infrastructure vulnerability analysis from a climate change perspective, Deltas in time of climate change II, Rotterdam, Netherlands, September 24-26.
26. Johansson, J., Kjølle, G., Gjerde, O., (2014). Methods for Vulnerability Analysis of Power Systems, NORDAC 2014, Stockholm, Sweden, September 8-9.
27. Hassel, H., Johansson, J., (2013). Developing a new method for mapping societal functions, flows and their dependencies – results from an initial study. SRA Annual Meeting, Baltimore, USA, December 8-11.
28. LaRocca, S., Johansson, J., Hassel, H., Guikema, S., (2012). Topological performance measures as surrogates for physical flow models for electric power systems. SRA Annual Meeting, San Francisco, USA, December 9-12.
29. Johansson, J., Svensson, S., (2008). Risk and Vulnerability Management of Electrical Distribution Grids, NORDAC 2008, Bergen, Norway, September 8-9.
30. Johansson, J., Willhelmsson, A., (2008), Vulnerability Analysis of Socio-Technical Systems: Addressing Railway System Vulnerabilities, Young Researches Seminar, Malmö, Sweden.

Monographs

31. Johansson, J., (2010). Risk and Vulnerability Analysis of Interdependent Technical Infrastructures, Doctoral Thesis, Department of Measurement Technology and Industrial Electrical Engineering, Lund University, Lund.
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