Aalto University
School of Science

Allocating Resources to Secure the Performance of Complex Networks

Jussi Kangaspunta and Ahti Salo

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Research Background and Objectives

- Recent events have highlighted the importance to protect critical infrastructure
  - E.g. Natural disasters and securing the power networks

- Research project funded by the Scientific Advisory Board for Defence of Finland (MATINE)

- The main objectives is to develop methods to protect critical infrastructure systems in Finland:
  1. How to identify most critical systems?
  2. How to allocate resources to actions in order secure the performance of these systems?

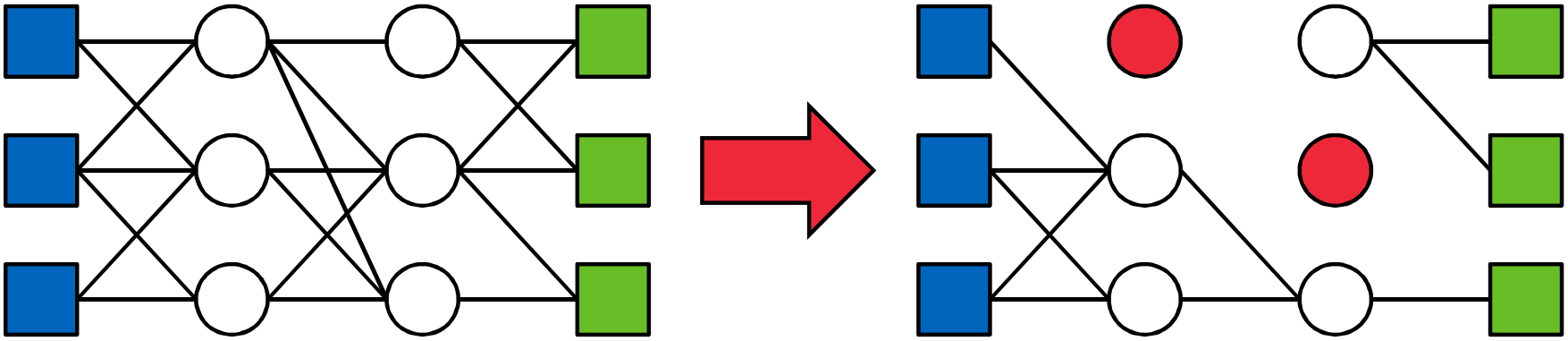
Critical Transportation Networks

- Complex networks that consist of nodes and edges
  - E.g. Railway stations and railways connecting them
- The performance of a network is measured by the extent to which the transportation objectives are achieved
  - E.g. The number of delivered shipments or traveling time
- Nodes are vulnerable to disruptions that may decrease the network performance
  - E.g. Due to exceptional weather phenomena or sabotage
- Which nodes are most critical to network performance?

Assessing the Impacts of Disruptions

- Disrupted nodes are no longer available

- Impacts on performance depend on other disruptions
  - ⇨ Need to consider combinations of disruptions



Nine connections

Three connections

Evaluating the Performance

- Value function *v* maps the combination of network disruptions *x* to performance (or value) scale [0,1]
  - E.g. Three connections out of nine is worth 0.25

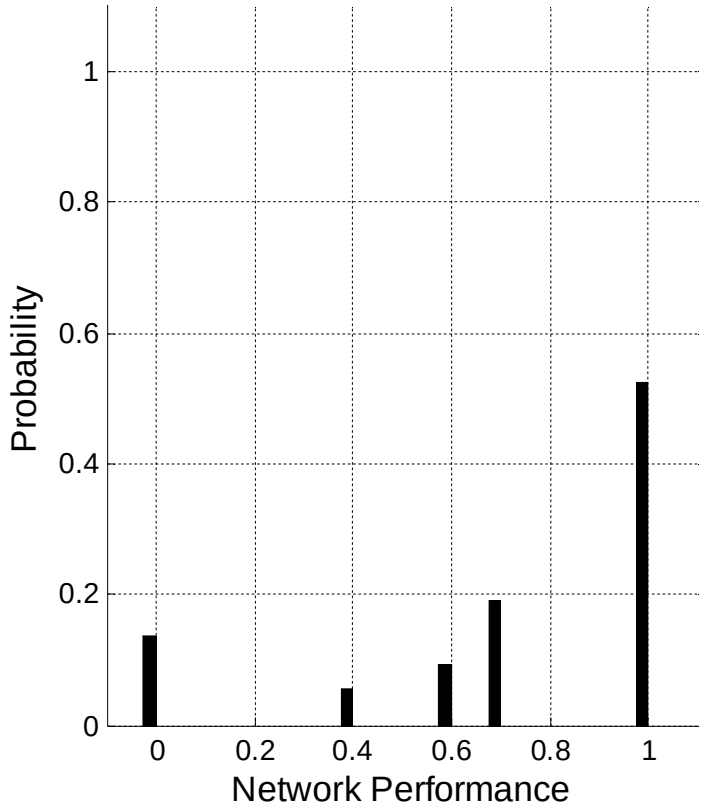
- Joint distributions of the disruption probabilities of the nodes are needed
  - Independent probabilities are possible e.g.

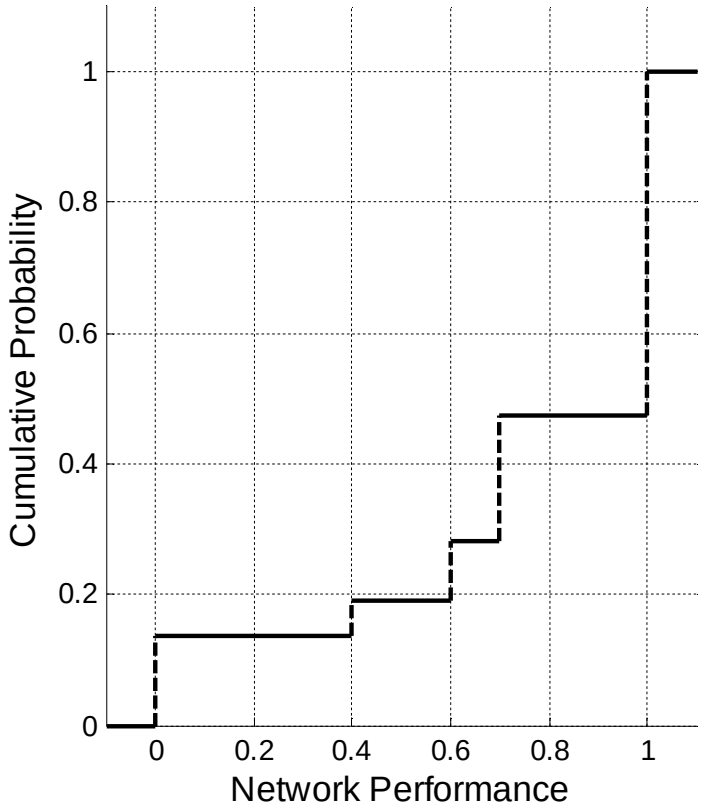
Node	1	2	3	4	5	6
Probability of disruption	0.05	0.05	0.05	0.05	0.05	0.05

- Interdependencies could also be accounted for
  - E.g. Node 3 disrupts with probability 0.75 if node 2 is disrupted

Probabilities for Performance

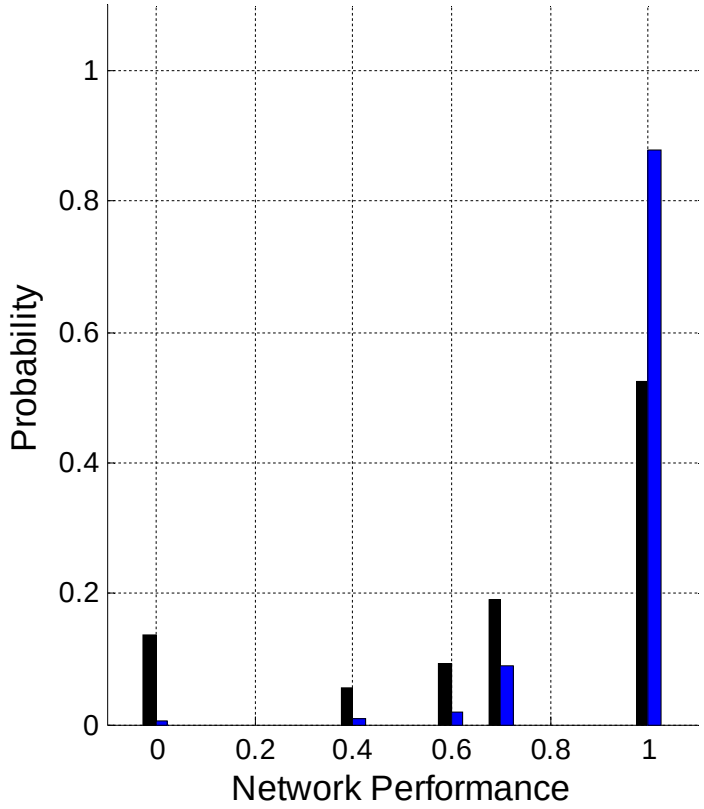
- Probability distributions correspond to risk profiles
  - E.g. What is the probability that performance is less than 0.50?

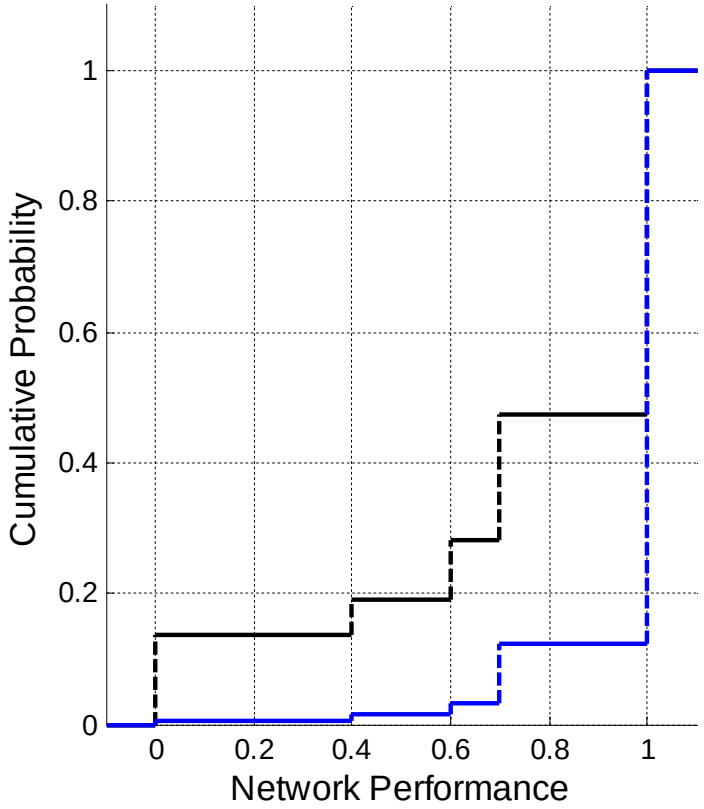




Securing the Network Performance

- Actions seek to secure performance by decreasing
  1. the probabilities of node disruptions or
  2. the impacts of disruptions (e.g. by building alternative routes)

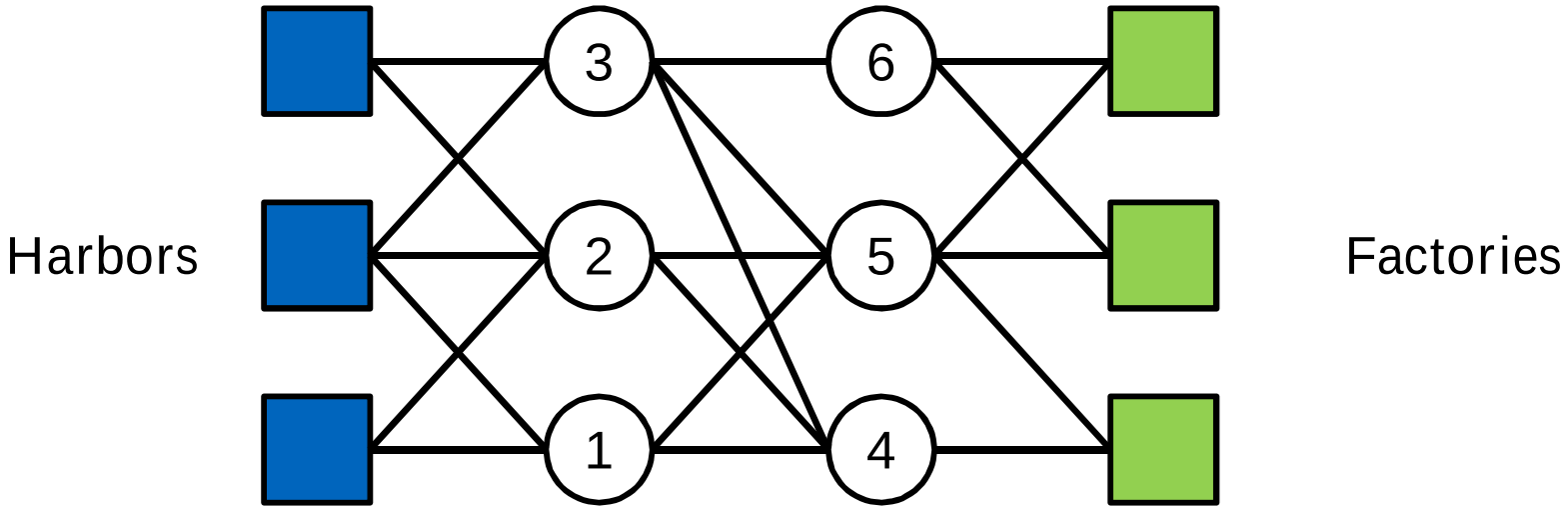




An Illustrative Example

- Nine connections between three harbors and factors
  - Each connection is worth 1/9 of the network performance

- Intermediate nodes (1-6) disrupt with probability 10%

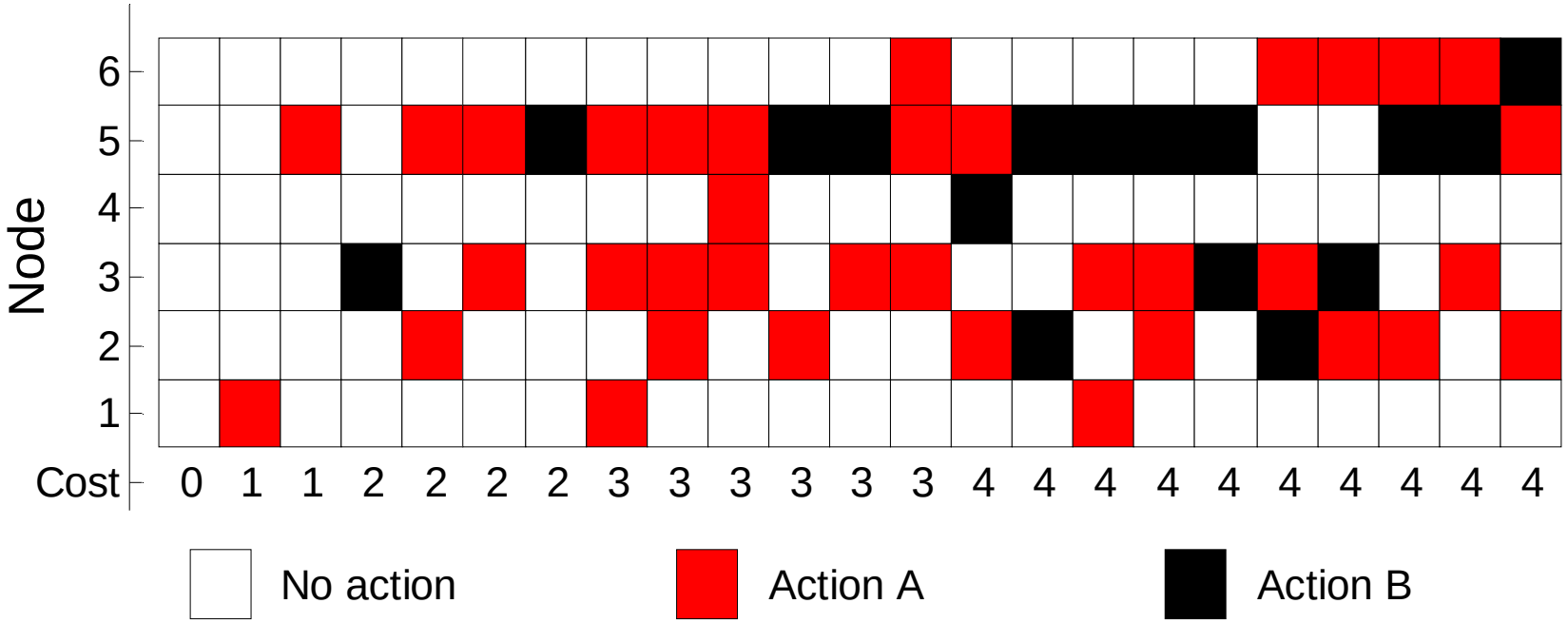


Actions to Secure the Performance

- Two alternative actions to protect network nodes:
  - Action A decreases the disruption probability to 5%
  - Action B decreases the disruption probability to 1%
- Action A costs one unit and action B costs two units
  - The maximum budget is four units
- Which portfolios of actions are cost-effective in securing the performance of the network?
  - Portfolio is cost-effective if it's not stochastic dominated by another less (or equal expensive) portfolio

Cost-Effective Portfolios of Actions

- There are 23 cost-effective portfolios of actions
  - Thus 86% of the feasible portfolios are ineffective



Extensions and Further Research

- Modeling other critical infrastructure systems
  - E.g. Food supply and energy distribution
- Considering partial disruptions or disruptions in edges
  - E.g. Decrease in the capacity of a network edge
- Computational algorithms for larger problem instances
- Connecting the developed methods to spatial measures and simulation models
  - E.g. Evacuation planning simulations

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