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Cost-efficient portfolios of reinforcement actions to secure the performance of transportation networks (topic presentation)

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Background (1/2)

- External hazards and malfunctions may cause disruptions
- The DM can minimize their impacts

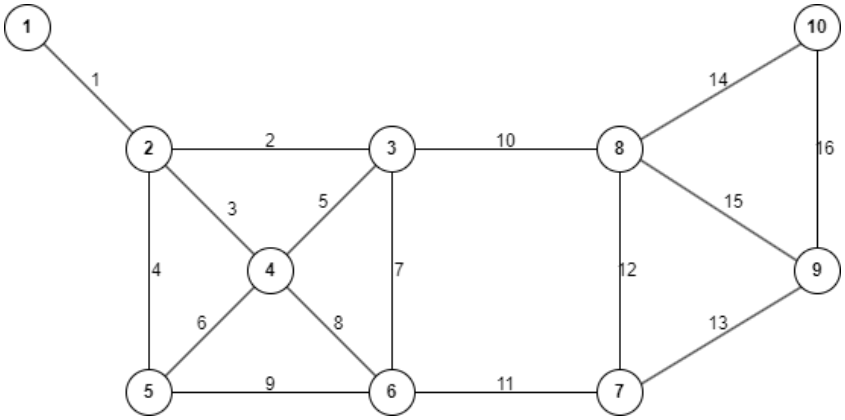

Figure 1: Example of a transportation network from Ip. W. H, Wang. D. (2011)

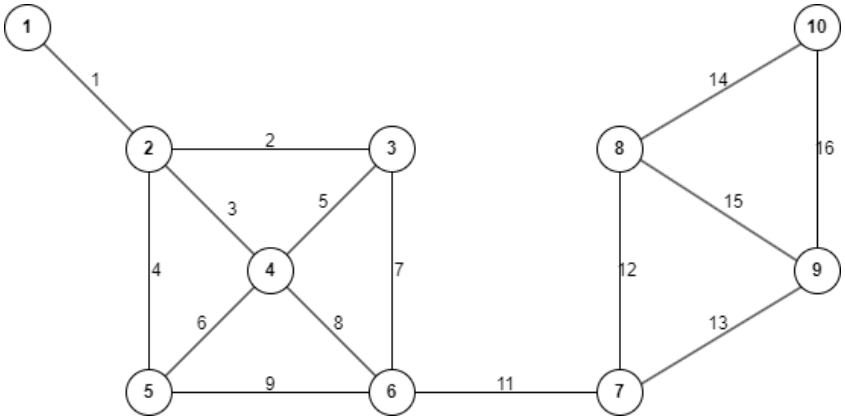

Figure 2: Disruption at edge number 10

Background (2/2)

- The DM seeks to improve performance
- There are many performance metrics
  1. Minimize the expected harm due to disruptions
  2. Minimize the investment cost

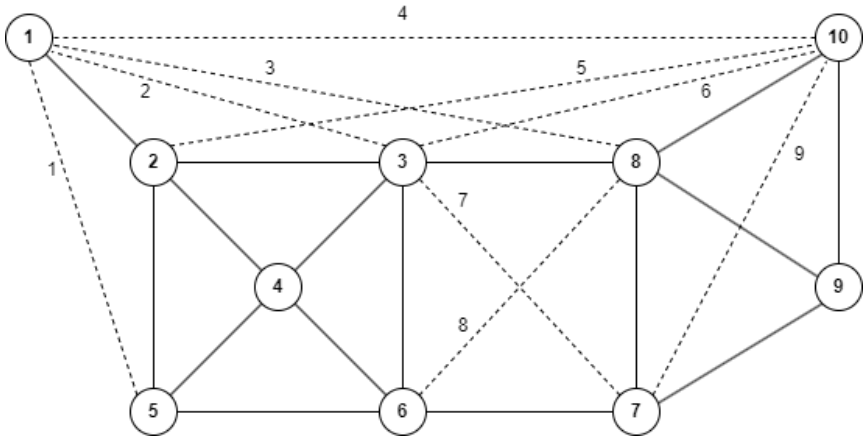

Figure 3: Example of possible edges to add to the network from Ip. W. H, Wang. D. (2011)

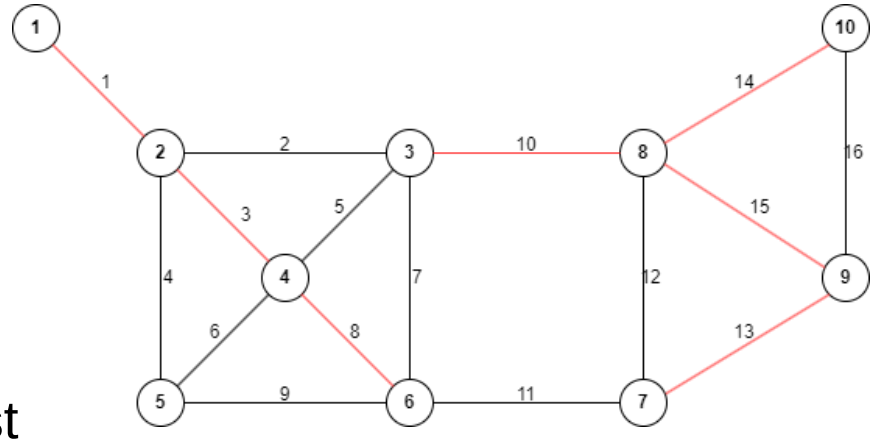

Figure 4: Example of possible edges to strengthen

Measuring performance

1. Average number of independent passageways (IP)

$$IP = \frac{2}{N(N-1)} \sum_{i=1}^{N} \sum_{j=i+1}^{N} k(i,j)$$

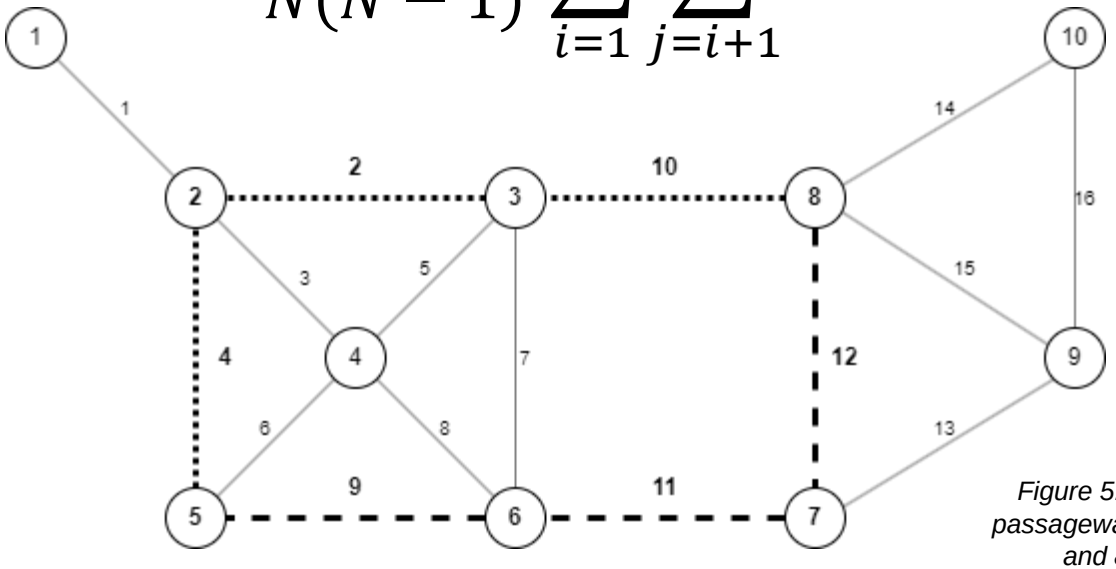

*Figure 5: **Two** independent passageways between nodes 5 and 8 ⇒ $k(5,8) = \mathbf{2}$*

Measuring performance

2. Global Efficiency (GE)

$$GE = \frac{2}{N(N-1)} \sum_{i=1}^{N} \sum_{j=i+1}^{N} \frac{1}{d(i,j)}$$

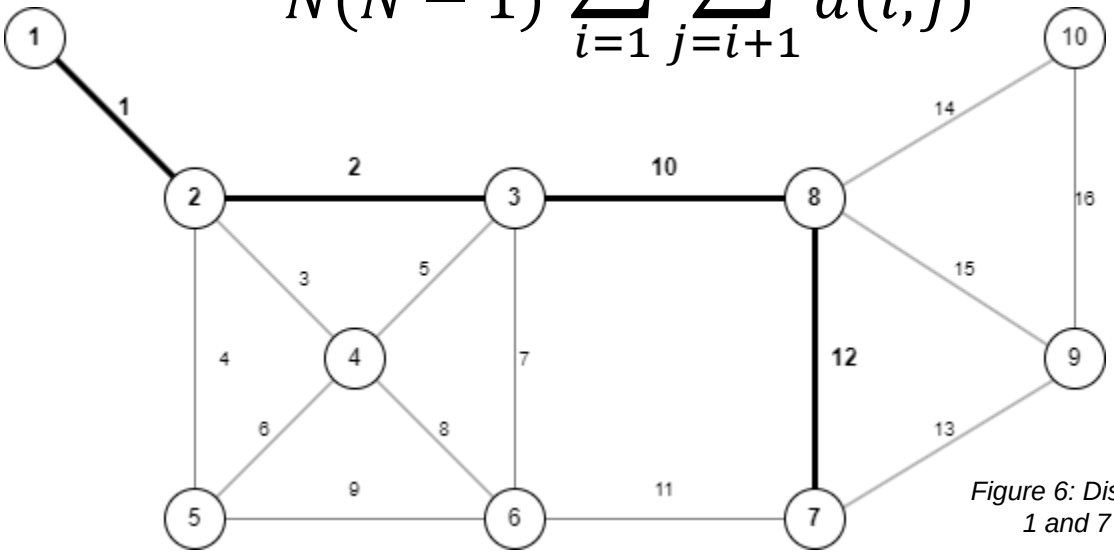

*Figure 6: Distance between nodes 1 and 7 is **4** ⇒ $d(1,7) = \mathbf{4}$*

Measuring performance

- Linear combination of all metrics:

$$V(w) = w_1 IP + w_2 GE\ , \qquad w \in S$$

- The set of feasible weights S

$$S \subseteq S^0 = \{w \in \mathbb{R}^2 \mid w_1 + w_2 = 1, w_1, w_2 \geq 0\}$$

Reinforcement actions

- Consider r alternate reinforcement actions
  - Type 1: Add new edges to the graph
  - Type 2: Reinforce existing edges

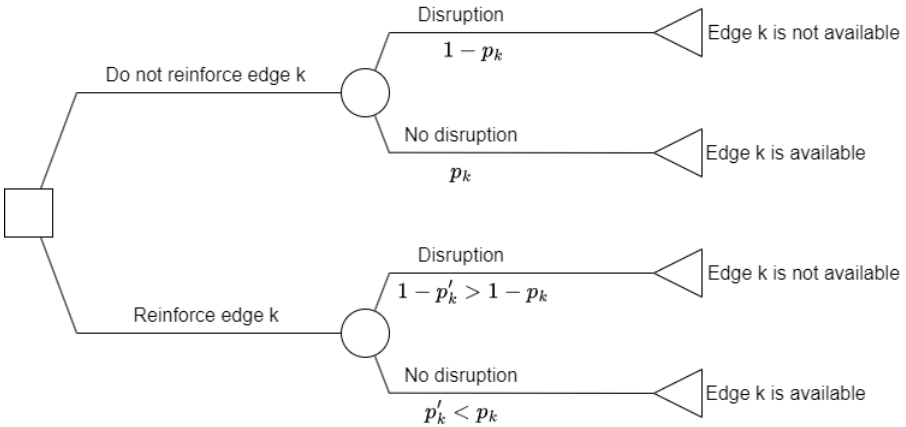

Figure 7: Decision tree for reinforcing edge k in the network

Portfolios of reinforcement actions

$$q = [q_1, \dots, q_r] \in \{0,1\}^r$$

$$q_m = \begin{cases} 1, & \text{if action m is implemented} \\ 0, & \text{otherwise} \end{cases}, m = 1, \dots, r$$

- A portfolio q^k dominates portfolio q^j, denoted $q^k \succ q^j$, in S if and only if

$$\begin{cases} V(q^k, w) \geq V(q^j, w) \text{ for all } w \in S \\ V(q^k, w) > V(q^j, w) \text{ for some } w \in S \end{cases}$$

Example of dominance

- Portfolio x^1 dominates x^3
- Portfolios x^1 and x^2 are non-dominated

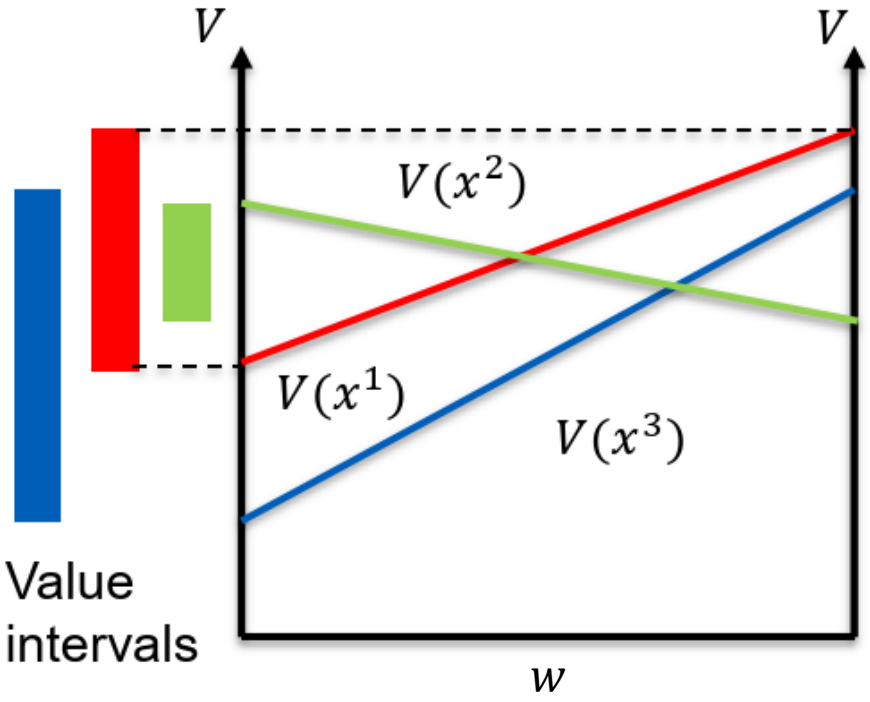

Figure 8: Example of dominance from the course MS-E2135 Decision Analysis D 2023, Lecture 6b by Ahti Salo

Objectives

- Evaluate portfolios of reinforcement actions with a linear combination of different performance metrics
- Implement an algorithm to determine the cost-efficient portfolios of reinforcement actions
- Improve the performance of the network cost-efficiently

Assumptions

- Relatively small undirected network
- Two states for each edge
  - operational vs. disrupted
- There is no ripple effect in the disruptions

Tools

- Python
  - Library ”NetworkX”
    - Modelling the transportation network
  - Library ”Polytope”
    - Figuring out the extreme points of the set of feasible weights
  - Construction and evaluation of the network
  - Computation of the cost-efficient portfolios

Methodology

- Inputs
  - Transportation network with populations
  - Estimates of the disruption probabilities
  - Reinforcement actions and their costs and effects
  - Preference statements regarding metrics
- Incomplete information
  - Disruption probabilities
  - Weights of performance metrics
- Outputs
  - Cost-efficient portfolios of reinforcement actions

Schedule

- Literature review 04/2024
- Presentation of the topic 7.5.2024
- Analysis and writing the thesis 5/2024 - 6/2024
- Results ready 6/2024
- Presentation of the results 17.6.2024
- Thesis ready 7/2024

Literature and references

- Kangaspunta, J., Salo, A. (2014). A Resource Allocation Model for Improving the Resilience of Critical Transportation Systems
- Ip, W.H., Wang, D. (2011). Resilience and Friability of Transportation Networks: Evaluation, Analysis and Optimization, *IEEE Systems Journal*, 5(2), 189-198
- Haritha, P.C., Anjaneyulu, M.V.L.R. (2024). Comparison of topological functionality-based resilience metrics using link criticality*, Reliability Engineering and System Safety*, 243, article 109881