Selecting Optimal Data for Creating Informed Maintenance Decisions in a Manufacturing Environment

The Data Dump - *Don’t Drown in Trash: Curating ‘Minimum Viable’ Data Sets*

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Introduction

- Optimal maintenance strategies require informed decision making that utilizes timely, concise, and contextualized information gathered from a range of sources throughout a manufacturing facility.

- In an age where data production is ubiquitous, how do you structure a monitoring program to provide needed information at every decision level of a production facility without overwhelming a decision maker?
Who We Are

NIST EL Manufacturing Division:

• System Integrations Division -
  • Model-Based Smart Manufacturing Operations Management
    • Facilitate standards and test methods for connecting and utilizing shop floor information in operations decision making and execution.
  • Knowledge Extraction and Application for Manufacturing Applications
    • Discover and synthesize implicit or tacit knowledge from human driven input sources for use in maintenance and procedurally driven activities

• Intelligent Systems Division -
  • Prognostics and Health Management and Control
    • Develop the necessary measurement science to verify and validate emerging monitoring, diagnostics, prognostics, and maintenance technologies and strategies for smart manufacturing.
Overview

• Motivation
  • What is the need?
  • What is the design process requirements philosophy?
• Terminology
  • Loose definitions
  • Basic concepts
• Thought Process
  • Process Flow
  • Information Flow
  • Designation of Monitoring Systems
• Information Level Needs Breakdown
  • Decision Levels and Requirements
Motivation

- Modern manufacturing facilities have the ability to collect unprecedented amounts of data and information about both processes and assets
  - Not all relevant to every action or decision
  - Some could be relevant, but lack some critical element limiting its usefulness
- Superfluous or unused data collection ties up valuable resources and wastes both time and money
Motivation

- How do you optimize a monitoring program to provide critical information for a given goal without inundating the user with extraneous data?

- Should support:
  - Automated or AI augmented decision making
  - Model based monitoring and predictive analytics
  - Factory floor changes
  - Disparate information sources
    - Qualitative & Quantitative reports
    - Digital sensing and data records
    - Analog inspections and reports

Optimized Maintenance Operations

- Timeliness
- Synthesize Relevant Info
- Contextualization
- Filter Bad/Useless data
- Sensors
- Inspections
Motivation

- Effectiveness is the extent to which planned activities are realized and planned results achieved - ISO 55000

- Ideal data collection should be ‘goal oriented’
  - The end use of the data/information directly informs what data is required

- Top down design of decision support asks:
  - ‘What is the minimum data I need to answer my questions?’
Terminology

• Broad Levels of Decision Making
  • System
    • Composed of equipment and subsystems
    • Completes one or more production tasks
  • Equipment
    • Composed of components and/or other equipment
    • Described as “functionally complete” units
  • Component
    • Defined by a single, static functional capability controlled parametrically by well-defined inputs and expected effects
    • Can be maintained (or replaced) independently of the equipment it’s a part of

Lowest Replaceable (Reparable) Unit

• The level at which it is no longer feasible to subdivide an asset for maintenance activities
System Level

Example Decisions
- Which jobs should be assigned?
- Are my technicians available?
- When should maintenance be scheduled?
- What parts are needed for jobs?

Equipment Level

Example Decisions
- What caused equipment failure?
- How to fix the failure?
- When will the equipment fail next?
- How long will it take to maintain?

Component Level

Example Decisions
- Should this component be operated?
- Has the component failed?
- What is the component condition?
- Does the component meet the needs?
Supporting data is contextualized and pushed up through each level to provide critical information relevant to the active decision being made.

Example Information Workflow

- **Maintenance Tasks**
- **Production Tasks**
- **System State**
  - Capability
  - Capacity
  - Availability
  - Performance
- **Equipment State**
  - Capability
  - Capacity
  - Availability
  - Health
- **Component Performance**
  - Health
  - Availability
Information Feed Breakdown

Major Input → 
Minor Input →

Note that a Process Task breakdown would have more reliance on the System Level.
How do you decide what to monitor?

The goal is to monitor mission critical assets and supporting assets that are above a risk threshold and have failure modes that allow for preventative or corrective actions to be taken.

General Recommendations:
- Manage the minimum set of sensors and inspections that fulfill your needs
- Sense or inspect no more detailed than the LRU level
How do you decide what to monitor?

**Typical Questions:**

What are the mission critical / high value assets?

What assets are directly linked to, or interact with those assets?

What are the impacts of failure of each asset?

What is the frequency of these failure?

Which assets can be quickly replaced/ repaired with in house resources?

What are the failure mechanisms that exhibit symptoms with an actionable time window?

Which failure modes can be monitored by active sensors?

Which are better served by having human investigators?
Information Level Needs Breakdown

- What is the availability of this equipment?
- Can this component safely complete the planned duty cycle?
- What Operations tasks are needed?
- When? Where?
- Which resources?

Design of Decision Support Systems
Concerned with performance metrics such as: throughput, cycle-time, and cost

Production Scheduling

- Which production jobs can be assigned to this piece of equipment?
- Is it available and capable?
- If the equipment is down, what other equipment can this job be routed to?

Maintenance Scheduling

- When should maintenance tasks be generated (planning)?
- How to prioritize maintenance jobs?
- When they be performed (scheduling)?
System Level Supporting Data

Equipment State (Current and Future)
- Capability
- Availability
- Capacity

Maintenance Queue
- Priority/Criticality of tasks
- Availability of resources (personnel, material, parts, etc.)
- Impacts on throughput
- Coordination of tasks (i.e. opportunity-driven priority)

Production Queue
- Priority/Criticality of tasks
- Availability of resources (personnel, systems, material, parts, etc.)
- Current buffer states

Design of Decision Support Systems
- Production & Maintenance Queues
- Priority Rankings
- Resource Availabilities

System Level
- What is the availability of this equipment?

Equipment Level
- Can this component safely complete the planned duty cycle?

Component Level
System Level Example

• Observation:
  • Equipment State -
    > Mill Machine Unavailable
    >> Milling bit damaged

• Decision:
  • Production –
    Assign jobs to different equipment
  • Maintenance –
    Generate and schedule a maintenance task

- What is the availability of this equipment?
- Can this component safely complete the planned duty cycle?
Equipment Level Example Decisions

- What is the availability of this equipment?
  - Should I operate this equipment?
    - Are all critical components in a state to allow safe completion of the planned duty cycle?
    - Can the equipment produce parts or perform services to the required minimum level of quality in its current state?
    - Can the equipment be in a different configuration to better meet requirements?
- What maintenance activities should be prioritized?
  - How critical are component level maintenance requests?
  - What, if any, is the equipment level relationship between diagnosed component degradation?
  - What is the criticality and time horizon of potential faults or failures?
Equipment Level Supporting Data

- **Maintenance Work Order Data**
  - Past Problem/solution records
  - Risk assessments
  - Resource needs (e.g., people, parts, tools)

- **Equipment Specifications**
  - Equipment manuals and schematics
  - Taxonomy of components in equipment
  - Population fault/failure rates

- **Equipment State**
  - Health information
  - Predicted faults/failures/etc.
  - Component level maintenance requests

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- **System Level**
  - What Operations tasks are needed?
  - When? Where?
  - Which resources?

- **Equipment Level**
  - Current Capability / Capacity
  - Dependent Component States
  - Component interactions

- **Component Level**
  - Can this component safely complete the planned duty cycle?
Equipment Level Example

• Milling Machine
  • Observation:
    – System Request: Available to Mill Part?
    – Component State: Mill Bit Damaged
  • Decision:
    – Reduce availability: Refuse Milling
  • Maintenance Task:
    – Request Replace Bit

Design of Decision Support Systems

- What Operations tasks are needed?
- When? Where?
- Which resources?

Current Capability / Capacity
- Dependent Component States
- Component interactions

Can this component safely complete the planned duty cycle?

Supporting Data Needs
- Design of Decision Support Systems
- Equipment Level
- System Level
- Component Level

Equipment Level Example
Component Level Example Decisions

- Can this component safely complete the planned duty cycle?
  - Is the component available?
    - Is the component functioning?
    - Is the component currently occupied with some other task?
    - What is the risk of failure during the current/next duty cycle?
  - Does it have required capability/capacity?
    - What is the current health?
    - What are the OEM specifications?
  - What are the upcoming maintenance actions required for this component?
    - What are the predicted time horizons of any currently identified incipient faults?
    - Are any event-based or condition-based maintenance triggers eminent?

Design of Decision Support Systems

- What Operations tasks are needed?
- When? Where?
- Which resources?

- What is the availability of this equipment?

- Health or Fault Trends
- Expected Workload
- Maintenance Needs
Component Level Supporting Data

Capacity Specifications
- Possible configurations of component
- Nominal work loads

Condition assessment information
- Human interrogators
- Sensors
- Analytic models

Anticipated Future Performance
- Planned duty cycles
- Probabilistic modeling

Maintenance planning
- Needed resources
- Maintenance work order data
- OEM Maintenance recommendations

- Design of Decision Support Systems
  - What Operations tasks are needed?
  - When? Where?
  - Which resources?

- System Level
  - What is the availability of this equipment?

- Equipment Level
  - Health or Fault Trends
  - Expected Workload
  - Maintenance Needs

- Component Level
Component Level Example

• Milling Tool
  • Observation:
    – Elevated vibrations
  • Decision:
    – Reduce availability:
      Limit Max RPM
  • Maintenance Task:
    – Replace Tool

Design of Decision Support Systems

- What Operations tasks are needed?
- When? Where?
- Which resources?

- What is the availability of this equipment?

Component Level
- Health or Fault Trends
- Expected Workload
- Maintenance Needs

System Level
- What Operations tasks are needed?
- When? Where?
- Which resources?

Equipment Level
- What is the availability of this equipment?
Example Case – Maintenance Planning

System level
Input - Maximize throughput
Tasks - Identify & Prioritize Critical Equipment:
Goal – Maximize Availability

Equipment level – Critical Equipment
Input - Maximize Availability
Tasks - Identify High Risk Components
Goal – Minimize Component Failure

Component Level – High Risk Components
Input – Minimize Component Failures
Tasks – Identify Failure Modes
Monitor Failure Modes
Goal – Predict Failure Time Horizon
System Level

Equipment Level

Equipment 1
- MTBF: 30 mins
- MTTR: 45 mins

Equipment 2
- MTBF: 60 mins
- MTTR: 30 mins

Component Level

Component 1

Component 2

Production

Fix Eq 1 then Eq 2
Fix Eq 2 then Eq 1
Thank you

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