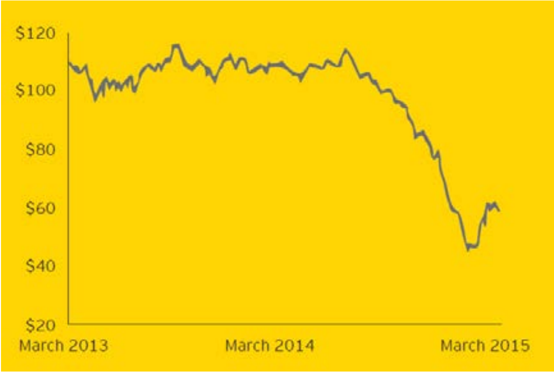
Predictive Subsea Integrity Management: Effective Tools and Techniques

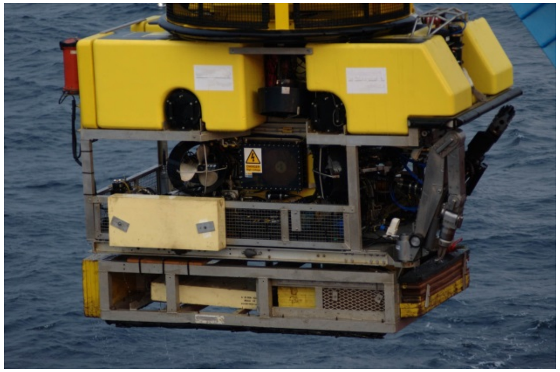
The Leading Edge of Value-Based Subsea Inspection

1st November Aberdeen 2017

Background

- Low oil price having major impact on oil and gas business
- Operators need to significantly reduce OPEX
  - Looking for better strategy for managing subsea assets which will reduce costs
- Opportunities to decrease OPEX
  - Inspect less often - increase time between inspections
  - Inspect fewer items - only inspect items at risk of degradation
  - Inspect items more rapidly – less time on station
  - Remote condition monitoring rather than ROV inspection
  - Increase time between failures - improve reliability
  - Decrease time to repair or replace
  - Use lower cost vessels
- New technologies needed to reduce operating costs without compromising asset integrity





Asset Integrity Management Strategies

- **Breakdown**
  - Fix when broke
  - Expensive

- Unscheduled interventions
- Process and service disruptions
- High maintenance costs

- **Preventive**
  - Scheduled inspection and replacement
  - Less suitable for permanently installed subsea hardware

- Regular interventions
- Equipment inspection
- Replacement before failure

- **Predictive**
  - Monitor equipment and process conditions
  - Predict and prevent

- Predicted best time for intervention
- Detect & correct root causes of failure
- Deliver inherent plant reliability

Fundamental Questions

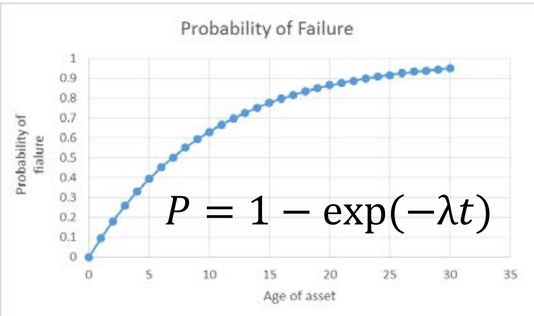
- When will an equipment item fail?
- How soon before we need to replace or repair the item?
- How often should we inspect or test?

Difficult to forecast these

- Important to understand
  - How equipment items degrade and fail (mechanisms)
  - How fast degradation progresses and leads to failure
  - How much degradation can be tolerated before action needed to prevent failure
- Inspection, monitoring and testing can be used to indicate:
  - Actual state/condition of equipment to support decision making
  - Changes of state/condition over time (if monitored)
- Currently industry approach
  - Mainly to detect current state/condition
  - Not making best use of this data to forecast asset life

Predicting Time of Failure

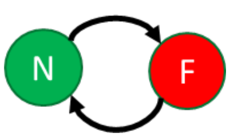
- Conventional reliability based on two states: working and failed
- Historically simple reliability models used to forecast probability of failure with time
  - λ is the asset failure rate $\mathrm{MTTF} = 1/\lambda$
  - t is the age of the asset

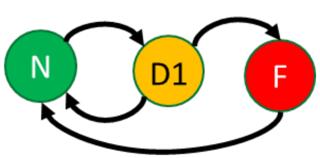


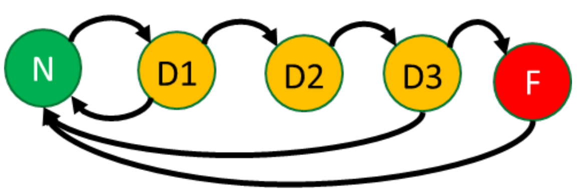
- Failure rate assumed constant
- Typically obtained from data bases e.g. OREDA
- Time of failure is “statistical” - assumed random
- Generic and based on population of observed failures from different installations

How do we move forward?

- Fundamentally 2 states not enough to manage asset reliability and integrity
- Need additional states - working, degraded, failed







Advanced Predictive Analytics and Tools

- Forward prediction methods
  - Markov chains - state space models
  - Damage accumulation and limit state models
  - Reliability growth analysis

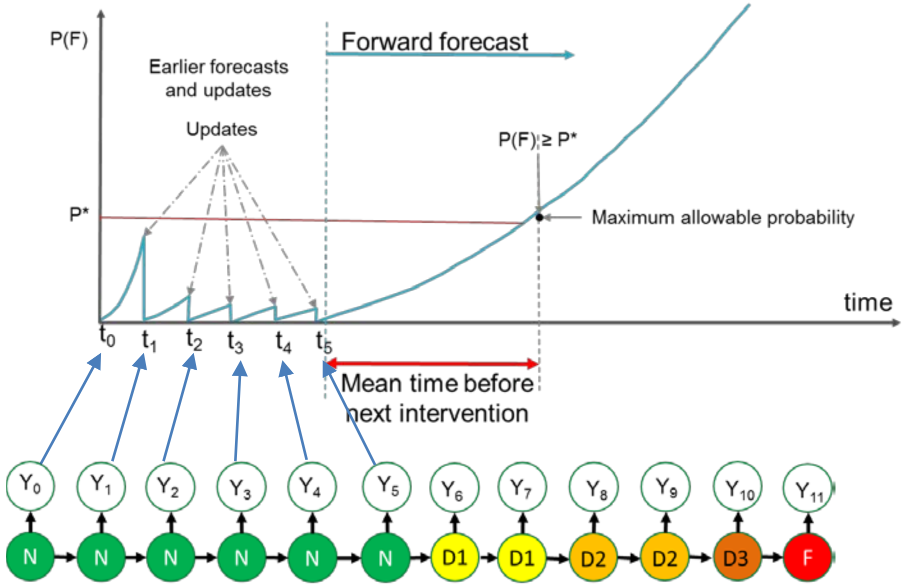
- Predictive models must be realistic representation of the degradation and failure mechanisms of monitored equipment

- Monitored data must be relevant to the actual degradation/failure mechanisms of monitored equipment

- Tools for using and analysing observed data
  - Hidden Markov models with Bayesian updating
  - Bayesian updating of damage accumulation and limit state models
  - Machine learning from observed data
    - Supervised and unsupervised learning

Hidden Markov Model

- State is hidden
- State revealed by observable Y_i
  - Monitored data
  - Inspection data
- Y indicates if state is
  - N (working as good as new)
  - D (degraded) or
  - F (failed)

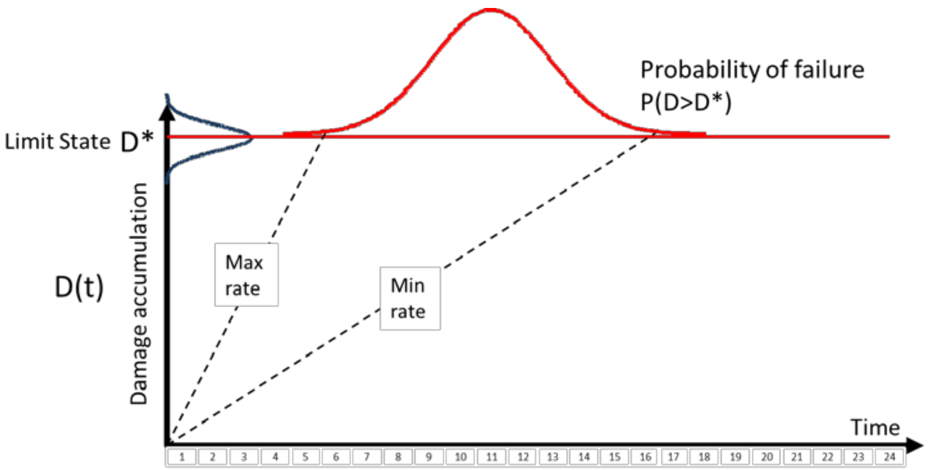


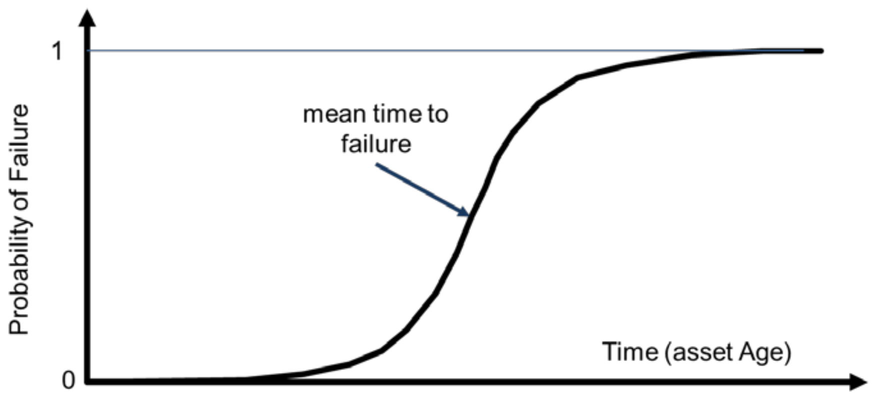
Markov chain

- Forward forecast by state space Markov model
- State probability updated using advanced analytics e.g. Bayes or ML algorithm
- Time to next action = time to reach maximum allowable probability for that action e.g.
  - Time to next inspection
  - Time before need to replace or repair
- Predicts time to reach unacceptable damage state

Damage Accumulation - Limit State Models

- Damage accumulates from time t=0 until failure
- Damage rate varies with time (e.g. corrosion, erosion, wear, fatigue)
- Failure occurs when damage D exceeds allowable damage D*
- For example: D* can be corrosion allowance or wall thickness

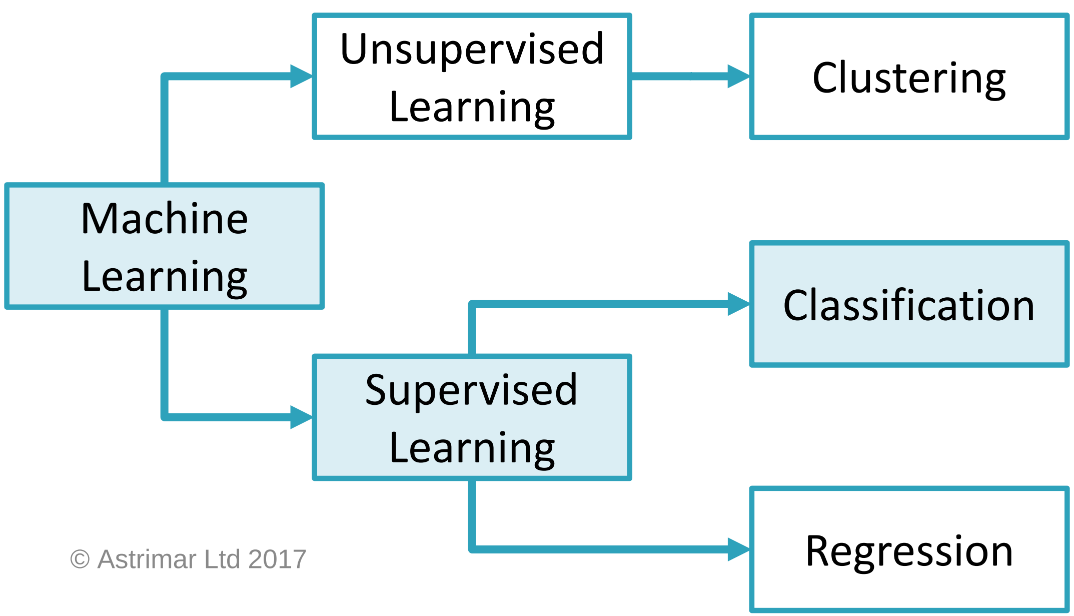


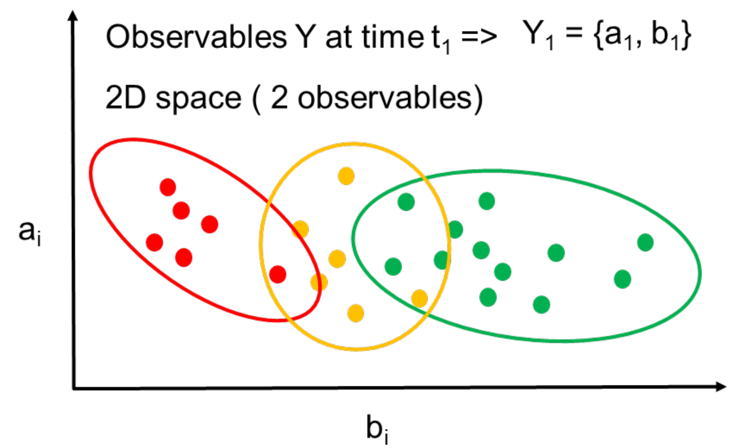


- Can be used where there is a well understood failure mechanism e.g. corrosion
- Predictions based on historical degradation rate data and equipment design
- Can be updated given actual measurements of degradation rate

Machine Learning Techniques

- Machine Learning - a powerful tool for analysing data
- Applicable to analysis of monitored data or inspection data
- A number of different algorithms available e.g.
  - Supervised learning commonly used
  - Train the model using classification algorithm to recognise which observables indicate when state is working , degraded or failed





Note: machine learning will be in 6D space if there are 6 observables relevant to equipment state

Practical Application Examples

Subsea Valves

- Signature test data
  - Time to close/open
  - Actuated hydraulic volume
- Predictive Models
  - Use of observed test data to update and forecast degraded and failed states
  - Integration of individual valve forecasts into system isolation model

Pipelines

- Typical external observables from ROV inspection
  - Coating condition
  - Anode wastage
  - Visible corrosion
  - Leaks
- Predictive Models to update and forecast degraded and failed states
  - Include equipment states and barrier states

Summary and Conclusions

- Currently not enough use made of existing data collected as part of the Operators Integrity Management
- Existing IM data are limited in scope and quality
- Significant amount of subsea integrity data based on inspection
- Operators looking to make more use of remote condition monitoring approaches that rely less on expensive vessels
- Advanced Predictive Analytics applicable to any subsea asset or asset barrier (e.g. CP, coatings, inhibition systems) that can be monitored or inspected
  - Valves (trees, manifolds, down hole safety, chokes)
  - Jumpers, pipelines, flow lines
  - Control system and umbilicals
  - Pumps and subsea processing