Condition Based Maintenance with PI AF

Keith Pierce and Curt Hertler, OSIsoft
2016 T & D Users Group
Moving Away from Calendar-based Maintenance

- **Preventive**
  - Calendar-based
  - Runtime-based

- **Condition-based**
  - Instrumented
  - Automated Readings
  - Manual Analysis

- **Predictive**
  - Model-Based Learning Systems

**Efficiency**

**Effectiveness**

**Reactive**
- “Break-Fix”
- Run-to-failure
CBM means different things to different people

Incipient Failure Detection
Condition Monitoring
Condition Assessment
CBM Preventive Maintenance
The 6 Steps of CBM with the PI System

1. Connect to relevant sources
2. Collect and archive data
3. Assign context (asset-based)
4. Execute condition monitoring logic
5. Visualize real-time conditions
6. Alert and notify
Data Flow and PI System Tools
Condition Monitoring with PI

- Bearing Vibration High Limit: 2 mils
- Control Oil Pressure Low Limit: 32 psi
- Discharge Flow Low Limit: 1700 lb/hr

Event Frame Template: Boiler Feed Pump Vibration Anomaly

- Name: OutboardYFault
  Expression: 'Outboard Bearing Vibration Y' > Limit
- StartTrigger: if InboardXFault or InboardYFault or OutboardXFault
  Evaluated at 3/29/2015 7:10:46 PM
Notify asset owner – include links to displays

http://dfpicoresight/Coresight/#/PBDISplays/10073
Linked PI System display from Notifications
PI Asset Analytics can be used to create Event Frames

- Event Frames
- Analyze Events over time
- Find common cause/failure modes
- Report on efficiency
Framing data - Start/End of a time window...

Define your Events

Start Time

End Time

Context

Event

Downtime

Referenced Asset(s)

Turbine WT12

Attributes

Reason Code

Comment

Excursion

Referenced Asset(s)

HVAC 039

Attributes

Average Humidity

Deviation from SP

Batch

Referenced Asset(s)

Mixer PM31

Attributes

Recipe

Product

Feed Source

Context

Framing data

- Start/End of a time window...

PI EF (Microsoft SQL)
Analytics Outcomes

Insights
- Operational Insight
- Unsuspected or Validated Correlation
- Multivariate analysis

Monitoring
- Limit, Rate of Change
- Efficiency, Performance, Accumulation
- Pattern Recognition

Use PI (time-series) data within IT
- Variety of data correlation
- Transform Business Process
- KPI Reporting (BI)
“We get a detailed breakdown on equipment costs and man/hours to service that gives us important business benefits. Without the use of the PI System, it would have taken us several months to gather and analyze the information.”

Angela Rothweiler, Principal Engineer

Customer Business Challenge
- Providing the highest reliability
  Power Distribution is requirement
- Minimize Maintenance Costs

Solution
- Implemented automatic data collection and notifications to SAP PM
- Set up standard business rules for condition based maintenance using the PI System Analytics
- Provided focused view into equipment
- Provided Financial access to data by Business Objects query

Customer Results / Benefits
- Holds Reliability award for Mid Atlantic States for last 7 years
- Named most reliable Power Company in America
- Focused maintenance expenditures on needed targets
Calculation Approach

• Calculation Structure
  – CA = F1(M1) + F2(M2) + F3(M3) + ...
  – Factors driven by data available
  – Example Factors
    • CM Cost & Count for Past 6 Months
    • Operation Count for Past 6/12 Months
    • Gas Analysis – Change over time
    • Average Load over Time

• Peer Groups
  – Apply calculations by peer group
  – Voltage, Class, Type
  – Example Groups:
    • 26KV – 69KV GCB
    • 138KV+ Power Transformer
    • LTC Vacuum Tanks
CBM data sources (T&D example)

PI System

Distribution SCADA

Transmission SCADA

ESOC PI

Transformer loads

MV90

Weekly substation inspection

PI

Transformer oil analysis

Hydran

Gas equipment results

CMMS order history Asset registry updates

Doble

Electrical results

Breaker Tests

Diagnostic data

Delta-X

Transformer oil analysis

External

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Asset health score - details

Algorithm Factors

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CA Score

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Benefits Summary

- More targeted capital expenditures with eventual overall reductions
- As incipient failures are reduced, corrective maintenance costs go down
- With a move to condition-based maintenance, calendar-based preventive maintenance is reduced
- Automation of condition-based notifications (emails, pages, maintenance notifications, etc.)
- Codification of organizational intelligence into condition-based algorithms
- Prioritization of maintenance, shorter downtimes, do the right work at the right time
- Improved visualization of asset health status
- Improved decision making capabilities
SDG&E Technical Overview
Condition Monitoring Examples

- Transformer
  - Detect Loss of Cooling Fans/Pumps
  - Detect Failed Control Contactor for Cooling Fans/Pumps
  - Collect Data on Run Hours for Fans/Pumps
  - Oil Temperature (Top & Bottom)
  - Winding Hot Spot Temperature (Calculated)
  - LV Load Current
  - Ambient Temperature
  - Eight gas DGA
  - Cooling System Manager / Monitor
  - HV Bushing Power Factor
  - LV Bushing Power Factor
  - LTC Position Indication & Operations Counter
  - LTC Motor Energy
  - Conservator Integrity
  - Provide Break-Out of Miscellaneous Bank Alarms

- Breakers
  - Gas Pressure / Density
  - Ambient Temperature
  - Air Compressor / Hydraulic Motor Hour Meter (optional-not in use)
PI Visualization
PI Visualization
OSIsoft Partner Ecosphere

Partner Types

**System Integrator**
System Integrator's (SI's) are partners who provide a variety of services, such as implementation and integration, strategic consulting, configuration, application.

**Application**
Application partners or Independent Software Vendors are partners that provide their own software applications and products which integrate and extend the PI System to provide additional functionality for customers.

**Technology**
Technology partners provide products and services with demonstrated interoperability with OSIsoft’s technologies and demonstrated relevance to OSIsoft’s customers.

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Roadmap to Readiness Resources

- www.osisoft.com/corporate/business-analytics
- https://techsupport.osisoft.com/Products/Product-Roadmap
- Learning channel, techcon, AF Example Kits, SPOC, etc.
CBM Prescriptive Guidance

Terms & Definitions

Implementation Guidance

PI System Overview for CBM

PI System Integration w/ CMMS

Enabling Opportunities

Solution Examples

Industry References

Predictive Analytics
**Statistical Modelling - Predict Asset Failure**

Complex systems; descriptive equations are too numerous and interrelated.

- Create an operationalized model to reduce unplanned downtime for 100 engines.
- Extract data for 2,300 sensors leading up to engine failures.
- Developed a statistical model using R for predicting failure.
- Tested and operationalized for all engines against historical data.

![Graph showing predicted vs. actual failures](image)
Using data taken from 100 engine failures, develop and operationalize a model for predicting failure to avoid unplanned downtime in real time.

Step 1 - Use AF Analytics to create Event Frames for engine operating periods.

Step 2 - Publish a text file “Event View” dataset from the PI AF using the PI Integrator for Business Analytics (BA).

Step 3 - Use the functionality of R to analyze this dataset and to develop a qualified predictive model for determining remaining useful life (RUL).

Step 4 - Implement the predictive model in AF Analytics, at scale, for all 100 engines.

Step 5 - Evaluate the predictive model using the PI Integrator for BA and Power BI Desktop.
Step 1
PI Analytics to create Event Frames
Lab PI System and AF Model “Engines”

• Actual data for 100 engines
  • 21 sensors
  • 3 settings

Lab PI System and AF Model “Engines”

- Actual data for 100 engines
  - 21 sensors
  - 3 settings
- Operating time to failure varies
  - Start time is always 2/21/16 12 am
  - Failure times are no later than 2/21/16 7:00 am
- Operating status
  - “Running”, “Failed”, “Stopped”

Event Frames for Engine Failure

• Create Event Frame template.

• Add “Event Frame Generation” analysis to “Engine” template.
  • StartTrigger: ‘Status’ = “Started”
  • EndTrigger: ‘Status’ = “Failed”

• Backfill analysis to generate Event Frames for each engine.
Step 2
PI Integrator to publish Event View
PI Integrator for Business Analytics - Select Data

- Create a PI Event View published as a text file.
- “Select Data”
  - Event Frames
  - Asset Template
  - Attributes
PI Integrator for Business Analytics – Modify View

- Create a PI Event View published as a text file.
- “Select Data”
  - Event Frames
  - Asset Element
  - Attributes
- “Modify View”
  - One minute samples
PI Integrator for Business Analytics – Publish

• Create a PI Event View published as a text file.
• “Select Data”
  • Event Frames
  • Asset Element
  • Attributes
• “Modify View”
  • One minute samples
• “Publish”
  • Create text file
Step 3
R script to derive predictive analytic
### R Script Summary - Review Engine Dataset

```r
sapply(e, sd)  # sdev for each variable
```

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**Setting 1**
- s1
- s2
- s3
- s4
- s5
- s6

**Setting 2**
- s7
- s8
- s9
- setting1
- setting2

**Setting 3**
- s9
- 0.000000e+00

---

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## R Script Summary – Remaining Useful Life

Remaining Useful Life (RUL) = (Event Frame Duration – Cycle) + 1

(Example, for engine (id) 1: 191 - 1 - 1)

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R Script Summary – Principal Components

Extract principal components

e.odd.pca = pcomp(e.odd.obs, scale = T, center = T)  # fit principal components (PC), use only odd engine data

# get pcl equation
pcleq = ""
for (j in 1:17) {
  pcleq <- cat(pcleq, " + ", names(e.odd.pca$center[j]), " * ", e.odd.pca$center[j], " + ", e.odd.pca$scale[j], " * ", e.odd.pca$rotation[j, 1])
}

# +('s11'-(47.5148)(521.4901))/0.2701003+0.3090913+(’s12’-(521.4901))/0.7517117-0.3049236+(’s13’-(238.09))/0.07484883+(’s14’-(338.81))/0.02845465+(’s15’-(8143.50))/19.7965+0.04163657+(’s16’-(8.438634))/0.03782789+0.2668222+(’s17’-(393.0714))/1.5619+64*0.2685557+(’s2’-(64.2.638))/0.5043607*0.2734667+(’s18’-(38.83337))/0.1812555*0.2819219+(’s19’-(23.29963))/0.10+0.2834525+(’s21’-(1590.048))/6.186916*0.2604444+(’s22’-(1408.104))/9.077463*0.3006121+(’s23’-(21.60976))/0.00+0.1539259*0.06360376+(’s24’-(553.4522))/0.9893562*0.2995252+(’s25’-(2388.091))/0.0738882+0.2847322+(’s26’-(9064.651))/22.72082+0.08204075+(’setting1’-(-3.554925e-05))/0.002184843*0.003580013+(’setting2’-(5.022518e-06))/0.0002931999*0.003136759
R Script Summary – Predictive Approach

- Calculate pc1 in real time for each engine.
- If pc1 is greater than a limit of 6.5, post warning in digital state tag.
Step 4
PI Analytics to test and operationalize analytic
Operationalizing in AF Analytics

- Copy R model into Engine analysis template.
- Use AF Analytics to scale up model for all 100 engines.
- Backfill calculation, trend Status and Predicted Status attributes check for sufficient advanced warning.
Step 5
Power BI Desktop to evaluate analytic
Evaluating the Prediction for All 100 Engines

- Use trending tool in PI System Explorer to evaluate on an engine-by-engine basis.
- PI Integrator with Power BI Desktop provides a much more efficient approach.
Evaluating the Prediction for All 100 Engines
Evaluating the Prediction for All 100 Engines

- Use the PI Integrator for BA to create a second dataset containing the Status and Predicted Status for all engines.

- Create a filtered bar graph in Power BI showing the amount of lead time the prediction gives before actual failure occurs.
Useful Links

Microsoft Power BI Desktop

Microsoft R Application Network
https://mran.microsoft.com

Power BI Custom Visuals
https://app.powerbi.com/visuals
Contact Information

Curt Hertler
curt@osisoft.com
Global Solutions Architect
OSIsoft
Thank You

감사합니다  
謝謝  
Merci  
Danke  
Gracias  
ありがとう  
Спасибо  
Obrigado