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*
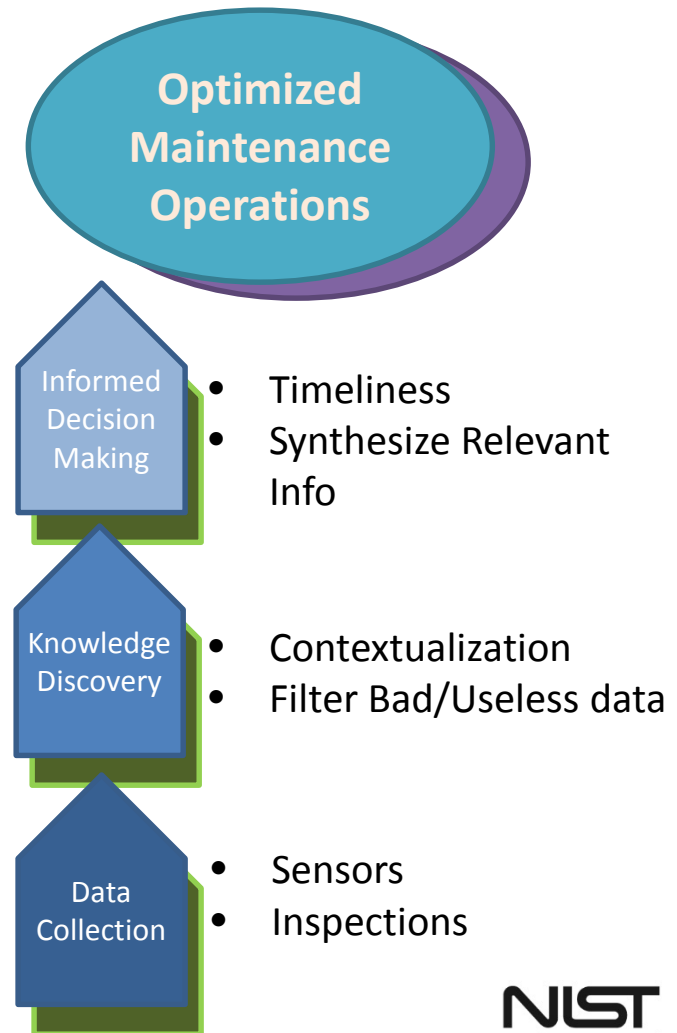
Authors: Michael Sharp, Michael P. Brundage, Timothy Sprock, Brian A. Weiss

NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

Disclaimer:

Commercial equipment and materials might be identified to adequately specify certain procedures. In no case does such identification imply recommendation or endorsement by the U.S. National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

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?

Optimized Maintenance Operations

Informed Decision Making
- Timeliness
- Synthesize Relevant Info

Knowledge Discovery
- Contextualization
- Filter Bad/Useless data

Data Collection
- Sensors
- Inspections

NIST
National Institute of Standards and Technology
U.S. Department of Commerce
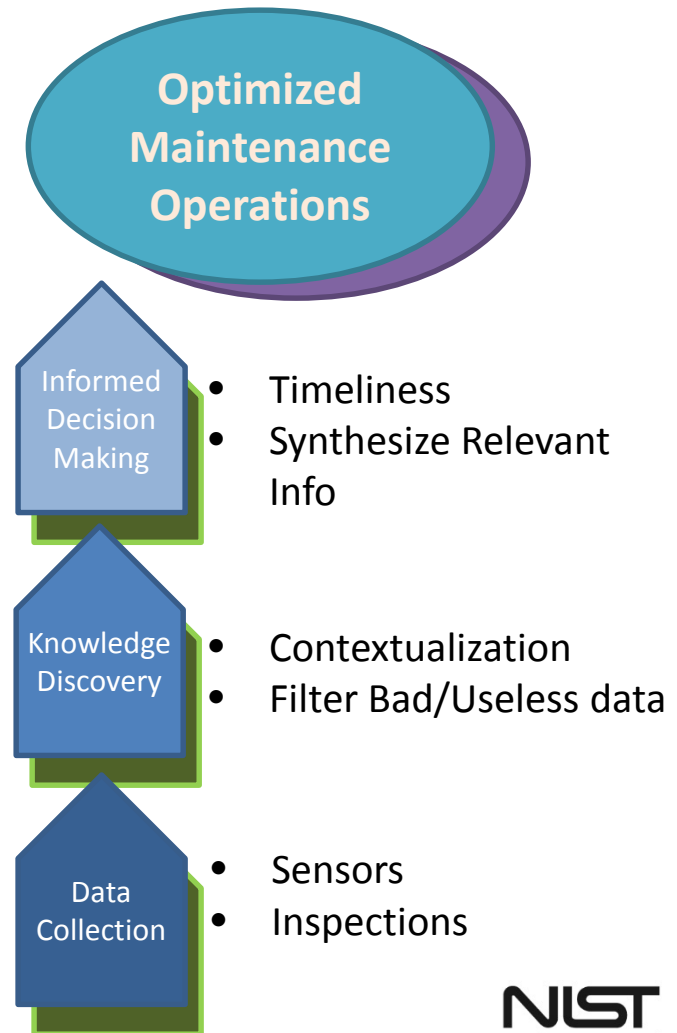
Who We Are

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

NIST
National Institute of
Standards and Technology
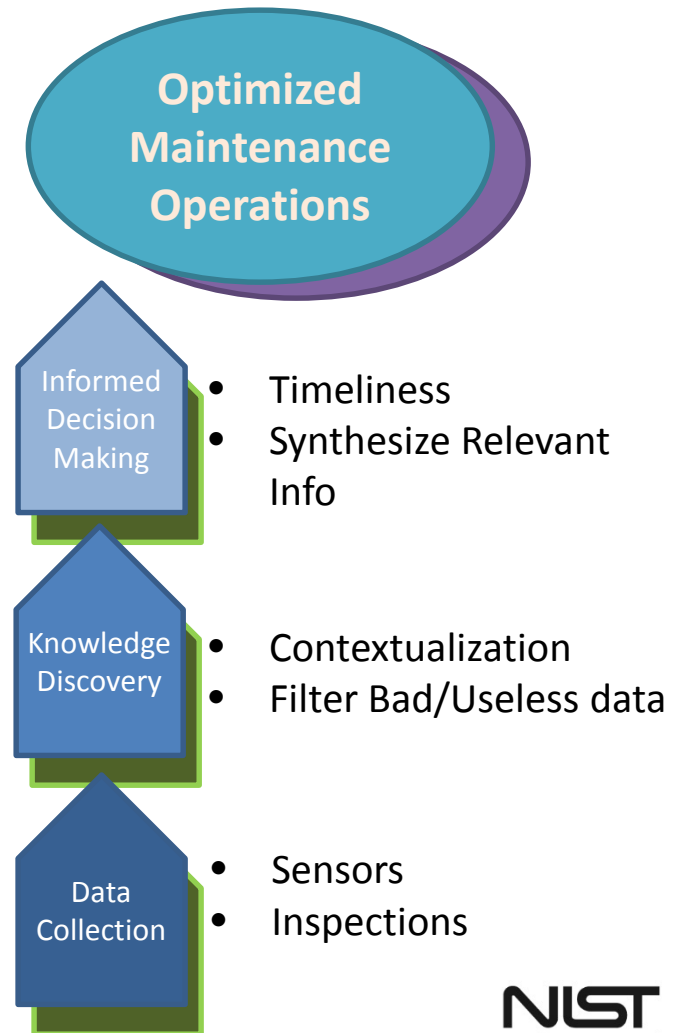U.S. Department of Commerce

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

Optimized Maintenance Operations

Informed Decision Making
- Timeliness
- Synthesize Relevant Info

Knowledge Discovery
- Contextualization
- Filter Bad/Useless data

Data Collection
- Sensors
- Inspections

NIST
National Institute of
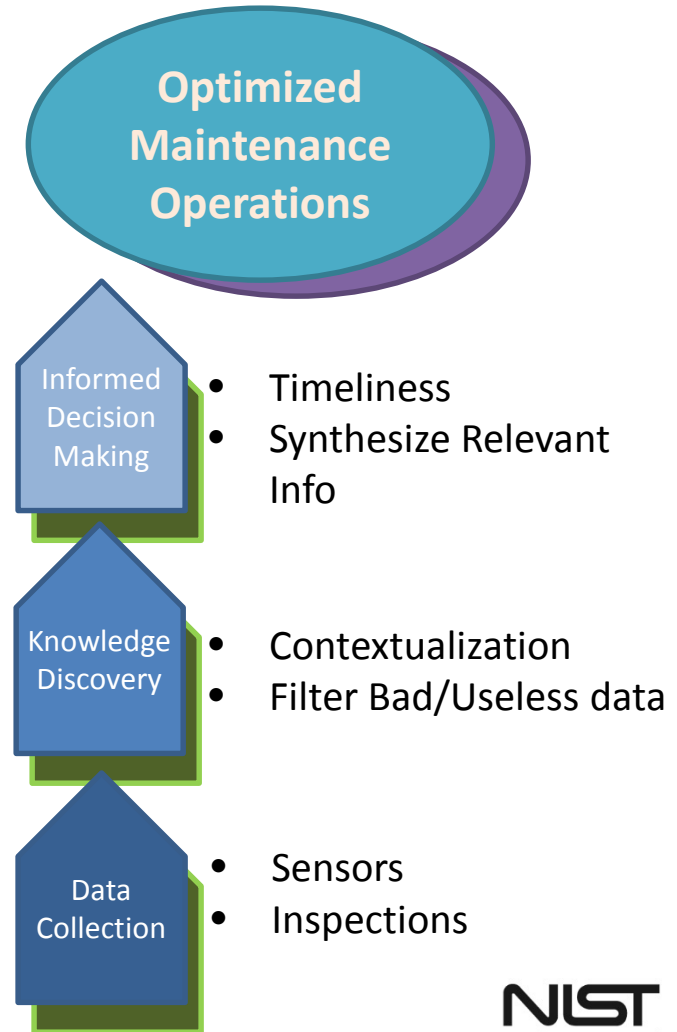Standards and Technology
U.S. Department of Commerce

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

Informed Decision Making
- Timeliness
- Synthesize Relevant Info

Knowledge Discovery
- Contextualization
- Filter Bad/Useless data

Data Collection
- Sensors
- Inspections

NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

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?'

Optimized Maintenance Operations

Informed Decision Making
- Timeliness
- Synthesize Relevant Info

Knowledge Discovery
- Contextualization
- Filter Bad/Useless data

Data Collection
- Sensors
- Inspections

NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

Terminology

- Broad Levels of Decision Making

  - ## System
    - Composed of equipment and subsystems
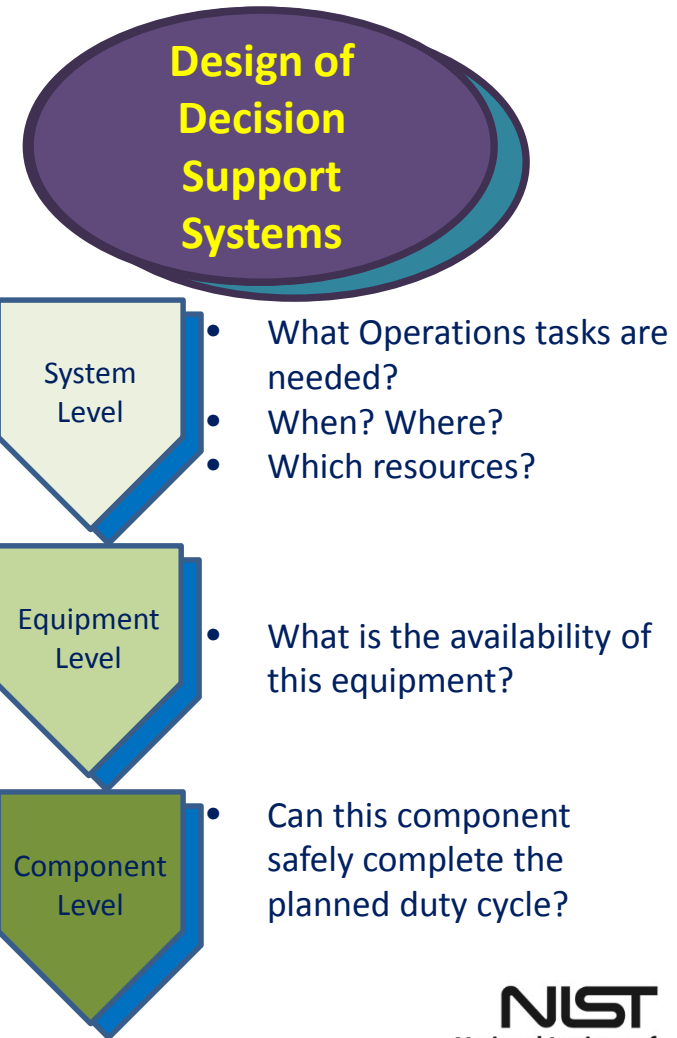   - Completes one or more production tasks

  - ## 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
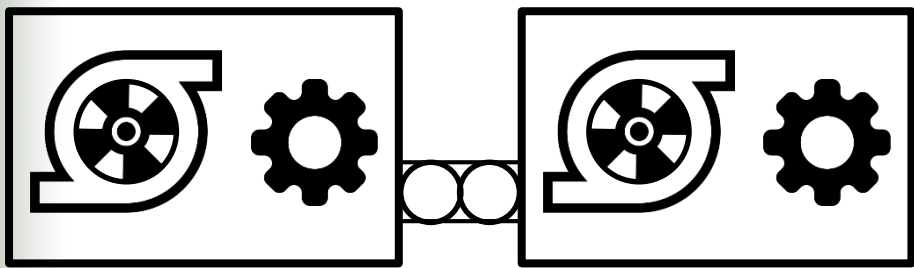   - Can be maintained (or replaced) independently of the equipment it's a part of

Lowest Replaceable (Reparable) Unit

- *The level at which it is no longer feasible to sub-divide an asset for maintenance activities*

**Design of Decision Support Systems**

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

Equipment Level
- What is the availability of this equipment?

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

4/5/2019

9

NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

System Level

Which jobs should be assigned?

Are my technicians available?

When should maintenance be scheduled?

What parts are needed for jobs?

Equipment Level

Example Decisions
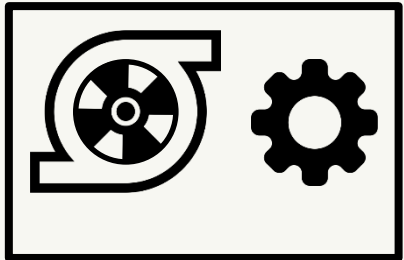
What caused equipment failure?

How to fix the failure?

When will the equipment fail next?

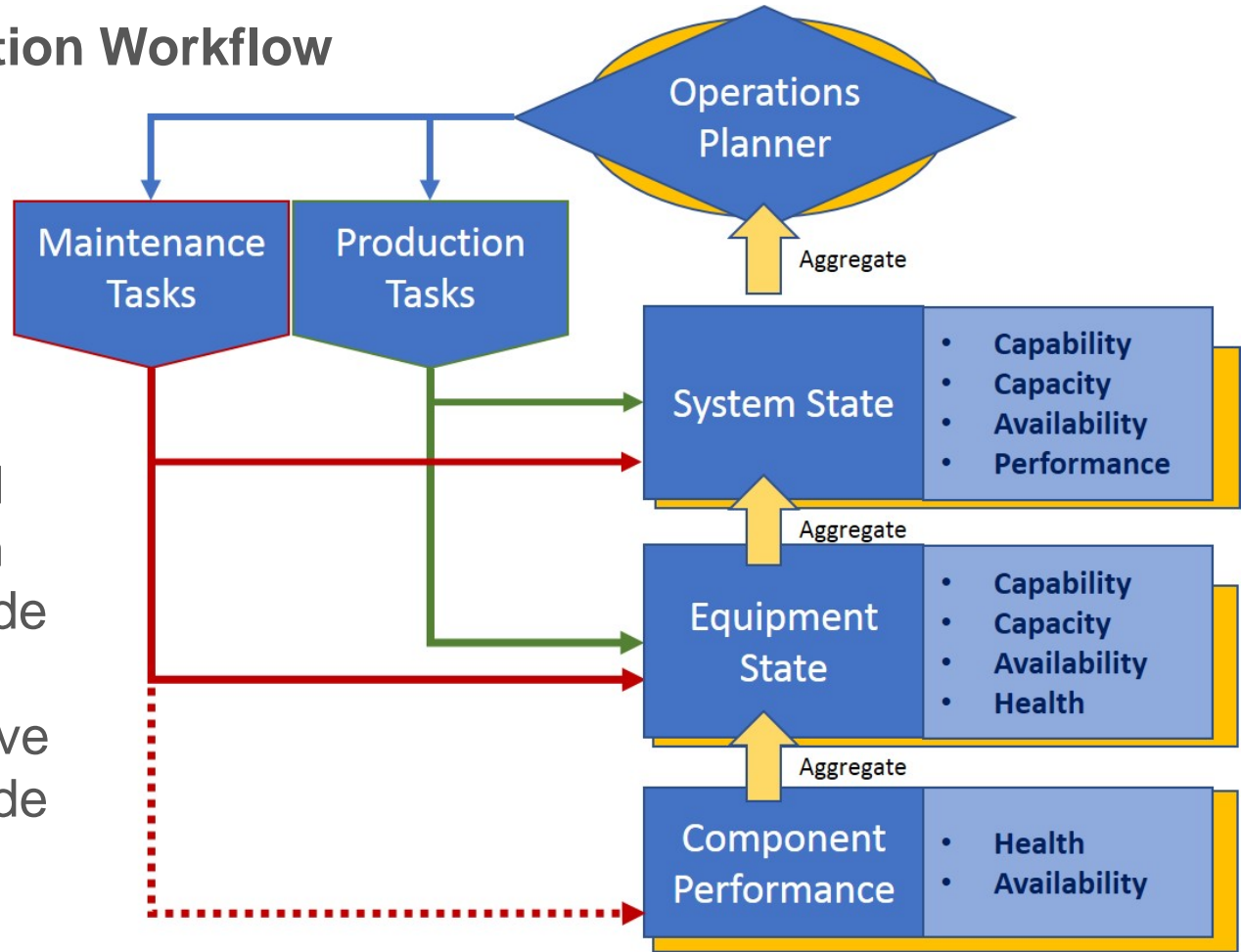How long will it take to maintain?

Component Level

Example Decisions

Should this component be operated?

Has the component failed?

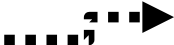What is the component condition?

Does the component meet the needs?

NIST
National Institute of Standards and Technology
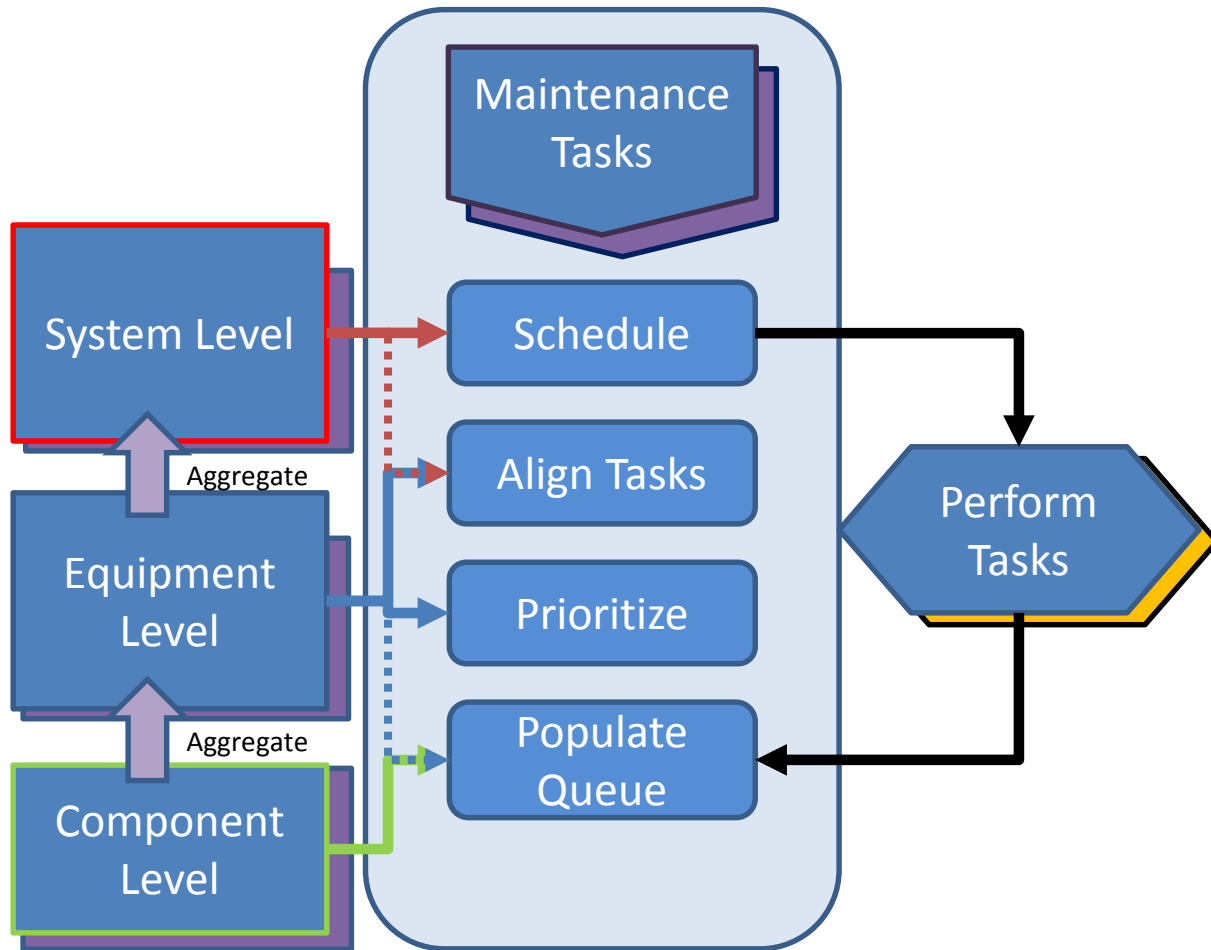U.S. Department of Commerce

General Process

Example Information Workflow

Supporting data is contextualized and pushed up through each level to provide critical information relevant to the active decision being made

NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

Information Feed Breakdown

Major Input

Minor Input

Maintenance Tasks

System Level

Equipment Level

Component Level

Aggregate

Aggregate

Schedule

Align Tasks

Prioritize

Populate Queue

Perform Tasks

Note that a Process Task breakdown would have more reliance on the System Level

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

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

(1) Identification Critical Assets

(2) Map Related Assets Through LRU Level

(3) Assess Failure Consequence / Frequency (Risk)

(4) Map Fault Modes to Monitoring Methods

(5) Continually Reassess

NIST
National Institute of
Standards and Technology
U.S. Department of Commerce
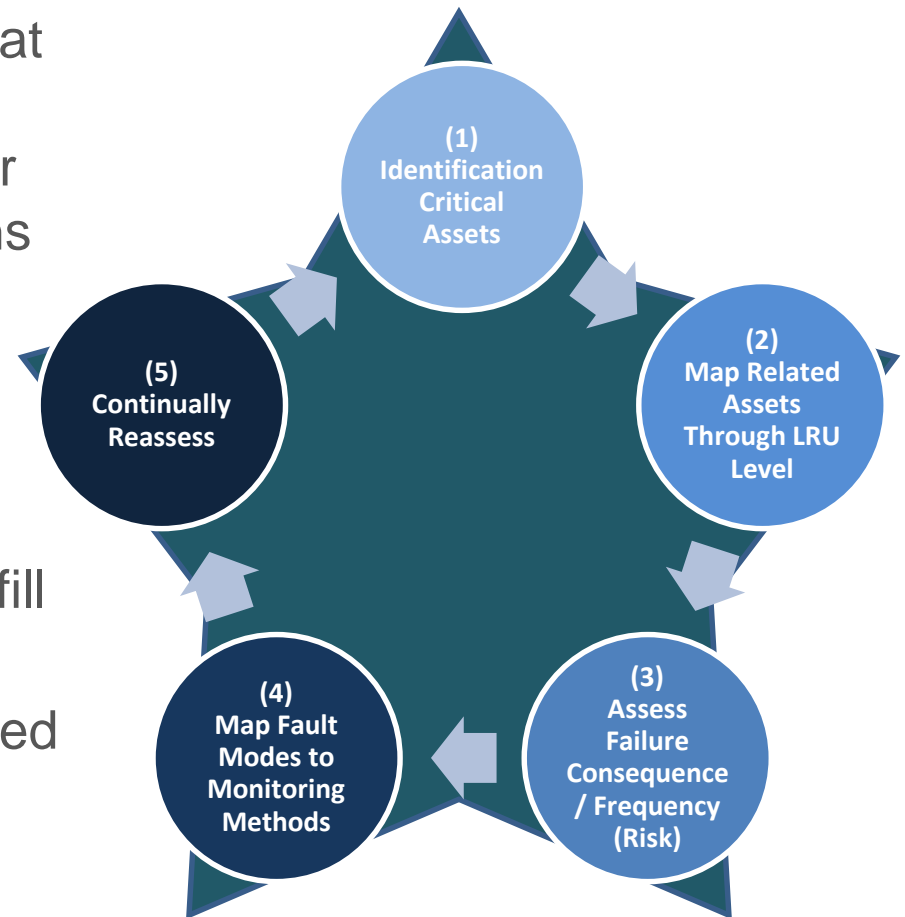
How do you decide what to monitor?

Typical Questions:

What are the mission critical / high value assets?

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

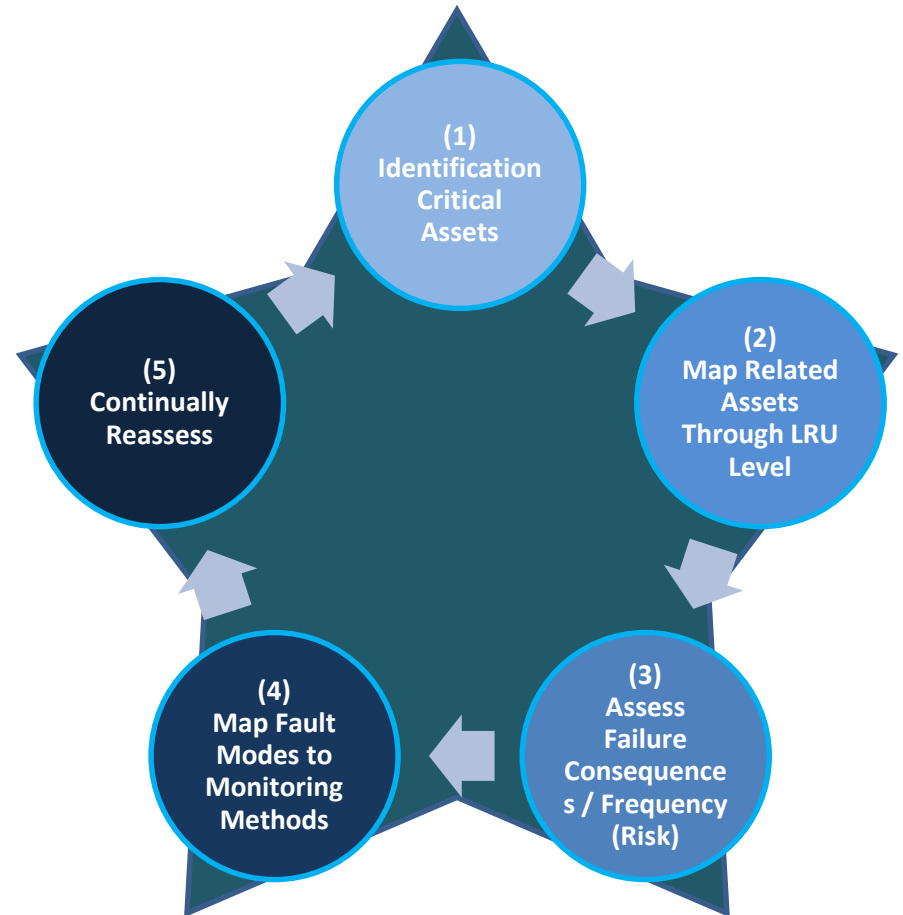What are the impacts of failure of each asset?

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?

(1) Identification Critical Assets

(2) Map Related Assets Through LRU Level

(3) Assess Failure Consequences / Frequency (Risk)

(4) Map Fault Modes to Monitoring Methods

(5) Continually Reassess

NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

Information Level Needs Breakdown

Design of Decision Support Systems

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

Equipment Level
- What is the availability of this equipment?

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

Component

Equipment

System

NIST
National Institute of
Standards and Technology
U.S. Department of Commerce
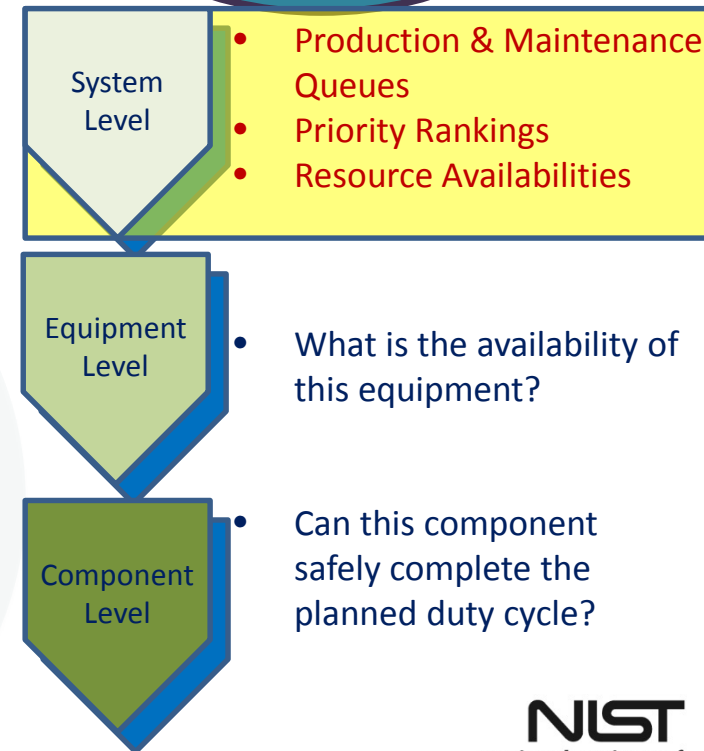
System Level Example Decisions

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)?

Design of Decision Support Systems

System Level
- Production & Maintenance Queues
- Priority Rankings
- Resource Availabilities

Equipment Level
- What is the availability of this equipment?

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

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

System Level Supporting Data
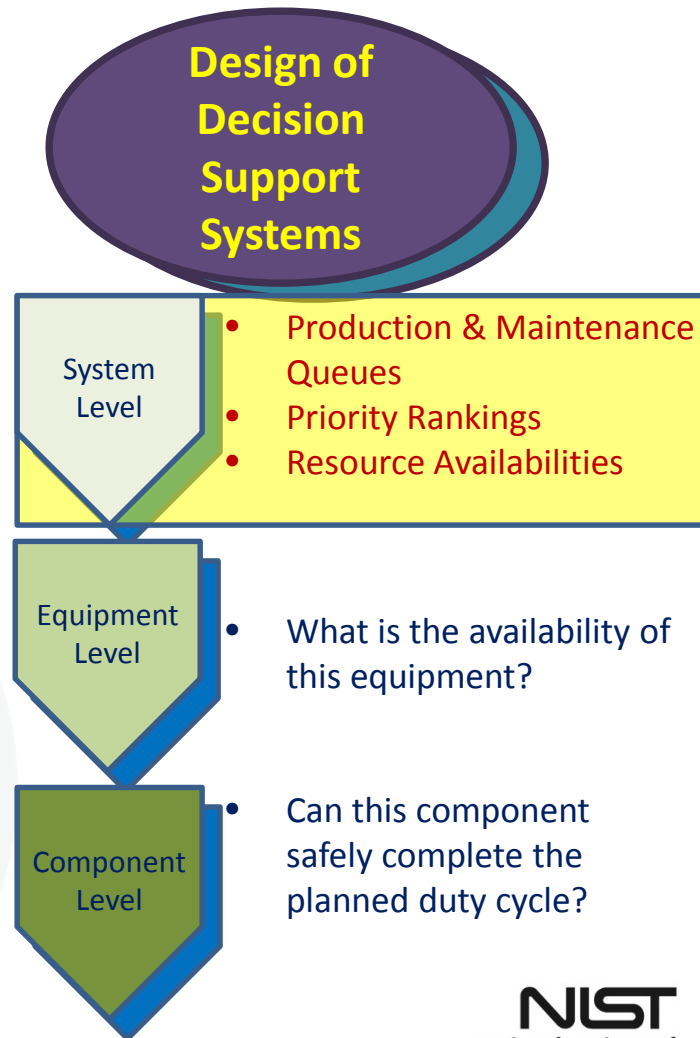
Equipment State (*Current and Future*)

- Capability
- Availability
- Capacity

Maintenance Queue

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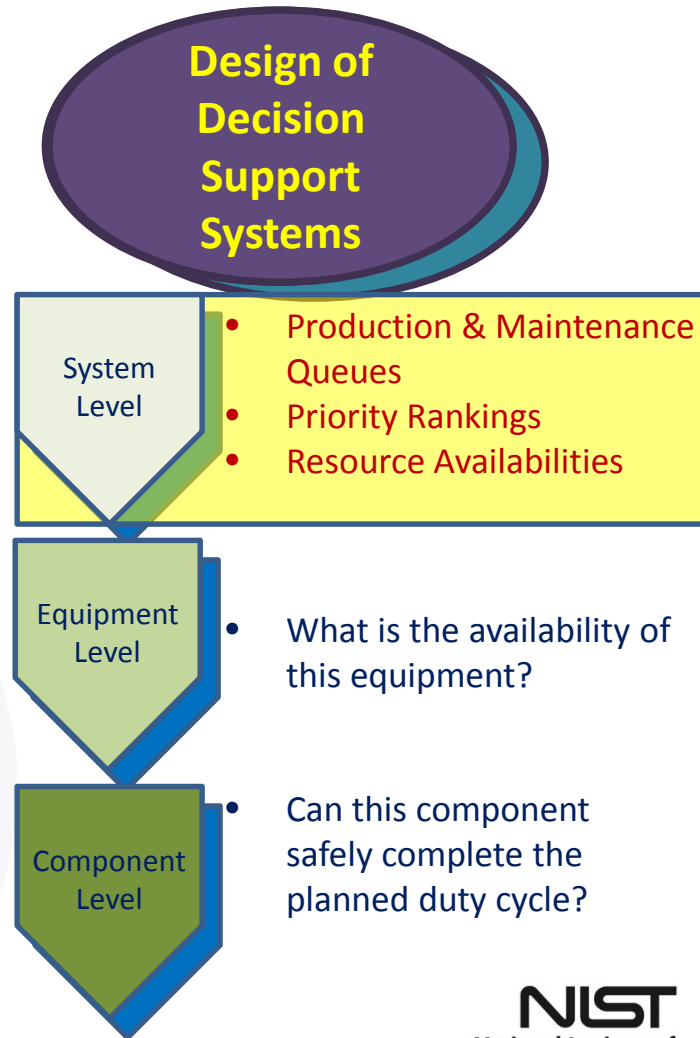- Coordination of tasks (i.e. opportunity-driven priority)

Production Queue

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

Design of Decision Support Systems

System Level
- Production & Maintenance Queues
- Priority Rankings
- Resource Availabilities

Equipment Level
- What is the availability of this equipment?

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

NIST
National Institute of
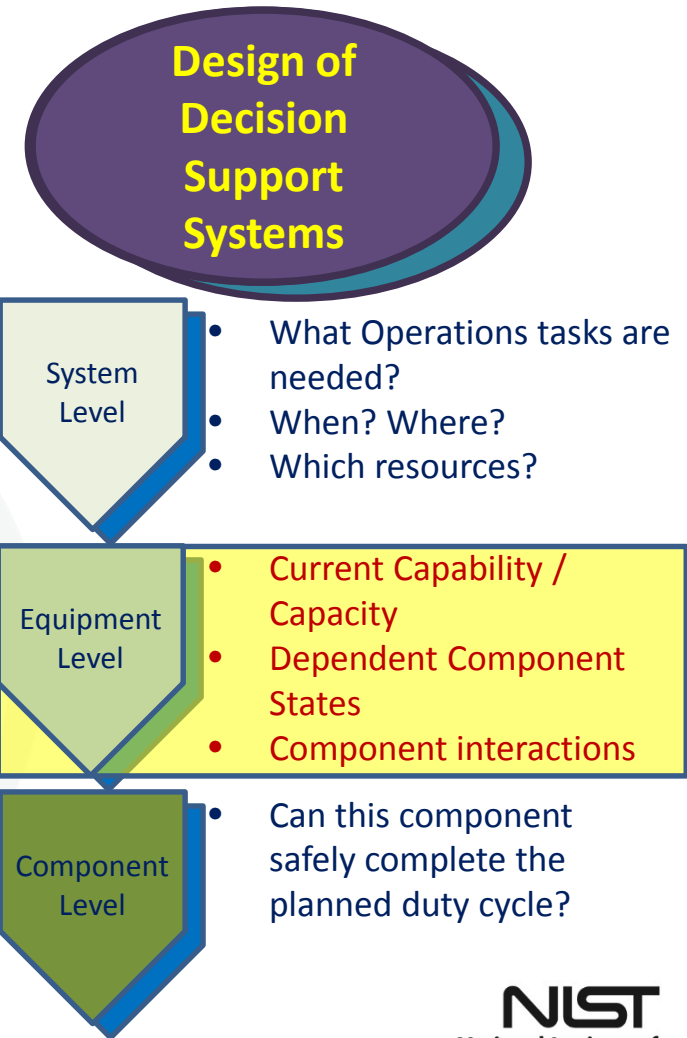Standards and Technology
U.S. Department of Commerce

System Level Example

- Observation:
  - Equipment State -
    > Mill Machine Unavailable
    >> Milling bit damaged
- Decision:
  - Production –
    Assign jobs to different equipment
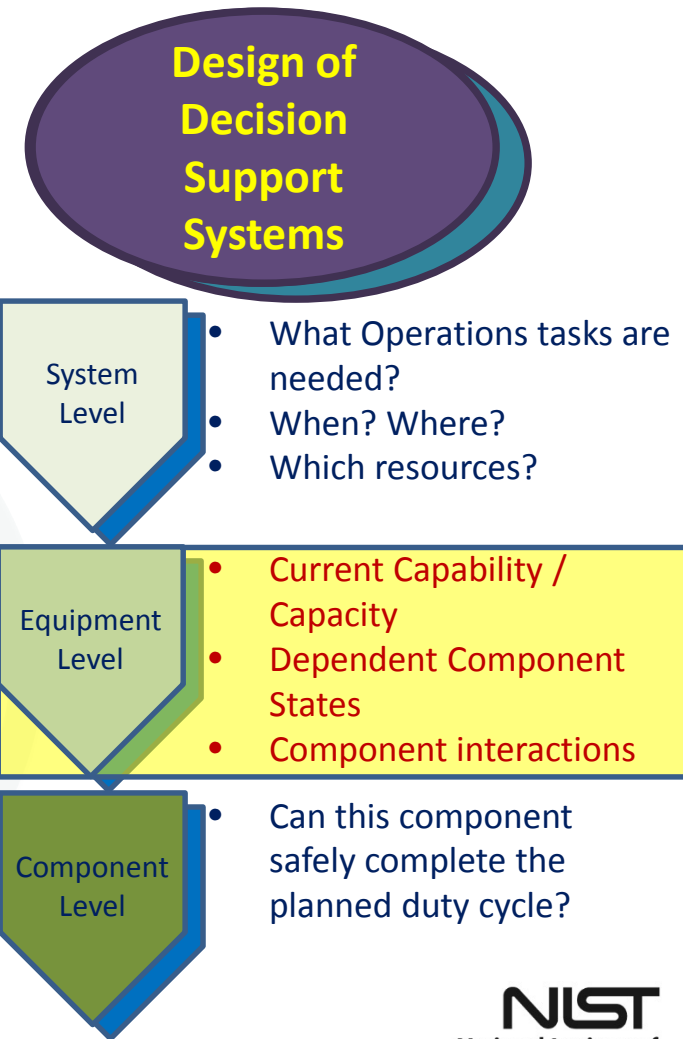 - Maintenance –
    Generate and schedule a maintenance task

Design of Decision Support Systems

System Level
- Production & Maintenance Queues
- Priority Rankings
- Resource Availabilities

Equipment Level
- What is the availability of this equipment?

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

NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

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?

Design of Decision Support Systems

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?

NIST
National Institute of Standards and Technology
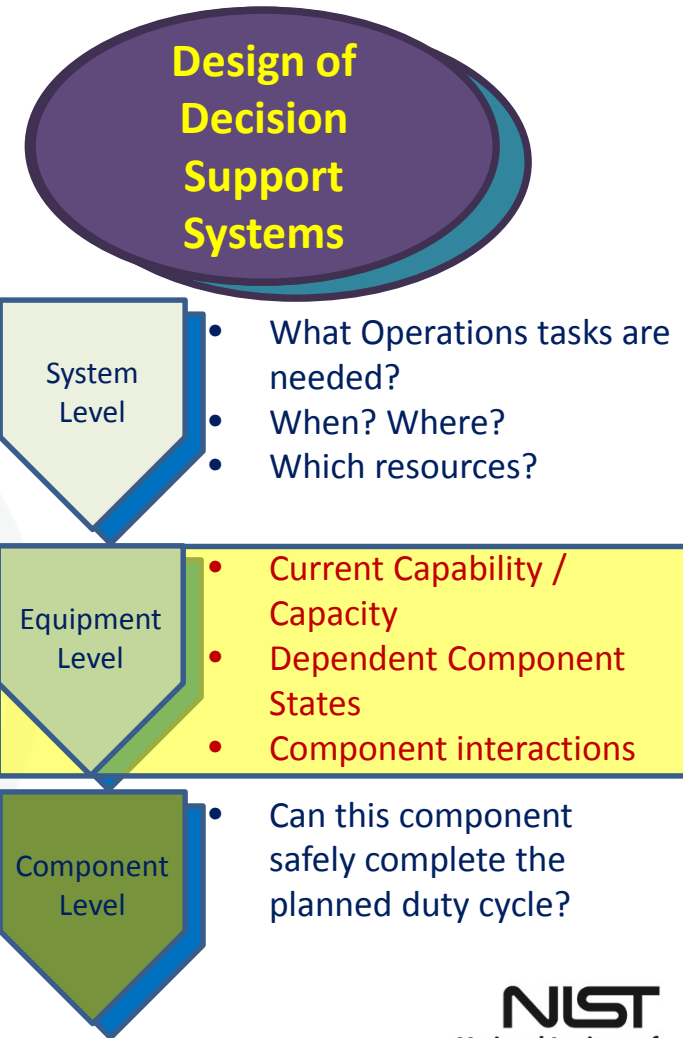U.S. Department of Commerce

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

Design of Decision Support Systems

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?

NIST
National Institute of Standards and Technology
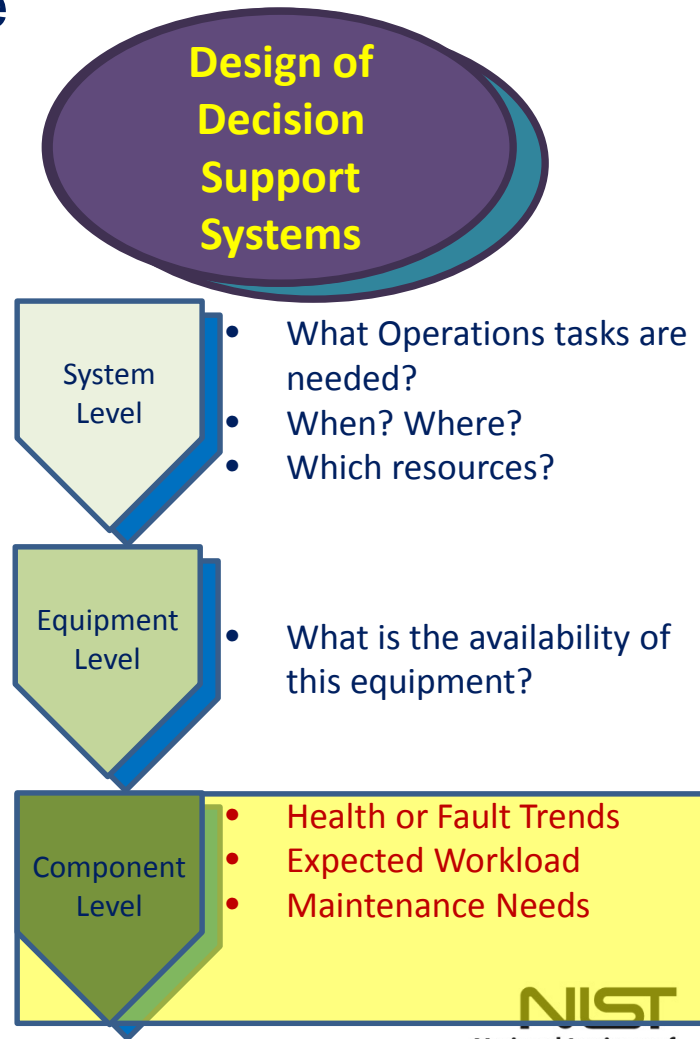U.S. Department of Commerce

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

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?

NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

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

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

Equipment Level
- What is the availability of this equipment?

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

National Institute of
Standards and Technology
U.S. Department of Commerce

Component Level Supporting Data

Capacity Specifications
- Possible configurations of component
- Nominal work loads
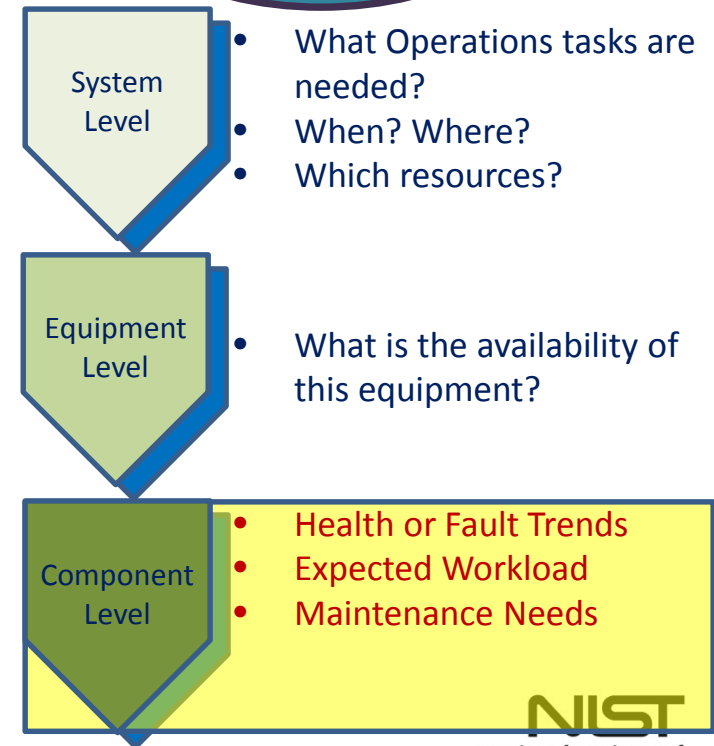
Condition assessment information
- Human interrogators
- Sensors
- Analytic models

Anticipated Future Performance
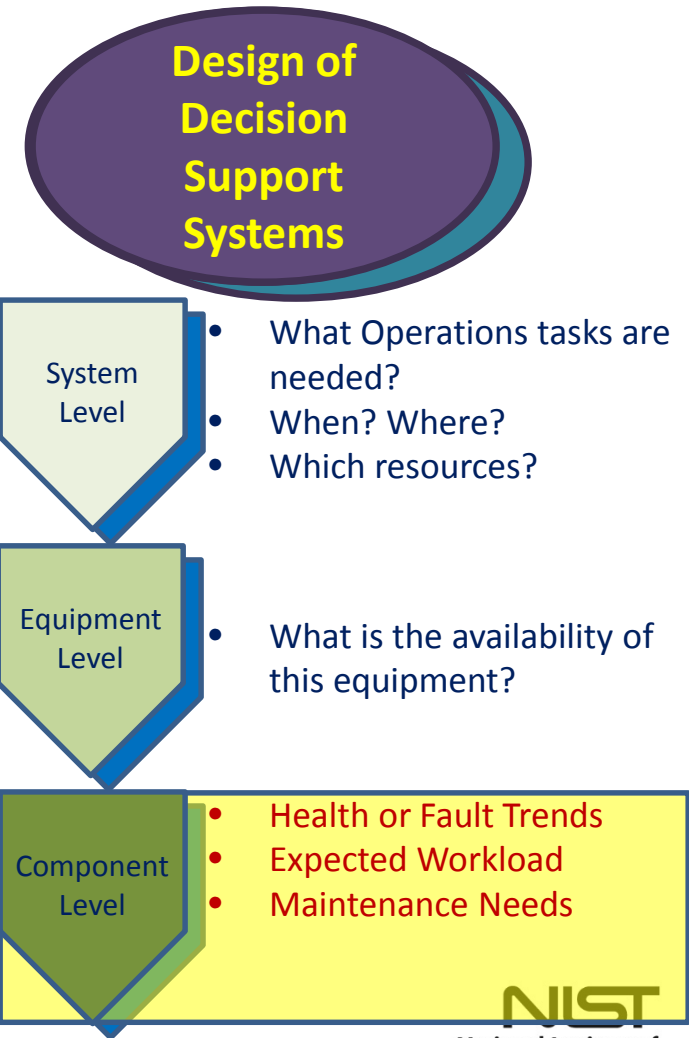- Planned duty cycles
- Probabilistic modeling

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

Design of Decision Support Systems

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

Equipment Level
- What is the availability of this equipment?

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

NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

Component Level Example

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

Design of Decision Support Systems

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

Equipment Level
- What is the availability of this equipment?

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

NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

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
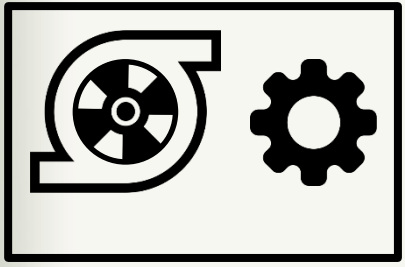>> Monitor Failure Modes
>
> Goal – Predict Failure Time Horizon

NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

System Level

Production — Fix Eq 1 then Eq 2 — Fix Eq 2 then Eq 1
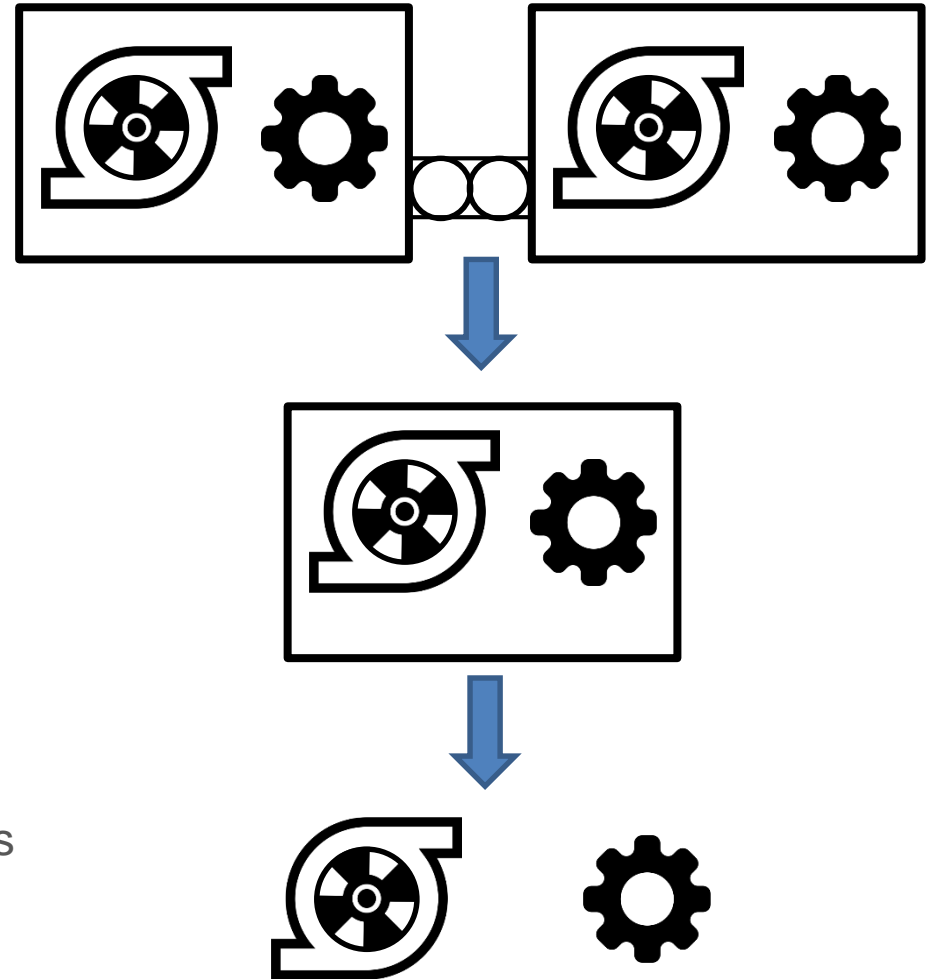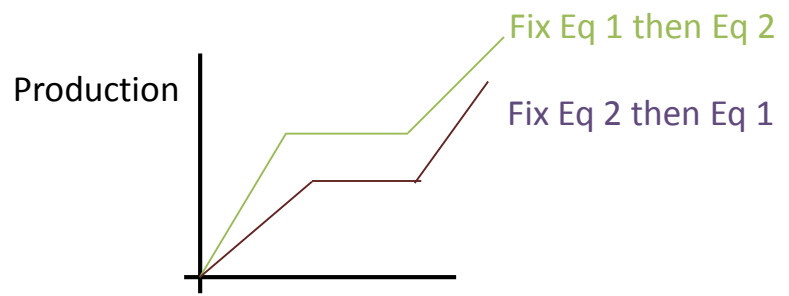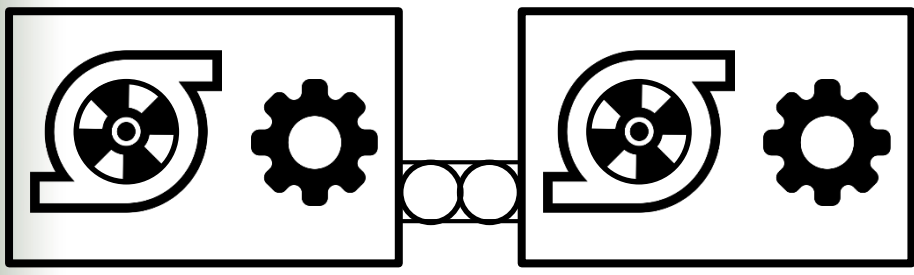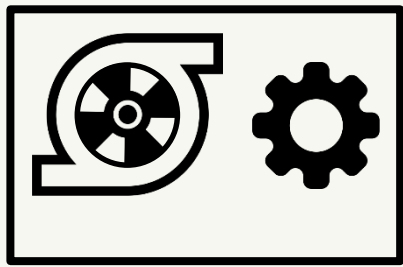
Equipment Level

Equipment 1

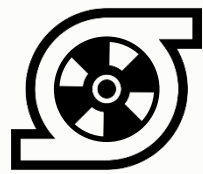Equipment 2

Equipment 1
MTBF: 30 mins
MTTR: 45 mins

Equipment 2
MTBF: 60 mins
MTTR: 30 mins

Component Level
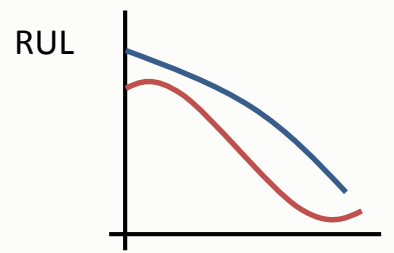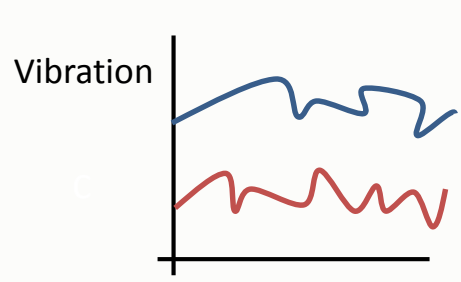
Component 1

Component 2

Vibration

RUL

NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

END

Thank you

michael.sharp@nist.gov
michael.brundage@nist.gov
timothy.sprock@nist.gov
brian.weiss@nist.gov

NIST
National Institute of
Standards and Technology
U.S. Department of Commerce