Best Practices in PHM and Application to Manufacturing

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IMPACT CORE TECHNOLOGY AREAS

HARDWARE

- Smart Embedded Monitoring Devices
- Wired/Wireless Data Collectors
- Wireless Vibration Sensor
- Fluid Condition and Debris Monitoring

SOFTWARE

- IMPACT CORE TECHNOLOGY AREAS
- Wired/Wireless Data Collectors
- Wireless Vibration Sensor
- Fluid Condition and Debris Monitoring
SOME EXAMPLE PHM SUCCESSES

Health Alerts

Data Driven Inspection

New Condition Indicators

Maintenance Triggers

Component Retirement Adjustment S-92 MR Hub

Fleet Analysis

Focused Troubleshooting

TBO Extensions

Anomaly Detection
TOTAL PRODUCTIVE MAINTENANCE

The 5S (or 6S) Foundation

- Sort (eliminate anything that is not truly needed in work area)
- Set in Order (organize remaining items)
- Shine (clean and inspect work area)
- Standardize (create standards for performing above three activities)
- Sustain (ensure the standards are regularly applied)
- Safety (Job 1)

<table>
<thead>
<tr>
<th>Component</th>
<th>TPM Goal</th>
<th>Type of Productivity Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability</td>
<td>No Breakdowns</td>
<td>Availability takes into account <strong>Down Time Loss</strong>, which includes all events that stop planned production for an appreciable length of time (typically several minutes or longer).</td>
</tr>
<tr>
<td>Performance</td>
<td>No Small Stops or Slow Running</td>
<td>Performance takes into account <strong>Speed Loss</strong>, which includes all factors that cause production to operate at less than the maximum possible speed when running.</td>
</tr>
<tr>
<td>Quality</td>
<td>No Defects</td>
<td>Quality takes into account <strong>Quality Loss</strong>, which factors out manufactured pieces that do not meet quality standards, including pieces that require rework.</td>
</tr>
<tr>
<td>Overall Equip.</td>
<td>Perfect Production</td>
<td>OEE takes into account all losses (Down Time Loss, Speed Loss, and Quality Loss), resulting in a measure of truly productive manufacturing time. &gt;85% considered WC</td>
</tr>
</tbody>
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### OVERALL EQUIPMENT EFFECTIVENESS

<table>
<thead>
<tr>
<th>Six Big Losses</th>
<th>OEE Category</th>
<th>Examples</th>
<th>Comments</th>
</tr>
</thead>
</table>
| Breakdowns           | Down Time    | • Tooling Failure  
                      | Loss                                                                 | There is flexibility on where to set the threshold between a Breakdown (Down Time Loss) and a Small Stop (Speed Loss). |
| Setup and Adjustments| Down Time    | • Setup/Changeover  
                      | Loss                                                                 | This loss is often addressed through setup time reduction programs such as SMED (Single-Minute Exchange of Die). |
|                      | Speed Loss   | • Component Jam  
                      |                                                                 | Typically only includes stops that are less than five minutes and that do not require maintenance personnel. |
| Slow Running         | Speed Loss   | • Incorrect Setting  
                      |                                                                 | Anything that keeps the equipment from running at its theoretical maximum speed. |
|                      | Quality Loss | • Scrap  
                      |                                                                 | Rejects during warm-up, startup or other early production. |
| Production Defects   | Quality Loss | • Scrap  
                      |                                                                 | Rejects during steady-state production. |

\[
\text{OEE} = \frac{\text{Good Pieces} \times \text{Ideal Cycle Time}}{\text{Planned Production Time}}
\]
COMPARING PHM/CBM WITH OTHER APPROACHES

<table>
<thead>
<tr>
<th>Corrective Maintenance</th>
<th>Condition-based Maintenance</th>
<th>Preventive Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment Neglect and Corrective Actions Dominate</td>
<td>PHM/Predictive CBM – the Right Amount</td>
<td>Overly Preventive &amp; Maintenance Induced Failures Dominate</td>
</tr>
</tbody>
</table>

Availability or Equipment Effectiveness

Total Ownership Cost

Number of Maintenance Actions
VALUE OF PROGNOSTICS & CONDITION MONITORING

Early detection of incipient fault and warnings based on health and usage-based prognostics

Value of quality monitoring: (SPC, TPM)
- Condition Monitoring Threshold Alarms
- Quality and Performance Issues
- Component failure
- Catastrophic failure & secondary damage

Timeline

Value of prognostics:
Remaining useful life (Prognostic Maintenance)

Value of better condition monitoring:
Detect failures at an early stage (Condition-Based Maintenance)

Value of safety system:
Prevent catastrophic failure (Reactive maintenance)

Value is a function of how failure progresses, its detectability & detection and prediction methods used
PROGNOSIS AND CBM

With Reliability Centered Maintenance

Time to Action

Based on Population Statistics

Results in:
Scheduled preventative maintenance

With Condition-Based Maintenance + Prognostics (CBM+)

Remaining Useful Life

Results in:
Opportunistic maintenance at no additional risk

Aggressive

Actual conditions

Benign
ELEMENTS OF A CBM SOLUTION

Monitoring and Anomaly Detection

Maintenance Tasking and Scheduling

Diagnosis and Prognosis
A DISTRIBUTED ARCHITECTURE

- Data Archival and Management
- Anomalies and Asset Monitoring
- Diagnostic and Prognostic Functions
- Local and Remote Decision Support
- Connection to SCADA and CMMS

Central CBMi Software

Data Acquisition Node - produces ‘features’ from High-Bandwidth Data

Node

Wired or wireless

Sensor

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GENERAL PROGNOSTICS
CLASSES/APPROACHES

Usage-based Prognostics

This approach incorporates reliability data, life usage models and varying degrees of measured or proxy data. Forecast based on actual usage when possible. Incipient fault detection may not be available due to sensor or fault mode coverage limitations.

Condition (Health)-based Prognostics

This approach involves utilizing the assessed health or diagnostic fault classifier output to predict a failure evolution. Feature trending or physics-of-failure based prediction may then be used. Incipient fault detection and diagnostic isolation is absolutely necessary.

*Hybrid techniques or fusion approaches may also be used.
DETECTION THROUGH PROGNOSTICS

Functionality, Design, Reliability, & Failure History

- FMECA & PHM Design Analysis
- Sensing and Feature Analysis
- Anomaly Detection & Diagnostics
- Prognostics

Healthy Unit and Fleet-wide Data/Models

- Naturally Occurring or Seeded Fault Data/Models
- Transitional Degraded State D/M

Physical Effects Models

Classification and Identification Algorithms

Tracking and Predictive Models
MAN-PHM SUMMARY AND CHALLENGES

- Typical manufacturing environments have rich data potential to develop greater prognostics using usage, health, and hybrid modeling approaches.

- A wide range of prognostic approaches is available with selection depending upon available system information and data quality.

- Predicting future events is difficult and the accuracy is highly influenced by multiple sources of uncertainty making a probabilistic approach vital.
  - Signal noise, operating modes, actual effective usage capture.
  - Condition indicators not fully characterized for failure mode identification.
  - Tracking of design life / wear / damage progression.
  - Uncertainty in data, system parameters, models, etc.
  - Insufficient data, case studies, diagnostic/prognostic validation.

- Combining both physics of failure and health based approaches often aid in managing these limitations and uncertainties.

- Goal is to reduce unscheduled maintenance to “near zero” and minimize scheduled maintenance to “truly” on-condition to produce highest uptime at lowest overall maintenance cost.

- Translate these capabilities to key manufacturing metrics such as OEE (Overall Equipment Effectiveness) and possibly others?