Assessment of a condition-based maintenance policy for Subsea systems: A preliminary study

European Safety and Reliability (2016 ESREL)
University of Strathclyde, Glasgow, 25 - 29 September

Yun Zhang
Anne Barros
Antoine Rauzy

Norwegian University of Science and Technology

September 27, 2016

Context

- Subsea system are
  - prone to degradation and failures
- Therefore,
  - designed not to fail
  - restricted maintenance
- Yet, we can
  - condition monitoring
  - maintenance policies

Figure: Photo by AkerSolutions

New trend and applications in Subsea

- More sensors installed
- Intelligent Field concept
- E-maintenance solutions

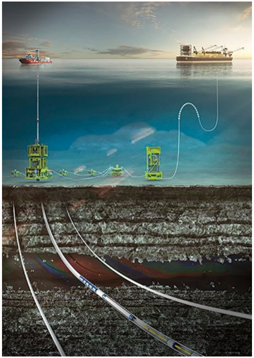


Figure: Photo by AkerSolutions

Need for maintenance

Stage 1 Reactive

- Monitor production
- Run to failure

Stage 2 Preventive

- Time based maintenance

Stage 3 Predictive and proactive

- Condition based maintenance

Figure: Photo by AkerSolutions

Key issues for Subsea systems (1)

Issue 1 **Degradation modelling**

- Failure rate distribution
- Regression based model
- Stochastic process

Aim: Study Remaining Useful Lifetime (RUL) estimation and implement prognostics.

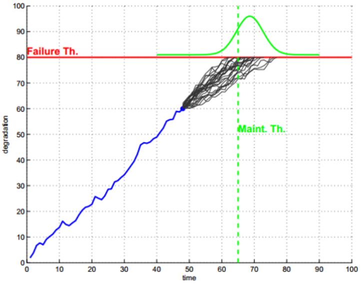


Figure: Stochastic degradation process

Key issues for Subsea systems (2)

Issue 2 **Maintenance with delay**

- Degradation state space: **green** (fully functional), **yellow** (degraded but not failed) and **red** (failed), see [SaSCT+11].
- To initiate a maintenance intervention or dismiss the alert.

Aim: Determine thresholds of proactive maintenance.

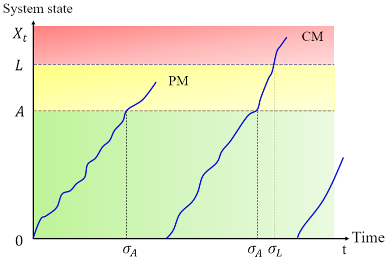


Figure: Three state spaces

Use case

Choke valve

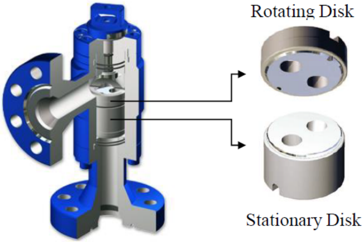


Figure: Photo by CORETEC

Use case

Health indicator

- **Erosion** in the disks and outlet sleeve;
- Valve current **flow coefficient** C_V starts to increase due to increased valve opening;
- One useful **indicator**: difference between reference and calculated value of flow coefficient $\delta_{C_V} = C_V^{cal} - C_V^{ref}$

Degradation modelling

- Stochastic Gamma process + power law

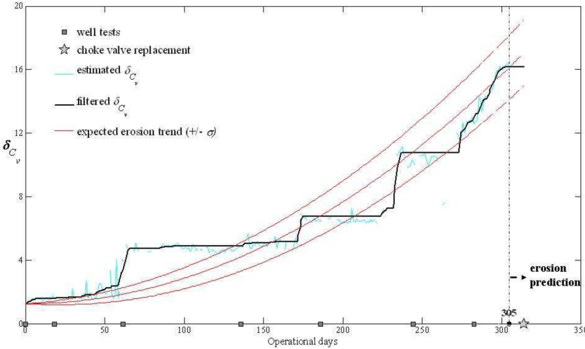


Figure: Trained degradation data of choke valve, see [NGH12]

Maintenance policy

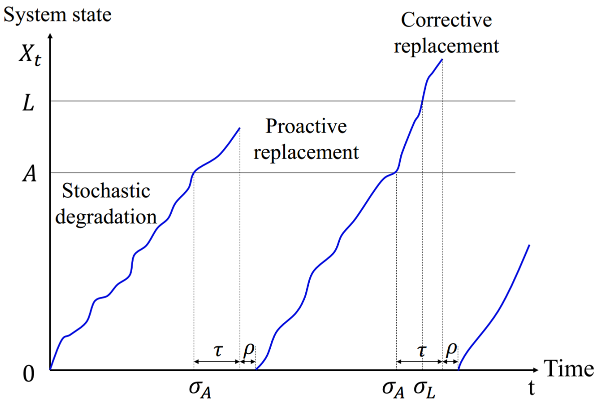


Figure: Sketch of degradation model and maintenance policy

Maintenance policy

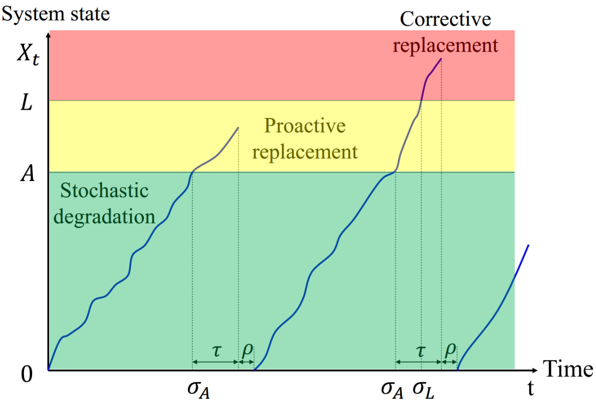


Figure: Sketch of degradation model and maintenance policy

Reliability measure and optimisation

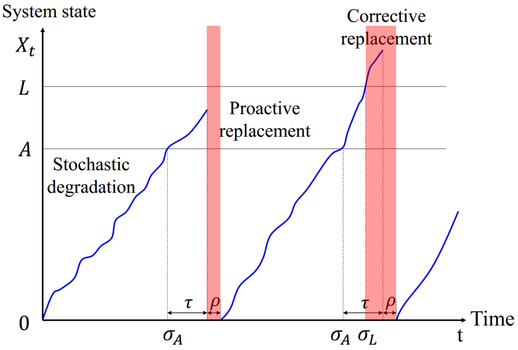
- Reliability measure: average unavailability
- Maintenance optimization: an optimal A level to minimize the average unavailability of the system

Analytical result

$$\textbf{Average unavailability} = \frac{\textbf{mean downtime in one renewal cycle}}{\textbf{mean duration of a renewal cycle}} \quad (1)$$

Analytical result

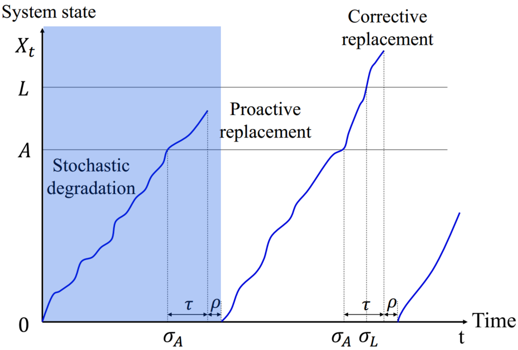
mean downtime in one renewal cycle



$$U_1 = (\sigma_A + \tau + \rho - \sigma_L) \cdot \mathbf{1}_{\{\sigma_L \leq \sigma_A + \tau\}} + \rho \cdot \mathbf{1}_{\{\sigma_L > \sigma_A + \tau\}} \quad (2)$$

Analytical result

mean duration of one renewal cycle



$$D_1 = \sigma_A + \tau + \rho \qquad (3)$$

Analytical result

Thus, the average unavailability U_∞ can be calculated as the mean downtime in one renewal cycle divided by the mean duration of a renewal cycle:

$$\begin{aligned} U_\infty &= \frac{E[(\sigma_A + \tau + \rho - \sigma_L) \cdot \mathbf{1}_{\{\sigma_L \le \sigma_A + \tau\}} + \rho \cdot \mathbf{1}_{\{\sigma_L > \sigma_A + \tau\}}]}{E[\sigma_A + \tau + \rho]} \\ &= \frac{\rho + E[(\sigma_A + \tau - \sigma_L) \cdot \mathbf{1}_{\{\sigma_L \le \sigma_A + \tau\}}]}{E[\sigma_A] + \tau + \rho} \\ &= \frac{\rho + \tau - E[\inf(\tau, (\sigma_L - \sigma_A))]}{E[\sigma_A] + \rho + \tau} \end{aligned} \tag{4}$$

Analytical result

- $E[\sigma_A]$

$$E[\sigma_A] = E[\eta^{-1}(\tilde{\sigma}_A)] \simeq \eta^{-1}(E[\tilde{\sigma}_A]) \tag{5}$$

$$E[\tilde{\sigma}_A] \simeq Au + \frac{1}{2} \tag{6}$$

- Refer to [FN07, BGDR03], combining Equation (5) and (6), we have:

$$E[\sigma_A] = \left(\frac{Au}{c} + \frac{1}{2c}\right)^{1/b} \tag{7}$$

Analytical result

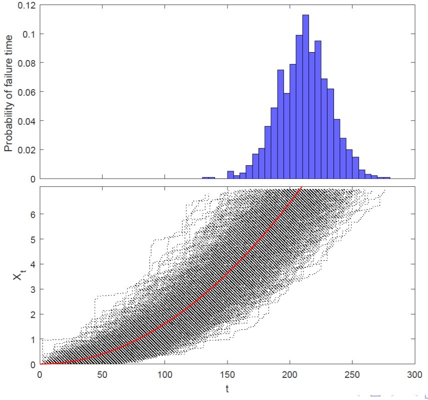
- $E[\inf(\tau, (\sigma_L - \sigma_A))]$

$$= \int_0^{L-A} \bar{F}_{\{c\tau^b,u\}}(z) \left(\int_0^{\infty} f_{\{ct^b,u\}}(L-z)dt \right) dz \qquad (8)$$

  refer to [BGDR03].
- Calculate (8) for a power law Gamma process is demanding
- Resort to Monte Carlo simulation

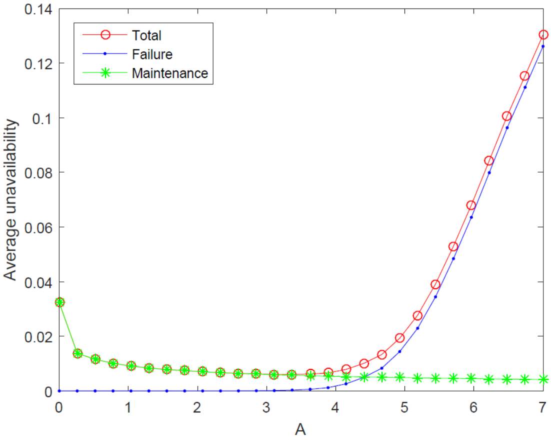
Monte Carlo Simulation

1000 realizations of Gamma stochastic process with $\hat{c} = 0.00059$, $\hat{b} = 2$, $\hat{u} = 3.65543$.



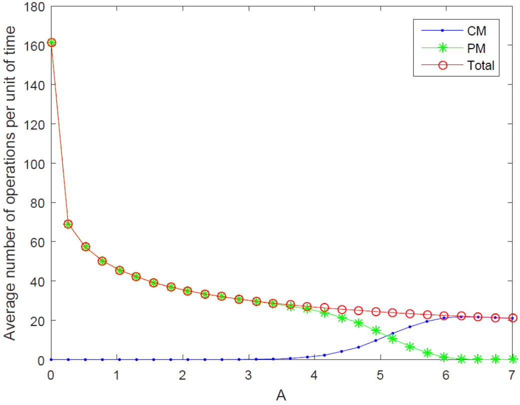
Monte Carlo Simulation

Unavailability (U_∞) versus alarm level (A)



Monte Carlo Simulation

Average number of operations versus *A* due to PM and CM



Summary

- A model of maintenance optimization of a subsea system with a Gamma degradation process, continuous monitoring and maintenance delay.
- Choke valve use case.
- Inputs from expert judgement and real data.
- Optimal average unavailability and correspondent optimal alarm level.
- Analytical formulas and Monte Carlo simulations.

Further work

1. Challenge Gamma process and propose alternative degradation models.
2. Distinguish between system degradation and abnormal readings of sensors.
3. Address the system level with multiple degradation indicators and grouping activities.

Thank you for your attention

Contact information

- Yun Zhang yun.zhang@ntnu.no
- Anne Barros anne.barros@ntnu.no
- Antoine Rauzy antoine.rauzy@ntnu.no

sfi Centre for Research-based Innovation
Established by the Research Council of Norway

NTNU
Norwegian University of Science and Technology

Some references

C. Brenguer, A. Grall, L. Dieulle, and M. Roussignol.
Maintenance policy for a continuously monitored deteriorating system.
Probability in the Engineering and Informational Sciences, 17:235–250, 4 2003.

JBG Frenk and Robin P Nicolai.
Approximating the randomized hitting time distribution of a non-stationary gamma process.
Technical Report ERS-2007-031-LIS, Econometric Institute, Erasmus University Rotterdam, 2007.

Andrew KS Jardine, Daming Lin, and Dragan Banjevic.
A review on machinery diagnostics and prognostics implementing condition-based maintenance.
Mechanical systems and signal processing, 20(7):1483–1510, 2006.

Bent Helge Nystad, Giulio Gola, and John Einar Hulsund.
Lifetime models for remaining useful life estimation with randomly distributed failure thresholds.
In *First european conference of the progostics and health management society*, volume 3, Dresden, Germany, 2012. Progostics and health management society.

Bent H Nystad, Giulio Gola, John E Hulsund, and Davide Roverso.
Technical condition assessment and remaining useful life estimation of choke valves subject to erosion.
In *Prognostics and Health Management Society*, pages 11–13, Portland, Oregon, 2010. Prognostics and Health Management Society.

Ulf Skytte af Sätra, Rebecca Christensen, Adrian Tanase, Ingvar Koppervik, Espen Rokke, et al.
Proactive maintenance in the context of integrated operations generation 2.
SPE Economics & Management, 3(02):102–108, 2011.