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Modelling and simulation of interdependent critical infrastructures

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Introduction

- Critical infrastructures, such as transportation systems and power distribution systems provide commodities and services that are vital for the functioning of the modern society.
- Previous events, such as hurricane Katrina or the North American blackout has shown, that if they are disrupted it could lead to life threatening situations as well as large societal and economical consequences.
- Critical infrastructures are complex systems consisting of several interdependent system. A System-of-system perspective is important since negative effects are likely to cascade throughout this complex system.

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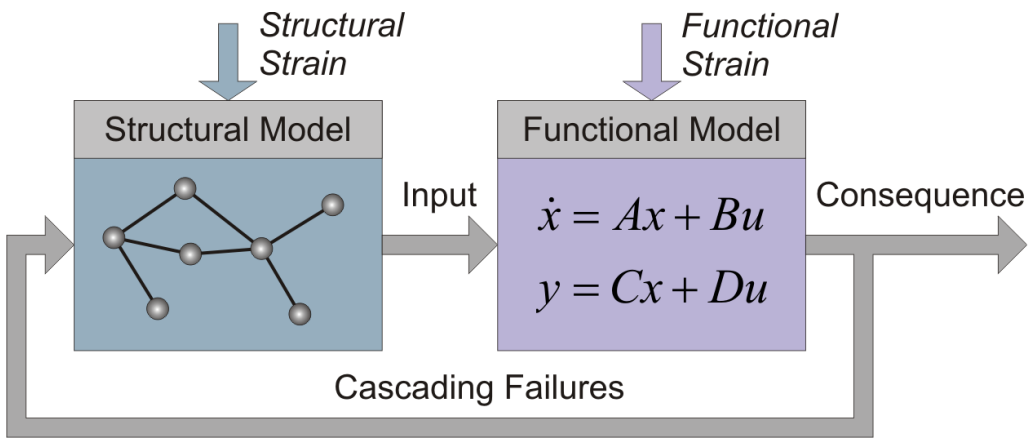
Technical infrastructures

- Technical infrastructures, such as power and water supply, road transportations, railway and telecommunications, form a subpart of critical infrastructures.
- Need to develop models and simulation methods for technical infrastructures that takes into account interdependencies, to be able to inform decisions from a more holistic perspective.

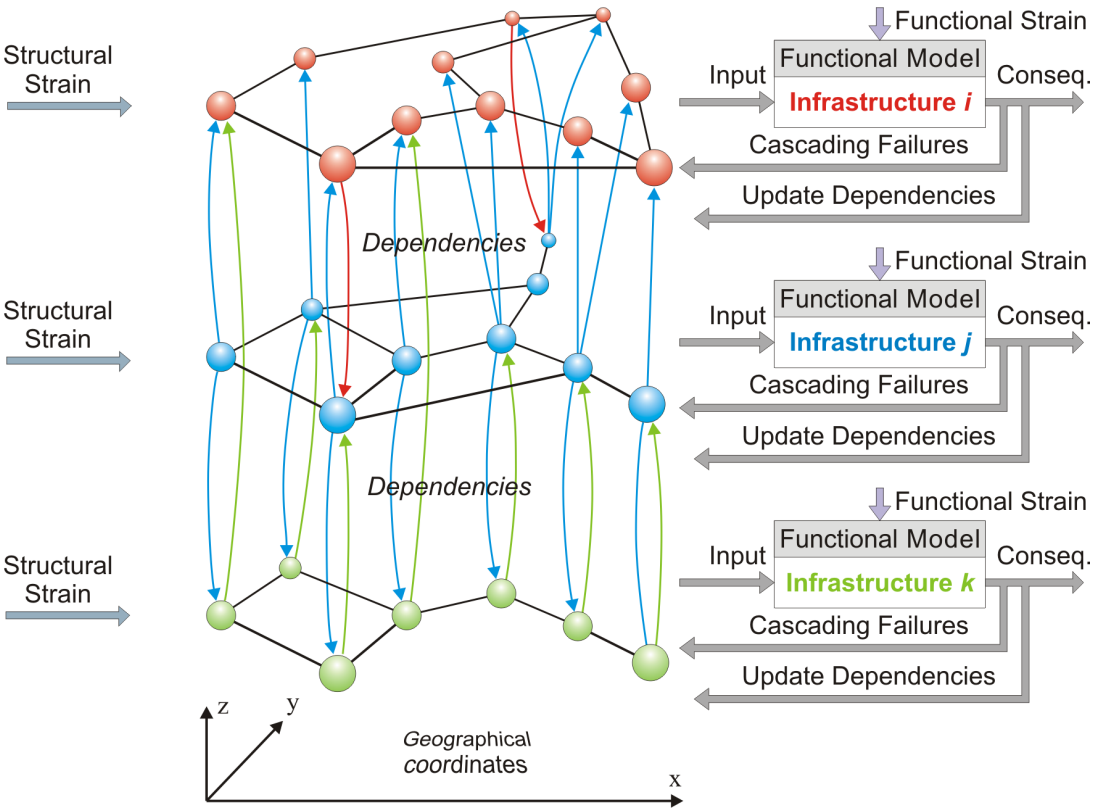
Modelling Approach – Interdependent infrastructures



- The overall approach is to divide the modelling of technical infrastructures into two parts, a structural part and a functional part.
- The individual infrastructure systems are each individually modelled according to this.

Modelling Approach – Interdependent infrastructures

The individual models of the infrastructures are then merged together into a system-of-systems

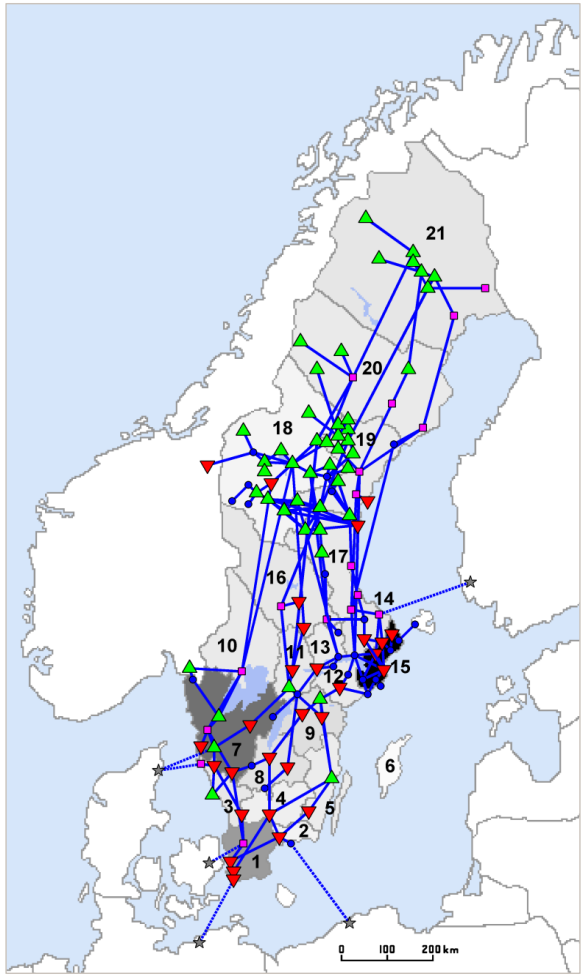


Case study

Case study using real-life data and models of the Swedish national power transmission system and Swedish national railway system.

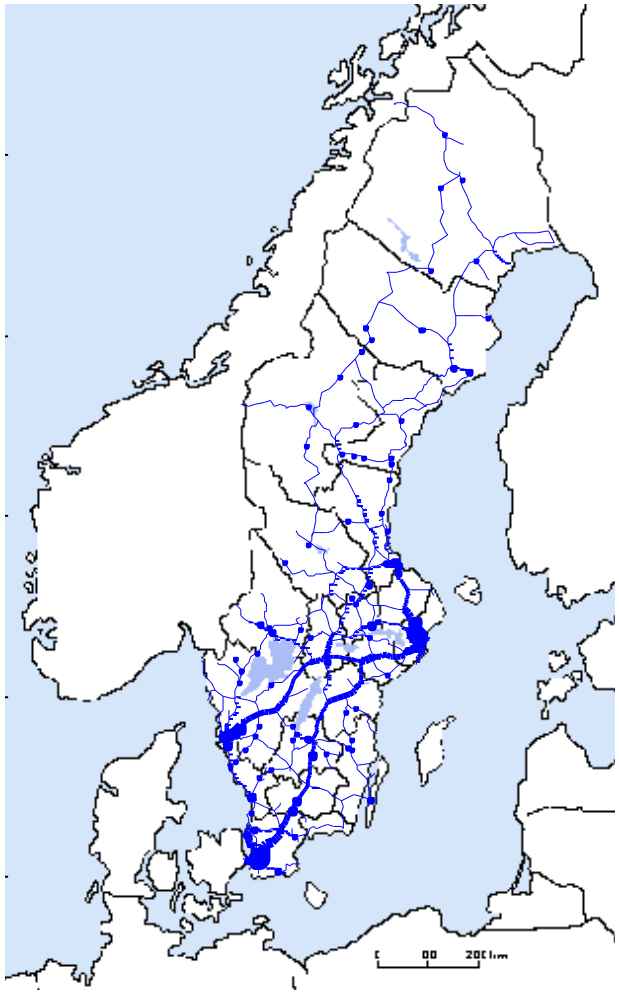
Case study – the national power transmission system

- Representative DC-model of the Swedish Transmission system (400kV and 230kV)
- Configuration in accordance with 23rd of September blackout in 2003
- 119 buses (nodes) and 186 power lines (edges)
- Total generation capacity is 29 940 MW and total loading is 15 000 MW



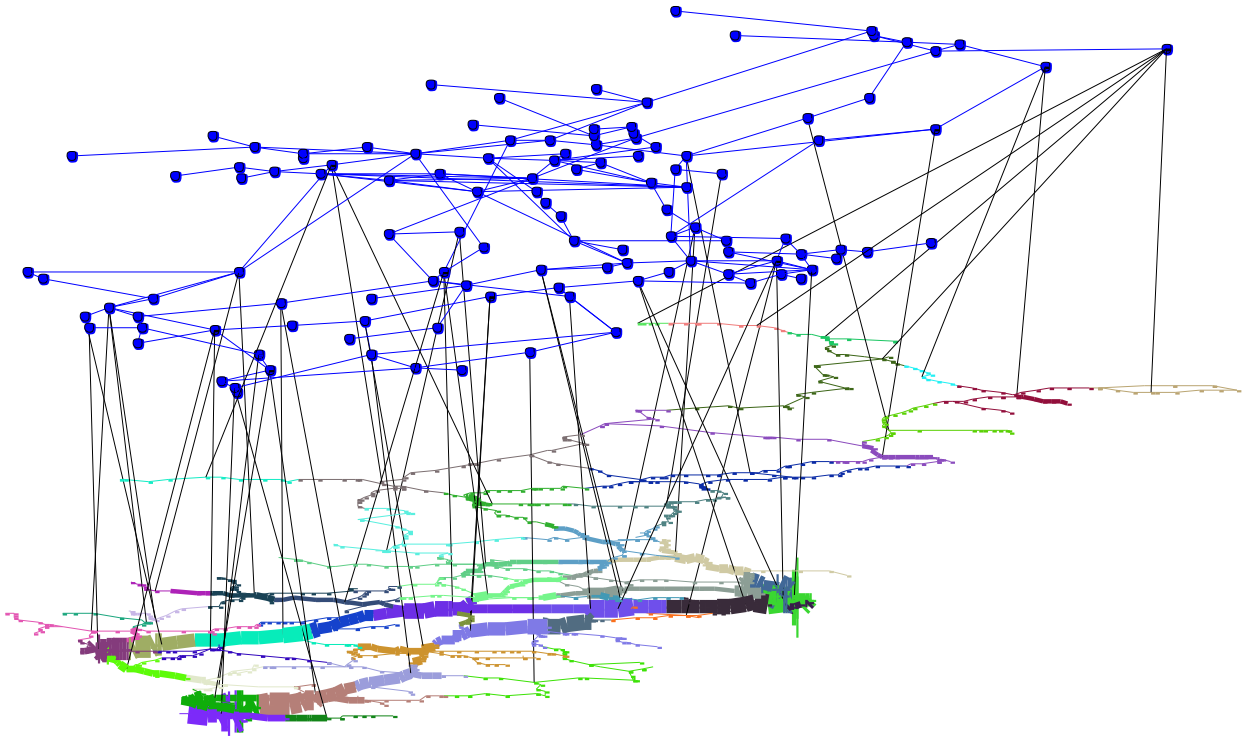
Case study– the national railway system

- 1365 railway stations (nodes) and 1440 railway sections (edges)
- Total traffic load is 3453 trains per day (2012)
- Edge capacity (trains/hour) depends on the number of tracks for the different sections
- The flow of trains takes into account the structural constraints, the railway section capacity, rerouting of trains and if electrified railway sections are supplied by power



Case study– interdependencies

- Functional and geographical dependencies between the systems are explicitly modelled.



Vulnerability analyses

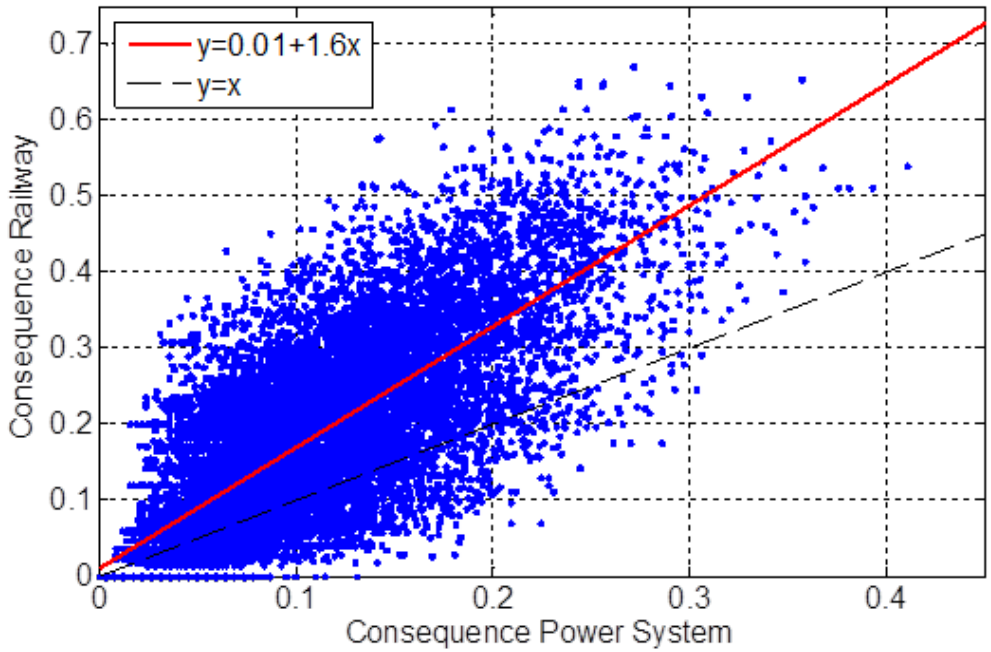
- Several different types of vulnerability analyses and reliability analyses that can be performed with this System-of-systems model.
- For example:
  - Vulnerability analysis of the railway system with respect to its functional dependencies of the power transmission system
  - Vulnerability analysis of cascading effects with respect to both functional and geographical dependencies

Railway system (functional dependencies)

Remove component in power system → Calculate consequence for the power system → Assess impact on railway system through functional dependencies → Calculate consequence for the railway system

The vulnerability analysis of the railway system with respect to its functional dependencies to the power transmission system (the railway system is directly affected by disruptions in the supply of power)

Result - Railway system (functional dependencies)



Svegrup, L. & Johansson, J. (2015) Vulnerability Analyses of Critical Infrastructures: Case Study of the National Power Transmission and Railway system, in proceedings of ESREL 2015, Zurich

Conclusion

- By not accounting for cascading effects and indirect consequences when evaluating vulnerability the total consequences can by severely underestimated.
- A more holistic view can be adopted when assessing vulnerability and implementing vulnerability reducing measures if indirect effects are included.
- The presented modelling approach is well-suited for modelling interdependent critical infrastructures. The modelling approach can account for cascading effects by including interdependencies between systems in a System-of-systems models.

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