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 systems are prone to degradation and failures.
- Therefore, designed not to fail and restricted maintenance.
- Yet, we can condition monitoring and 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 $\delta C_V = C_{cal}^V - C_{ref}^V$
Degradation modelling

- Stochastic Gamma process + power law

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

Average unavailability = \frac{\text{mean downtime in one renewal cycle}}{\text{mean duration of a renewal cycle}} \tag{1}
mean downtime in one renewal cycle

\[
U_1 = (\sigma_A + \tau + \rho - \sigma_L) \cdot 1_{\{\sigma_L \leq \sigma_A + \tau\}} + \rho \cdot 1_{\{\sigma_L > \sigma_A + \tau\}} \quad (2)
\]
mean duration of one renewal cycle

\[ D_1 = \sigma_A + \tau + \rho \]
Thus, the average unavailability $U_\infty$ can be calculated as the mean downtime in one renewal cycle divided by the mean duration of a renewal cycle:

$$U_\infty = \frac{E[(\sigma_A + \tau + \rho - \sigma_L) \cdot 1\{\sigma_L \leq \sigma_A + \tau\} + \rho \cdot 1\{\sigma_L > \sigma_A + \tau\}]}{E[\sigma_A + \tau + \rho]}$$

$$= \frac{\rho + E[(\sigma_A + \tau - \sigma_L) \cdot 1\{\sigma_L \leq \sigma_A + \tau\}]}{E[\sigma_A] + \tau + \rho}$$

$$= \frac{\rho + \tau - E[\inf(\tau, (\sigma_L - \sigma_A))]}{E[\sigma_A] + \rho + \tau}$$  \hspace{2cm} (4)
Analytical result

- $E[\sigma_A]$

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

\[
E[\tilde{\sigma}_A] \simeq Au + \frac{1}{2} \quad (6)
\]

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

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

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

$$= \int_0^{L-A} \bar{F}_{cTb, u}(z) \left( \int_0^\infty f_{ctb, u}(L-z) \, dt \right) \, dz \quad (8)$$

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 ($U_\infty$) versus alarm level ($A$)
Monte Carlo Simulation

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

![Graph showing average number of operations per unit of time versus $A$. The graph compares CM, PM, and Total operations.](image-url)
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

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. 

- JBG Frenk and Robin P Nicolai.
  Approximating the randomized hitting time distribution of a non-stationary gamma process.

- Andrew KS Jardine, Daming Lin, and Dragan Banjevic.
  A review on machinery diagnostics and prognostics implementing condition-based maintenance.

- Bent Helge Nystad, Giulio Gola, and John Einar Hulsund.
  Lifetime models for remaining useful life estimation with randomly distributed failure thresholds.

- 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.

- Ulf Skytte af Sätra, Rebecca Christensen, Adrian Tanase, Ingvar Koppervik, Espen Rokke, et al.
  Proactive maintenance in the context of integrated operations generation 2.