TRUSS ITN

Workshop

CERI, UCD, Dublin

Wednesday 29th August 2018

On the effectiveness and uncertainty of inspection methods for fatigue crack management

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Lloyd's Register

UCD DUBLIN

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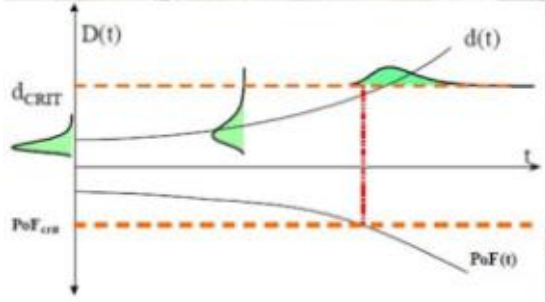
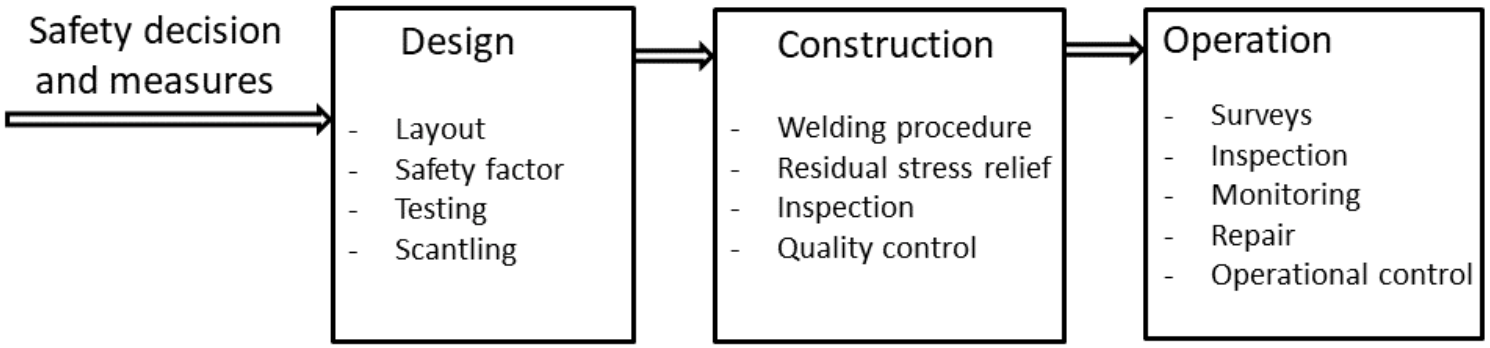
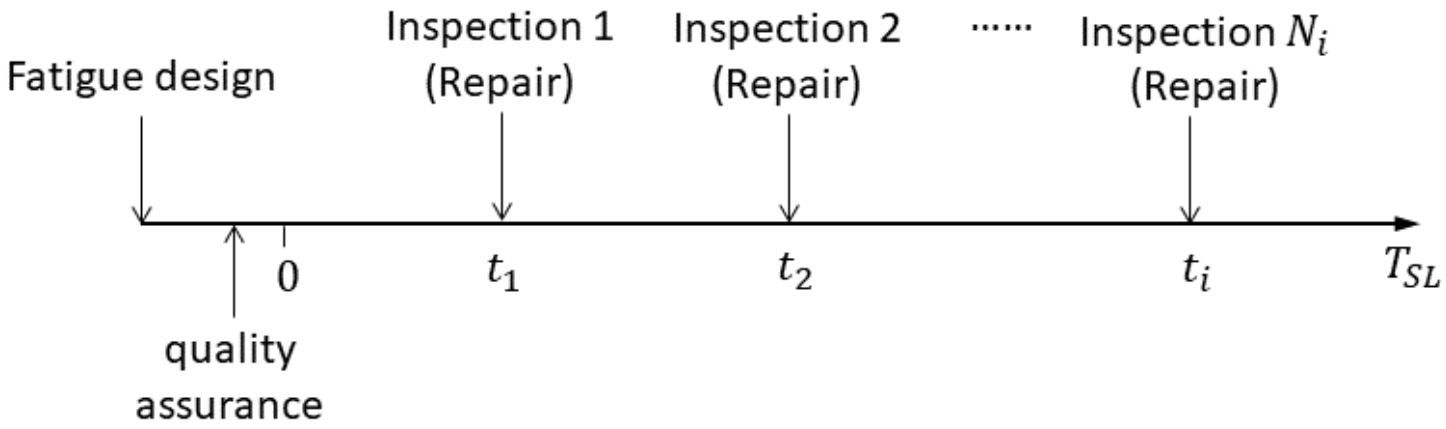
Fatigue cracks & failures

- Hot-spot areas
- Consequences
- Operational safety
- Uncertainties
- Life cycle costs

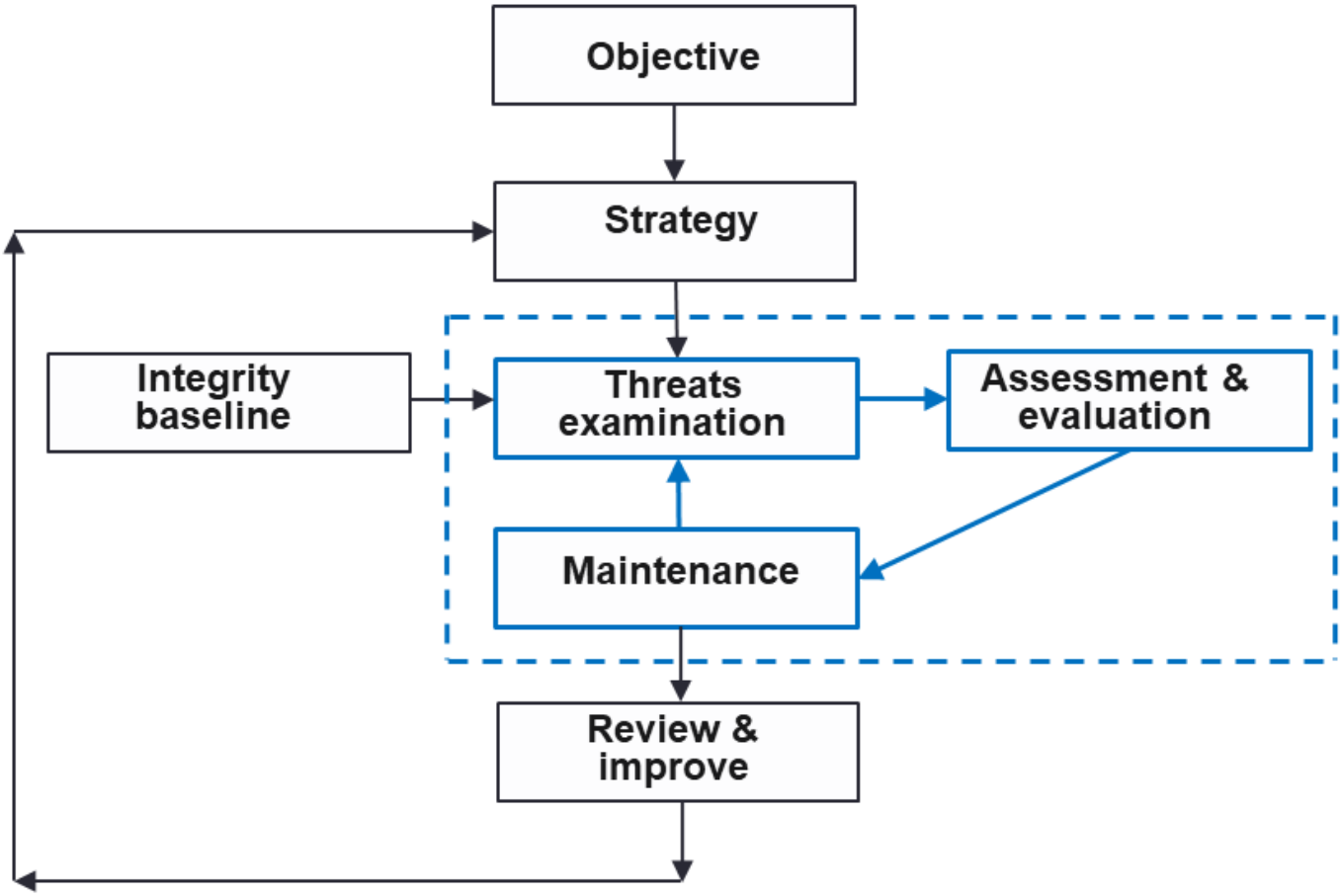


Engineering decisions against fatigue





Structural integrity management



Probabilistic maintenance optimization

Inputs
- Select structural detail and S-N curve
- Required service life
- Fatigue crack growth model and associated parameters
- Critical crack size
- Inspection method and the associated PoD function
- Repair method and model for repair effect
- The number of interventions
- Probabilistic models for variables
- Number of samples for variables

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Probabilistic crack growth modelling
- Simulate random variables for crack growth model
- Compute crack sizes

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Reliability-based maintenance optimization

Objective
- Maximize lifetime fatigue reliability

Constraints
- $\Delta t_i \geq 0.5\,\text{year}$

With respect to
- Repair criterion
- Inspection times

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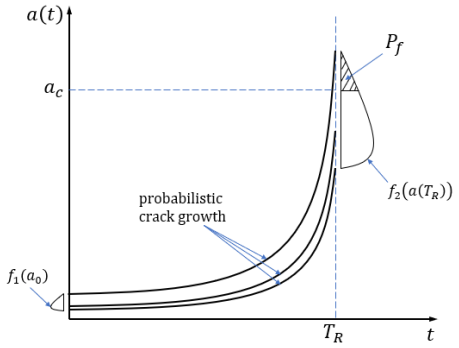
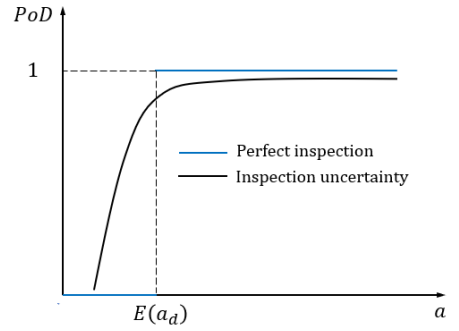
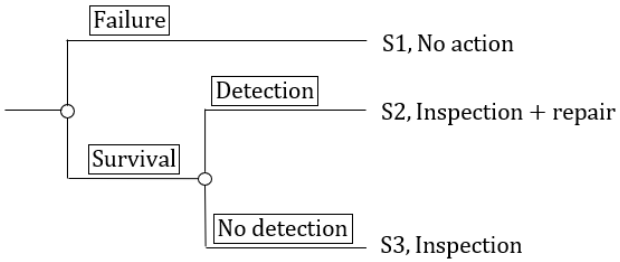
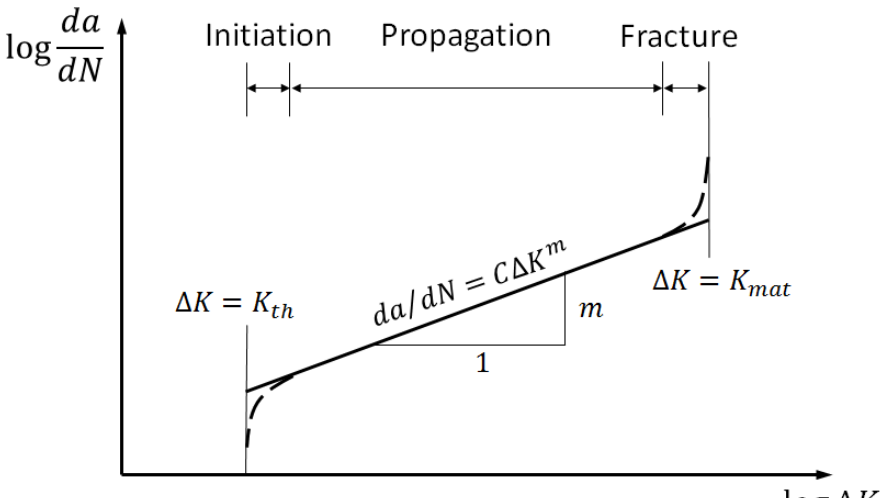
Reliability-based optimum maintenance plans

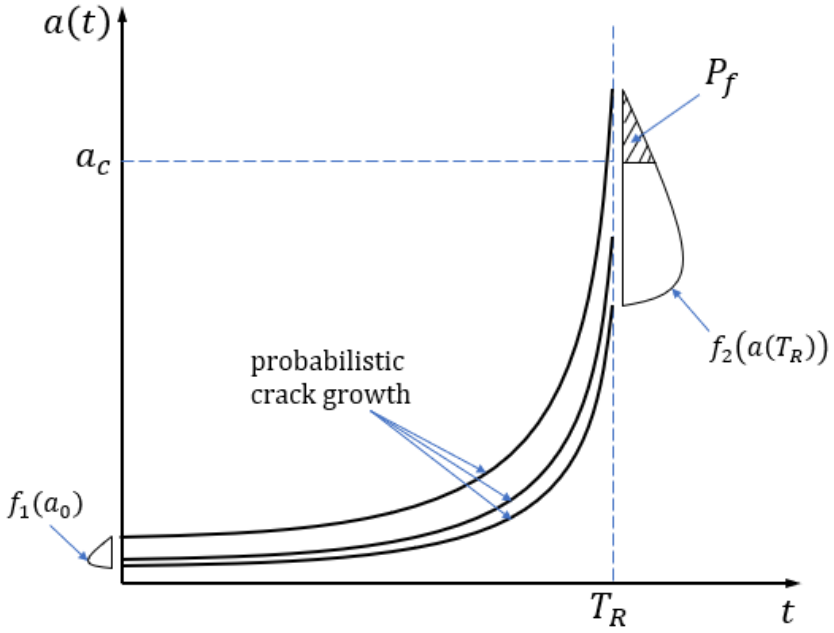






Probabilistic physical model





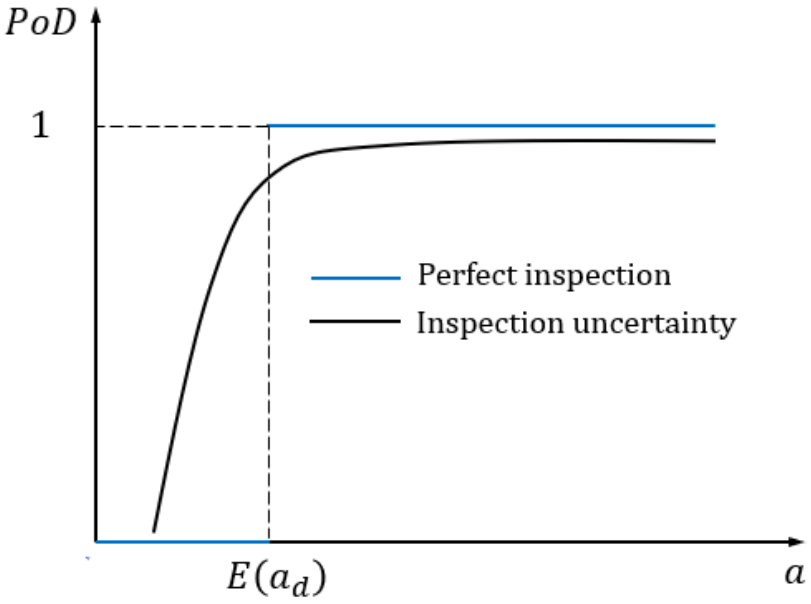
$$\frac{da}{dN} = C\Delta K^m, \Delta K_{th} \leq \Delta K \leq K_{mat}$$

$$N_P = \frac{1}{\pi^{m/2} C \Delta\sigma^m} \int_{a_0}^{a_c} \frac{da}{a^{m/2} Y(a)^m}$$

$$\Delta K = \Delta\sigma Y(a)\sqrt{\pi a}$$

$$\Delta a(t) = \pi^{m/2} C \Delta\sigma^m \int_0^{N(t)} a^{m/2} Y(a)^m dN$$

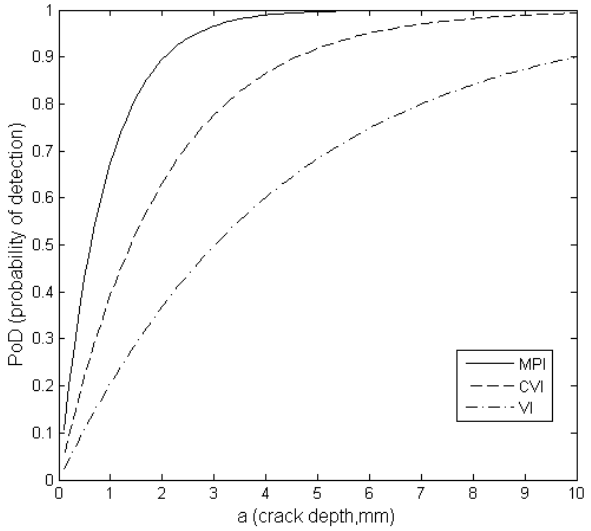
Probabilistic inspection modelling



- Crack characteristics
- Instrumentation reliability
- The environments
- Inspection procedure
- Human factors

$$PoD(a) = F(a) = 1 - \exp(-a/E(a_d))$$

$$PoD(a) = \begin{cases} 0 & a < E(a_d) \\ 1 & a \geq E(a_d) \end{cases}$$

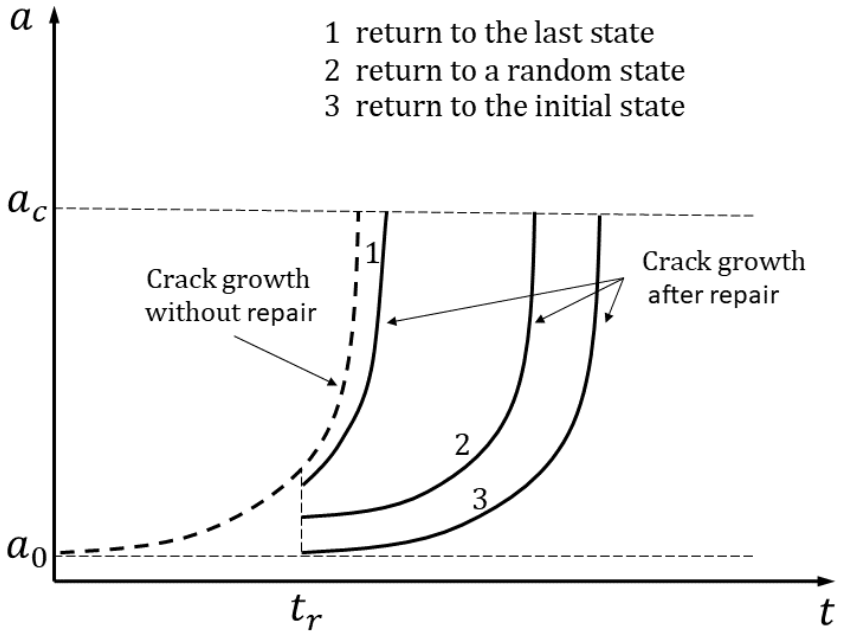


Maintenance strategy and repair effect

- The time, criterion or condition to carry out repair?
- In case of repair, what's the repair effect on a structural details?

- Drilling a stop hole
- Welding
- Welding plus post-weld treatment
- Replacement
- Grinding

- Damage size
- Deterioration rate
- Fatigue resistance
- Failure probability



Formulation of fatigue reliability

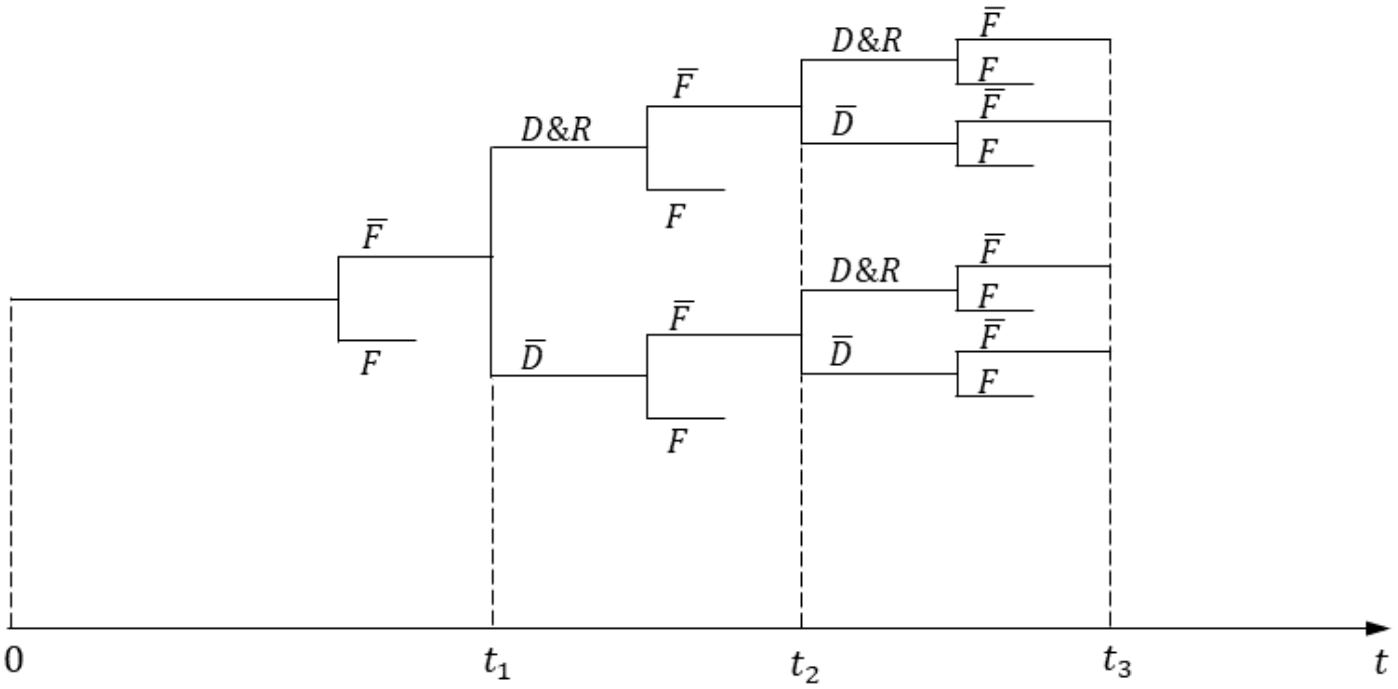
$$M(t) = a_c - a(t)$$

$$P_f(t) = P(M(t) < 0)$$

$$\beta(t) = -\Phi^{-1}\left(P_f(t)\right)$$

$$P'_f(t_i) = \sum_{b=1}^{N_b} P_b \cdot P_{f|b}$$

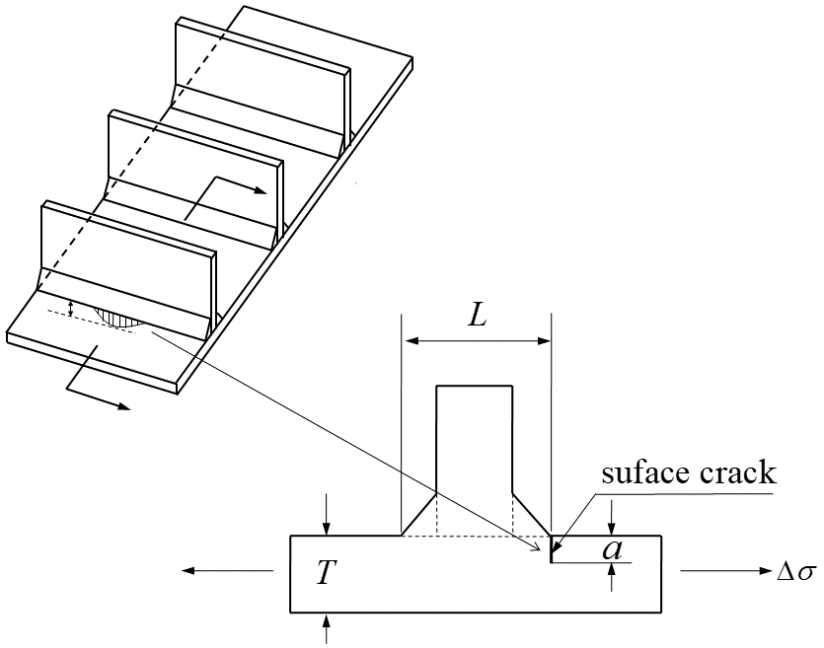
$$\beta'(t_i) = -\Phi^{-1}\left(P'_f(t_i)\right)$$



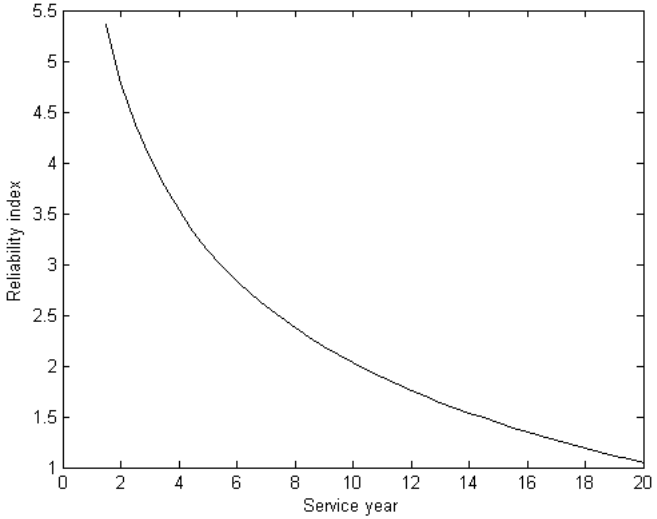
An illustrative example

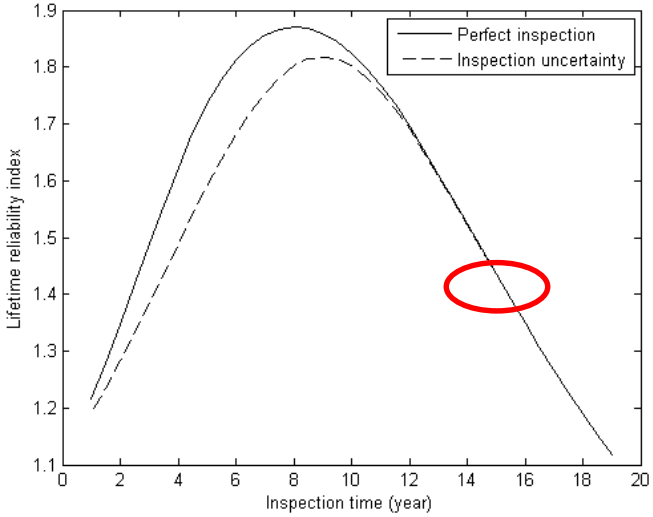
Parameter	Unit	Value
T_R	Year	20
N_0	Cycle	5×10^6
$\log_{10} \overline{a_1}$	[N, mm]	11.855
$\log_{10} \overline{a_2}$	[N, mm]	15.091
T	mm	25
$\Delta\sigma_e$	MPa	17.28
m_1	-	3
m_2	-	5

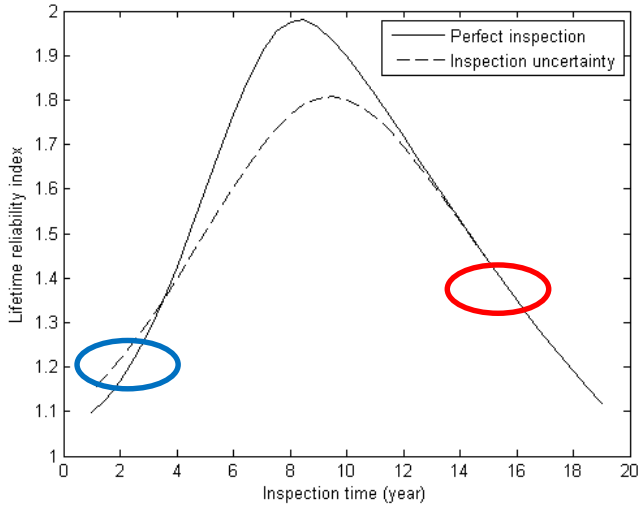
Variable	Distribution	Unit	Mean	SD
a_0	Exponential	mm	0.50	0.50
$\log_{10} C$	Normal	[N, mm]	-12.74	0.11
B	Normal	-	1.00	0.30
a_d	Exponential	mm	$E(a_d)$	$E(a_d)$

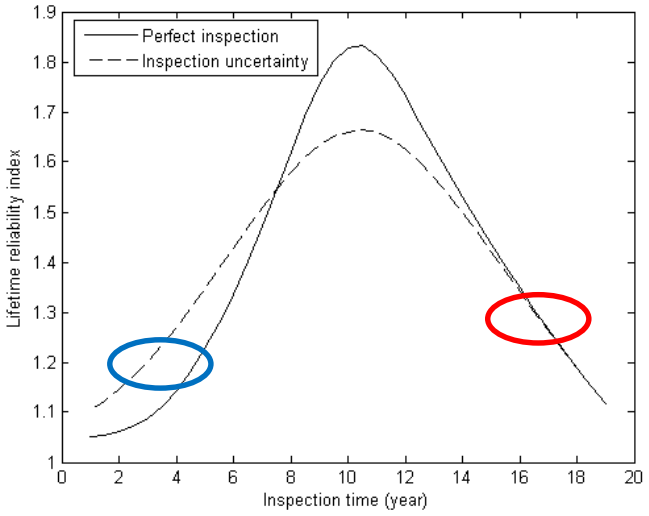


Results and discussions









Conclusions

- Generally, fatigue reliability is lower when inspection uncertainty is considered.
- Fatigue reliability can be higher when inspection uncertainty is considered (the inspection (by CVI, VI) is scheduled at the early stage of service life)
- Inspective uncertainty has little influence on fatigue reliability when the inspection is scheduled at the late stage of service life.
- When inspection uncertainty is considered, the effectiveness of an planned inspection increases with the decrease of the mean detectable crack size.

Thanks for your attention

The TRUSS ITN project (http://trussitn.eu) has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 642453