Aalto University
School of Science

Risk-based optimization of pipe inspections in large underground networks with imprecise information

Hilkka Hännikäinen

Presentation *21*

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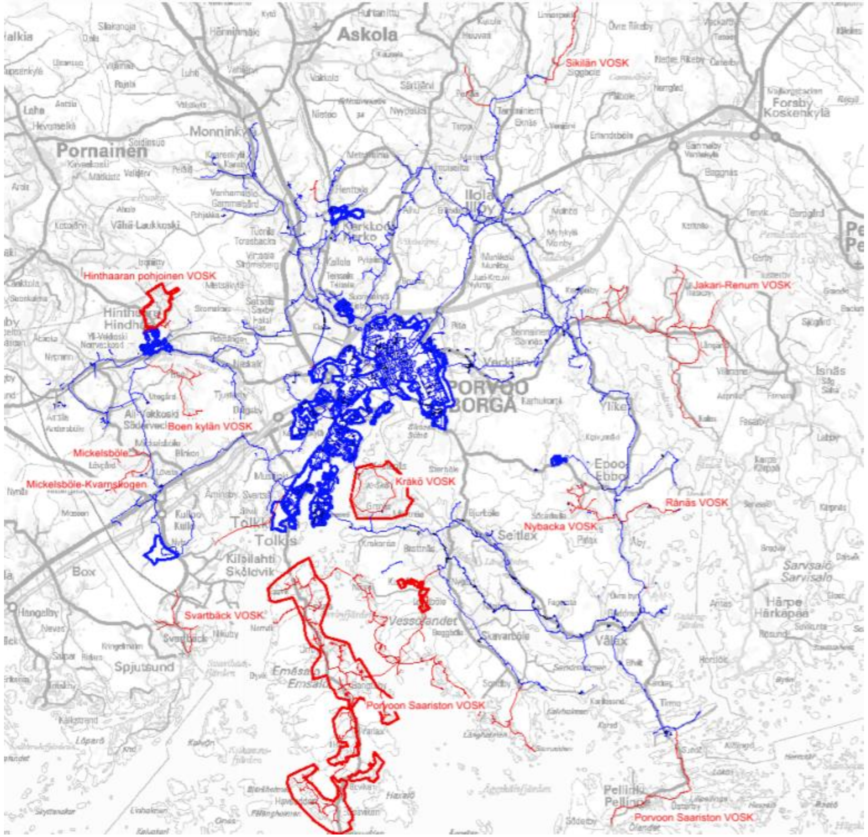


Porvoon kaupungin vesihuollon kehittämissuunnitelma 2015-2020

Buried Pipe Element (Undergroung piping) from https://www.passuite.com/kbase/doc/start/WebHelp_en/pipesoil.htm

Renovation planning

i. Identify an optimal set of inspections of network items so that possible renovation actions are expected to decrease the risks and the cost of negative consequences

ii. Determine the degradation state of the network items in the selected portfolio and plan the maintenance actions for the network

Risk-based methodology

Likelihood and severity evaluation (1/2)

Risk = combination of the likelihood of the failure and the severity of the failure

The risk of every network item is quantified from value intervals for likelihood and severity determined using methods from MAVT

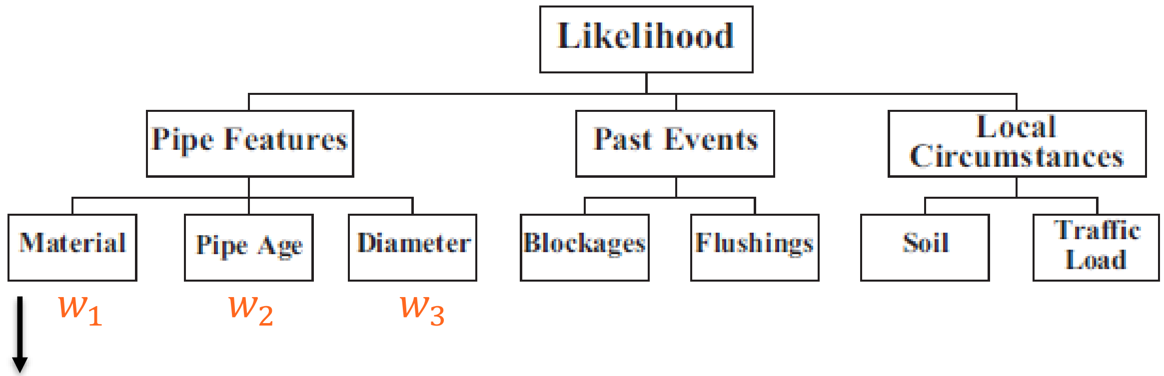
Likelihood and severity evaluation (2/2)

Mancuso et al. (2016)

objective

subobjective

attributes



- quality classes e.g. PVC, polyethene, cast iron and concrete
  → for every quality class, assign an interval valued score describing its contribution to the (sub)objective relative to the other classes
- for network item x^j, determine a value interval based on its quality class w.r.t to attribute i

$$v_i\left(x_i^j\right) = [\underline{v}_i\left(x_i^j\right); \overline{v}_i(x_i^j)]$$

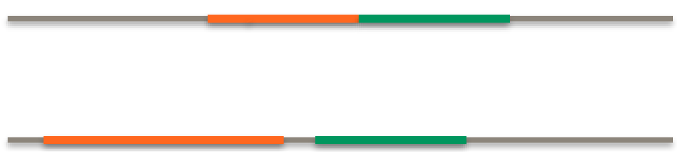
- aggregate the attribute values using weight information to obtain new value interval

$$V_L\left(x^j\right) = \left[\underline{v}_L\left(x^j\right); \overline{v}_L\left(x^j\right)\right]$$
$$= [\min_w \textstyle\sum_i w_i v_i\left(x_i^j\right); \max_w \textstyle\sum_i w_i v_i\,(x_i^j)]$$

Risk assessment

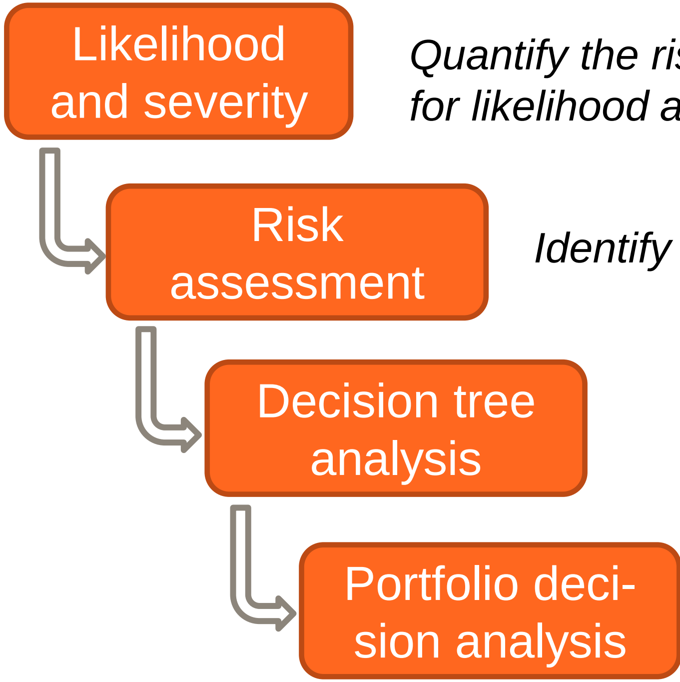
Identify the most critical components by constructing a frontier of Pareto-optimal solutions through dominance relation

$$x^j \succ x^k \leftrightarrow \begin{Bmatrix} \underline{v}_L(x^j) \geq \overline{v}_L(x^k) \\ \underline{v}_C(x^j) > \overline{v}_C(x^k) \end{Bmatrix} \vee \begin{Bmatrix} \underline{v}_L(x^j) > \overline{v}_L(x^k) \\ \underline{v}_C(x^j) \geq \overline{v}_C(x^k) \end{Bmatrix}$$



$$L = likelihood$$

$$C = severity$$



Quantify the risk using value intervals V_L and V_C for likelihood and severity

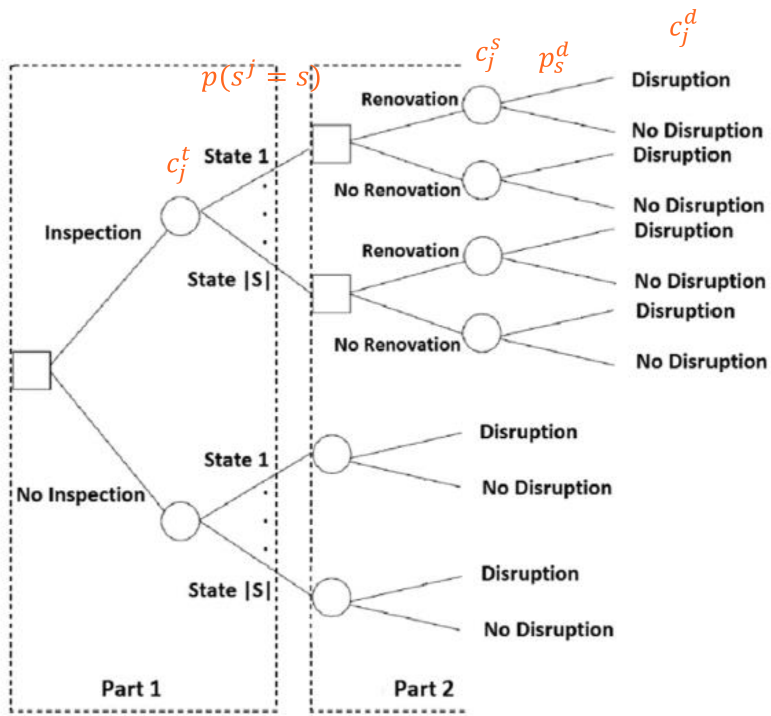
Identify the riskiest network items

Step 1

Step 2

Select optimal portfolio of items to be inspected

Decision tree analysis (1/2)



Mancuso et al. (2016)

Quantify the benefit of inspection and possible maintenance

Information required:

i. State probabilities $p(s^j = s)$

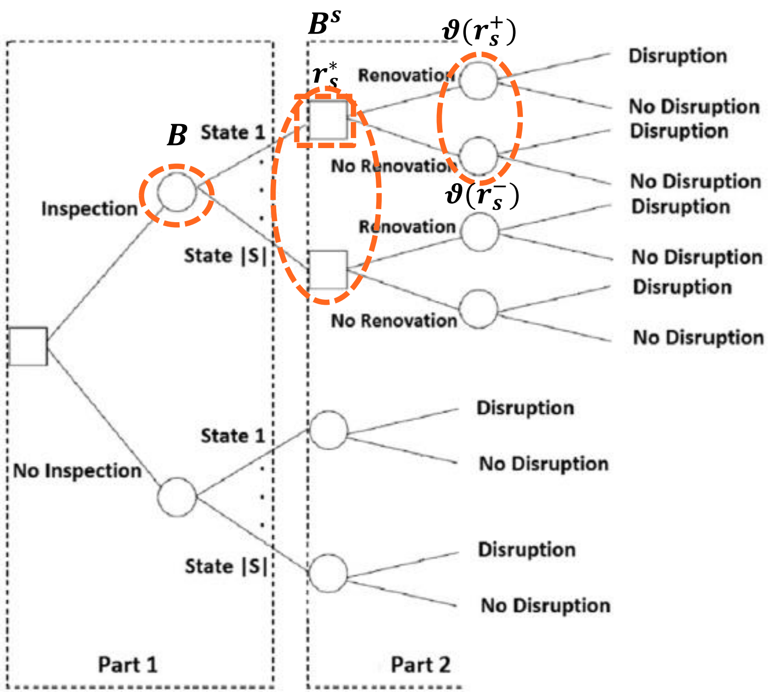
ii. Disruption probabilities $p_s^d = [\underline{p}_s^d, \overline{p}_s^d]$

iii. Inspection costs $c_j^t = [\underline{c}_j^t, \overline{c}_j^t]$

iv. Renovation costs $c_j^s = [\underline{c}_j^s, \overline{c}_j^s]$

v. Disruption consequences $c_j^d = [\underline{c}_j^d, \overline{c}_j^d]$

Decision tree analysis (2/2)



Mancuso et al. (2016)

- Calculate the expected costs of two alternatives:
  - Renovate r^+: $\vartheta(r_s^+) = [\underline{\vartheta}(r_s^+); \overline{\vartheta}\,(r_s^+)]$
  - Do not renovate r^-: $\vartheta(r_s^-) = [\underline{\vartheta}(r_s^-); \overline{\vartheta}\,(r_s^-)]$
- Calculate the optimal decision:

$$r_s^* = \begin{cases} r^+, if\ \overline{\vartheta}(r_s^+) < \underline{\vartheta}(r_s^-) \\ r^-, otherwise \end{cases}$$

- For each state s, calculate the benefit $B^s = [\underline{B}^s; \overline{B}^s]$ of possible renovation
- Aggregate the values to get the expected benefit $B = [\underline{B}; \overline{B}]$

Portfolio decision analysis

Identify cost efficient portfolios of item inspections with two objectives of cost minimization and benefit maximization

Robust portfolio modeling (RPM): find non-dominated solutions to problem of maximizing portfolio value

$$\max_{p} V(p, w, v) = \max_{z(p)} \{ z(p) v w \mid A z(p) \leq U, z(p) \in \{0,1\}^m \}$$

- $z(p)$: which items belong to the portfolio
- v: includes information about the inspection costs and benefits
- w: objective weights
- $Az(p) \leq U$: budget constraint, portfolio balance, project dependencies etc.

Calculate the Core Index (CI) for each item to determine the convergence criterion and compare different network items

Likelihood and severity — *Quantify the risk using value intervals v_L and v_C for likelihood and severity*

Risk assessment — *Identify the riskiest network items*

Step 1

Decision tree analysis — *Assess the pipe state and calculate the benefit of inspection*

Portfolio decision analysis — *Find the non-dominated portfolios*

Step 2

References

A. Mancuso, M. Compare, A. Salo, E. Zio, and T. Laakso. *Risk-based optimization of pipe inspections in large underground networks with imprecise information*, pages 228-238. Reliability Engineering and System Safety 152, 2016.

J. Liesiö, P. Mild, and A. Salo. *Robust portfolio modeling with incomplete cost information and project interdependencies*, pages 679-695. European Journal of Operational Research 190, 2008.

J. Liesiö, A. Punkka, A. Salo, and E. Vilkkumaa. *Course: Decision Making and Problem Solving*, lecture notes, Aalto University, delivered April 2019.

Homework (1/2)

a) Consider the four items given in the template. The value intervals for the likelihood and severity and the disruption costs of the items are given in a table. Using the dominance relation on slide 7, determine the non-dominant alternative.

b) Using the formulas given in the next slide and the decision tree in the template, calculate the aggregated inspection benefit $B = [\underline{B};\ \overline{B}]$ for that item.

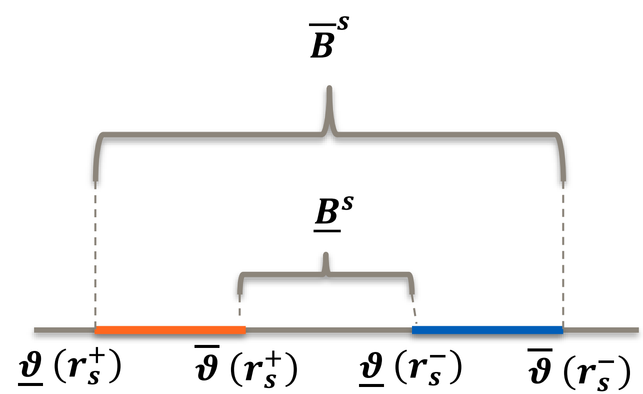
Return your solution by 27.11. at 9.15 to hilkka.hannikainen@aalto.fi

Homework (2/2)

The benefit $B^s = [\underline{B}^s; \overline{B}^s]$ in state s is

$$\underline{B}^s = \begin{cases} 0, & r_s^* = r^- \text{ (don't renovate)} \\ \underline{\vartheta}(r_s^-) - \overline{\vartheta}(r_s^+), & r_s^* = r^+ \text{ (renovate)} \end{cases}$$

$$\overline{B}^s = \begin{cases} 0, & r_s^* = r^- \text{ (don't renovate)} \\ \overline{\vartheta}(r_s^-) - \underline{\vartheta}(r_s^+), & r_s^* = r^+ \text{ (renovate)} \end{cases}$$



The aggregated benefit $B = [\underline{B}; \overline{B}]$ is

$$\underline{B} = \sum_s p(s)\underline{B}^s, \quad \overline{B} = \sum_s p(s)\overline{B}^s$$

where $p(s)$ is the probability of state s