Strategies for the rehabilitation of water distribution networks

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Sustainable management of water resources is depending on an sophisticated and strategic management of the water network infrastructure.

For a strategic management of the water network infrastructure a long-term forecast of rehabilitation needs and network development is mandatory.

Only by using a holistic network management system, identification and activation of saving potentials (water resources or finances) is achievable in the long run.
Guideline ▶ Search for best strategy

- Risk-minimising strategy
- Budget oriented strategy
- Asset oriented strategy
Forecast of asset age development

![Average asset age graph]

- **Do Nothing**
- **Current strategy**
- **Substance oriented strategy**
Forecast of rehabilitation priority development

![Average Priority in the network graph]

- **Do Nothing**
- **Current strategy**
- **Substance oriented strategy**

**Prognosis year**
- 2010
- 2020
- 2030
- 2040
- 2050

**Priority [%]**
- 0
- 20
- 40
- 60
- 80
- 100
Forecast of capital asset development

Substance Value of Network

- Substance oriented strategy
- Current strategy
- Do Nothing

Prognosis year

Substance Value [Mil. EUR]

2010 2020 2030 2040 2050
STATUS Water
Scope of services

Operative Maintenance Planning

- Strategy development and analysis
- Aging Models, Survival Functions and Forecast
- Differentiated Defect- and Section Assessment
- Data Management & Plausibility Analysis
Plausibility analysis identifies missing and incorrect data and gives advice for solutions
STATUS Water
Differentiated Defect- and Section Assessment

Strict thresholds as evaluation criteria are replaced by fuzzy-membership-functions reflecting the possible scope of decisions
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Structural investigation (Damage Classification)
Differentiated defect assessment - example

<table>
<thead>
<tr>
<th>Defect Type:</th>
<th>Longitudinal Crack</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size</strong></td>
<td>2 mm</td>
</tr>
<tr>
<td><strong>Material</strong></td>
<td>Concrete</td>
</tr>
<tr>
<td><strong>Diameter</strong></td>
<td>500 mm</td>
</tr>
<tr>
<td><strong>Cover</strong></td>
<td>4 m</td>
</tr>
<tr>
<td><strong>Ground-water</strong></td>
<td>below</td>
</tr>
<tr>
<td><strong>Traffic-load</strong></td>
<td>SLW 30</td>
</tr>
</tbody>
</table>

Rehabilitation priority

- Low (DC 1)
- High (DC 5)

Stability ($\gamma_{\text{rec}} = 2.20$): $\gamma = 2.18$
Structural investigation (Damage Classification) Differentiated defect assessment - example

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Rehabilitation priority
- Low (DC 1)
- High (DC 5)

Stability ($\gamma_{rec} = 2.20$): $\gamma = 1.08$
Structural investigation (Damage Classification)
Differentiated defect assessment - Fuzzy

Abolishment of the strict condition class limitations
Differentiated defect assessment - Fuzzy
Abolishment of the strict condition class limitations
Differentiated defect assessment - Fuzzy
Abolishment of the strict condition class limitations

Concrete KW DN 400

Safety factor – depending on crack width and cover
Differentiated defect assessment - Fuzzy
Abolishment of the strict condition class limitations

Including ancillary conditions into assessment (linked by fuzzy logic) gives the possibility to change to a risk-based (pro-active) approach
Structural investigation (Damage Classification)
Result – RISK REDUCTION
Differentiated Defect- and Section Assessment

Section Assessment

<table>
<thead>
<tr>
<th>Condition (Priority)</th>
<th>Substance (Residual wear reserve)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criterion for the present function fulfilment</td>
<td>Criterion for the remaining function fulfilment</td>
</tr>
<tr>
<td>⇒ Rehabilitation priority</td>
<td>⇒ Wear reserve/ remaining service life + Rehabilitation type</td>
</tr>
<tr>
<td>Consideration of the most severe single defect</td>
<td>Consideration of distribution, extent and degree of the defects</td>
</tr>
</tbody>
</table>
Differentiated Defect- and Section Assessment

Section Assessment

Substance (Residual wear reserve)

Criterion for the remaining function fulfilment

⇒ Wear reserve/remaining service life + Rehabilitation type

Consideration of distribution, extent and degree of the defects
STATUS Water
Aging Models, Survival Functions and Forecast

- Clustering of the network to determine of the survival functions
STATUS Water
Aging Models, Survival Functions and Forecast

- Determination of the parameter for the Weibull distribution for the condition and substance classes according to the cluster attributes
- Determination of the survival functions for the related cluster as integral of the service life distribution
STATUS Water
Aging Models, Survival Functions and Forecast

Example of survival functions based on a "bad" cluster
Material is not sufficient as a criterion for describing a homogeneous cluster.

Comparison of two methods, including confidence intervals (95%).

Many combination were examined.
EXAMPLE:
First aging functions for the water network were derived based on the documented damages and experience of the operators and the network data. For a stable prognosis a long-term documentation of damage data in a defined form is necessary.
EXAMPLE:
Here we see a comparison with a typical German water network. In general the aging function show a higher service life. One of the main causes for the difference, besides of the quality of installation (15%) or pipe materials (20%) can be seen in the stress and temporary high pressure caused by the non-continuous water supply.
Strategy development and –analysis
Risk assessments for strategies

Maximum likelihood

- **pessimistic**
- **optimistic**
- **Monte-Carlo Simulation**
Strategy development and – analysis
Risk assessments for strategies based on the aging behavior of a pipeline (e.g., a pipeline with typical service life of 80 years)?:

Maximum likelihood
- **pessimistic**
- **optimistic**
- **Monte-Carlo Simulation**

![Diagram showing risk assessments over time](image)
Strategy development and –analysis
Prediction of the future network development

Predicting the future network development allows long-term strategic planning for increasing service level, reducing leakage and risk.
Assessment of water distribution pipes

Statistics
- Failures
- Leakages
- Rehabilitation

Inventory of water mains
Current stock of pipes by:
- Year of construction
- Length
- Pipe type (material, diameter ...)
- Pipe surroundings (soil type, customer sensitivity ...)

Analytical clustering of the water network

Determination of survival functions

Cohort survival model forecasting the network rehabilitation needs

Definition of rehabilitation strategies

Cohort survival model forecasting the future network development

Long-term water network rehabilitation strategies

Rehabilitation options
- Area scope
- Material
- Time scope
- Type (renovate/replace)

Rehabilitation criteria
- Residual service life
- Age
- Failure/leakage rates

Selection of the optimal rehabilitation strategy

Economic data
- Unit costs
- Inflation/discount rate
- Water tariffs
- Fixed and variable costs
- Budget restrictions

Annual costs of
Repair | Water losses

Costs [T€]

Year
2005 2015 2025 2035 2045

Annual costs of Repair and Water losses
Assessment of water distribution pipes
Pro-active rehabilitation management

<table>
<thead>
<tr>
<th>Situation 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Network failure rate</td>
</tr>
<tr>
<td>• Network leakage rate</td>
</tr>
<tr>
<td>• Deterioration rate</td>
</tr>
<tr>
<td>• Replacement cost</td>
</tr>
<tr>
<td>• Relining cost</td>
</tr>
<tr>
<td>• Repair cost</td>
</tr>
<tr>
<td>• Variable part of water price</td>
</tr>
<tr>
<td>• Inflation rate of water price</td>
</tr>
<tr>
<td>water work</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strategy A</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 100% replacement</td>
</tr>
<tr>
<td>• Linear increase of rehab rate from 0.2 (2005) to 1.0 (2020)</td>
</tr>
<tr>
<td>• Rehab needs beyond 2020 as forecast</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strategy B</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 1/3 replacement / 2/3 relining</td>
</tr>
<tr>
<td>• Linear increase of rehab rate from 0.3 (2005) to 1.5 (2020)</td>
</tr>
<tr>
<td>• Rehab needs beyond 2020 as forecast</td>
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## Assessment of water distribution pipes
### Pro-active rehabilitation management

<table>
<thead>
<tr>
<th>Decision criteria</th>
<th>Strategy A</th>
<th></th>
<th>Strategy B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative to 2005</td>
<td>2020</td>
<td>2050</td>
<td>2020</td>
<td>2050</td>
</tr>
<tr>
<td>Network share rehabilitated</td>
<td>9%</td>
<td>54%</td>
<td>13.5%</td>
<td>58%</td>
</tr>
<tr>
<td>Average age</td>
<td>+11 yrs.</td>
<td>+4 yrs.</td>
<td>+9 yrs.</td>
<td>+3 yrs.</td>
</tr>
<tr>
<td>Average residual service life</td>
<td>-2 yrs.</td>
<td>+30 yrs.</td>
<td>-4 yrs.</td>
<td>+5 yrs.</td>
</tr>
<tr>
<td>Reduction of failure rate</td>
<td>4%</td>
<td>70%</td>
<td>4%</td>
<td>46%</td>
</tr>
<tr>
<td>Reduction of leakage rate</td>
<td>4%</td>
<td>70%</td>
<td>19%</td>
<td>75%</td>
</tr>
<tr>
<td>Years to break even</td>
<td>29</td>
<td></td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>Internal rate of return</td>
<td>7 %</td>
<td></td>
<td>11 %</td>
<td></td>
</tr>
<tr>
<td>Best strategy</td>
<td>??</td>
<td></td>
<td>??</td>
<td></td>
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</table>
Thank you for attention!