Reliability Assessments of Subsea Well Components at Petrobras

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Subsea & Drilling – November 29th 2019
Agenda

Normative sources
Identifying hazards and risks (Current portfolio)
New developments
Challenges and/or Opportunities
Final considerations

Subsea & Drilling – November 29th 2019
Normative sources

ANP, API, ISO, NORSOK and BSEE

ANP Res. 46 – SGIP (Well Integrity Management System)
API RP-96 – Deepwater Well Design and Construction
ISO TS 16530-2 – Well Integrity Resources
ISO 14224 – Collection and exchange of reliability and maintenance data for equipment
NORSOK D-10 – Well integrity in drilling and well operations
Current portfolio

Identifying hazards, failure modes and consequences

- FMEA/FMECA – Failure Mode, Effects and Criticality
- FTA – Failure Tree
- PHA/HAZOP – Process Hazard

Modeling, analysis and decision support

- Markov Modeling & Analysis (MDP etc.)
- Simulation modeling (Monte Carlo etc.)
- Statistical Analysis (Cox regression etc.)
FMECA studies

- Safety Valves and Intelligent Completion Valves
- Well Intervention Systems
- DP Services
- Sand-Control
- Well Stimulation
- BOP Anchoring
- Subsea Well Test Trees (Electro-Hydraulic)
- B-Annulus' Monitoring
- Formation Isolation Valves
The idea is to identify and evaluate the cut sets.
Process Hazard

Subsea well systems’ design (new and/or some revitalizations) in Pre- and Post-salt fields

PHA & HAZOP studies for FPSOs’ hull & topside systems
Barrier management

Indicates a perfect barrier that can not fail

Formation/cement will not be able to withstand the well pressure, cratering may result

Major Hazard, Category A (A main = wellhead connector splits, not lift). Ar (A rare = wellhead connector splits and lifts off), and B (PAB connector splits or spuriously open, not lift)
Barriers elements

Examples of Barrier Elements

• Downhole Safety Valve
• Cemented Casing
• Production String
• X-Tree valves (M1, M2, AI1 and AI2)

Examples of Failure Modes

• FTC – Fail to close on demand
• FTO – Fail to open on demand
• LCP – Leakage in closed position
• TAC – Tubing to A-annulus communication
• EXL – External leakage – process medium
Workover demand estimation/learning

Monte Carlo Simulation

Wells’ (start date)

Wells’ Abandonment

Modeling

Processing

Operational Data

Maintenance & Construction data

Failure Prob.

Intervention scopes (mix)

Prob | Duração
--- | ---
E1 | 60% 30 días
E2 | 40% 20 días

Estimate

<table>
<thead>
<tr>
<th>Year</th>
<th>P50</th>
<th>P90</th>
</tr>
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<tbody>
<tr>
<td>2017</td>
<td>50</td>
<td>70</td>
</tr>
<tr>
<td>2018</td>
<td>30</td>
<td>60</td>
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</table>

Duration (days)

Who are the bad actors?
Critical components (bad actors)

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>FAILURE RATE ($10^{-6}$ h)</th>
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<tbody>
<tr>
<td>Gas Lift Valve + Gas Lift Mandrel</td>
<td>11,900</td>
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<tr>
<td>Subsea X-Tree</td>
<td>2,957</td>
</tr>
<tr>
<td>Down Hole Safety Valve</td>
<td>1,596</td>
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<tr>
<td>Production Adapter Base</td>
<td>0,757</td>
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<tr>
<td>Tubing Hanger</td>
<td>0,359</td>
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<tr>
<td>Production String</td>
<td>0,303</td>
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<tr>
<td>Wellhead Assembly</td>
<td>0,153</td>
</tr>
<tr>
<td>PACKER</td>
<td>0,121</td>
</tr>
<tr>
<td>Cemented Casing</td>
<td>0,015</td>
</tr>
</tbody>
</table>

\[
\frac{d}{dt} P(t) = MP(t) \quad (1)
\]

\[
P(t) = e^{Mt} P(0) \quad (2)
\]

$P(t)$ is the state probability vector (179 states)

$M$ is the transition matrix previously obtained

$eq. 2$ is the solution of the differential $eq. 1$

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>SENSITIVITY</th>
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<tr>
<td>Production Adapter Base</td>
<td>0.886</td>
</tr>
<tr>
<td>Gas Lift Valve + Gas Lift Mandrel</td>
<td>0.409</td>
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<tr>
<td>Wellhead Assembly</td>
<td>0.086</td>
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<tr>
<td>Cemented Casing</td>
<td>0.057</td>
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<tr>
<td>Subsea X-Tree</td>
<td>0.044</td>
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<tr>
<td>Down Hole Safety Valve</td>
<td>0.034</td>
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<tr>
<td>Tubing Hanger</td>
<td>0.011</td>
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<tr>
<td>Production String</td>
<td>0.008</td>
</tr>
<tr>
<td>PACKER</td>
<td>0.004</td>
</tr>
</tbody>
</table>

$Sensibilidade = \frac{\Delta \lambda_{poco}}{\Delta \lambda_{eqpto}}$
Challenges and/or Opportunities

• Specification (functional / technical)
• Modeling (model- & data-driven → representation, inference & learning)
• Data integration/sharing (collection, processing & analysis)
• Decision analysis (the amount of preventive, ALARP criterion)
• Interdisciplinary cooperation (new business models, startups)
• Industry 4.0 (digital twins, proxy models etc.)
New developments

A new RM Well Database – Data Collection & Analysis (Concept & Design)
  • Based on: ISO 14224, OREDA® and Wellmaster–RMS®

A new Framework for Technology Development Process (Concept & Design)
  • At CENPES – Petrobras Research Center

Data Analytics for Offshore Well Integrity and Lifecycle Management (Starting in 2010)
  • R&D case with Norwegian Univ. of Science and Technology – NTNU

A new Dynamic Barrier Management System “My Barrier” (Prototype)
  • Software development in partnership with DNV-GL
The Petrobras’ reliability journey has its own story, but there is a long way ahead, specially regarding to well engineering, towards a FRACAS (the HOLY GRAIL)

We should combine:

- Qualitative and quantitative approaches
- Expert knowledge and accumulated data
- Data driven and model-based approaches
- Simulation and analytical solutions

And facilitate:

- Interdisciplinary cooperation
- Data sharing
- Work process’ analysis and re-design (Kaizen)
Thank you for your attention

Questions?

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