Planning of operation and maintenance using risk and reliability based methods

Mihai Florian, John Dalsgaard Sørensen
Aalborg University, Denmark

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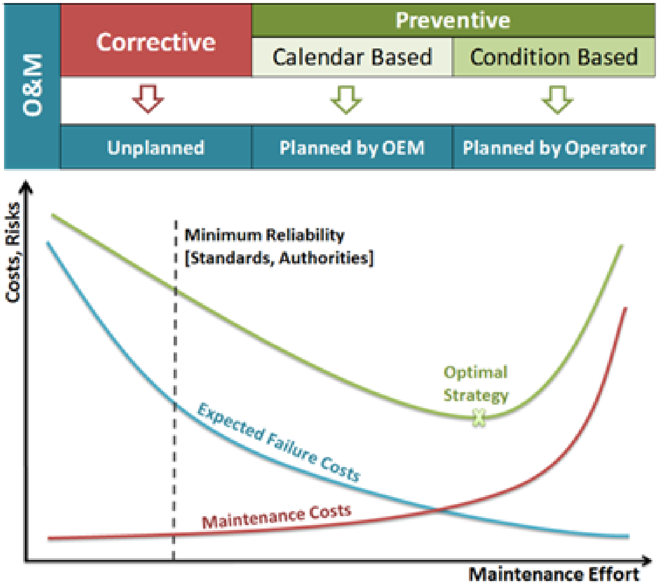
Introduction - O&M in offshore wind farms

Corrective maintenance

Run-to-failure

Preventive maintenance

- Time/condition based
- Risk-based inspections



Risk-based techniques can be used for optimal planning of

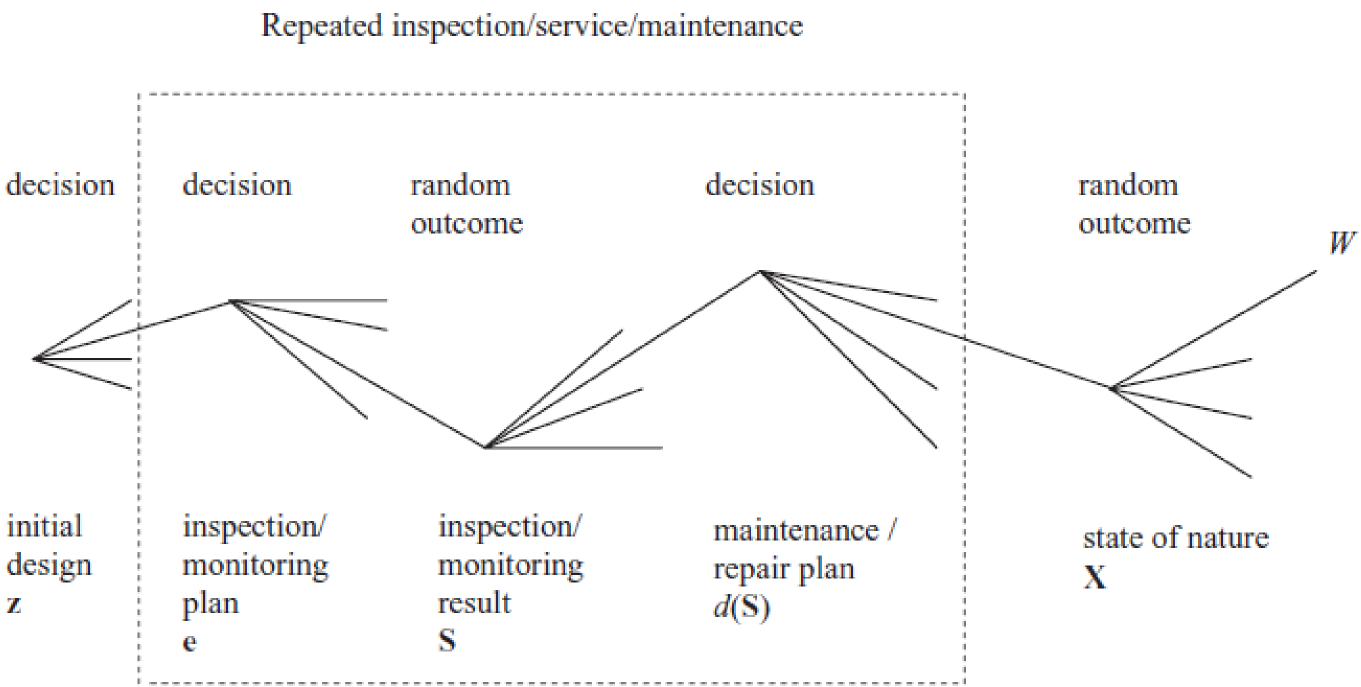
- future inspections / monitoring (time / type)
- decisions on maintenance/repair on basis of (unknown) observations from future inspections / monitoring

taking into account uncertainty and costs

Successful application in offshore oil & gas

Particular applicability to wind farms – low safety restraints

Theoretical basis –
Bayesian preposterior decision theory



- Decision rule $d(s)$
- Reliability modeling

Theoretical basis – Reliability modeling

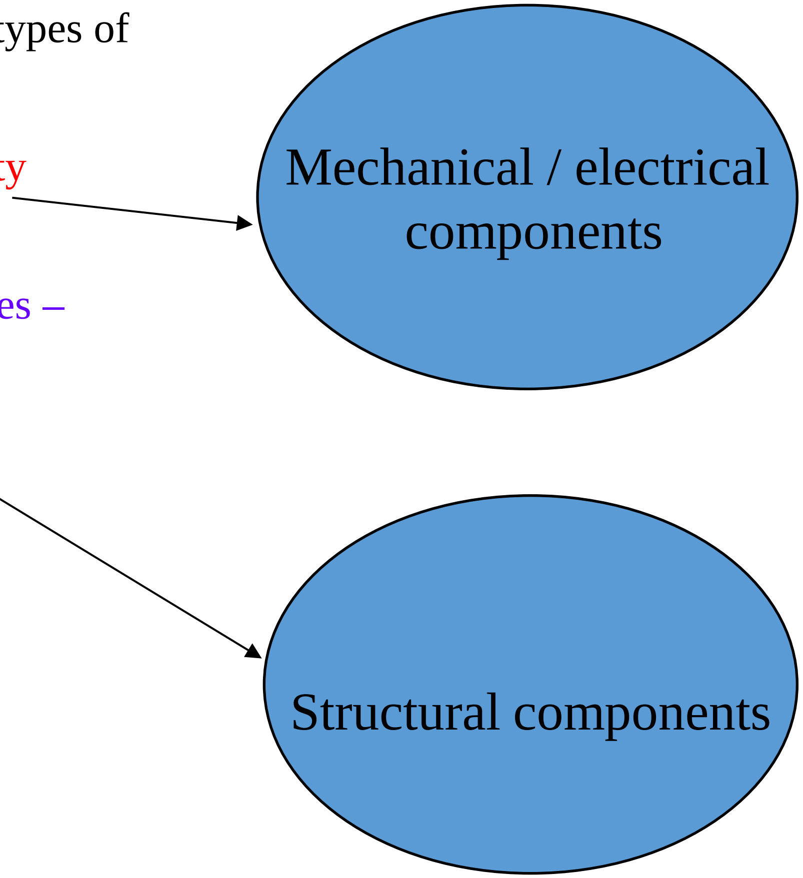
Analysis of failure probabilities based on different types of information:

- Observed failure rates – Classical reliability theory

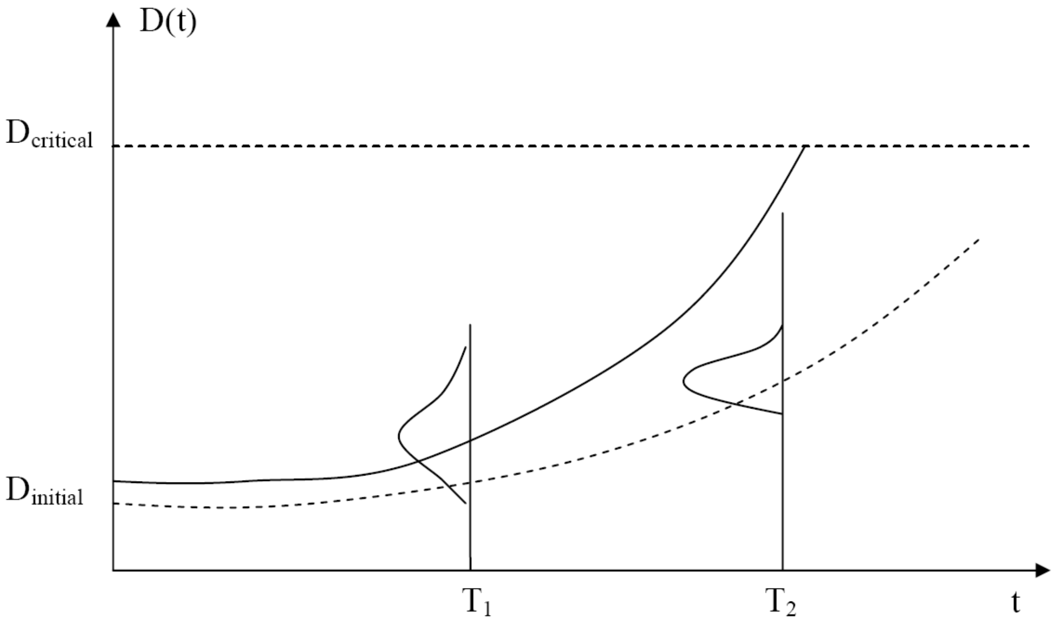
- Probabilistic models for failure probabilities –

  Structural Reliability Theory:

  Limit state modeling & FORM / SORM / simulation



Theoretical basis – Damage modeling



- Corrosion
- Erosion
- Fatigue
- Wear
- Etc.

Deterioration – damage accumulation:

- Deterioration processes are connected with significant uncertainty
- Observations of the actual deterioration / condition by monitoring or inspections can be introduced in the models and significantly improve the precision of forecasts

Life cycle model

Simplified life cycle model – wind turbine is represented by a single component blade/welded detail

Modules

- Environment
  - wind/wave time series
- Component health
  - damage and reliability models for blade/welded details
- Maintenance strategy
  - inspection scheduling
  - decision criteria for repair
- Access to wind turbine
  - weather limitations for vessels

Example applications

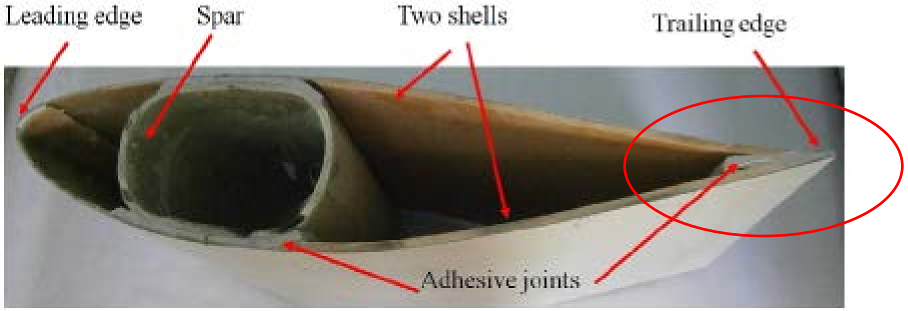
Inspection planning for wind turbine blades

- Condition based
- Risk based
- Minimise life cycle cost
- What is the impact on overall cost?

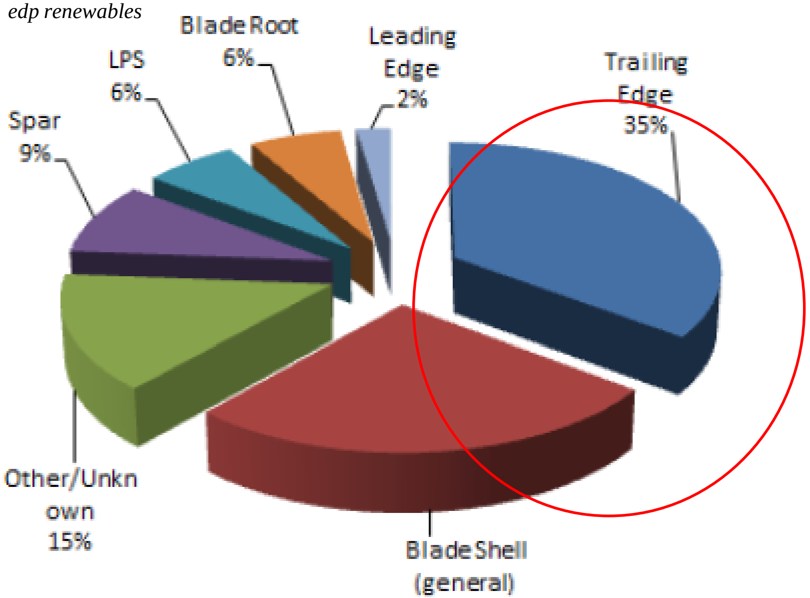
Design of welded steel details

- Reducing safety factors – reduced material consumption
- Regular inspections – maintain reliability levels
- What is the impact on overall cost?

Inspection planning for wind turbine blades



S. Ataya, M.M.Z. Ahmed / Engineering Failure Analysis 35 (2013) 480–488

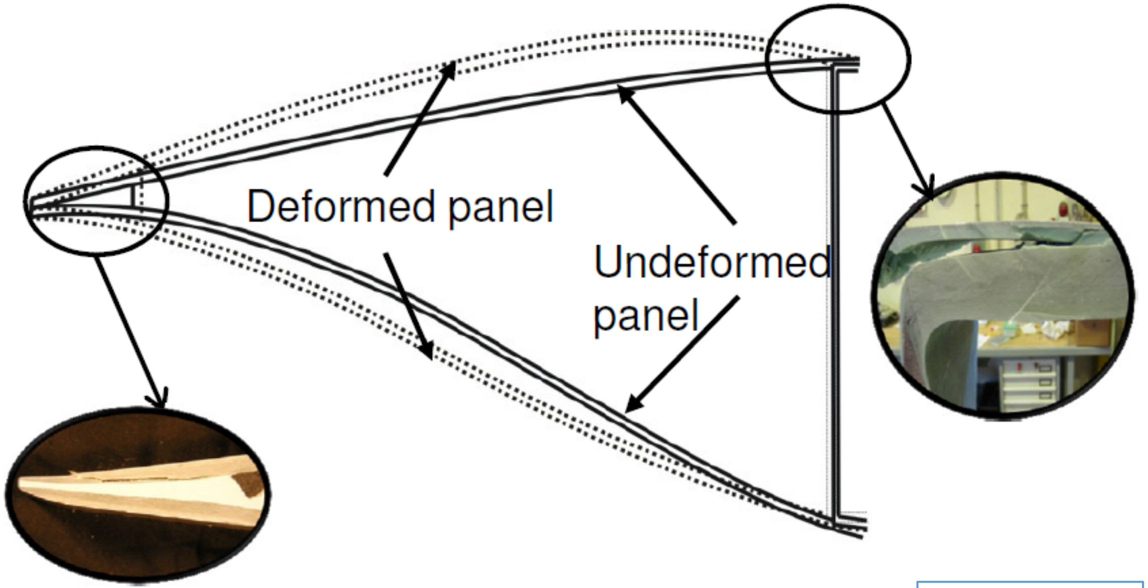


Failure modes

- Shells
  - erosion
  - delamination
  - cracking
- Cracking on main spar
- Debonding of glue joints
- Random (lightning) or unknown

Inspection planning for wind turbine blades

Initial cracking → Development → Failure



Bladena, 2014

Inspection planning for wind turbine blades

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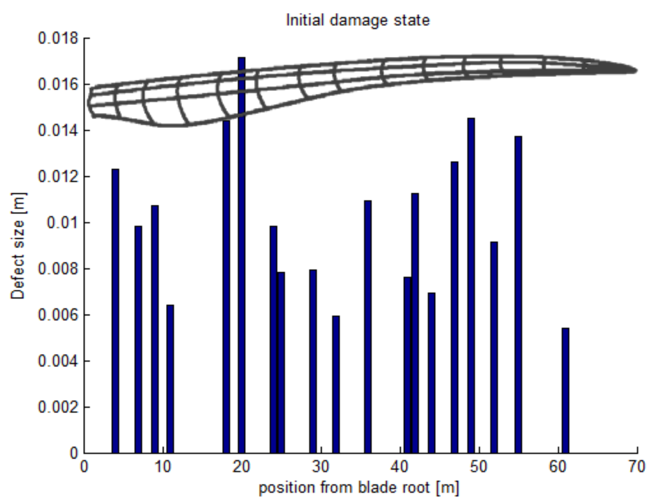
Initial cracking → Development → Failure

- cracks generated at random locations on trailing edge blondline
- size of cracks generated using lognormal distribution



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Inspection planning for wind turbine blades

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Initial cracking → Development → Failure

Fracture mechanics approach

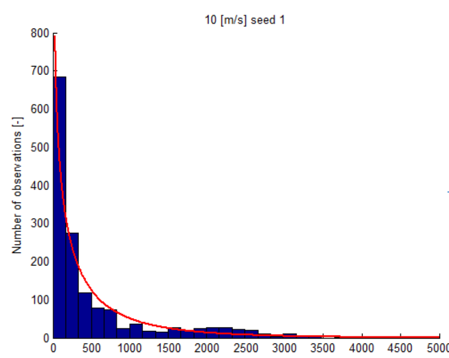
$$\frac{da}{dt} = \frac{A(\Delta K)^m}{(1-R)^{m(1-\lambda_w)}}$$

material parameters

stress intensity factor

- simulations on NREL 5MW turbine
- determine stress distribution for operational wind speeds

→ Aero-elastic simulations (FAST/TURBSIM) →



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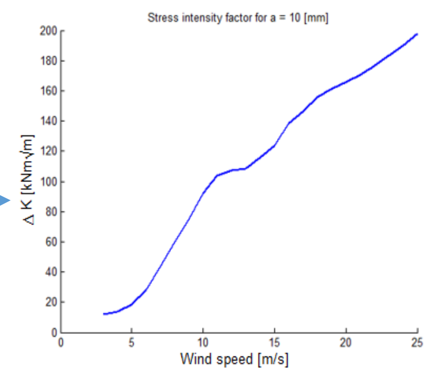
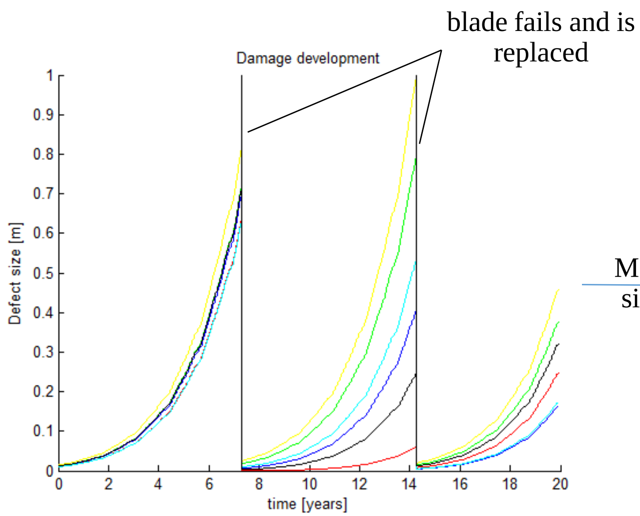
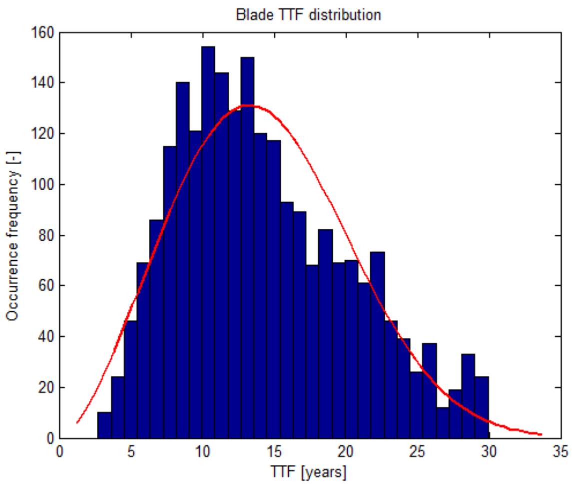


Inspection planning for wind turbine blades

Initial cracking → Development → Failure



Monte Carlo simulations



- failure limit modeled as stochastic variable
- failure limit and material parameters calibrated to fit observed failure frequencies

Optimisation study

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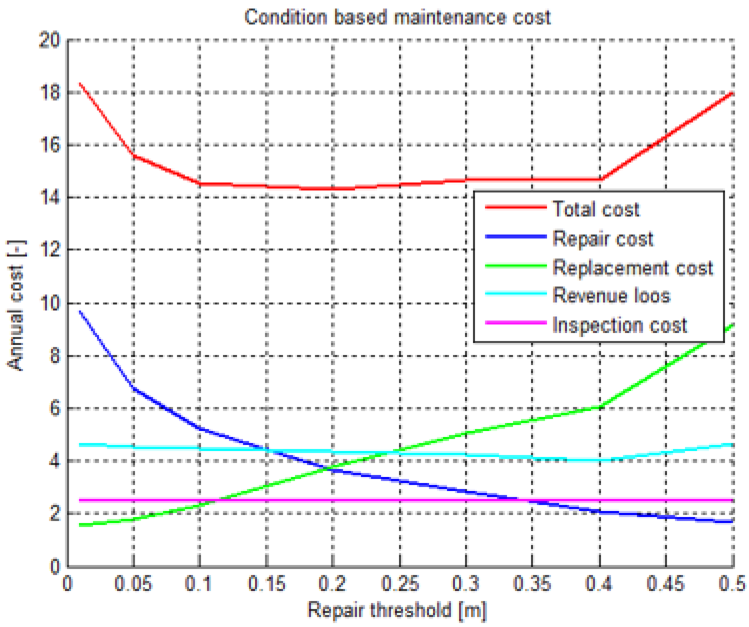
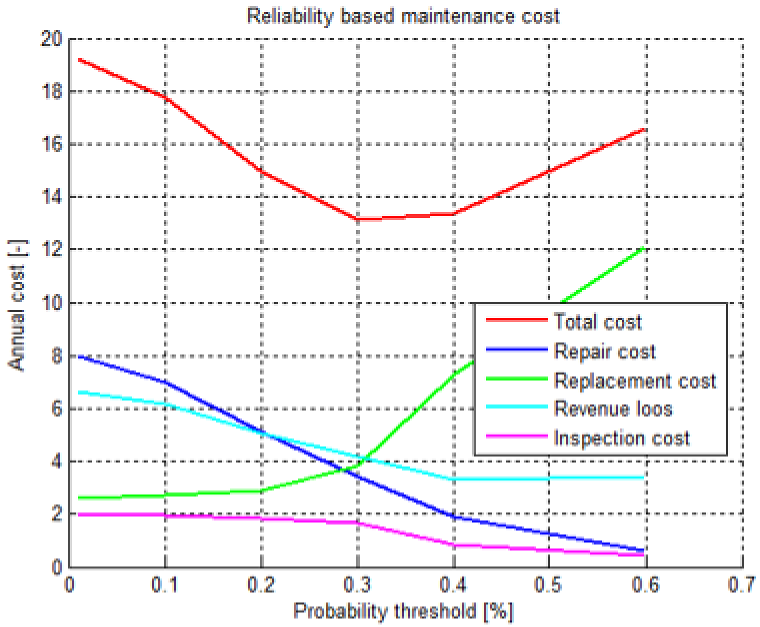
Fixed inspection interval 2 years

Decision criteria - damage threshold

- failure probability





Lower overall cost from risk optmisation

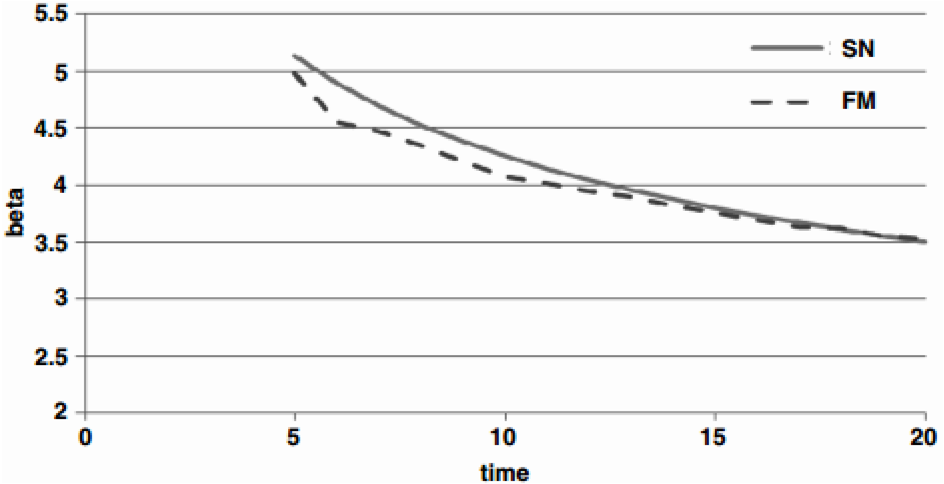
Example 2 - welded detail

Design of welded steel details accounting for inspections

- Reducing safety factors – reduced material consumption
- Regular inspections – maintain reliability levels
- What is the impact on overall cost?

Damage model

- 1 dimensional fracture mechanics model based on *
- Material parameters calibrated to fit * reliability estimates



Sørensen JD, 2012

*Sørensen JD. Reliability-Based Calibration of Fatigue Safety Factors for Offshore Wind Turbines

Safety factor reduction

Required inspection plan determined in [Sørensen JD, 2012]

γ_m [-]	Inspection interval [years]
1.00	5
1.05	5
1.10	10
1.15	10
1.20	10
1.25	10

Life cycle model used to estimate overall cost for "repair on detect policy"

$$C(\gamma_m) = C_c \cdot \gamma_m + n_i \cdot C_i + E[n_r] \cdot C_r$$

Inspection cost is expressed as [%] of capital cost

Cost of repair is fixed at 4 times cost of inspection

Safety factor reduction

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Overall cost

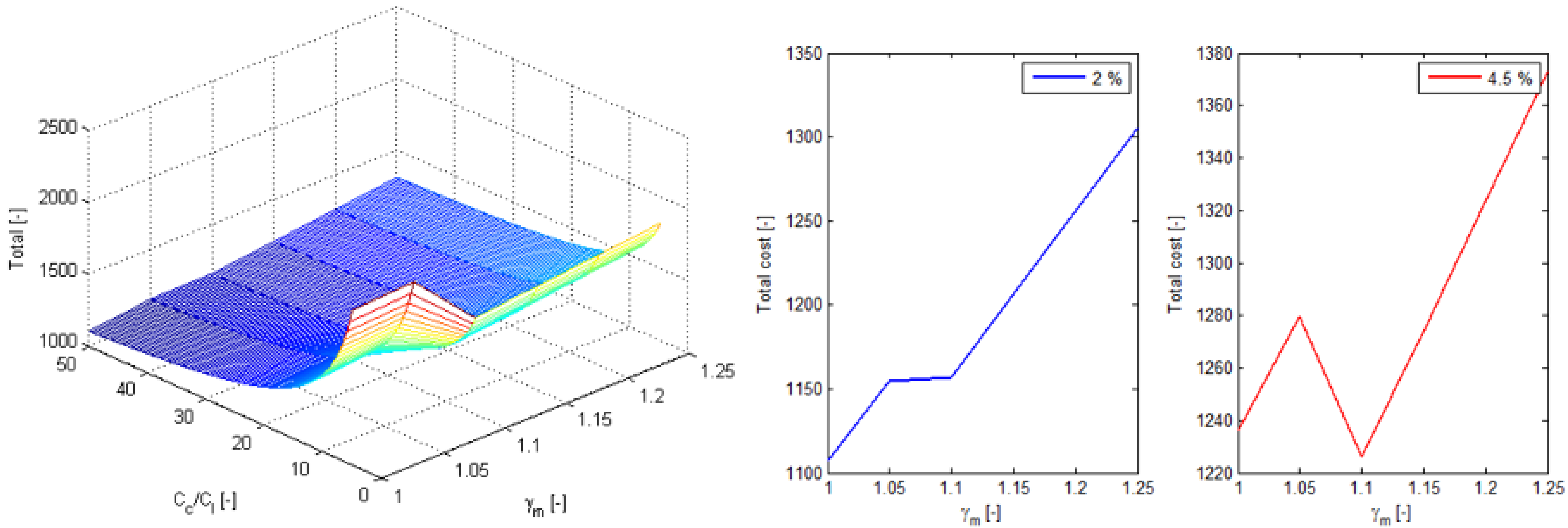

Fig.6. (a) Total lifetime cost - surface (b) Total lifetime cost - sections

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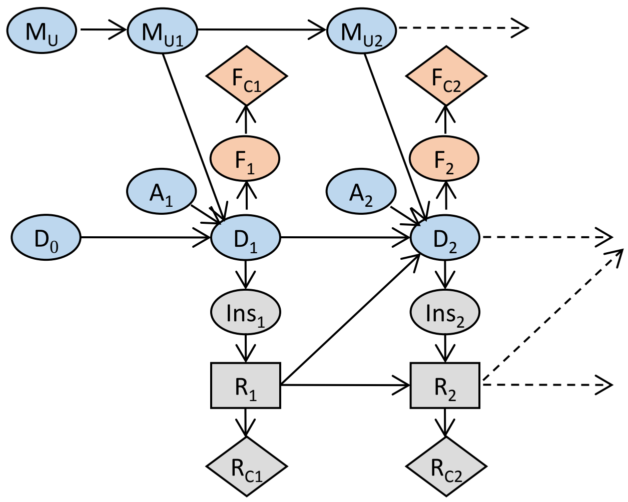
Conclusions

- Potential for lowered lifetime O&M cost through risk-based inspection planning
- Potential for lowered safety factors through risk-based inspection planning
- Two applications presented by illustrative examples

Future work

- More examples to be developed
- System aspects
- Applications of Bayesian networks tools are being investigated
- Applications using NORCOWE reference wind farm



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Thank you for your attention!