Operational Experience Feedback and reliability data

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“Good judgment comes from experience. Experience comes from bad judgment.”

– Nasrudin
Where does this fit into risk engineering?

data → curve fitting → probabilistic model

probabilistic model

event probabilities

risks

consequence model

event consequences
Where does this fit into risk engineering?

- Data
- Probabilistic model
  - Event probabilities
  - Risks
- Consequence model
  - Event consequences
  - Costs
- Decision-making

Curve fitting
Where does this fit into risk engineering?

These slides

data

curve fitting

probabilistic model

event probabilities

risks

decision-making

criteria

costs

consequence model

event consequences

risks

decision-making

criteria

costs

These slides

data

curve fitting

probabilistic model

event probabilities

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criteria

costs

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costs
Use of reliability data

▷ **Managing maintenance:**
  - forecasting cost of maintenance during system design
  - preventive maintenance: stock management

▷ **Component design:**
  - better knowledge of the reliability and the failure modes of your products

▷ **Risk analysis:**
  - analyze and predict the occurrence of major accidents
  - supply quantitative information used in safety cases & QRA
Use for safety cases

- Framework: use of **probabilistic methods in safety cases** or QRAs

- The top event whose probability we wish to estimate is rare
  - little statistical information on frequency is available

- One possible approach to quantifying probability:
  - decompose the rare event into a chain of events that have an observable frequency
  - determine, for each initiating event, the accident sequences that may lead to the top event
  - quantify the frequency of the initiating event
  - quantify the availability of the preventive and protective barriers
Fault tree

Source1 → A1 → B → Receiver
Source2 → A2 → B → Receiver

- No flow to receiver
- No flow from component B
- No flow into component B
- No flow from component A1
- No flow from component A2
- Component B blocks flow

G02
G03
G04
G05
B01
B02
B03
T01
T02
### Event Tree: Hull Failure Example

<table>
<thead>
<tr>
<th>IE</th>
<th>FE</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC suffers flooding event</td>
<td>Flooding event due failure of hull envelope</td>
</tr>
<tr>
<td></td>
<td>Served space floods: 1 COMPARTMENT</td>
</tr>
</tbody>
</table>

#### Secondary event: slow progressive flooding
- Primary flooding event
- Flooding event due failure of hull envelope

<table>
<thead>
<tr>
<th>FL1</th>
<th>FL2</th>
<th>FL3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

#### Secondary event: RAPID Progressive flooding
- Adjacent Hold, ballast, store or void space floods: 2 COMPARTMENTS

<table>
<thead>
<tr>
<th>LS</th>
<th>OUTCOME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Side shell failure: holds + other space(s) flooded—total loss—Fatalities</td>
</tr>
<tr>
<td>No</td>
<td>Side shell failure: holds + other space(s) flooded—total loss—No fatalities</td>
</tr>
</tbody>
</table>

#### Frequency per ship year
- Fatalities per ship year
- Average ship age
- Total number of fatalities

<table>
<thead>
<tr>
<th>Side shell</th>
<th>No flooding—Ship survives—No fatalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>3.49E-05</td>
</tr>
<tr>
<td>No</td>
<td>2.61E-04</td>
</tr>
</tbody>
</table>

#### Flooding Scenarios Other Than Side Shell Failure
- Events separately assessed

<table>
<thead>
<tr>
<th>Flooding scenarios other than side shell failure</th>
<th>Events separately assessed</th>
</tr>
</thead>
<tbody>
<tr>
<td>No flooding—Ship survives—No fatalities</td>
<td>0.00E+00</td>
</tr>
<tr>
<td>Served space alone flooded—No fatalities</td>
<td>0.00E+00</td>
</tr>
<tr>
<td>Served space alone flooded—total loss—Fatalities</td>
<td>0.00E+00</td>
</tr>
<tr>
<td>Served space alone flooded—total loss—No fatalities</td>
<td>0.00E+00</td>
</tr>
<tr>
<td>No flooding—Ship survives—Fatalities</td>
<td>0.00E+00</td>
</tr>
<tr>
<td>Served space alone flooded—ship survives—Fatalities</td>
<td>0.00E+00</td>
</tr>
<tr>
<td>Served space alone flooded—ship survives—No fatalities</td>
<td>0.00E+00</td>
</tr>
</tbody>
</table>

#### Sub-Total
- 1.20E-03
- 2.48E-03
- 361

**Note:**
- Other flooding scenarios
- Total 3.55E-03
- Tournament 1.21E-02
- Total 1.73E-03
Bow tie diagram
Data sources

- Databases based on accidents on units identical to yours
  - good level of representativity
  - requires a large number of similar equipment observed over a long time period
- Tests of equipment in similar conditions to expected operation
  - very expensive; difficult to “accelerate time”
  - difficult to reproduce all details of operational conditions (temperature stress, vibration, corrosion, impact of maintenance...)
- Reliability data collected in the same industry
  - doesn’t account for the specifics of your equipment, your maintenance policy
- “Generalist” data sources
  - don’t account for the differences between industrial sectors
- Academic/technical literature
- Expert judgment
  - subjective, but allows the specificity of your plant/equipment to be taken into account
Reliability of reliability data

IEC 61511:2016, clause 11.9.3 states

"The reliability data used when quantifying the effect of random failures shall be credible, traceable, documented, justified and shall be based on field feedback from similar devices used in a similar operating environment."

Reliability databases

- **OREDA**: collection of reliability data on offshore equipment, managed by petroleum companies
  - detailed information on failure rates, repair times, failure modes

- **NPRDS** (Nuclear Plant Reliability Data System): data on reliability of equipment used in civil nuclear power plants in the USA

- **Base Process Equipment Reliability Database (PERD)** of the Center for Chemical Process Safety (CCPS), AIChE

- Hydrocarbon Release Database (HCRD) compiled by UK HSE

- **ESReDA Handbook on Quality of Reliability Data** published by DNV

- **The Red Book** published by TNO, Dutch R&D organization
Reliability databases

*Reliability Data for Safety Instrumented Systems*

Handbook with reliability data estimates for components of control and safety systems, based on the work of the PDS Forum. Data dossiers for input devices (sensors, detectors, etc.), control logic (electronics) and final elements (valves, etc.) are presented, including data for subsea and drilling related equipment.
### Main uses of OREDA reliability data are in the following areas:

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Typical Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design / Engineering</td>
<td><strong>Production availability and reliability management:</strong></td>
</tr>
<tr>
<td></td>
<td>- Production availability estimates (e.g. system performance simulation)</td>
</tr>
<tr>
<td></td>
<td>- Design optimisation (e.g. evaluate justification for redundancy)</td>
</tr>
<tr>
<td></td>
<td>- Reliability engineering (e.g. FMECA, equipment selection)</td>
</tr>
<tr>
<td>Safety and risk:</td>
<td>- Estimate probabilities of critical events</td>
</tr>
<tr>
<td></td>
<td>- Estimate survival time and system unavailability for safety-critical items</td>
</tr>
<tr>
<td></td>
<td>- Analysis (SIL) of instrumented safety systems (ref.: IEC 61508/ 61511)</td>
</tr>
<tr>
<td>Operation/ Maintenance</td>
<td><strong>Asset management:</strong></td>
</tr>
<tr>
<td></td>
<td>- Benchmarking/ KPI parameters</td>
</tr>
<tr>
<td></td>
<td>- Production assurance and decision-support</td>
</tr>
<tr>
<td>Reliability monitoring and maintenance optimisation:</td>
<td>- Optimise maintenance intervals and spare part storage</td>
</tr>
<tr>
<td></td>
<td>- Integrated operations</td>
</tr>
<tr>
<td></td>
<td>- Analyse reliability characteristics (e.g. lifetime distribution, failure mechanisms)</td>
</tr>
<tr>
<td></td>
<td>- Reveal weak designs that need modification or redesign (feedback to manufacturer)</td>
</tr>
<tr>
<td>Typical analyses</td>
<td><strong>Quantitative risk assessment, reliability centred maintenance, reliability based inspection, life cycle cost, production availability, safety integrity level (SIL), spare parts storage, manning resources, FMEA-analysis, benchmarking/ KPI assessment, root cause analysis, (ref.: ISO 20 815)</strong></td>
</tr>
<tr>
<td>where data are used</td>
<td></td>
</tr>
</tbody>
</table>

Source: OREDA brochure, at oreda.com
Example: the OREDA taxonomy

The following types of equipment are covered in the OREDA database:

<table>
<thead>
<tr>
<th>Rotating machinery</th>
<th>Mechanical equipment</th>
<th>Control &amp; Safety</th>
<th>Subsea equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustion engines</td>
<td>Cranes</td>
<td>Control Logic Units</td>
<td>Control systems</td>
</tr>
<tr>
<td>Compressors</td>
<td>Heat exchangers</td>
<td>Fire &amp; Gas detectors</td>
<td>Dry tree riser</td>
</tr>
<tr>
<td>Electric generators</td>
<td>Heaters and Boilers</td>
<td>HVAC</td>
<td>El. power distribution</td>
</tr>
<tr>
<td>Electric motors</td>
<td>Loading arms</td>
<td>Input devices</td>
<td>Flowlines</td>
</tr>
<tr>
<td>Gas turbines</td>
<td>Swivels</td>
<td>Nozzles</td>
<td>Manifolds</td>
</tr>
<tr>
<td>Pumps</td>
<td>Turrets</td>
<td>Power transformers</td>
<td>Pipelines</td>
</tr>
<tr>
<td>Steam turbines</td>
<td>Vessels</td>
<td>UPS</td>
<td>Production risers</td>
</tr>
<tr>
<td>Turboexpanders</td>
<td>Winches</td>
<td>Valves</td>
<td>Running tools</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frequency converters</td>
<td>Subsea pumps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Switchgear</td>
<td>Subsea vessels</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Templates</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Wellhead &amp; X-mas trees</td>
</tr>
</tbody>
</table>

Source: OREA brochure, at oreda.com
### Example: an OREDA datasheet

#### Taxonomy no
2.2.2.13

#### Item
- Electric Equipment
- Electric motors
- Pump
- Oily water treatment

<table>
<thead>
<tr>
<th>Population</th>
<th>Installations</th>
<th>Aggregated time in service (10^6 hours)</th>
<th>Operational time</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>1</td>
<td>Calendar time * 0.0339</td>
<td>0.2406</td>
</tr>
</tbody>
</table>

#### Failure mode
- No of failures
- Failure rate (per 10^6 hours)
- Active repair hrs
- Repair (manhours)

<table>
<thead>
<tr>
<th>Failure mode</th>
<th>No of failures</th>
<th>Lower</th>
<th>Mean</th>
<th>Upper</th>
<th>SD</th>
<th>n/hr</th>
<th>Min</th>
<th>Mean</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical</td>
<td>15</td>
<td>30.42</td>
<td>49.36</td>
<td>66.00</td>
<td>49.36</td>
<td>9.8</td>
<td>3.0</td>
<td>18.3</td>
<td>39.0</td>
</tr>
<tr>
<td>Breakdown</td>
<td>3</td>
<td>2.70</td>
<td>9.87</td>
<td>25.52</td>
<td>9.87</td>
<td>9.87</td>
<td>11.2</td>
<td>8.0</td>
<td>19.7</td>
</tr>
<tr>
<td>Fail to start on demand</td>
<td>3</td>
<td>3.41</td>
<td>12.47</td>
<td>32.23</td>
<td>12.47</td>
<td>12.47</td>
<td>8.2</td>
<td>3.0</td>
<td>14.3</td>
</tr>
<tr>
<td>Spurious stop</td>
<td>2</td>
<td>1.17</td>
<td>6.98</td>
<td>23.73</td>
<td>6.98</td>
<td>6.98</td>
<td>4.0</td>
<td>5.0</td>
<td>5.5</td>
</tr>
<tr>
<td>Structural deficiency</td>
<td>3</td>
<td>2.70</td>
<td>9.87</td>
<td>25.52</td>
<td>9.87</td>
<td>9.87</td>
<td>10.8</td>
<td>4.0</td>
<td>21.7</td>
</tr>
<tr>
<td>Vibration</td>
<td>3</td>
<td>3.41</td>
<td>12.47</td>
<td>32.23</td>
<td>12.47</td>
<td>12.47</td>
<td>12.0</td>
<td>7.0</td>
<td>24.0</td>
</tr>
<tr>
<td>Degraded</td>
<td>10</td>
<td>17.85</td>
<td>32.91</td>
<td>55.81</td>
<td>32.91</td>
<td>32.91</td>
<td>6.4</td>
<td>3.0</td>
<td>11.9</td>
</tr>
<tr>
<td>Overheating</td>
<td>10</td>
<td>22.55</td>
<td>41.56</td>
<td>70.49</td>
<td>41.56</td>
<td>41.56</td>
<td>3.0</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Structural deficiency</td>
<td>5</td>
<td>6.48</td>
<td>16.45</td>
<td>34.63</td>
<td>16.45</td>
<td>16.45</td>
<td>7.4</td>
<td>3.0</td>
<td>13.4</td>
</tr>
<tr>
<td>Vibration</td>
<td>5</td>
<td>8.19</td>
<td>20.78</td>
<td>43.70</td>
<td>20.78</td>
<td>20.78</td>
<td>7.4</td>
<td>3.0</td>
<td>13.4</td>
</tr>
<tr>
<td>Incipient</td>
<td>4</td>
<td>5.67</td>
<td>16.62</td>
<td>38.05</td>
<td>16.62</td>
<td>16.62</td>
<td>5.5</td>
<td>10.0</td>
<td>11.0</td>
</tr>
<tr>
<td>Minor in-service problems</td>
<td>3</td>
<td>3.41</td>
<td>12.47</td>
<td>32.23</td>
<td>12.47</td>
<td>12.47</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Unknown</td>
<td>1</td>
<td>0.16</td>
<td>3.29</td>
<td>15.62</td>
<td>3.29</td>
<td>3.29</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>All modes</td>
<td>29</td>
<td>68.27</td>
<td>95.44</td>
<td>130.12</td>
<td>95.44</td>
<td>95.44</td>
<td>7.9</td>
<td>2.0</td>
<td>14.5</td>
</tr>
</tbody>
</table>

#### Comments

Source: oreda.com
# Process Equipment Leak Frequencies

**Equipment Type:** Flange  
**Source:** HCRD 10/92 – 03/10

<table>
<thead>
<tr>
<th>Equipment Size</th>
<th>Category</th>
<th>Total</th>
<th>Full Pressure</th>
<th>Zero Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 in</td>
<td>1 - 3 mm</td>
<td>8.880E-05</td>
<td>7.801E-05</td>
<td>1.884E-06</td>
</tr>
<tr>
<td></td>
<td>3 - 10 mm</td>
<td>3.252E-05</td>
<td>2.731E-05</td>
<td>1.430E-06</td>
</tr>
<tr>
<td></td>
<td>10 - 50 mm</td>
<td>1.176E-05</td>
<td>9.362E-06</td>
<td>1.225E-06</td>
</tr>
<tr>
<td></td>
<td>50 - 150 mm</td>
<td>2.077E-06</td>
<td>1.560E-06</td>
<td>5.388E-07</td>
</tr>
<tr>
<td></td>
<td>&gt; 150 mm</td>
<td>7.110E-06</td>
<td>5.780E-06</td>
<td>1.779E-06</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1.423E-04</td>
<td>1.220E-04</td>
<td>6.856E-06</td>
</tr>
<tr>
<td>14 in</td>
<td>1 - 3 mm</td>
<td>1.088E-04</td>
<td>9.559E-05</td>
<td>4.148E-06</td>
</tr>
<tr>
<td></td>
<td>3 - 10 mm</td>
<td>3.984E-05</td>
<td>3.346E-05</td>
<td>3.148E-06</td>
</tr>
<tr>
<td></td>
<td>10 - 50 mm</td>
<td>1.440E-05</td>
<td>1.147E-05</td>
<td>2.696E-06</td>
</tr>
<tr>
<td></td>
<td>50 - 150 mm</td>
<td>2.544E-06</td>
<td>1.912E-06</td>
<td>1.186E-06</td>
</tr>
<tr>
<td></td>
<td>&gt; 150 mm</td>
<td>7.360E-06</td>
<td>5.956E-06</td>
<td>3.316E-06</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1.729E-04</td>
<td>1.484E-04</td>
<td>1.449E-05</td>
</tr>
<tr>
<td>20 in</td>
<td>1 - 3 mm</td>
<td>1.379E-04</td>
<td>1.218E-04</td>
<td>1.454E-05</td>
</tr>
<tr>
<td></td>
<td>3 - 10 mm</td>
<td>5.051E-05</td>
<td>4.263E-05</td>
<td>1.103E-05</td>
</tr>
<tr>
<td></td>
<td>10 - 50 mm</td>
<td>1.826E-05</td>
<td>1.462E-05</td>
<td>9.450E-06</td>
</tr>
<tr>
<td></td>
<td>50 - 150 mm</td>
<td>3.226E-06</td>
<td>2.436E-06</td>
<td>4.158E-06</td>
</tr>
<tr>
<td></td>
<td>&gt; 150 mm</td>
<td>7.724E-06</td>
<td>6.218E-06</td>
<td>1.037E-05</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>2.176E-04</td>
<td>1.877E-04</td>
<td>4.955E-05</td>
</tr>
</tbody>
</table>


[Image: Example: datasheet for flange, DNV guidance]
**Example: complexity of data on “leak” event**

<table>
<thead>
<tr>
<th>Release Type</th>
<th>Total</th>
<th>GAS LEAK</th>
<th>OIL LEAK</th>
<th>CONDENSATE LEAK</th>
<th>2-PHASE LEAK</th>
<th>NON-PROCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero Pressure leak</td>
<td>6%</td>
<td>6%</td>
<td>7%</td>
<td>7%</td>
<td>2%</td>
<td>8%</td>
</tr>
<tr>
<td>Full pressure leak</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limited leak</td>
<td>48%</td>
<td>33%</td>
<td>75%</td>
<td>64%</td>
<td>67%</td>
<td>53%</td>
</tr>
<tr>
<td>Full leaks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESD isolated</td>
<td>43%</td>
<td>57%</td>
<td>16%</td>
<td>27%</td>
<td>30%</td>
<td>36%</td>
</tr>
<tr>
<td>Late Isolated</td>
<td>3%</td>
<td>4%</td>
<td>2%</td>
<td>2%</td>
<td>1%</td>
<td>3%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Leaks may be of very different natures:

▷ full pressure or partial pressure

▷ frequency dependent on pipe diameter

▷ impact dependent on success of emergency shutdown (ESD) valves

Source: issuu.com/dnv.com/docs/failure_frequency_guidance_process_
Example: uncertainty on initiating event frequency

Comparison between DNV guidance and Belgium government data

Source: Issuu.com/dnv.com/docs/failure_frequency_guidance_process_
Example: FIDES

▷ Reliability database for COTS electronic components
  • aeronautics and defence applications
  • detailed data on the impact of mechanical and thermal stress, on maintenance procedures; impact of design and quality assurance processes
  • data broken down by component supplier
  • also describes a reliability auditing method which allows the factors with most impact on reliability to be identified

▷ Aims to replace old standard MIL-HDBK-217F, which is overly pessimistic for COTS components

▷ Web: fides-reliability.org
Difficulties

- Pulling together information from **heterogeneous sources**

- Integrating the influence of numerous factors on reliability
  - operating conditions: vibration, product characteristics, climate
  - inspection and maintenance policies
  - technological evolution

- Integrating **uncertainty** from different data sources
  - level of representivity increases with the number of observations
  - safety cases: the level of risk estimated generally comprises a factor of 10 of uncertainty
Further reading

▷ IOGP report *Guide to finding and using reliability data for QRA*, available at www.iogp.org

▷ Booklet *Failure frequency guidance: process equipment leak frequency data for use in QRA* by DNV

▷ Risø technical report *Reliability Databases: State-of-the-Art and Perspectives*, available at orbit.dtu.dk

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