Monitoring & Diagnostic Center Technology: Transforming Equipment Reliability & Performance

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Who is WSC?

1. Equipment Reliability Program Deployment
2. M&D Center Development & Deployment Support
3. Continuous On-Line Monitoring (COLM) Technology Application
WSC Background

EPRI Monitoring & Diagnostics Center

- Communications
- Training
- Technical Services
- Networking
  - Maintenance
  - Controls
  - Monitoring
- Predictive Maintenance
- Condition Monitoring
- Technology Transfer
## On-Line Monitoring Technology Project in 2011 // 30K+ Sensors in 50 Plants

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### Turbine Critical Equipment
- Steam Turbine
- Combustion Turbine
- Generator
- Boiler

### Balance of Plant
- Motors, Pumps, Gearboxes, Fans
- Transformers
- Iso-Phase Bus Ducts
- Electrical Buses

### Phases

#### Phase I = Base Installation
- Temperature
- Accelerometers / Vibration
- Turbine Vibration Monitoring (VDMS - Vibration Diagnostics Monitoring System)
- Proximity
- Oil Analysis

#### Phase II = Critical Asset Sensors
- Cameras
- Thermal Cameras
- Infrared Sensors (IR)
- Electro Magnetic Signature Analysis (EMSA)
- Motor Current Signature Analysis Sensors (MCSA)
- CT (foreign object & leak detection)

#### Phase III = Performance Sensors
- Gaps in performance monitoring (combustion monitoring, etc.)
- Operational Sensors
- Focuses on reducing operational risk; event free index

### Equipment
- **NI CompactRIO** (reconfigurable embedded control and acquisition system)
- **NI cRIO-9024**
- **HP ProLiant Server ML350p Gen8**
- **NI InSightCM™ Enterprise**
- **NI InsightCM™ Data Explorer**
- **InStep PRiSM™ Pattern Recognition**
- **PlantView™ Health Modules / Fleet-Wide Dashboards**
- **MS Power Business Intelligence TBD**
Equipment Reliability Process

Monitor System & Component Health
Condition Based Maintenance Process

M&D Center
- Apply APR – Early Detection of Equipment Anomalies
- Apply Thermal Perf. Monitoring

Continuous On-Line Monitoring (COLM)
- Low cost advanced sensors
- Improve Early Detection of Equipment Anomalies

Identify Criticality of each Plant Component
- Establish MEL
  - Critical
  - Important
  - Run-to-Repair

PM Implementation (Time Based & CMT's)

CMT's: Condition Monitoring Tasks

Results Analysis & Corrective Action

Feedback for Improvement

Daily & Outage Work Management Process (Just-in Time)

Risk Grids
Project Prioritization

Long Term Asset Management

Establish Optimum PM Tasks

Results Analysis & Corrective Action
**Component Ownership Attributes**

- Component reliability/availability mgmt.
- Performing equipment assessments
- Update/management of component health status/reporting.
- 1ST called when component health is questioned.
- Component maintenance task basis (PM template)
- Continuous improvement of the maintenance task balance.

**Condition Monitoring Technologies**

- On-line Parameters
- Vibration
- Pressure
- Motor Current
- Lube Oil
- Thermography
- Performance Monitoring
Condition Based Maintenance Process

- Maintenance History
- Operator Logs
- Performance Testing
- Off-line Inspections
- Vibration
- IR Thermography
- Oil Analysis
- Electrical testing
- NDE
- Etc.
- Pressure
- Temperature
- Flow
- Amps
- Etc.

Acquire Data → Data Integration → Derive Information → Insights for Decision Making → Timely Corrective Action

“Communication is Key”
**Equipment Condition Status Report**

**Equipment Assessment** - on a periodic basis all the Collected (recent) Technology Exams are reviewed to form an overall assessment of the health of the equipment.

**Technology Exam** - equipment health information collected on a periodic basis via Manual or Automatic methods - such as Vibration, Lube Oil and Thermography, electrical testing, performance testing, etc.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Date</th>
<th>Vibration</th>
<th>Lube Oil</th>
<th>Health Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A5 seal air fan Motor (Mayo 1)</td>
<td>01/24/2012</td>
<td>01/22/2012</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1B Boiler Feed Pump Turbine (Mayo 1)</td>
<td>01/24/2012</td>
<td>01/30/2012</td>
<td>01/28/2012</td>
<td></td>
</tr>
<tr>
<td>1B absorber sruo pump (Mayo 1)</td>
<td>01/24/2012</td>
<td>01/30/2012</td>
<td>01/28/2012</td>
<td></td>
</tr>
<tr>
<td>1B secondary Hydrocyclone overflow</td>
<td></td>
<td>01/28/2012</td>
<td>01/28/2012</td>
<td></td>
</tr>
<tr>
<td>1B secondary Hydrocyclone overflow</td>
<td></td>
<td>01/28/2012</td>
<td>01/28/2012</td>
<td></td>
</tr>
<tr>
<td>1A5 pump motor (Mayo 1)</td>
<td>01/24/2012</td>
<td>01/22/2012</td>
<td>01/22/2012</td>
<td></td>
</tr>
<tr>
<td>1B boiler Feed Pump (Mayo 1)</td>
<td>01/24/2012</td>
<td>01/30/2012</td>
<td>01/11/2012</td>
<td></td>
</tr>
<tr>
<td>1B heater Drain Pump (Mayo 1)</td>
<td>01/23/2012</td>
<td>10/25/2012</td>
<td>12/16/2008</td>
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</tr>
<tr>
<td>1B absorber sruo pump motor</td>
<td>10/08/2008</td>
<td>10/01/2009</td>
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</tr>
<tr>
<td>1B1 Cooling Tower Fan Motor (K)</td>
<td>01/23/2012</td>
<td>01/23/2013</td>
<td>01/23/2013</td>
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<tr>
<td>1B2 primary air fan Motor (Mayo 1)</td>
<td>01/24/2013</td>
<td>01/22/2013</td>
<td>01/22/2013</td>
<td></td>
</tr>
<tr>
<td>1B4 Seal Air Fan Motor (Mayo 1)</td>
<td>01/23/2013</td>
<td>01/23/2013</td>
<td>02/21/2012</td>
<td></td>
</tr>
<tr>
<td>1B5 Pulverizer Motor (Mayo 1)</td>
<td>01/24/2012</td>
<td>01/23/2013</td>
<td>02/27/2012</td>
<td></td>
</tr>
<tr>
<td>1B4 fluid (Mayo 1)</td>
<td>01/24/2013</td>
<td>10/31/2012</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main Turbine Lube Oil (Mayo 1)</td>
<td>01/24/2013</td>
<td>10/31/2012</td>
<td></td>
<td></td>
</tr>
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Typical M&D Center

- Monitors process data available at the plants
- Utilizes Advanced Pattern Recognition Software
  - Applies New Smart Sensors
- Applies Thermal Efficiency Monitoring
  - Building dynamic models for major sites
- M&D Center detects small changes
- Notifies plant CBM specialist & system owners
APR Model Development

• Select related points

- Fan Amps
- Motor Winding Temp
- Motor OB Bearing Temp
- Motor IB Bearing Temp
- Fan IB Bearing Temp
- Fan OB Bearing Temp
- Inlet Vane Position
- Ambient Temp
- Air Flow
Monitoring with APR

Control System Alarm Level

Profile: Rox 2D BCWP
Signal: ROX02_TE-232DA

Actual (PRiSM History)  Predicted
### Equipment Condition Status Report – CBM Program Output

#### Equipment Assessments: Predictive Maintenance

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<tr>
<th>Equipment</th>
<th>Date</th>
<th>Vibration</th>
<th>Lube Oil Analysis</th>
<th>Infrared</th>
<th>On-Line Motor</th>
<th>Off-Line Motor</th>
<th>APR</th>
</tr>
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<tbody>
<tr>
<td>1A5 seal-air fan motor (Mayo 1)</td>
<td>02/07/2011</td>
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<td>05/15/2011</td>
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<tr>
<td>1B8 boiler feed pump turbine</td>
<td>02/15/2011</td>
<td>01/25/2013</td>
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<td>05/27/2013</td>
<td>10/13/2013</td>
<td>09/10/2011</td>
<td>05/15/2011</td>
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<tr>
<td>1B9 absorber sump pump</td>
<td>01/22/2013</td>
<td>01/25/2013</td>
<td></td>
<td>05/27/2013</td>
<td>10/13/2013</td>
<td>09/10/2011</td>
<td>05/15/2011</td>
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<tr>
<td>1A secondary hydracyclone overfl</td>
<td>01/28/2013</td>
<td>01/28/2013</td>
<td></td>
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<td></td>
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<td>02/01/2013</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>05/15/2011</td>
</tr>
<tr>
<td>81 fly ash pressure blower (Mayo</td>
<td>02/02/2013</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>05/15/2011</td>
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<tr>
<td>Hydrated Lime Unloading Pressure</td>
<td>01/24/2013</td>
<td></td>
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#### Equipment Assessment – on a periodic basis all the collected (recent) Technology Exams are reviewed to form an overall assessment of the health of the equipment.

#### Individual Component Health Status

#### Advanced Pattern Recognition - New Condition Indicator
Traditional & Advanced Continuous On-Line Monitoring

Advanced OLM – Level 4
Apply Advanced Prognostic Software Algorithms to Estimate Remaining Useful Life

Advanced OLM – Level 3
Apply Multiple Algorithms & Expert Systems for Auto Diagnosis

Advanced OLM – Level 2
Dynamic Signal Feature Extraction, & Advanced APR Models to Improve Anomaly Detection

Traditional OLM – Level 1
Apply APR Technology for Early Identification of Equipment Anomalies

Advanced COLM – Level 4: Prognostics
Requires both FMEA analysis and engineering studies on current condition and maintenance history to apply advanced algorithms to predict remaining useful life (RUL). Advanced applications also apply Artificial Intelligence (AI) and prescriptive technologies and provide recommended work packages associated with identified failure types.

Advanced COLM – Level 3: Diagnostics
Expands FMEA Analysis use to speed diagnosis. Greater application of advanced algorithm techniques and diagnosis support capabilities to validate anomalies and auto diagnose certain failures modes, based on sensor inputs.

Advanced COLM – Level 2: Additional Sensors
Uses FMEA analysis to influence addition of more online sensors. Dynamic signal feature extraction can improve “Anomaly Detection”. (Example: extract 1x, 2x features from a vibration sensor time waveform and APR models can be focused on identifying anomalies to allow for more effective diagnosis of equipment issues.

Advanced COLM – Level 1: APR Application
Use existing/available sensors/process data to apply APR software/models to provide for monitoring & alerting – “Identifying Anomalies”
M&D Center (and COLM level I) Limitations
Value of Additional Sensors - Pump Example

What we have in M&D APR Model Today:
- Pump Status – turn model on/off
- Thrust Bearing Temperature
- Stator Temperature
- Motor Lo Sleeve Bearing Temperature

What we don’t have:
- Individual Pump Suction Pressure (Local Gauge Instrument)
- Individual Pump Discharge Pressure (Local Gauge Instrument)
- Suction Flow (Not available – HDR.FLOW ONLY)
- Discharge Flow (Not available – HDR.FLOW ONLY)
- Header Discharge Pressure (in PI – cannot be correlated at the component level)
- Header Flow (in PI – cannot be correlated at the component level)
- No motor current or voltage
- No vibration data (taken monthly manually)
- No oil information in PI

Motor/Pump Failure Modes
- High Bearing Temperature
- High Motor Winding Temp
- Worn Thrust Bearing
- Motor Bearing Lubrication
- Worn Motor ODE Bearing
- Worn Pump DE Bearing
- Worn Pump Internals
- Shaft Misalignment
- Shaft Imbalance
- Power Supply Harmonics
- Power Cable Damage
- Rotor Bars Broken
- Stator Winding Fault
- Rotor Eccentricity
- Loose Foundation
- Pump Cavitation
- Supply Line Power Problem

Advanced Motor Current Analysis
NI Wireless Vibration & Temperature
Wireless Gauge Readers
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**NI CompactRIO**
- (reconfigurable embedded control and acquisition system)
  - NI cRIO-9068 / NI cRIO-9074

**NI InsightCM™ Enterprise**
- NI InsightCM™ Data Explorer
- NI InsightCM™ Server

**PlantView™**
- Health Modules / Fleet-Wide Dashboards

**InStep PRiSM™**
- Pattern Recognition

**NI InSightCM™ Data Explorer**
- Efficiency Monitoring & Thermal Modeling

**Advanced Analytics**
- TBD

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*Image: WSCInc.*
Continuous On-line Monitoring Transformation
New sensors - integrated analysis – automated diagnostics & prognostics

- Leveraging technology
- Remain the same

Reduced 90% of all manual vibration data collection (60,000 points)
COLM Levels III and IV
Advanced Monitoring Diagnostics & Prognostics

Remaining Useful Life (RUL) Indicators:
- >33% - Green
- <33% - Red

- Shaft Mis-alignment: 98%
- Diffuser Mechanical: 88%
- Motor ODE Brg. Worn: 24%
- Power Supply Harmonics: 74%
- Motor Brg. Lubrication: 82%
- Motor DE Brg.: 63%
- Shaft Imbalance: 82%
- Motor Overheat: 82%
- Motor DE Brg.: 82%
- Power Cable damage: 92%
- Motor Overheat: 82%
- Motor DE Brg.: 82%
- Stator Winding Fault: 74%
- RotorBars Broken: 30%
- Rotor Eccentric: 81%
- Pump Inboard Brg. Worn: 96%
- Pump Outboard Brg. Worn: 96%
- Loose Foundation: 88%
- Worn Internals: 88%
- Pump Cavitation: 77%
- Pump Inboard Brg. Worn: 92%
- Loose Foundation: 88%
ER Program – Return On Investment

<table>
<thead>
<tr>
<th>Total</th>
<th>Finds</th>
<th>584+</th>
<th>Cost Avoidance</th>
<th>$83.15M</th>
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<tr>
<td>2016 YTD</td>
<td>200+</td>
<td>200+</td>
<td>$51.65M</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>198</td>
<td>198</td>
<td>$18.26M</td>
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<tr>
<td>2014</td>
<td>134</td>
<td>134</td>
<td>$4.39M</td>
<td></td>
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<tr>
<td>2013</td>
<td>52</td>
<td>52</td>
<td>$8.85M</td>
<td></td>
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2016 has already exceeded $50M!!

From 2013 to 2016

4x increase in Equipment Anomaly Detection

$10M-$40M annual increase in avoided cost.
Questions?