A Physics-of-Failure Approach for Common Cause Failures Subject to Age-Related

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Outline

- Introduction
  - Background and Motivations
  - Objectives
- Methodologies and Results
  - A CCF Model for Components under Age-Related Degradation
- Summary
  - Conclusions and Recommendations
Background

- Sources: historical observations and expert judgment
- CCF Model: shock model and non-shock model

Limitations of the CCF models:
- Built from generic operational experience and not specific to components.
- Do not model asymmetrical components
- Difficulties in modeling dependencies among component groups
- Limited observed CCF events
- Do not model degraded components
Objectives

▪ Develop a CCF model for components under age-related degradation:
  – Using data related to degradation (i.e., sensor-based condition monitoring data).
  – Advance CCF models to assist the studies of internal events of MUPRA.
  – Extend the generic parametric models to component-specific and dynamic.
  – Assess maintenance impacts.
At Time Step $k$, the formula for $\beta_k$ is given by

$$\beta_k = \frac{\sum_{j=1}^{N} \left\{ \left[ 2, \sum_{s=1}^{2} I\left( x_k^{(s,j)}, L_{f_j} \right) \right] \cdot \sum_{s=1}^{2} I\left( x_k^{(s,j)}, L_{f_j} \right) \right\}}{\sum_{j=1}^{N} \left\{ \left[ 1, \sum_{s=1}^{2} I\left( x_k^{(s,j)}, L_{f_j} \right) \right] \cdot \sum_{s=1}^{2} I\left( x_k^{(s,j)}, L_{f_j} \right) \right\}} \quad s = 1, 2; j = 1, \ldots, N.$$
Experimental Setup & Failure Analysis

- Process Monitoring: flow Rate, differential pressure, electric current, and electric voltage
- Vibration Monitoring: three single-axis accelerometers
- AE Monitoring: three AE sensors located at suction, bearing and motor.

<table>
<thead>
<tr>
<th>Pump</th>
<th>Duration Until Failure</th>
<th>Failure Mode</th>
<th>Failure Mechanism</th>
<th>Failure Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1954 hours</td>
<td>Seal fracture</td>
<td>Fatigue</td>
<td>Excessive fluid pressure on seal</td>
</tr>
<tr>
<td>2</td>
<td>5103 hours</td>
<td>Shaft Corrosion</td>
<td>Fretting corrosion</td>
<td>Fretting corrosion in the contact surface</td>
</tr>
<tr>
<td>3</td>
<td>4654 hours</td>
<td>Leak</td>
<td>Pitting Corrosion</td>
<td>Pitting corrosion in the contact surface</td>
</tr>
</tbody>
</table>
Insights:
- The value of degradation index by the end of each test are close.
- All three types of failure mechanisms follow the same functional path.
CCF at 1500 hours estimated based on the fractions of concurrent exceedance of failure threshold.
Results for Sensor-Driven Scenario

- With newly acquired sensor monitoring data at each time instant, the degradation state of each pump would be estimated and utilized to update the CCF estimate.

- Phase-1: low $\beta$-factor and independent failure dominant.
- Phase-2: $\beta$-factor approaches one since pump degrades without mitigating actions.
- Allow one to determine the time that is required to implement mitigating actions. ($\beta$-factor=0.05 at 2870 hours)
A condition-based maintenance policy

- Subject to periodical Inspection that is perfect
- Failure can only be detected at the time of inspection
- The maintenance is imperfect due to degree of repair
- Effectiveness is modeled by the Beta Distribution ($\alpha, \gamma$).

Assumed An Inspection Interval of 720 hours
The evolution of $\beta$-factor shows a periodical increasing trend.
- Mostly $\beta$-factor is close to zero and its distribution is highly skewed
- Treating CCF using mean $\beta$-factor is not sufficient
Results for Sensitivity Analysis

- $\beta$-factor ranges from 0.01 to 0.16
  - With longer inspection intervals, the $\beta$-factor monotonically increases
  - Better maintenance quality is associated with low $\beta$-factor. Poor maintenance quality with larger $\beta$-factor
  - A small degradation in maintenance quality would lead to significant increase of $\beta$-factor
  - Even under the perfect maintenance, it is still possible to underestimate plant risk
Conclusions

- Demonstrate the significance of CCF using a component-specific study
- Demonstrate the dynamic characteristics of CCF
- The age-related degradation and maintenance could significantly affect CCF
- Treating CCF with generic CCF parameters potentially underestimate plant risk if components degradation accumulates
- Treating CCF with generic CCF parameter potentially overestimates plant risk if maintenance effectively removes degradations
- The proposed approach estimates more component-specific CCF parameters
- Application of this approach to cases where little or no operational data are available such