Use of Subsea Inspection Data to Estimate Failure Probability and Optimise Inspection Intervals

Subsea Integrity and Efficiency Conference
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www.astrimar.com

Background

• Estimation of asset specific equipment failure rates difficult
  – Sparse subsea industry / asset specific failure data
  – Failure rates typically based on generic data (operator, OREDA, etc.)

• Conservative approach often used to determine routine inspection intervals
  – e.g. annual or biennial basis
  – Do not necessarily reflect specific asset condition or risk
  – More frequent inspection and higher costs than a risk based approach
Use of both Failure and Inspection Data

- Subsea equipment failures relatively infrequent
  - Sparse data sets

- Field application often bespoke
  - Existing data not valid

- Large volume of anomaly data acquired from inspection campaigns
  - Much of this data not actually used but is valuable for implementing RBI

- Inspection also provides valuable data for equipment for which no anomalies or failures have been observed
  - Confirmation that there is no external deterioration

State-Space Model

- New tool developed based on state-space model

N – New State
A – Anomaly State
F – Failed State
P – Probability of Failure
\( \lambda, \mu \) – State Transition Rates
State Definitions

New State?  Anomaly State?  Failed State?

Damage accumulation

Key Steps

1. System, Inspection Scope and Anomaly Definition
2. Data Acquisition
3. Data Classification
4. Analysis
5. Risk Based Optimisation of Inspection Intervals
Define System, Inspection Scope and Anomalies

- Define system and inspection scope

- Identify failure modes
  - Helps with anomaly code definition

- Identify potential inspection anomalies
  - Code /description should indicate failure mechanism / type of damage
  - May need to be design specific
  - Use FMECA to support identification

### IM FMECA

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>ID Number</th>
<th>Function</th>
<th>Failure Mode</th>
<th>Failure Mechanism</th>
<th>Failure Cause</th>
<th>Applicable Inspection Anomaly</th>
<th>Observable Anomalies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Well Jumper</td>
<td>Production XT to manifold, Stainless Steel 12&quot;</td>
<td>WJP-FM3</td>
<td>Contain Production Fluid</td>
<td>Loss of Containment</td>
<td>External Corrosion</td>
<td>Coating damage/gaps</td>
<td>AN, AW, BM, CD, CP</td>
<td>10 CD anomalies after Year 3 1 AN anomaly after Year 1</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Local Effect</th>
<th>System Effect</th>
<th>Means of Failure Detection</th>
<th>Annual Failure Rate (field population)</th>
<th>Likelihood Score</th>
<th>Consequence Severity Score</th>
<th>Risk Categor</th>
<th>Note</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localised leak of production fluids to environment (isolation at XT)</td>
<td>Shutdown of XT until repair/replacement (1 year)</td>
<td>ROV inspection M2 pressure sensor</td>
<td>0.00003</td>
<td>C</td>
<td>D (medium)</td>
<td>Medium</td>
<td>Pin hole leak, Assumes leak detected before significant increase in hole size</td>
<td></td>
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- Component Description ID
- Number
- Function
- Failure Mode
- Failure Mechanism
- Failure Cause
- Applicable Inspection Anomaly
- Observable Anomalies
Data Gathering and Classification

- Identify relevant anomaly code for all significant observations with date of observation

- Enter data into equipment anomaly database
  - Data used to calculate new to anomaly transition rates

<table>
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<tr>
<th>Anomaly CD</th>
<th>Service: Production Inspection Year</th>
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<tr>
<td>WJP1</td>
<td>1 1 1 1 1 1 1 1</td>
</tr>
<tr>
<td>WJP2</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>WJP3</td>
<td>2 3 3 1 1 1 1 1</td>
</tr>
<tr>
<td>WJP4</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>WJP5</td>
<td>0 0 2 2 2 2 2 2</td>
</tr>
<tr>
<td>WJP6</td>
<td>1 1 1 1 1 1 1 1</td>
</tr>
<tr>
<td>WJP7</td>
<td>0 2 3 1 1 1 1 1</td>
</tr>
<tr>
<td>WJP8</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>WJP9</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>WJP10</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Total Number of Anomalies</td>
<td>4 7 10 10 10 11</td>
</tr>
</tbody>
</table>

Analysis of Anomaly Rates

- Calculation of New to Anomaly transition rates
  - Based on time history of observed anomalies
  - Statistical techniques used to provide confidence intervals
  - Whole population or selected items

- Significant uncertainty in new to anomaly transition rates in early life
  - Sparse anomaly data

- Need both installation date and start of operation date
  - Different failure modes will use different start date
Other state transition rates

- Identify other state transition rates

- New to Failure
  - Anomaly to Failure

  Engineering Judgement
  Engineering Assessments

- Restoration rates

  Sparing Strategy
  Vessel Logistics

Example Output

<table>
<thead>
<tr>
<th>Failure Mode</th>
<th>Consequence Severity</th>
<th>Maximum PoF for risk to be in Low Risk category</th>
<th>PoF per item in year 20 (2020)</th>
<th>PoF per item after 5 years (2025)</th>
<th>Equivalent failure rate per year per item (over next 5 years)</th>
<th>Time to reach Low Risk threshold (years)</th>
<th>Suggested inspection interval (years)</th>
<th>Suggested population annual failure rate for FMECA</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>1.00E-05</td>
<td>1.40E-04</td>
<td>2.50E-05</td>
<td>5.00E-06</td>
<td>2.7</td>
<td>2</td>
<td>5.00E-05</td>
<td></td>
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Summary of Pilot Study Feedback

• Tool enables inspection to be optimised based on observed equipment condition
• Significant uncertainty in early life (first 2 years) – sparse data
• Supports sensitivity studies (assumptions)
• Good anomaly definition required that reflects failure mechanism
• Need for time history – installation, start-up, anomaly observation
• Need clarity on units for failure rates – item versus population
• Good FMECA supports effective tool implementation

• Tool also used for failure modes/anomalies for which anomalies are not visible e.g. internal corrosion, erosion
  – Monitoring/sampling used to identify new, anomaly and failed state

• Tool extended for identification of valve testing intervals and forecasting valve probability of failure based on signature data
  – Active rather than passive equipment
  – Probability of failure on demand is important for integrity studies