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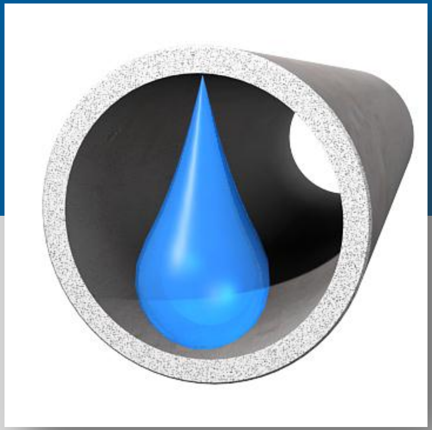
Strategies for the rehabilitation of water distribution networks



Dr.-Ing. Robert Stein

Prof. Dr.-Ing. Stein & Partner GmbH

S & P Consult GmbH

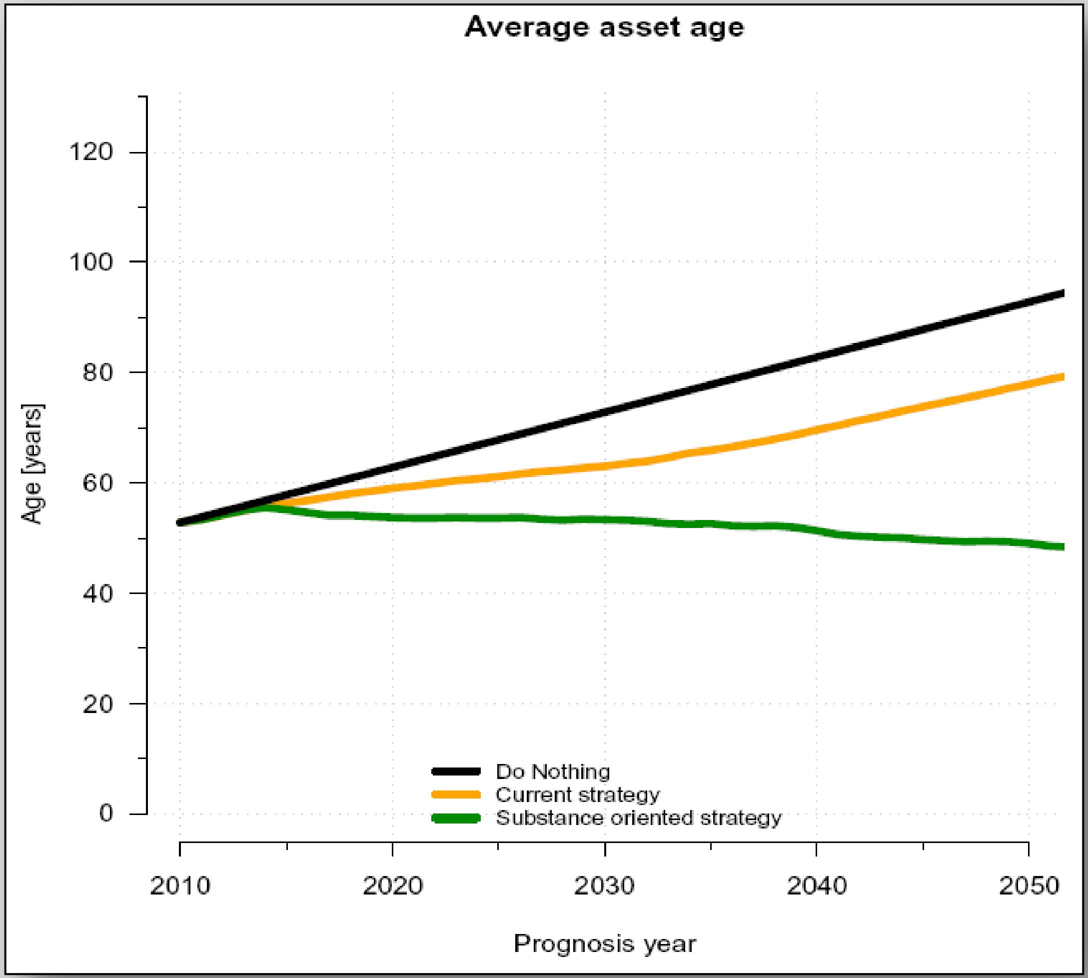
Thesis

- 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



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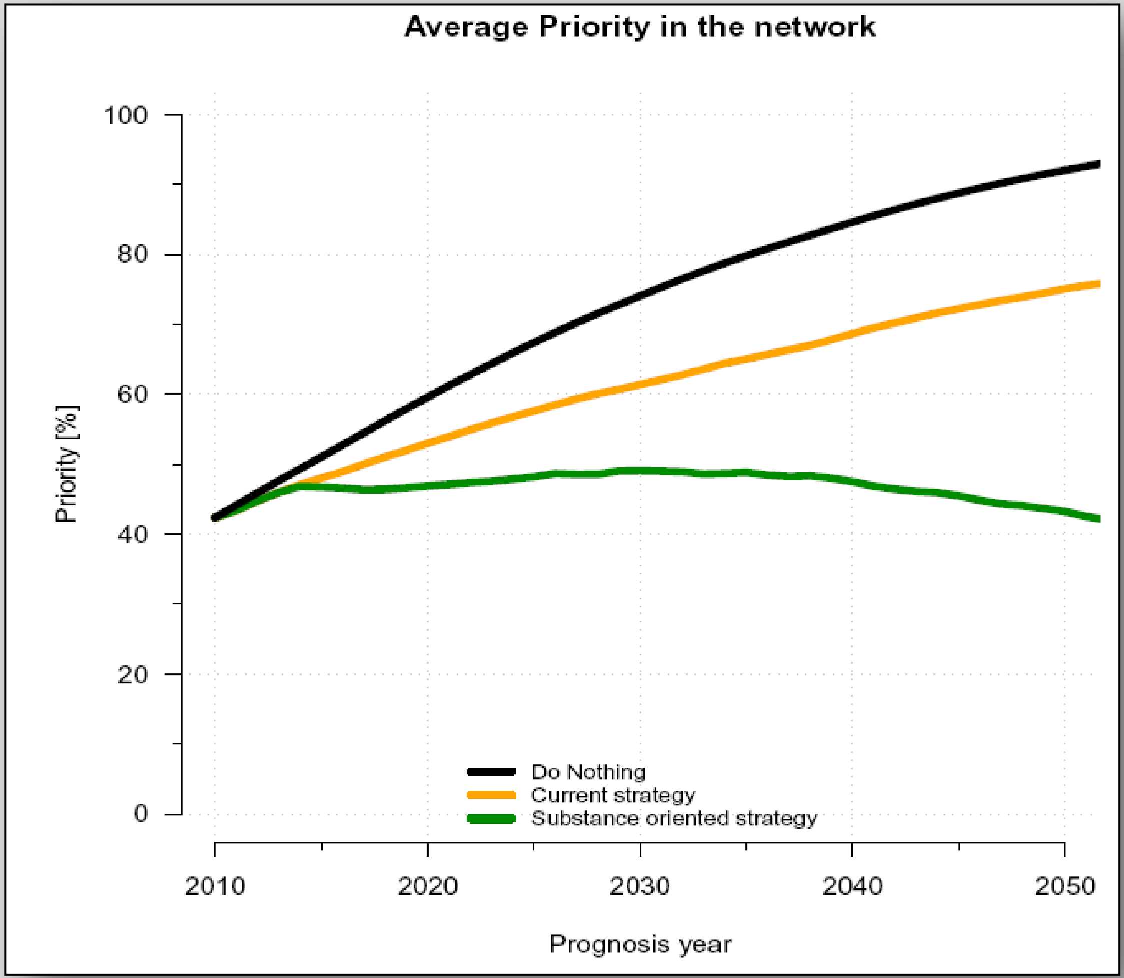
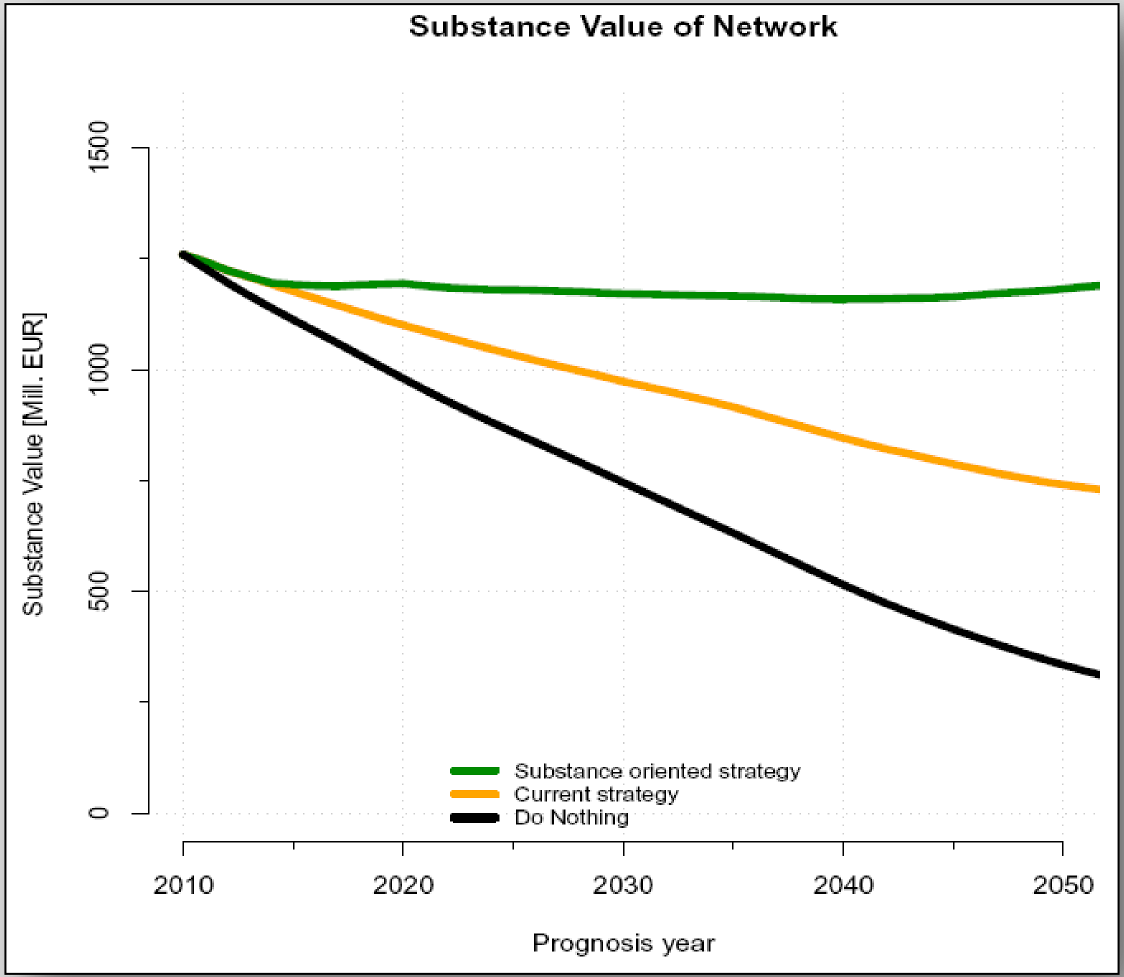
Forecast of rehabilitation priority development



Forecast of capital asset development



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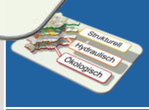
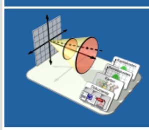
STATUS Water
Scope of services

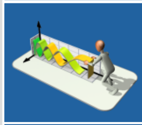
Operative Maintenance Planning



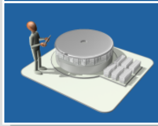
Strategy development and –analysis



Aging Models, Survival Functions and Forecast



Differentiated Defect- and Section Assessment



Data Management & Plausibility Analysis

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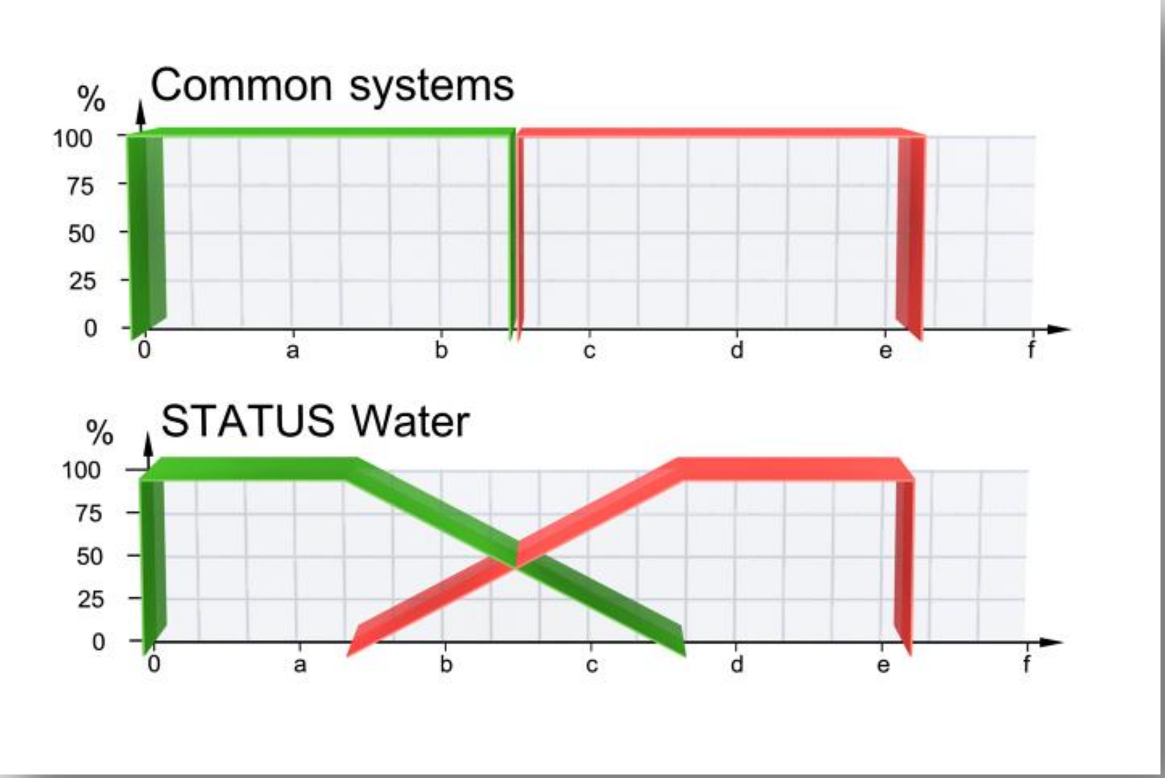
STATUS Water
Data Management & Plausibility Analysis

Plausibility analysis identifies missing and incorrect data and gives advice for solutions

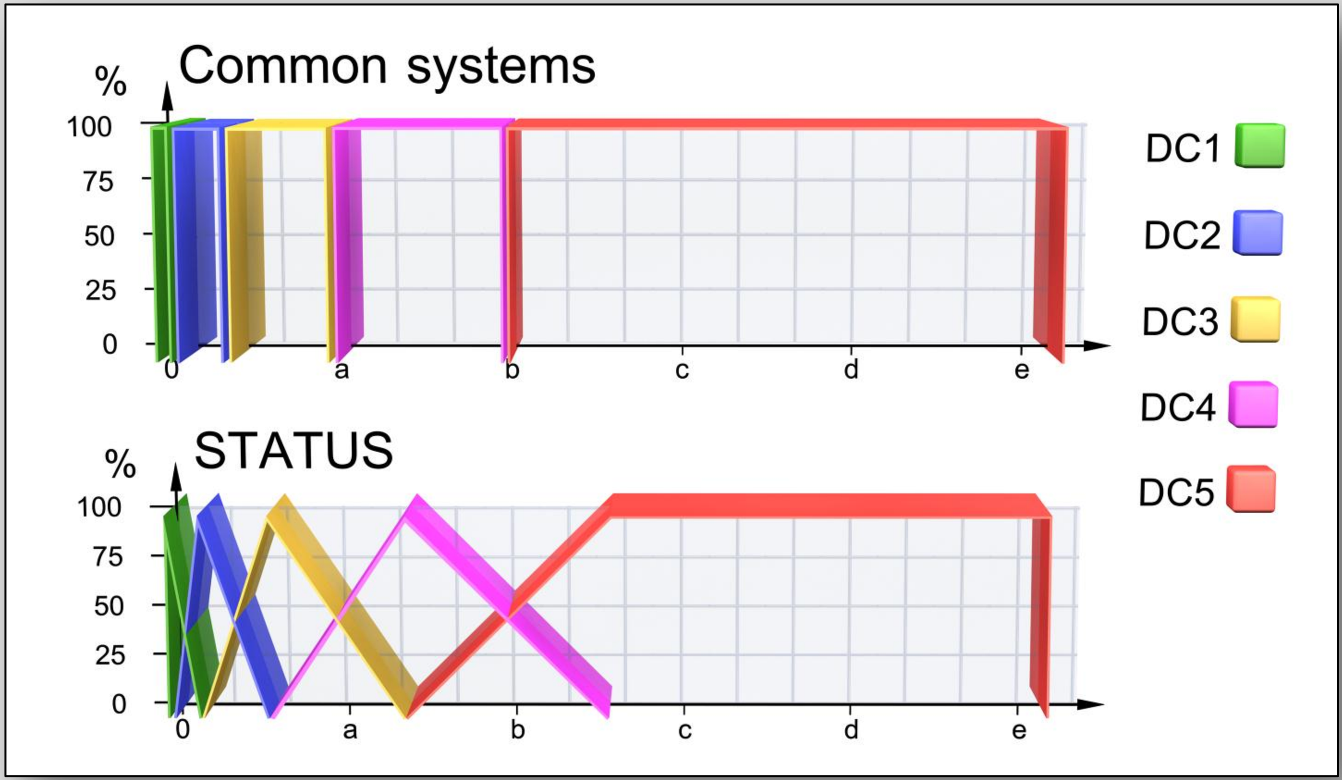
STATUS Water
Differentiated Defect- and Section Assessment

Strict thresholds as evaluation criteria are replaced by fuzzy-membership-functions reflecting the possible scope of decisions



STATUS Water
Differentiated Defect- and Section Assessment

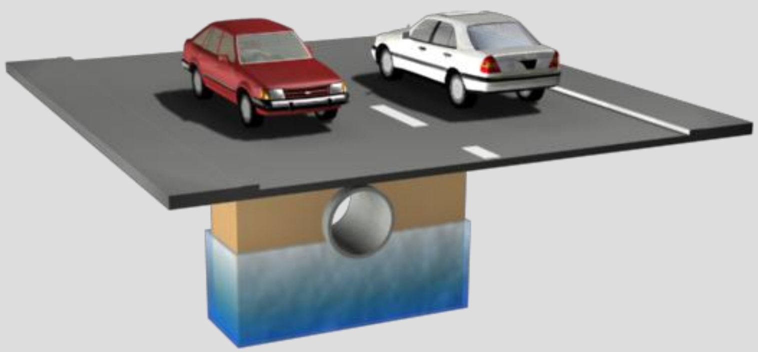
Strict thresholds as evaluation criteria are replaced by fuzzy-membership-functions reflecting the possible scope of decisions

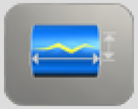
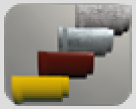
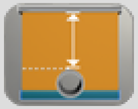
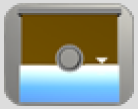


Abolishment of the strict condition class limitations

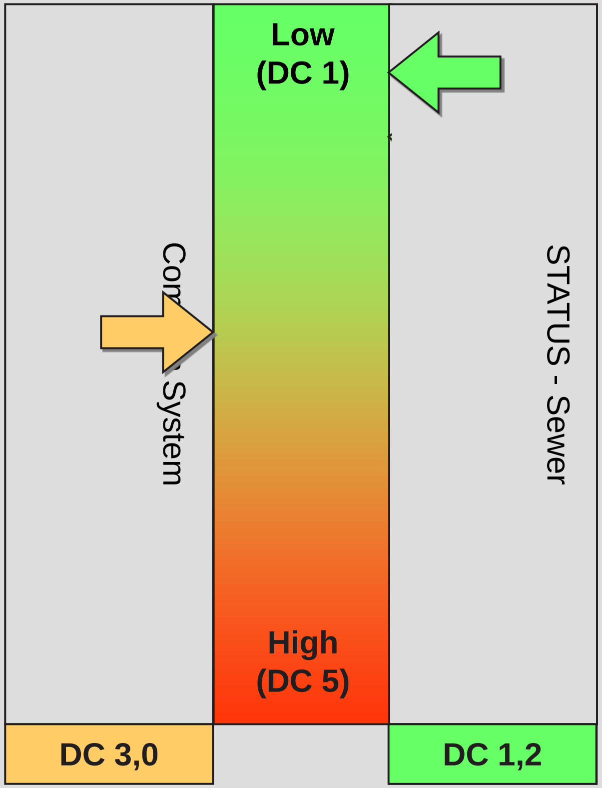
Structural investigation (Damage Classification)
Differentiated defect assessment - example

Defect Type:	Longitudinal Crack



Size	Material	Diameter	Cover	Ground-water	**Traffic- load**
					
2 mm	Concrete	500 mm	4 m	below	SLW 30

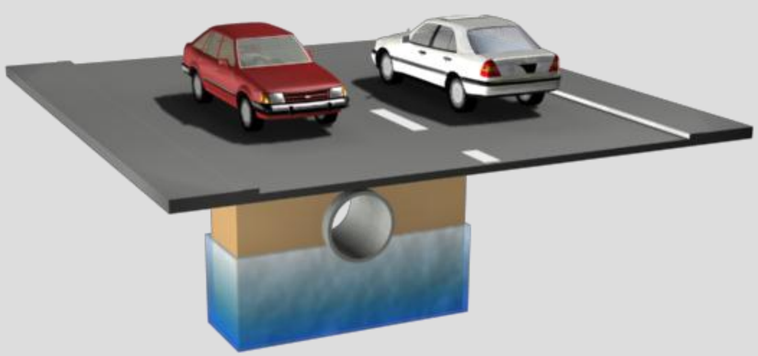
Rehabilitation priority

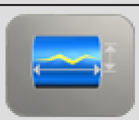
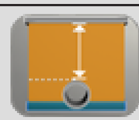


Stability (γ_{nec} = 2,20): γ = 2,18

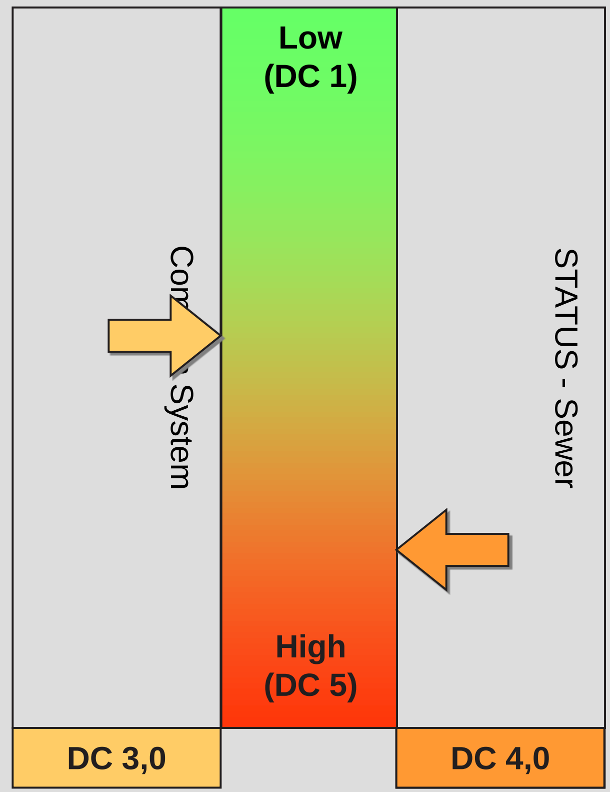
Structural investigation (Damage Classification)
Differentiated defect assessment - example

Defect Type:	Longitudinal Crack



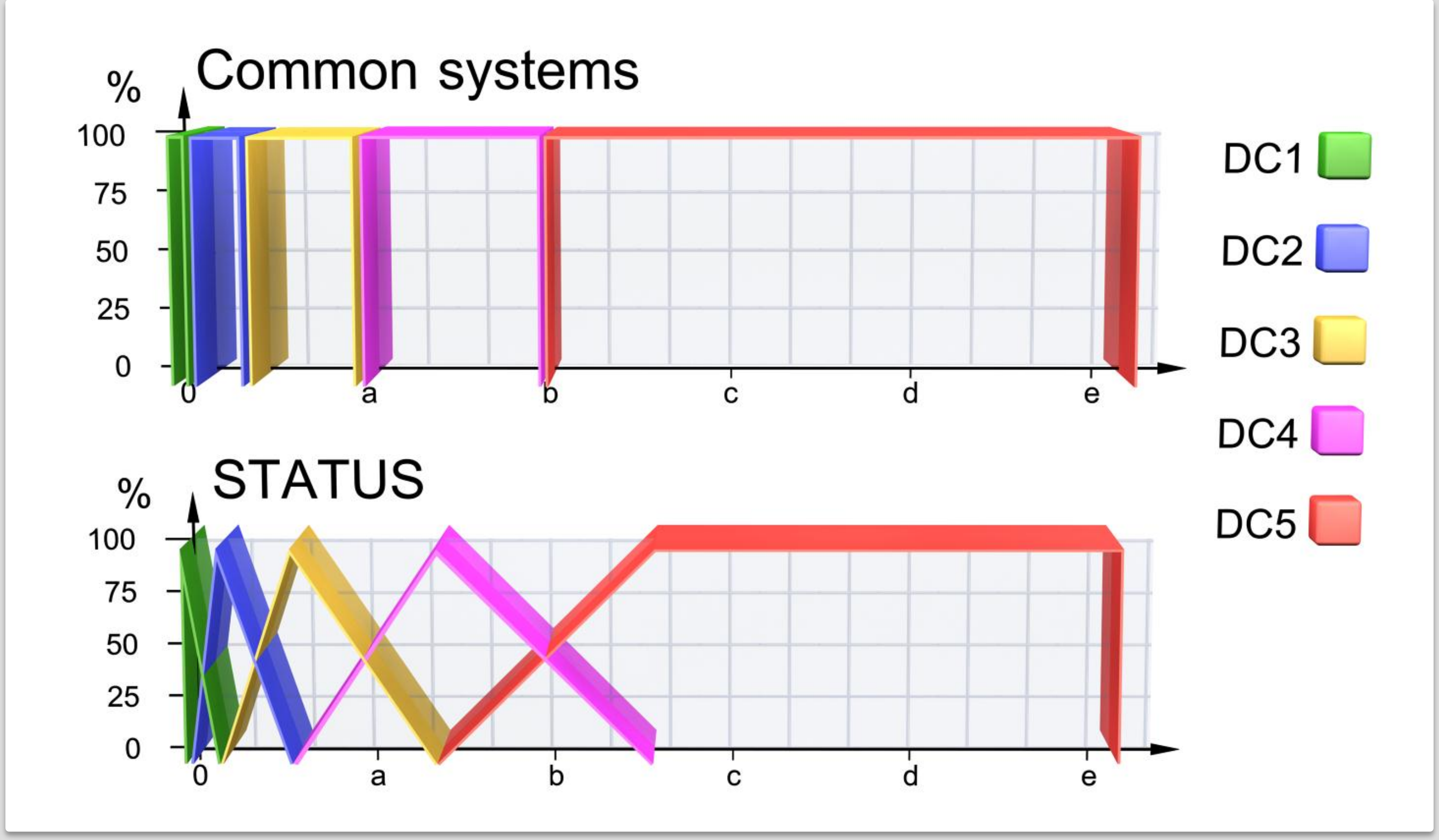
Size	Material	Diameter	Cover	Ground-water	Traffic-load
					
2 mm	Concrete	**300 mm**	**2 m**	below	SLW 30

Rehabilitation priority



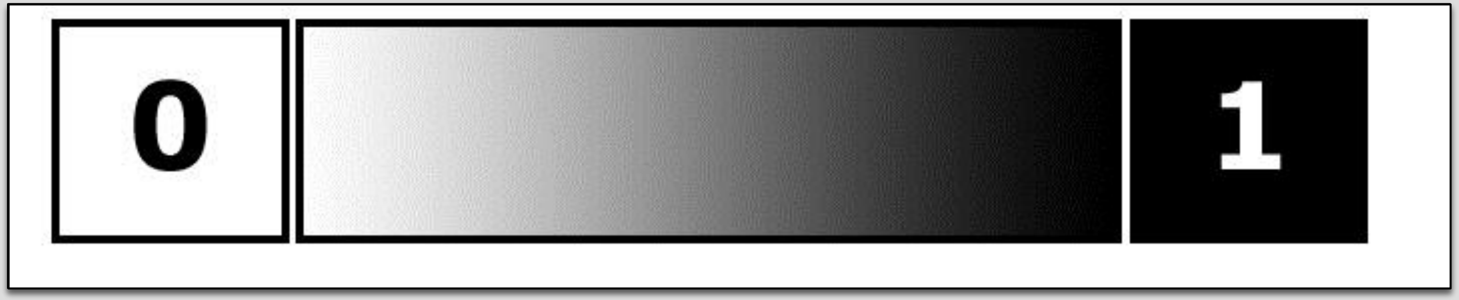
Stability (γ_{nec} = 2,20): γ = 1,08

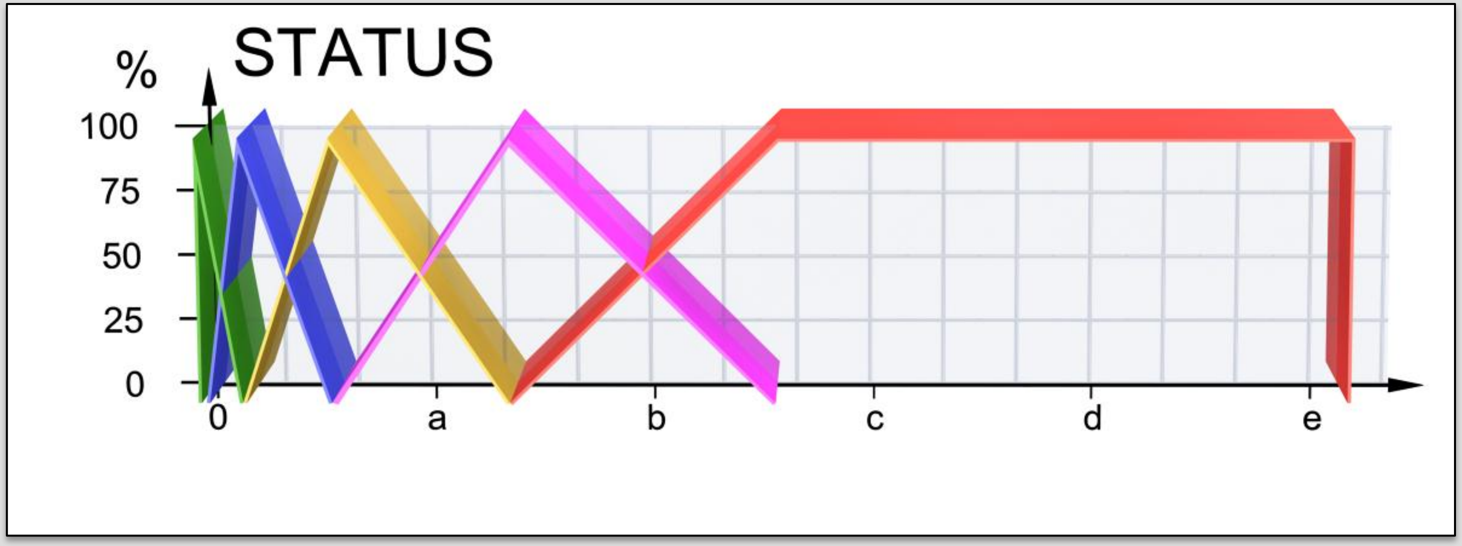
Structural investigation (Damage Classification)
Differentiated defect assessment - Fuzzy



Abolishment of the strict condition class limitations

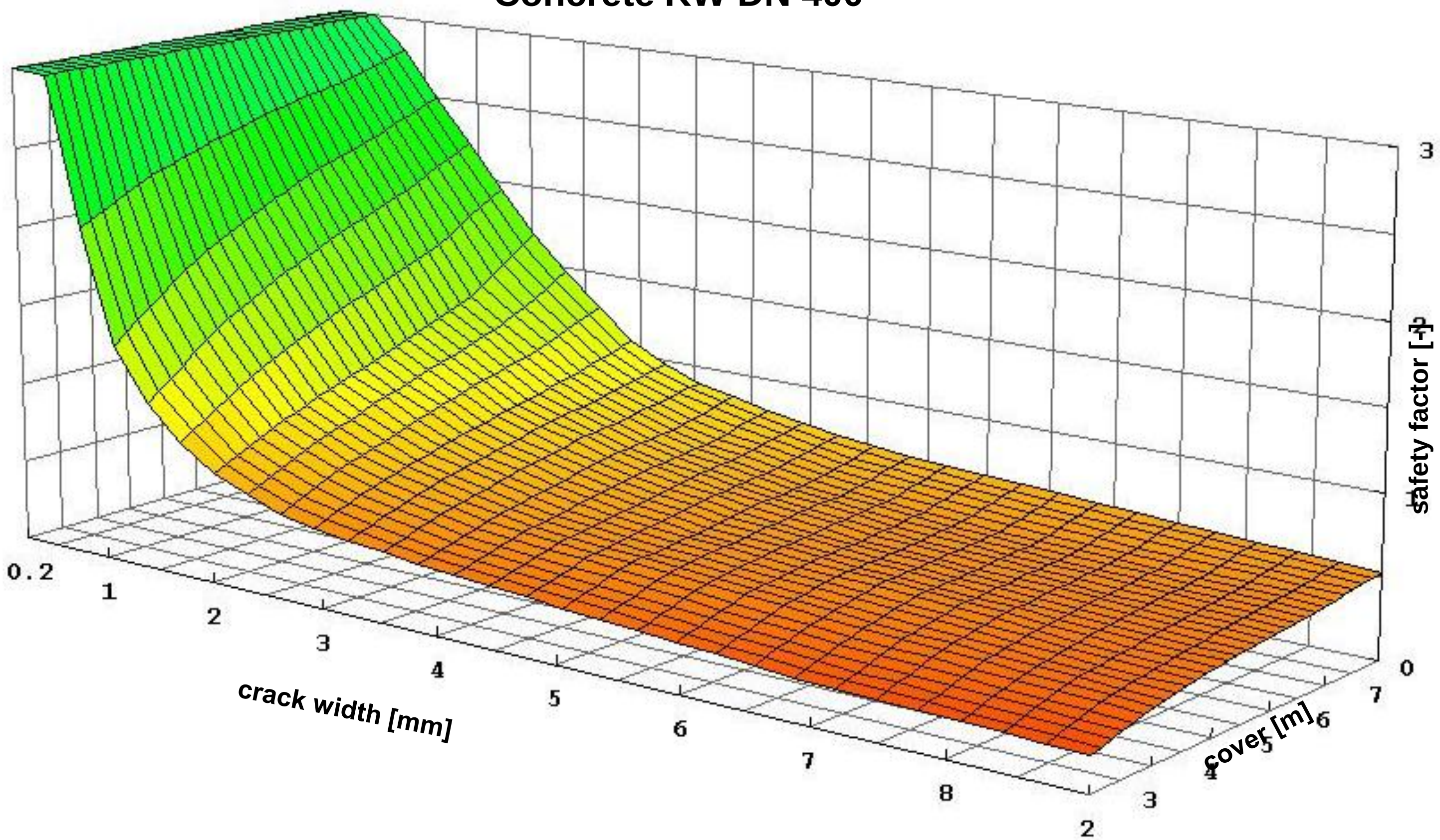
Differentiated defect assessment - Fuzzy
Abolishment of the strict condition class limitations





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

Concrete KW DN 400



Safety factor – depending on crack width and cover

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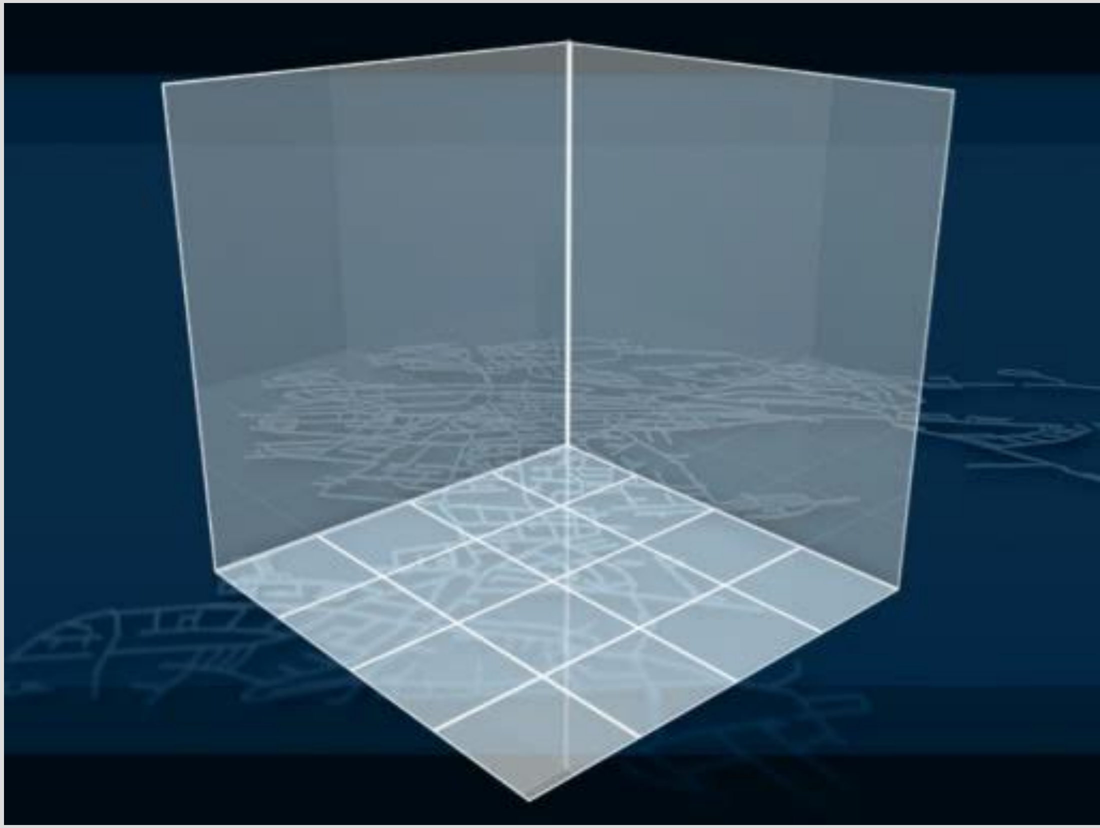
Differentiated defect assessment - Fuzzy
Abolishment of the strict condition class limitations

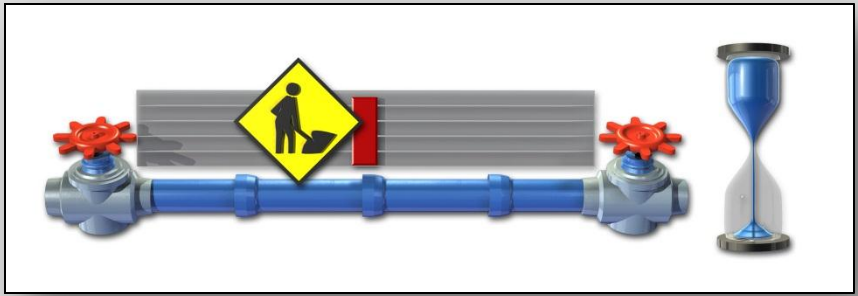
Including ancillary conditions into assessment (linked by fuzzy logic) gives the possibility to change to a risk-based (pro-active) approach

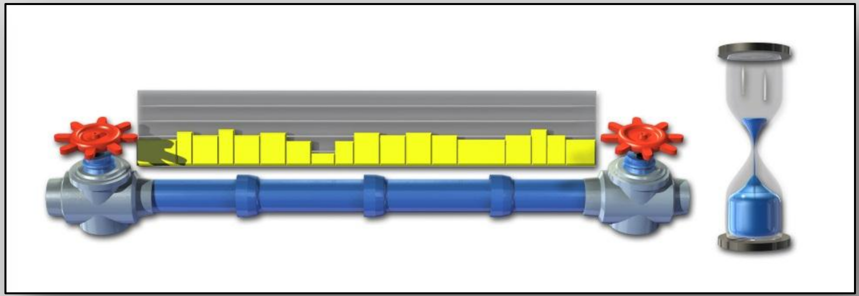


Structural investigation (Damage Classification)
Result – RISK REDUCTION

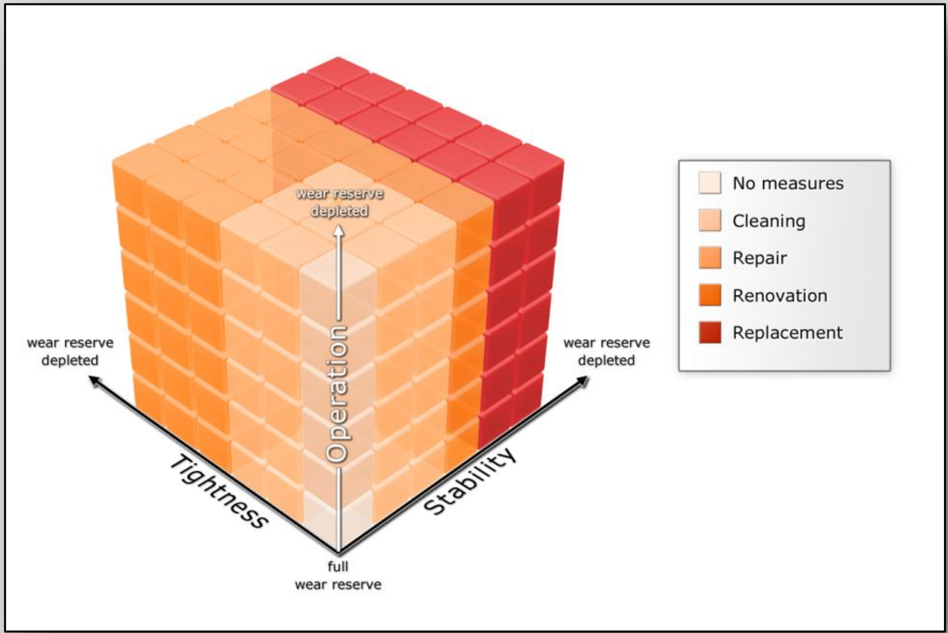
Differentiated Defect- and Section Assessment
Section Assessment

Condition (Priority)	Substance (Residual wear reserve)
Criterion for the present function fulfilment	Criterion for the remaining function fulfilment
⇒ Rehabilitation priority	⇒ Wear reserve/ remaining service life + Rehabilitation type
Consideration of the most severe single defect	Consideration of distribution, extent and degree of the defects





Differentiated Defect- and Section Assessment
Section Assessment

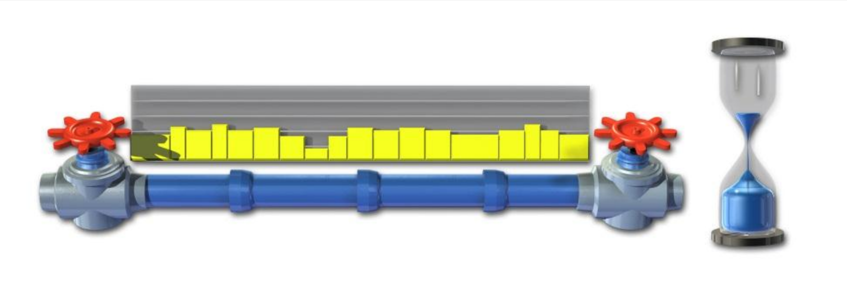


Substance (Residual wear reserve)

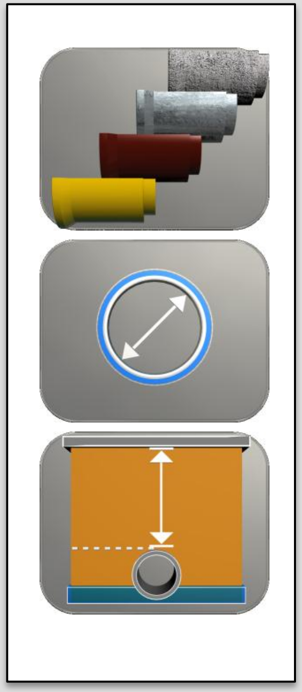
Criterion for the remaining function fulfilment

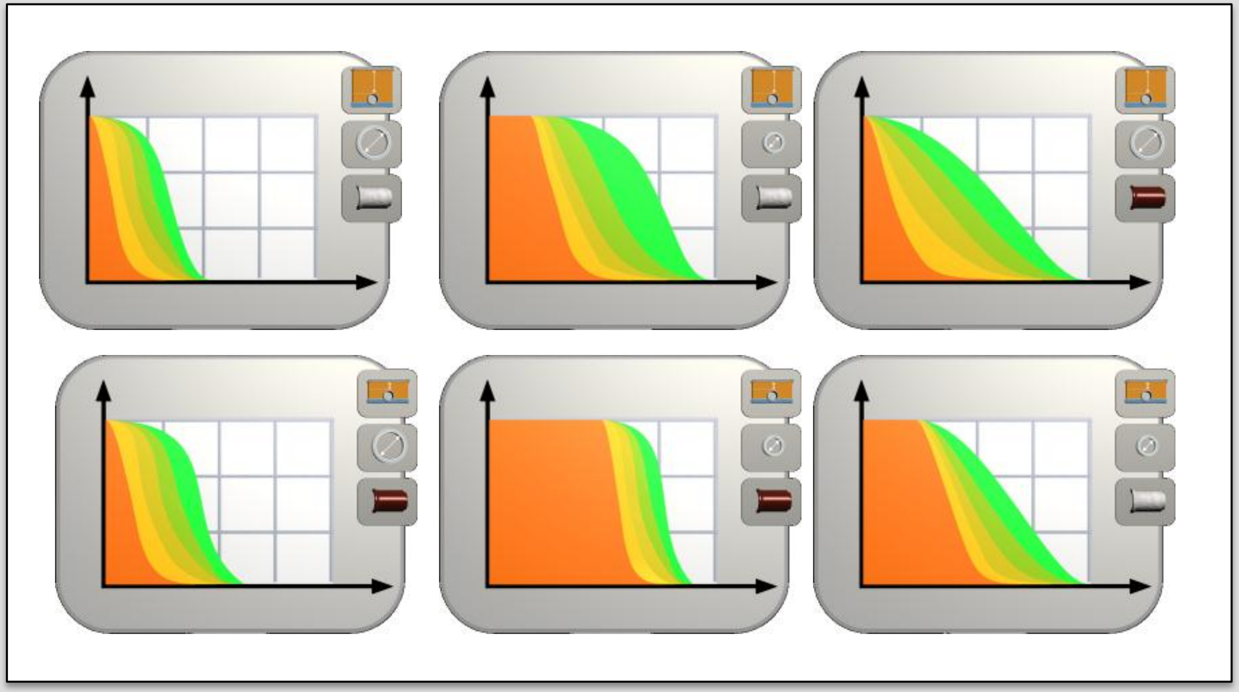
⇒ Wear reserve/ remaining service life + Rehabilitation type

Consideration of distribution, extent and degree of the defects



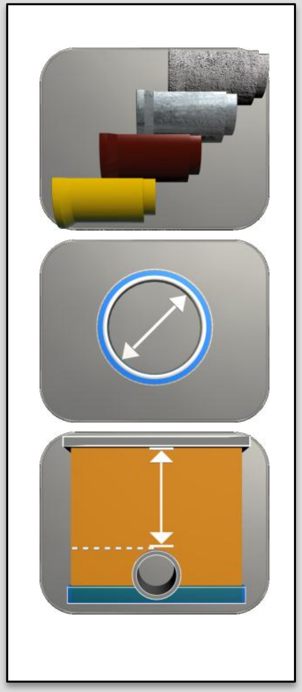
STATUS Water
Aging Models, Survival Functions and Forecast

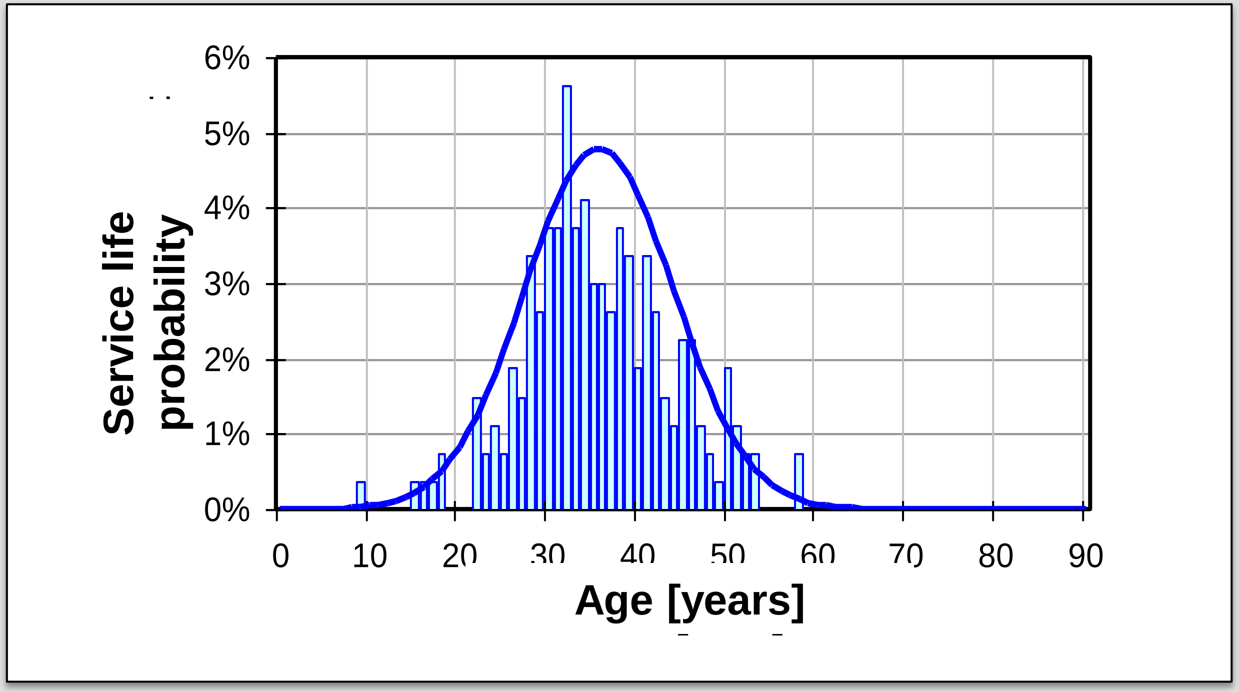




- Clustering of the network to determine of the survival functions

STATUS Water
Aging Models, Survival Functions and Forecast

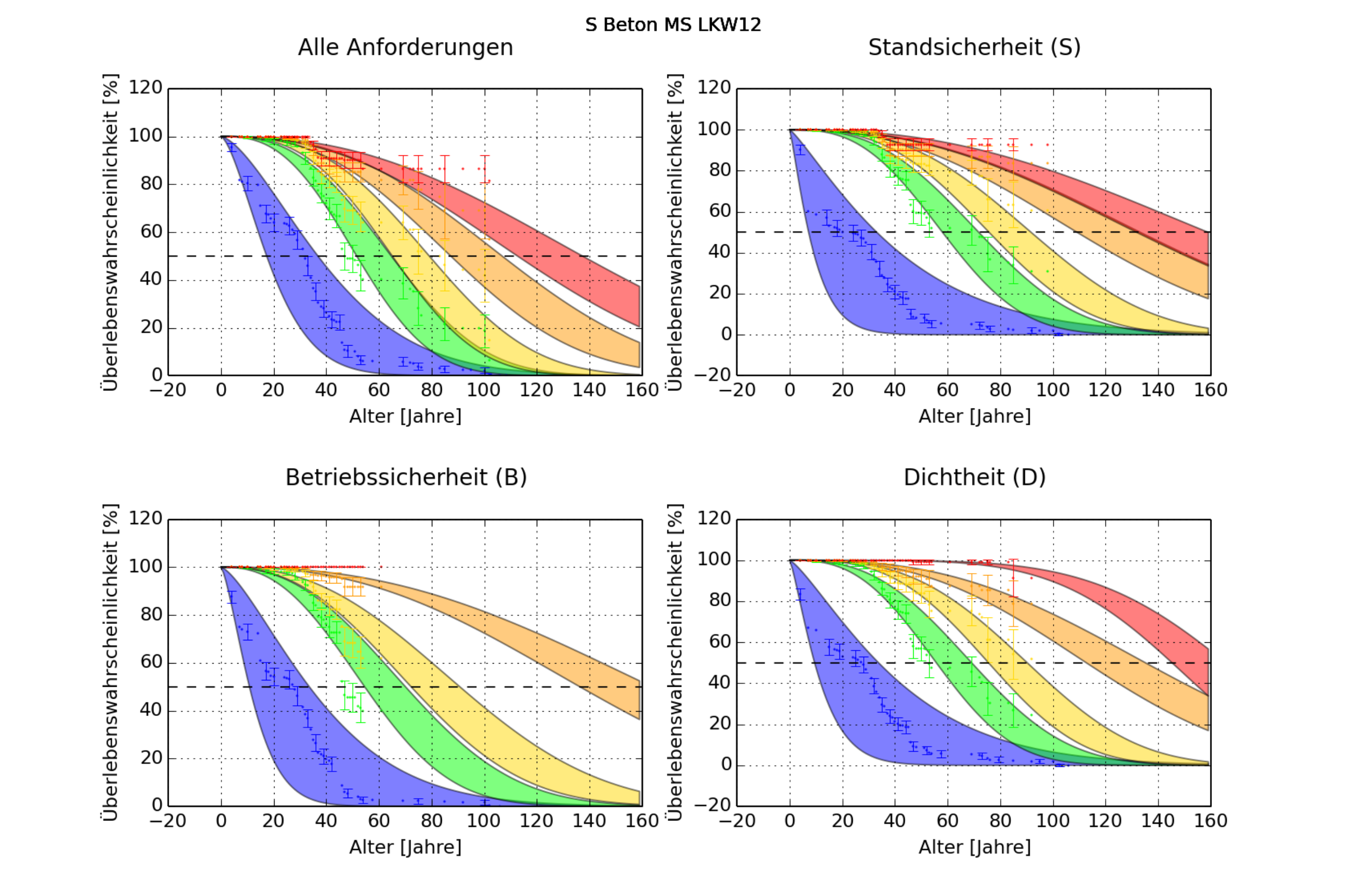




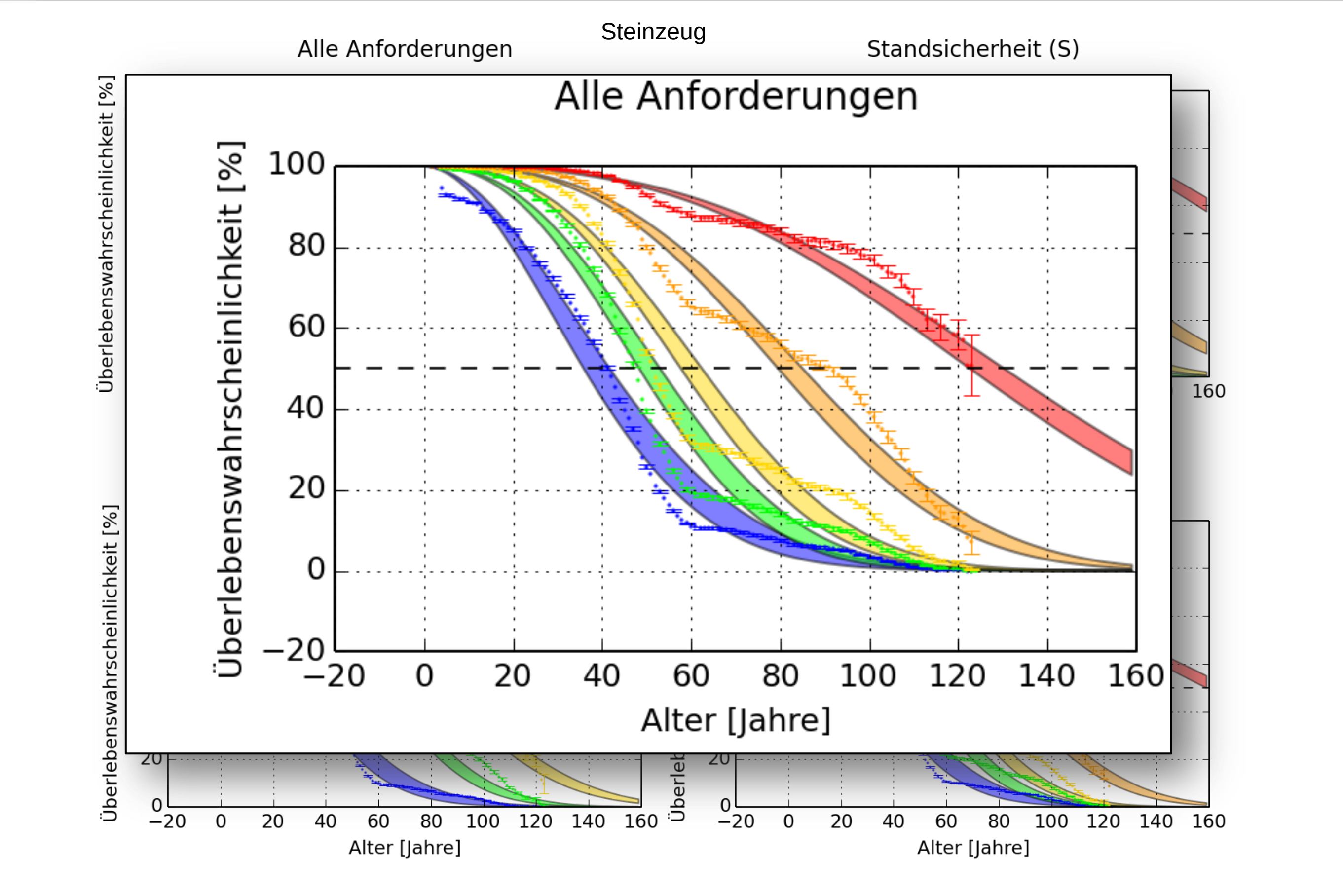
- Determination of the parameter for the Weibull distribution for the condition and substance classes according to the cluster attributes
- Determination of the survival functions for the related cluster as integral of the service life distribution

STATUS Water
Aging Models, Survival Functions and Forecast

Example of survival functions based on a "bad" cluster



STATUS Water
Aging Models, Survival Functions and Forecast



- Material is not sufficient as a criterion for describing a homogeneous cluster
- Comparison of two methods, including confidence intervals (95%)
- Many combination were examined

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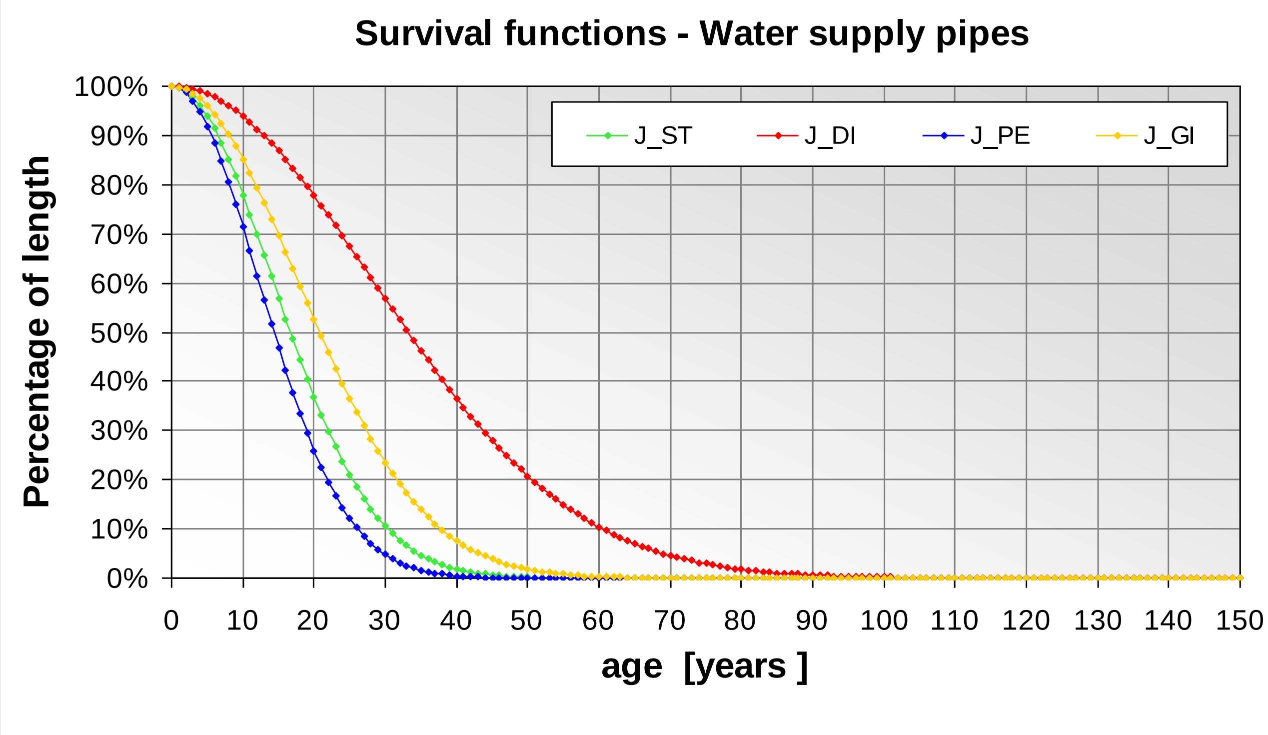
STATUS Water
Aging Models, Survival Functions and Forecast

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.

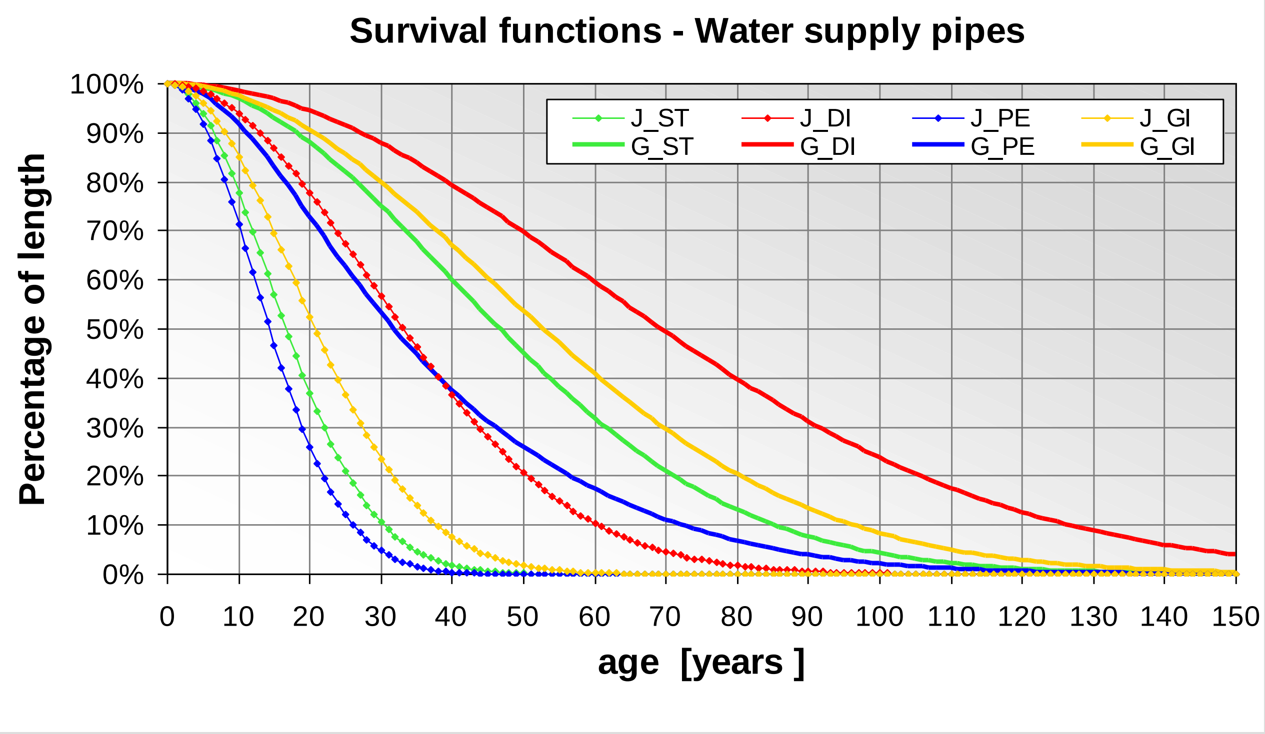


STATUS Water
Aging Models, Survival Functions and Forecast

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-continous water supply.



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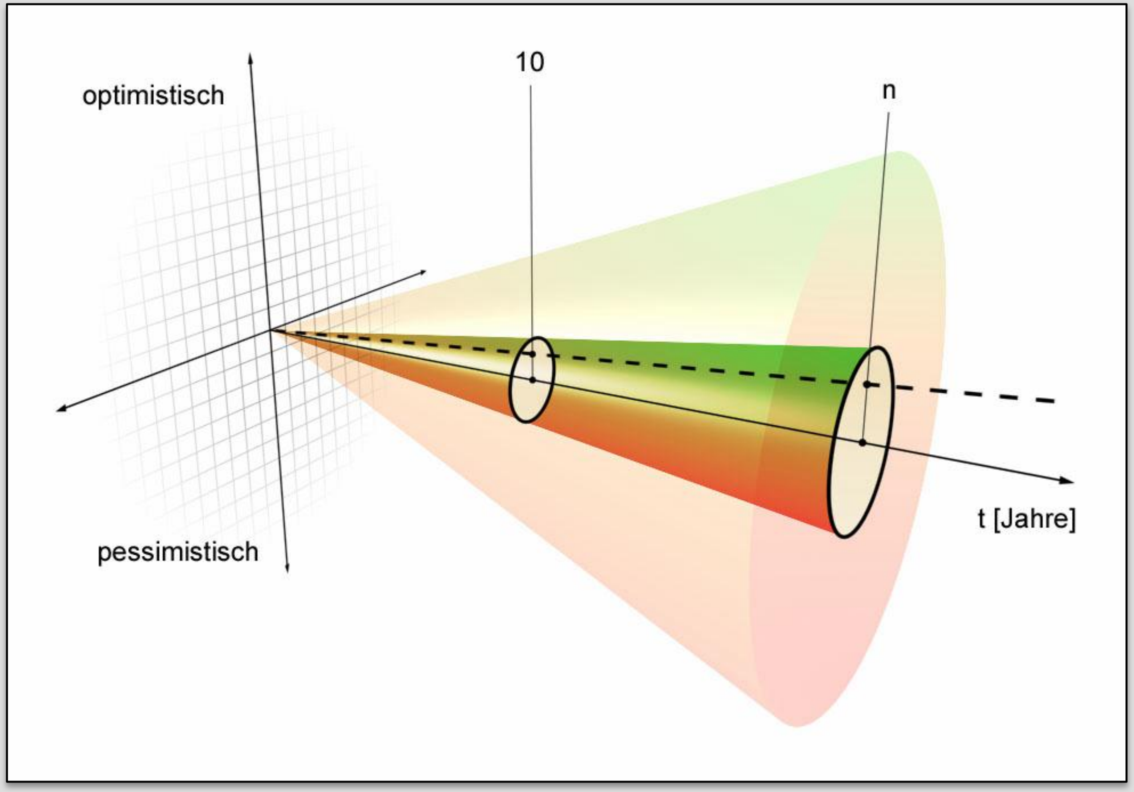
Strategy development and –analysis
Risk assessments for strategies

Maximum likelihood

- pessimistic
- optimistic
- Monte-Carlo Simulation

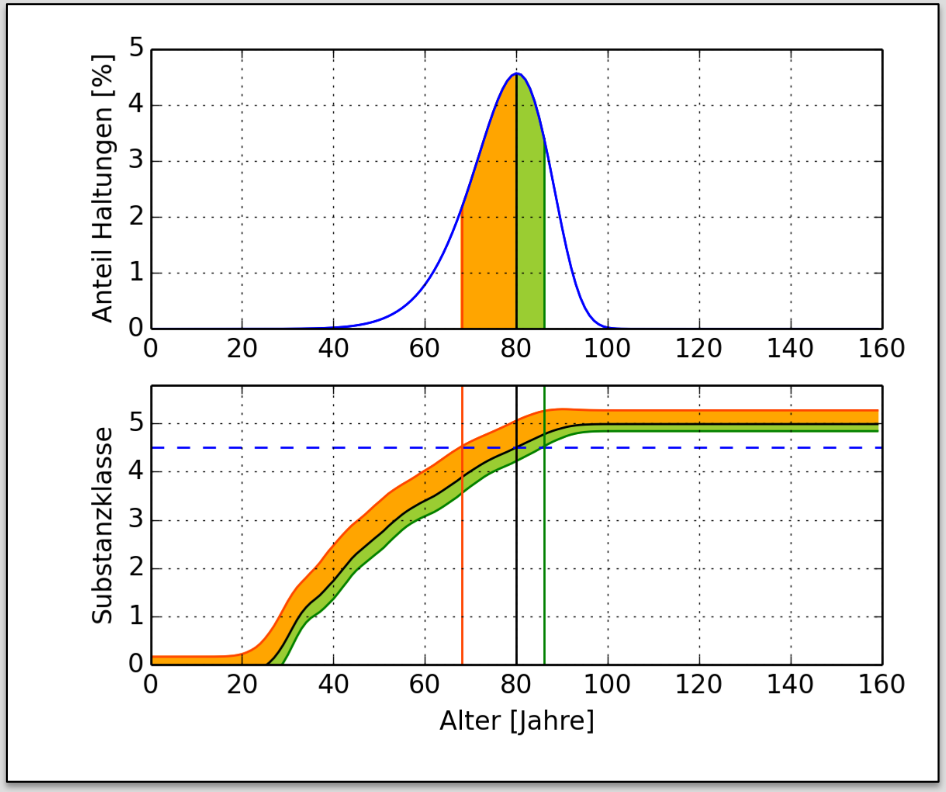


Strategy development and –analysis
Risk assessments for strategies

Risk assessments for strategies based on the aging behavior of a pipeline (eg a pipeline with typical service life of 80 years)?:

Maximum likelihood

- **pessimistic**
- **optimistic**
- **Monte-Carlo Simulation**



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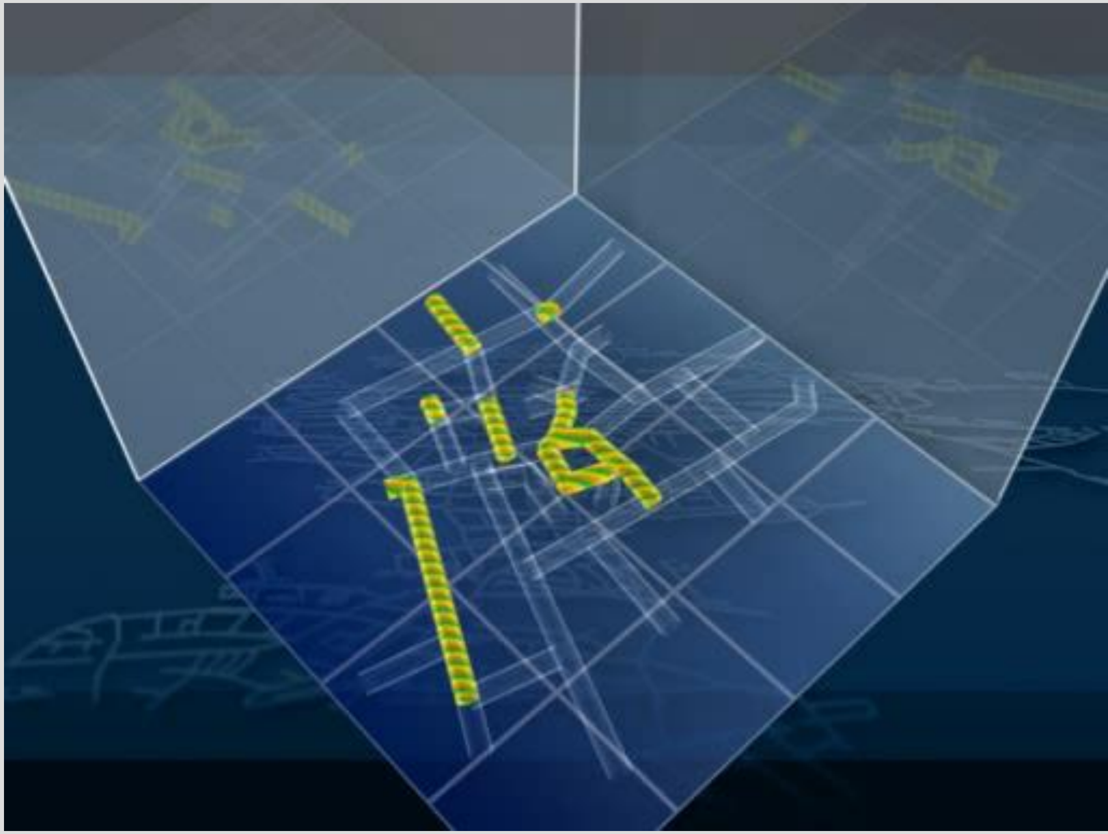
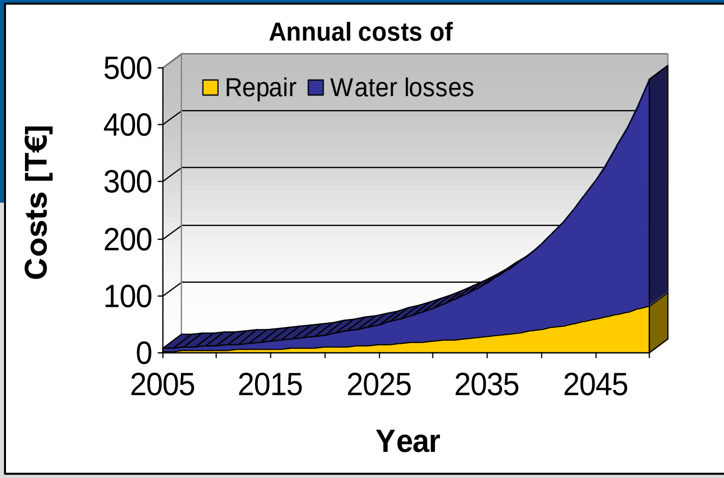
Strategy development and –analysis
Prediction of the future network development

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 …)

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

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

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Assessment of water distribution pipes
Pro-active rehabilitation management

Situation 2005

• Network failure rate	0.5	failures per km
• Network leakage rate	0.5	m^3 per km and hour
• Deterioration rate	2%	per year
• Replacement cost	54,000	€ per km
• Relining cost	28,000	€ per km
• Repair cost	350	€ per failure
• Variable part ofwater price	0.052	€ per m^3
• Inflation rate of water price	8%	per year
water work	5%	per year

Strategy A

- 100 % replacement
- Linear increase of rehab rate from 0.2 (2005) to 1.0 (2020)
- Rehab needs beyond 2020 as forecast

Strategy B

- 1/3 replacement / 2/3 relining
- Linear increase of rehab rate from 0.3 (2005) to 1.5 (2020)
- Rehab needs beyond 2020 as forecast

Assessment of water distribution pipes
Pro-active rehabilitation management

Decision criteria	Strategy A		Strategy B	
Relative to 2005	**2020**	**2050**	**2020**	**2050**
Network share rehabilitated	**9%**	**54%**	**13.5%**	**58%**
Average age	**+11 yrs.**	**+4 yrs.**	**+9 yrs.**	**+3 yrs.**
Average residual service life	**-2 yrs.**	**+30 yrs.**	**-4 yrs.**	**+5 yrs.**
Reduction of failure rate	**4%**	**70%**	**4%**	**46%**
Reduction of leakage rate	**4%**	**70%**	**19%**	**75%**
Years to break even	**29**		**19**	
Internal rate of return	**7 %**		**11 %**	
Best strategy	**??**		**??**	

Thank you for attention!