US Navy- Condition Based Maintenance for aircraft fleet

Ben Davis, Sr. Solution Architect, Teradata
Data Analytics delivers Decision Superiority in the battlefield
Agenda

• Introduction to Condition-Based Maintenance
• CBM benefits
• Example of CBM analysis within the US Navy
• Implementing a CBM program
• Questions/Discussion
What is CBM?

• Prior to CBM, maintenance was performed by one of two methodologies:

  • **Preventive:** A determined number of hours, miles, cycles, etc. This approach to maintenance could be costly if the part in question had remaining useful life left and was replaced prematurely.

  • **Corrective:** When something broke, causing disruption to an operational schedule or mission.
What is CBM?

- CBM is **predictive** and focuses on assessing the **health** of components, utilizing testing techniques and/or sensors, to capture component health information before events become critical.
- Testing techniques vary widely and include:
  - Visual inspection,
  - Corrosion monitoring,
  - Vibration analysis,
  - Ultrasonic inspection,
  - Sensor monitoring,
  - Lubricant analysis,
  - Eddy current testing,
  - Other forms of analysis…
Predicting the Likelihood of a Failure

The P-F Interval

Condition

Aging

The P-F Interval

Vibration

Noise

Heat

Smoke

Fire
Analyzing the Onset of Failure

- **Statistical analysis**: Comparison of collected data against norms.
- **Pattern recognition**: Relationships between a certain event and component failure.
- **Trend analysis**: Data analysis to spot downward trends in component performance.
- **Range testing**: Analysis to determine if a component performance exceeds acceptable limits.
CBM Applicability

- **Must be cost effective:** The CBM effort over time should cost less than the financial impact of a failure.

- **The failure must be detectable:** Leading indicators of a faulty component must be measurable to determine the optimal time to repair the component.

- **A reliable P-F interval:** Maintainers need to act before the failure, but not too soon as to waste the usefulness of the part.

- **A practical P-F interval:** Maintainers need time to act upon the failing part before it fails completely.
Benefits of CBM

• Provides an indication of problems in time to minimize an unexpected failure,

• Reduces costs by minimizing downtime and increasing equipment lifespan,

• Reduces likelihood of a failure causing damage to other components,

• Reduces preventative maintenance and associated labor costs
CBM Challenges

- Initial implementation costs can be high:
  - Instrumentation
  - Data Collection & Storage
  - Employing Analytics
  - Staffing

- Changing from preventative to unpredictable maintenance intervals can lead to maintenance culture regime change
Navy CBM V-22 Analysis

Photo courtesy of the U.S. Navy
The Navy’s V-22 Challenge

1. 12 months worth of sensor data from the entire V-22 fleet.

2. The Navy would not provide any details about the problem, other than provide us the data.

3. The Navy would not provide a subject matter expert that understood the aircraft or the problem.
Analytics Process

Loaded Data → Initial Research → Performed Analysis → Results
Analysis

Photo courtesy of the U.S. Navy
Results

Temperature

Left Hanger Bearing Temperature: 107
Right Hanger Bearing Temperature: 64

Vibration

Left Hanger Bearing Vibration: 2050
Right Hanger Bearing Vibration: 989
Navy CBM H-60 Analysis

Photo courtesy of the U.S. Navy
The Navy’s H-60 Challenge

1. 13 months worth of sensor data from one aircraft.

2. The Navy would not provide any details about the problem, other than provide us the data.

3. The Navy would not provide a subject matter expert that understood the aircraft or the problem.
Analytics Process

1. Loaded Data
2. Initial Research
3. Performed Analysis
4. Results

Photo courtesy of the U.S. Navy
### Navy CBM H-60 Analysis

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>ALLOWABLE:</th>
<th>OBSERVED:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airspeed in Kts:</td>
<td>180</td>
<td>170.4375</td>
</tr>
<tr>
<td>Turbine Gas Temperature:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DANGER &gt;851°</td>
<td></td>
<td>ENG1: 910.00</td>
</tr>
<tr>
<td>CAUTION 810-851</td>
<td></td>
<td>ENG2: 949.00</td>
</tr>
<tr>
<td>NORMAL &lt;810</td>
<td></td>
<td></td>
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<tr>
<td>Main Rotor (Nr):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DANGER &gt;120</td>
<td>90-96, 101-120%</td>
<td></td>
</tr>
<tr>
<td>CAUTION 90-96, 101-120%</td>
<td>96-101%</td>
<td></td>
</tr>
<tr>
<td>NORMAL &lt;90%</td>
<td>118.97</td>
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<tr>
<td>Engine Torque:</td>
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<tr>
<td>DANGER &gt;105%</td>
<td>100-105%</td>
<td>ENG1: 148.50</td>
</tr>
<tr>
<td>CAUTION 100-105%</td>
<td>&lt;100%</td>
<td>ENG2: 147.75</td>
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<tr>
<td>NORMAL ≤100%</td>
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<tr>
<td>Engine Oil Temp:</td>
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<tr>
<td>DANGER &gt;150°C</td>
<td>135-150°C</td>
<td>ENG1: 124.0</td>
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<tr>
<td>CAUTION 135-150°C</td>
<td>&lt;135°C</td>
<td>ENG2: 125.0</td>
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<tr>
<td>NORMAL ≤135°C</td>
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<td></td>
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<tr>
<td>Engine Oil Pressure:</td>
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<tr>
<td>DANGER &lt;22 psi, &gt;120psi</td>
<td>22-26, 100-120psi</td>
<td></td>
</tr>
<tr>
<td>CAUTION 22-26, 100-120psi</td>
<td>26-100psi</td>
<td>ENG1: 174.00</td>
</tr>
<tr>
<td>NORMAL ≤26psi</td>
<td></td>
<td>ENG2: 169.50</td>
</tr>
<tr>
<td>Gas generator turbine speed (Ng) RPMs:</td>
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<tr>
<td>DANGER &gt;102%</td>
<td>98-102%</td>
<td>ENG1: 104.01</td>
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<tr>
<td>CAUTION 98-102%</td>
<td>&lt;98%</td>
<td>ENG2: 103.55</td>
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<tr>
<td>NORMAL ≤98%</td>
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<tr>
<td>Engine Power Turbine (Np) RPMs:</td>
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<tr>
<td>DANGER &lt;90%, &gt;105%</td>
<td>90-96, 101-105%</td>
<td></td>
</tr>
<tr>
<td>CAUTION 90-96, 101-105%</td>
<td>96-101%</td>
<td>ENG1: 111.50</td>
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<tr>
<td>NORMAL ≤96%</td>
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<td>ENG2: 111.00</td>
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<tr>
<td>Main Trans Oil Temp:</td>
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<td>101.00</td>
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<tr>
<td>DANGER &lt;22 psi, &gt;130psi</td>
<td>65-130psi</td>
<td>113</td>
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<tr>
<td>CAUTION 65-130psi</td>
<td>30-65psi</td>
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<tr>
<td>NORMAL ≤30psi</td>
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<td></td>
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</tbody>
</table>
We found at least 7 areas of concern related to this specific aircraft:

- TGT exceeded design limitations by 12%
- $N_r$ exceeded design limitations by 18%
- Engine Torque exceeded design limitations by 42%
- Oil Pressure exceeded design limitations 71%
- $N_g$ exceeded design limitations by 2%
- $N_p$ exceeded design limitations by 11%
- Excessive chip detection on 1 out of every 11 flights
create table flev_2_4_2
distribute by replication
as select *
from nPath(
on (select * from h60_events_v2_flat_partial) as ttt
PARTITION by 1
ORDER BY date_time
MODE (OVERLAPPING)
SYMBOLS (  
    (eventcode = 'SHAFTO1G') as S,
    (eventcode = 'SHAFTO1G' and extract(epoch from date_time) - extract(epoch from LAG(date_time,1,'2012-04-05 04:06:02.678-07')) < 4 ) as X,
    (eventcode != 'SHAFTO1G' and extract(epoch from date_time) - extract(epoch from LAG(date_time,1,'2012-04-05 04:06:02.678-07')) < 900 ) as OTHER
)  
PATTERN ('S.(X | OTHER){4}')
RESULT (ACCUMULATE)
Implementing CBM

• Obviously, a business requirement that recognizes CBM as a benefit to the organization.

• CBM requires data. *Usually LOTS OF DATA!* You’ll need a place to store the data (i.e., Data Lake, Hadoop, Teradata Appliance/IntelliBase™, Cloud/IntelliCloud™, etc.) and perform analysis.

• Your analytical requirements will vary… A multi-genre advanced analytics platform works best to perform analysis.

With the announcement of the Teradata Analytics Platform, users can easily apply a wide variety of analytic functions and analytic engines while utilizing an array of languages against multiple data types.
Questions
Teradata Everywhere™

Thank You!

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Questions/Comments
Email: jim.Wakefield@teradata.com