

Standards Needs for Maintenance Work Order Analysis in Manufacturing

Thurston Sexton & Michael P. Brundage

Knowledge Extraction and Application for Manufacturing Operations Project

Systems Integration Division, Engineering Laboratory
National Institute of Standards and Technology

Problem

- Maintenance is expensive (\$50 billion in 2016) and expertise driven
- Smart manufacturing technologies can reduce costs [1]
- SMEs still not employing these technologies [2]
 - High Cost to implement – Risk is high with incorrect implementation
 - Lack of Support/Expertise in manufacturing
 - Leads to a lack of high quality sensor data
- No data -> Difficult to assess impacts of new technologies

[1] Thomas, D. S. (2018). *The Costs and Benefits of Advanced Maintenance in Manufacturing* (No. Advanced Manufacturing Series (NIST AMS)-100-18).

[2] Jin, X., Siegel, D., Weiss, B. A., Gamel, E., Wang, W., Lee, J., & Ni, J. (2016). The present status and future growth of maintenance in US manufacturing: results from a pilot survey. *Manufacturing review*, 3.

Problem

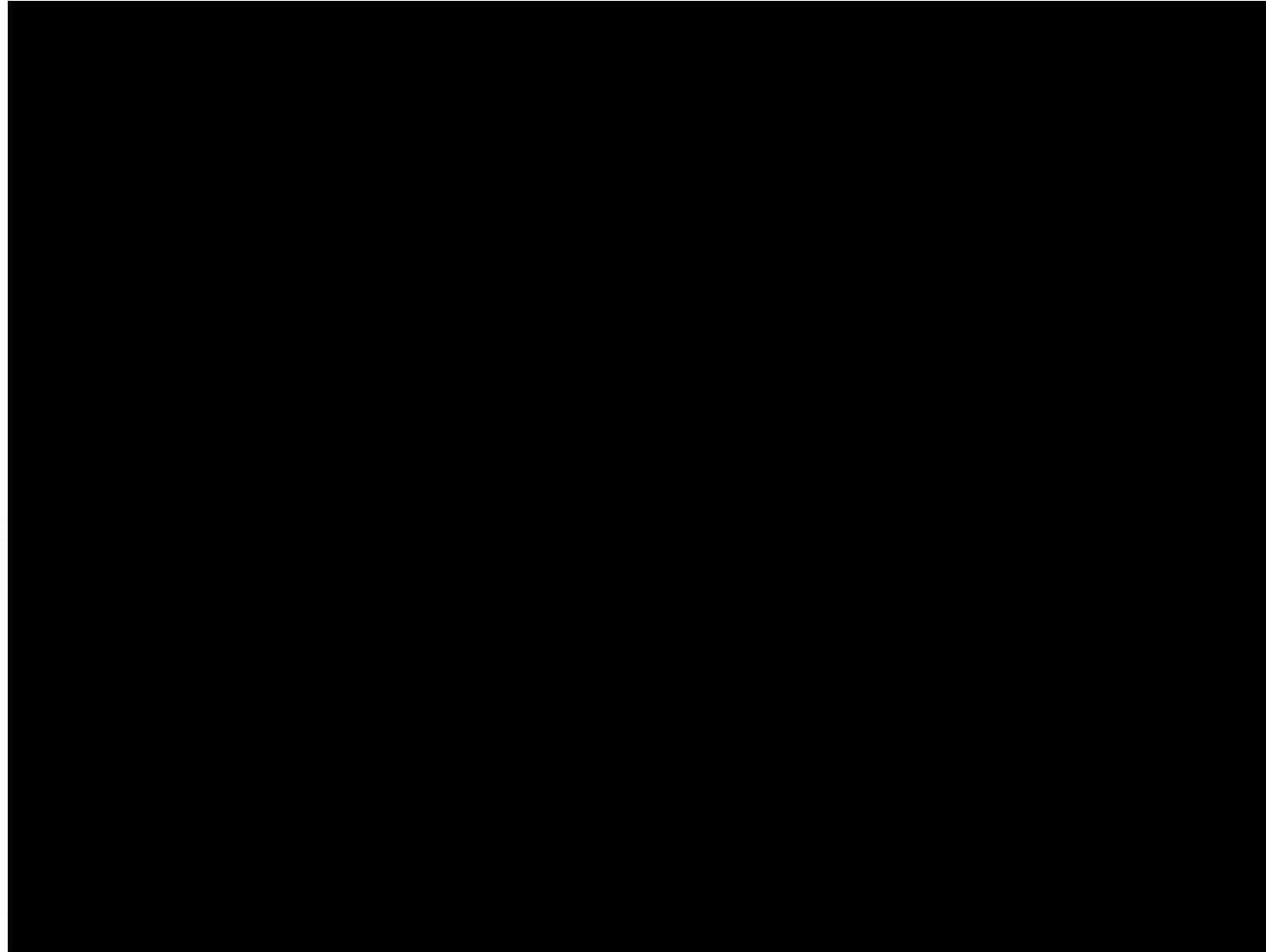
Untapped source of data that *could* be used, but...

- Natural Language Documents – Maintenance Work Orders (MWOs)
 - Contain historical tacit knowledge
 - Contain domain-specific abbreviations and jargon
 - Often unstructured input
- Current Natural Language Processing (NLP) solutions do not work

Outline

1. Current Paradigm with Maintenance Work Orders (MWOs)
2. Maintenance timeline
3. MWO Tasks and Standards Needs
 - a) Data Collection and Storage
 - b) Data Cleaning and Parsing
 - c) Data Analysis and Validation
4. Future Work

Interactive Case Study



Interactive Case Study

“The cutting tool snapped off. Need to replace tool and inspect spindle for damage. Looks like they were cutting too deep in one pass for the strength of the tool”

“All-around operator error. Looks to be too high a depth of cut at too high a feed-rate. Also looks like the move at the end put too high a stress on the tool. Operator should have retracted the tool before making that move if he/she wanted to keep that depth of cut.”

“The DOC is too large and the feed too high for the slot such that the forces increase until tool breakage as the tool approaches the vice. It probably wasn't smart either to machine towards the vice as they have anyway. A typical approach to avoid this problem is to ramp into the slot.”

“Too large of an engagement at tool high of a feed.”

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Tool is broken

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Depth of cut too large

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Feed rate too high

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“Too large of an engagement at **tool high of a feed!**”

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Bad process plan

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“All-around **operator error**. Looks to be too high a depth of cut at too high a feed-rate. Also looks like the move at the end put too high a stress on the tool. Operator should have retracted the tool before if he/she wanted to depth of cut.”

Operator error

“The DOC is too large and the feed too high for the slot such that the forces increase until tool breakage as the tool approaches the vice. It probably wasn't smart either to machine towards the vice as they have anyway. A typical approach to avoid this problem is to ramp into the slot.”

“Too large of an engagement at tool high of a feed.”

Current Maintenance Paradigm

**PHYSICAL PLANT
MAINTENANCE WORK ORDER**

Date: _____

Requested by: _____

Building/Room: _____

Description of Needs: _____

Org. to be Charged: _____

Estimated Cost Amount: _____

Supervisor Approval: _____ Date: _____

VP of Administration Approval: _____ Date: _____

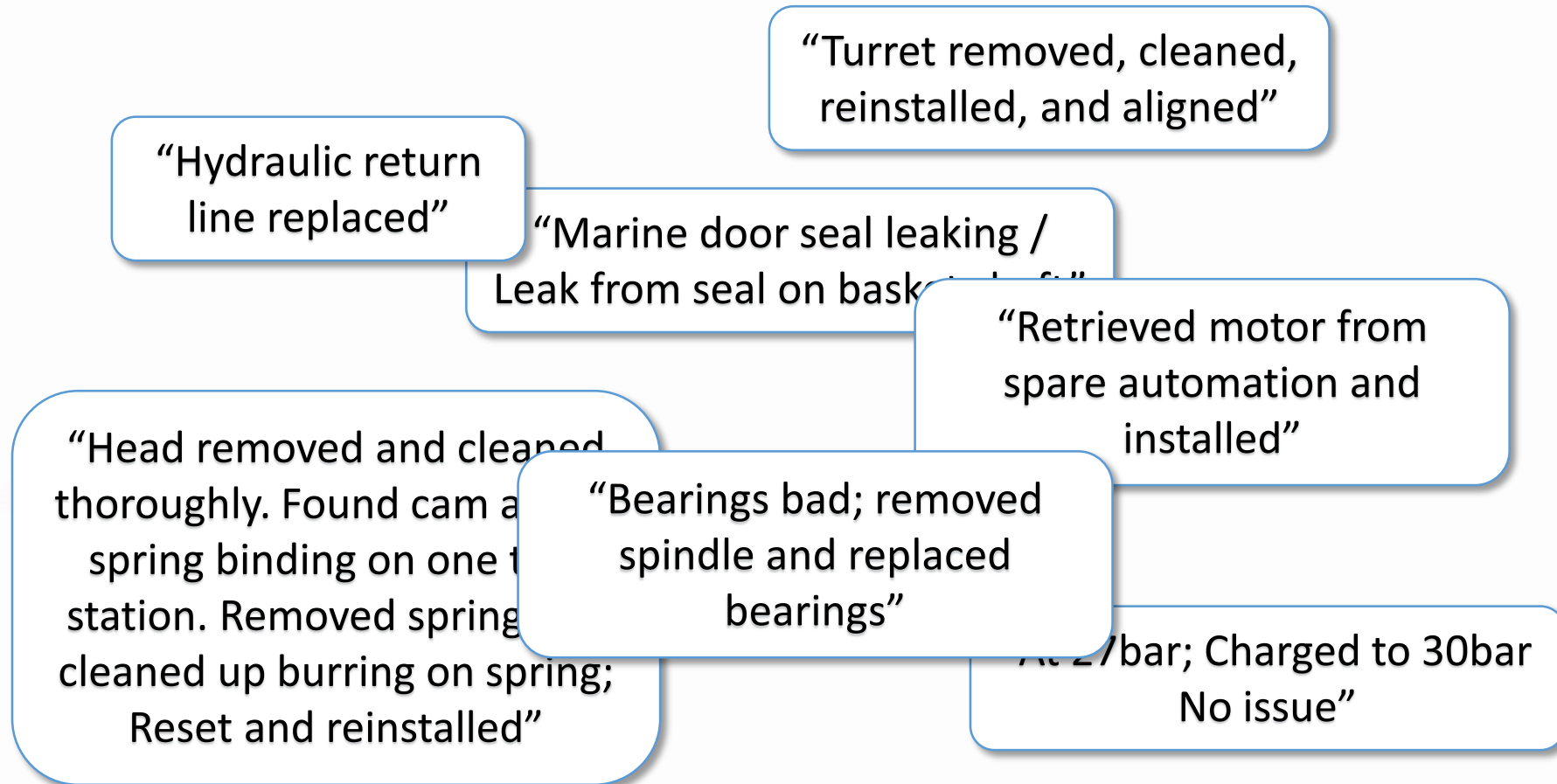
Work Completed by: _____ Date: _____

Return completed form to Administrative Services
Rev 5/01



| Date | Mach | Description | Issued By | Date Up | Maint Tech Assigned | Resolution |
|-----------|----------|----------------------------------------------------------------------|-----------|-----------|---------------------|-------------------------------------------------------------------------------------------|
| 29-Jan-16 | H15 | St#14 tool detect INOP | JS | 29-Nov-16 | SA | Slug detector at station 14 not working. Would not recognize "Start" signal. |
| 1-Jun-16 | Mitsu FT | Brakes worn -Not stopping when in gear | AB | 28-Jun-16 | Steve A | Repaired |
| 1-Jun-16 | H8 | St#7 rotator collet broken -wait for Bob B to show him how to remove | JS | 8-Jun-16 | John Smith | Machine went offline on 6/8 -Mark removed and instructed Bob B on removal/install process |

Maintenance Work Order Data

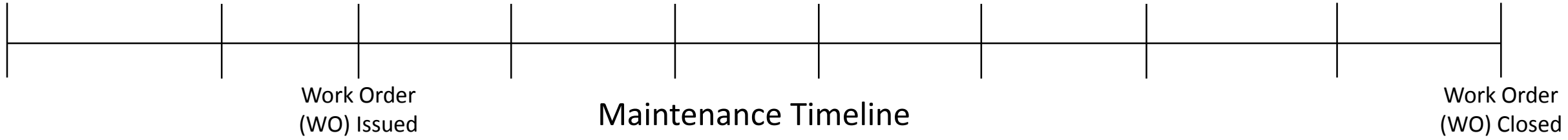


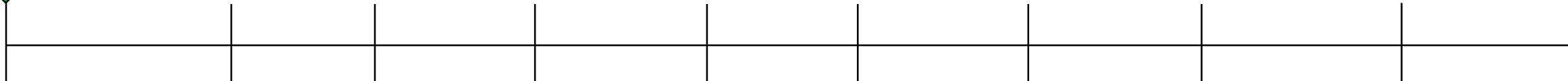
Current Maintenance Paradigm

- Expertise Driven
- Sensors not always present
- Often unstructured MWOs
 - natural language; domain-specific abr. and jargon
 - “tribal” knowledge
- Little structure in non-natural language data
 - Times/Dates different formats
 - Misspellings in Technician/Asset names
 - Non-matching WO #s to other systems

Outline

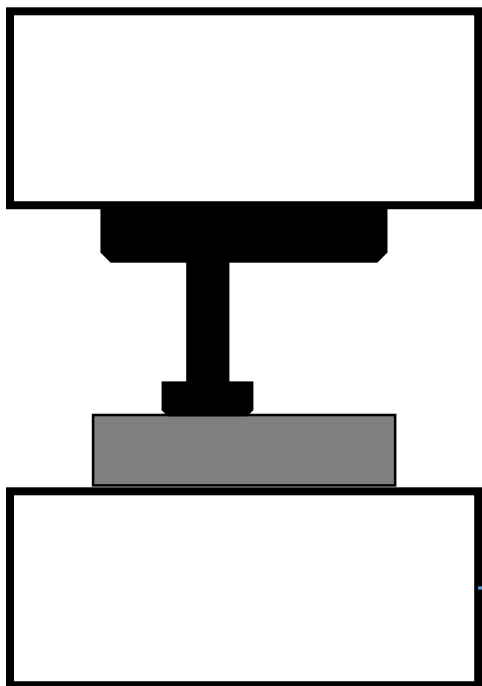
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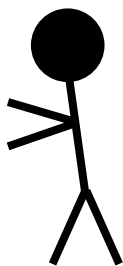
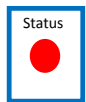
Maintenance Timeline

Milling Machine



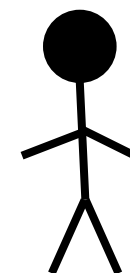
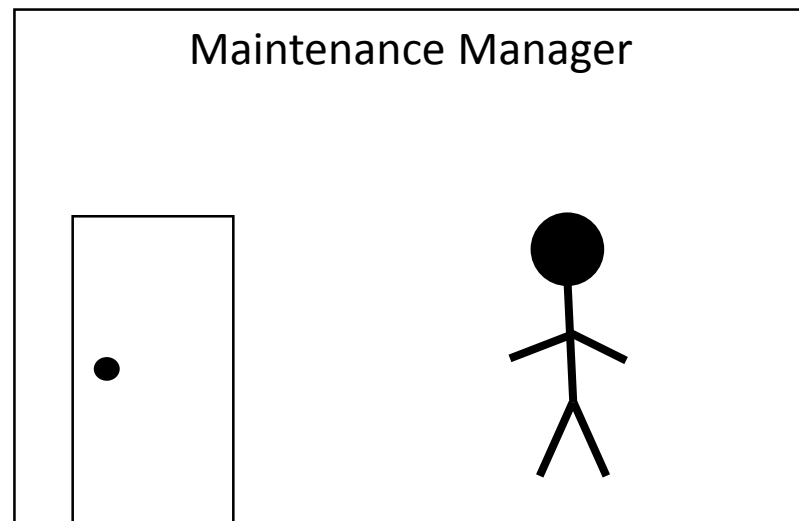
Illustrates Status of
Machine

- = Off
- = On

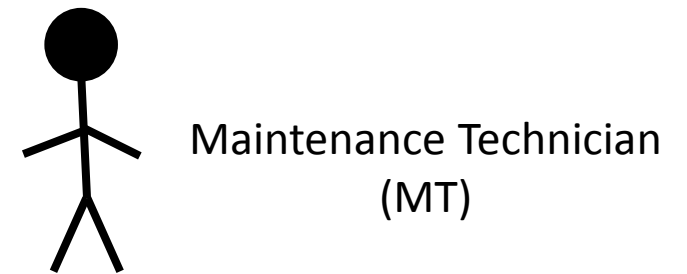
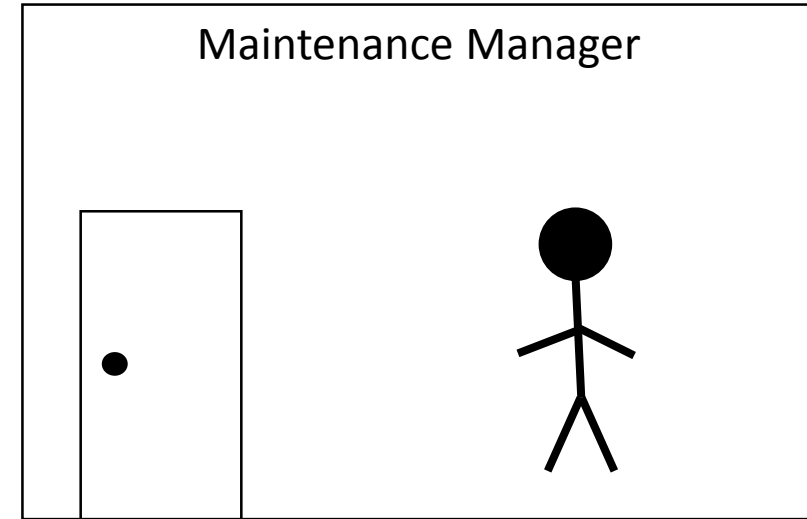
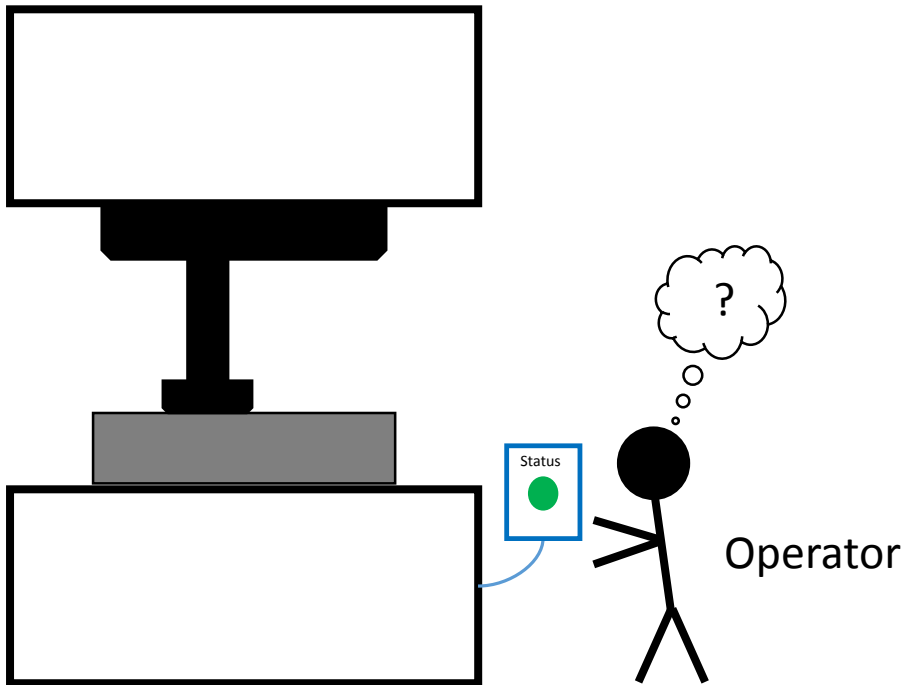
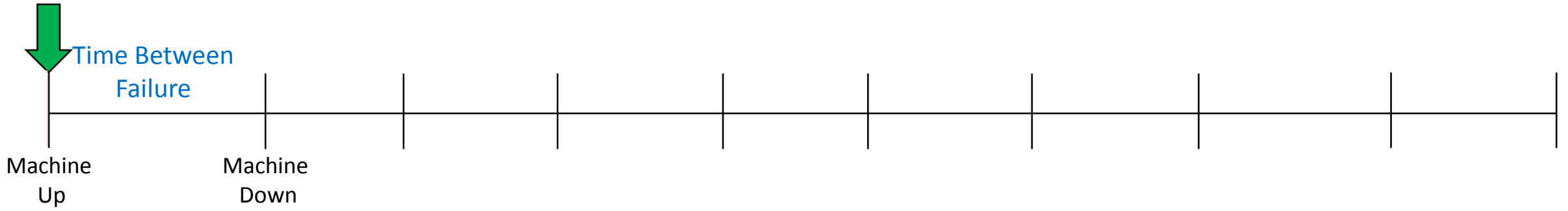


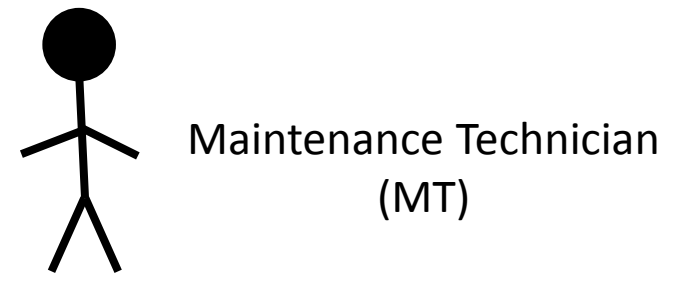
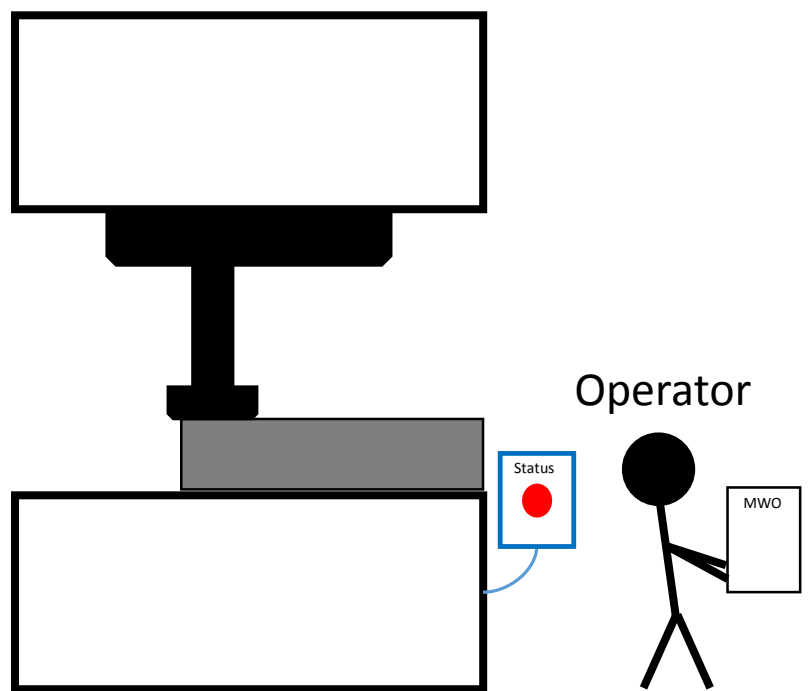
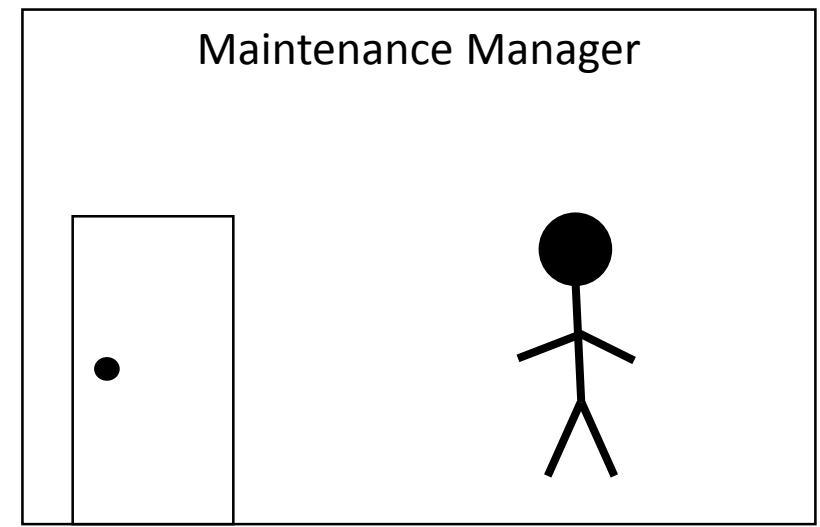
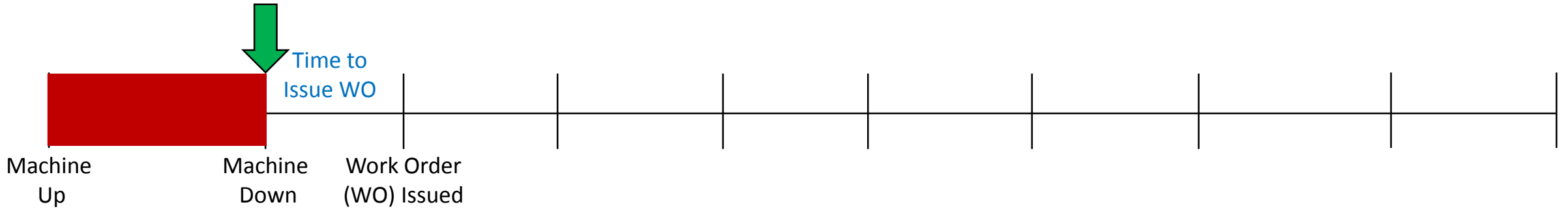
Operator

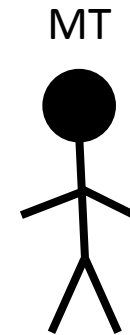
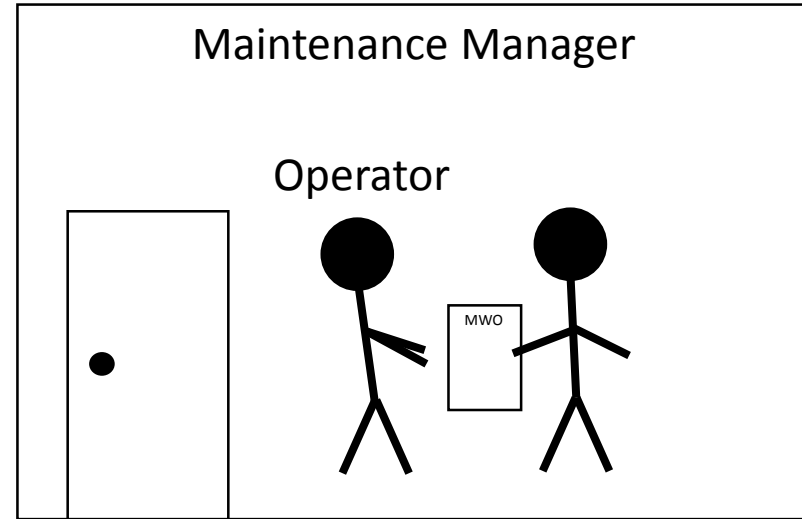
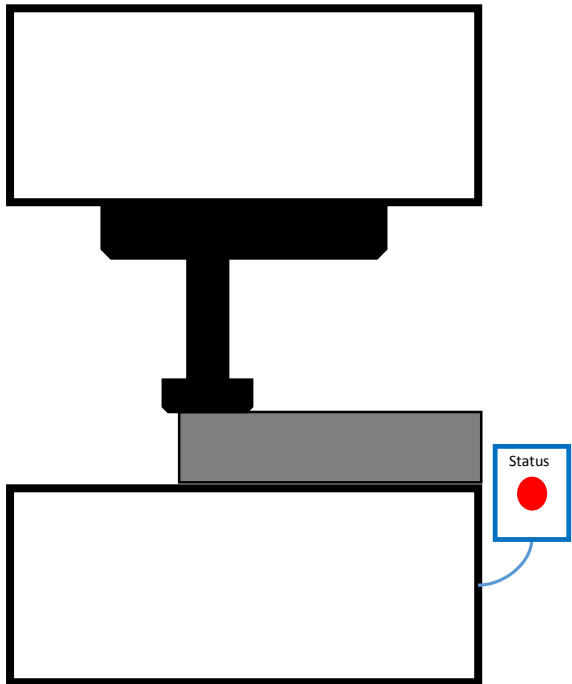
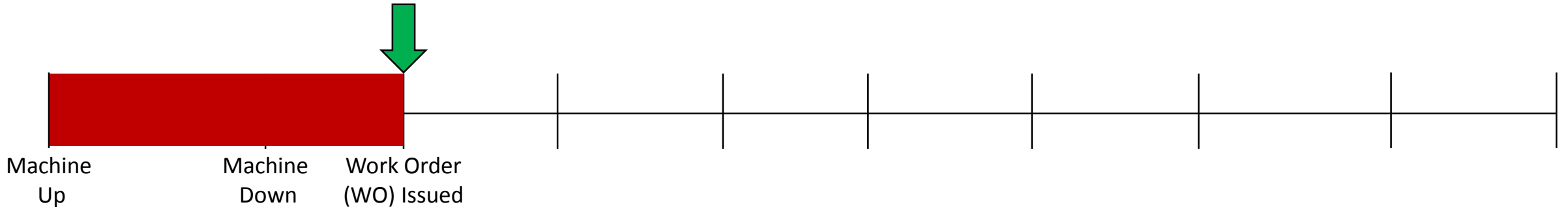
Maintenance Manager

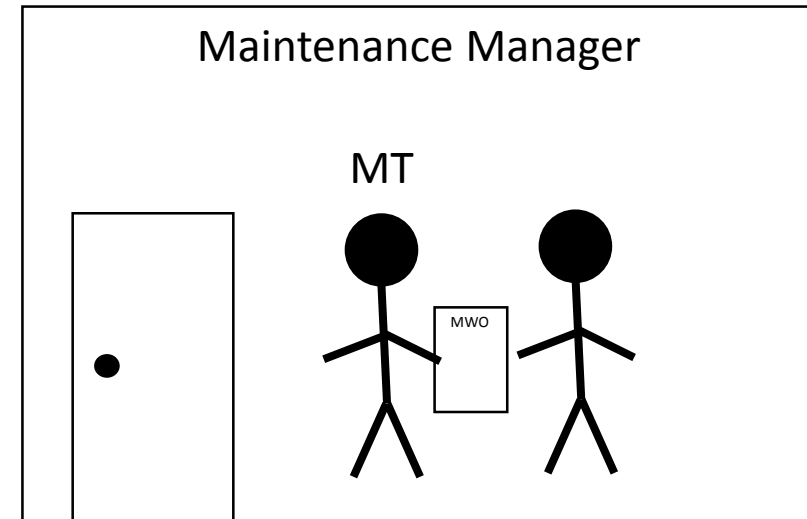
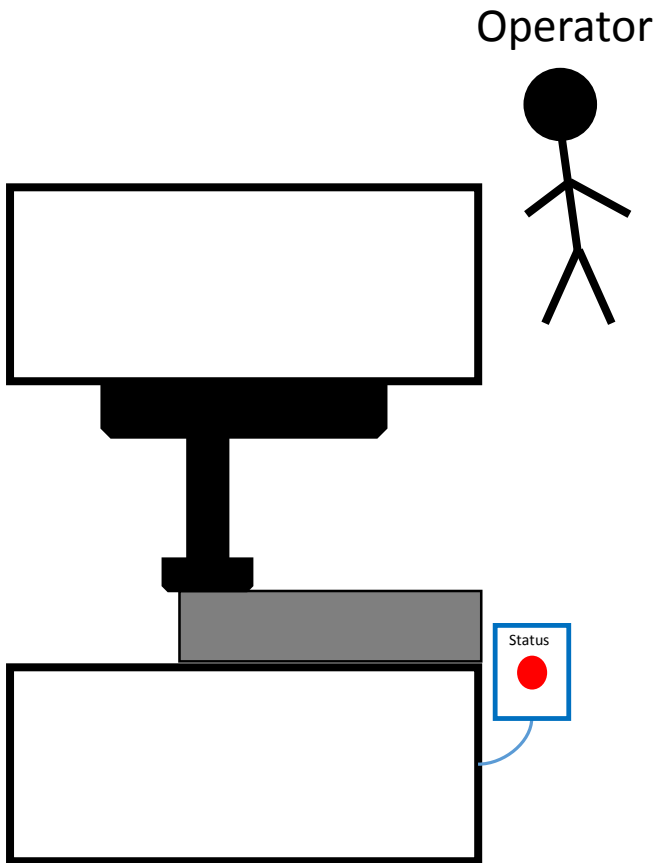
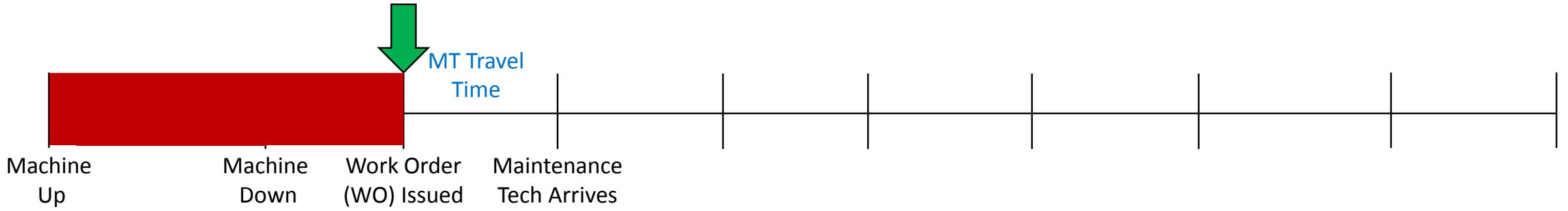


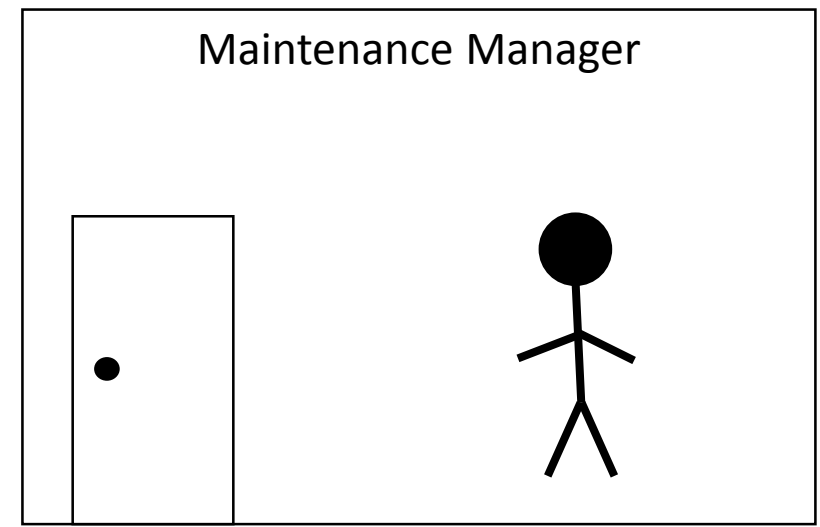
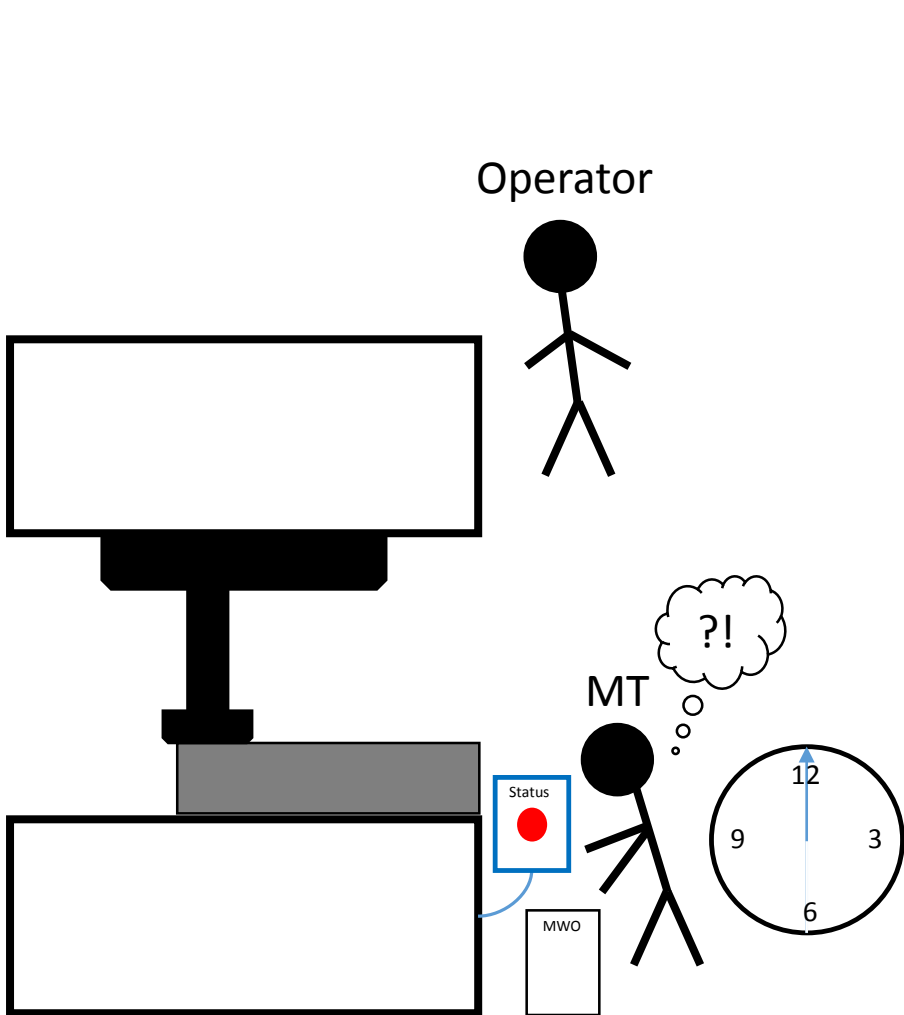
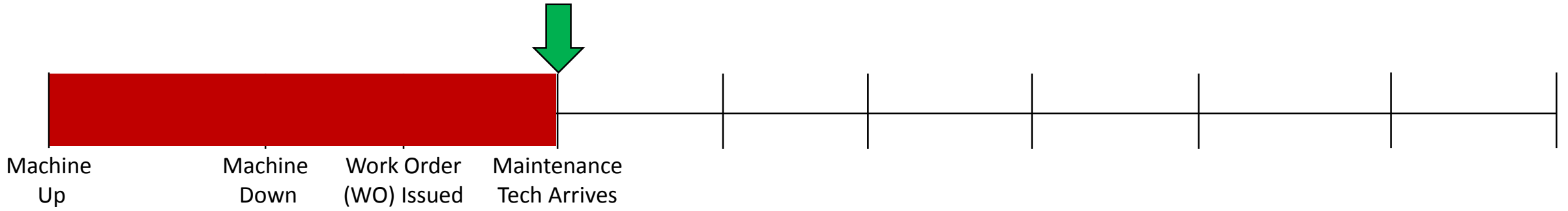
Maintenance Technician
(MT)

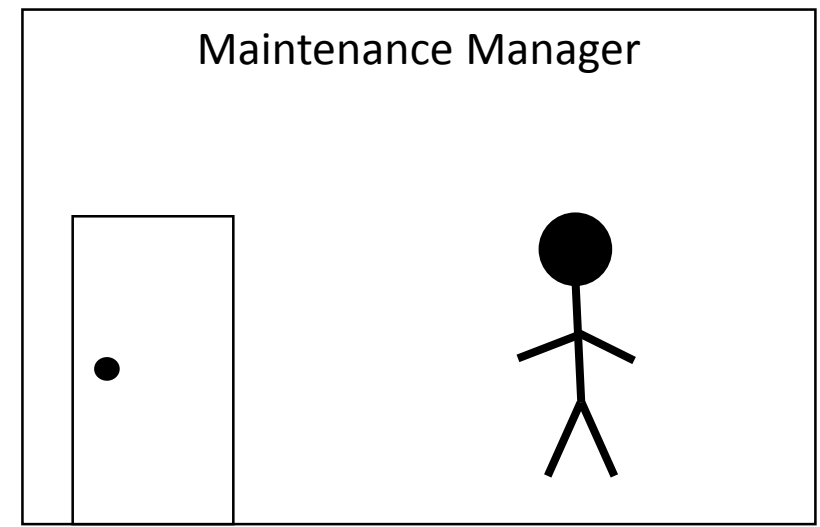
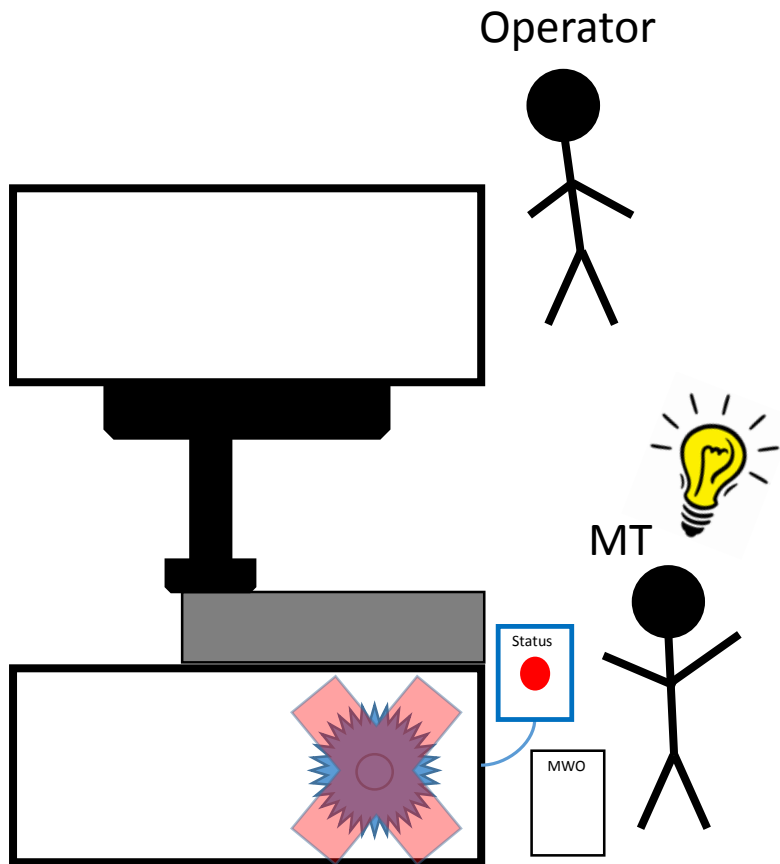
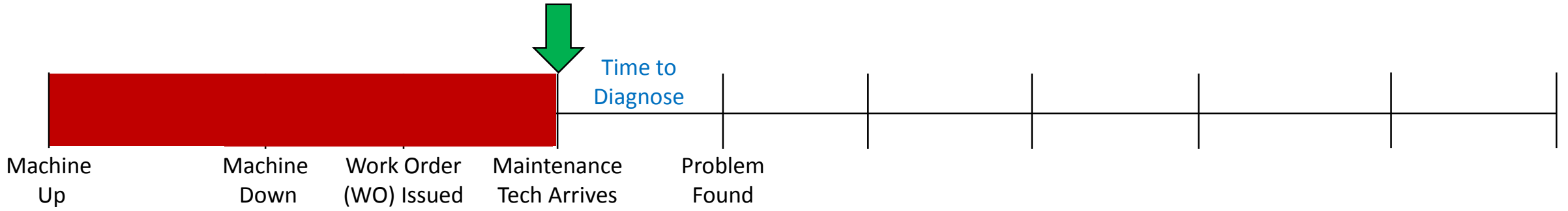


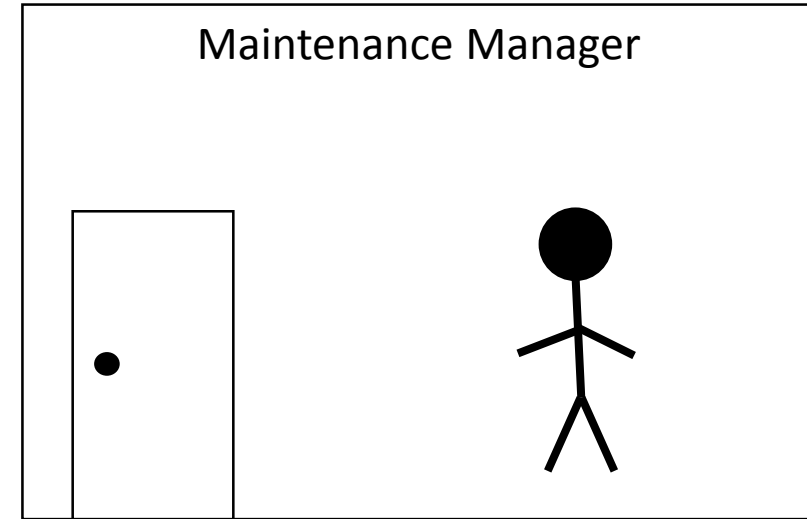
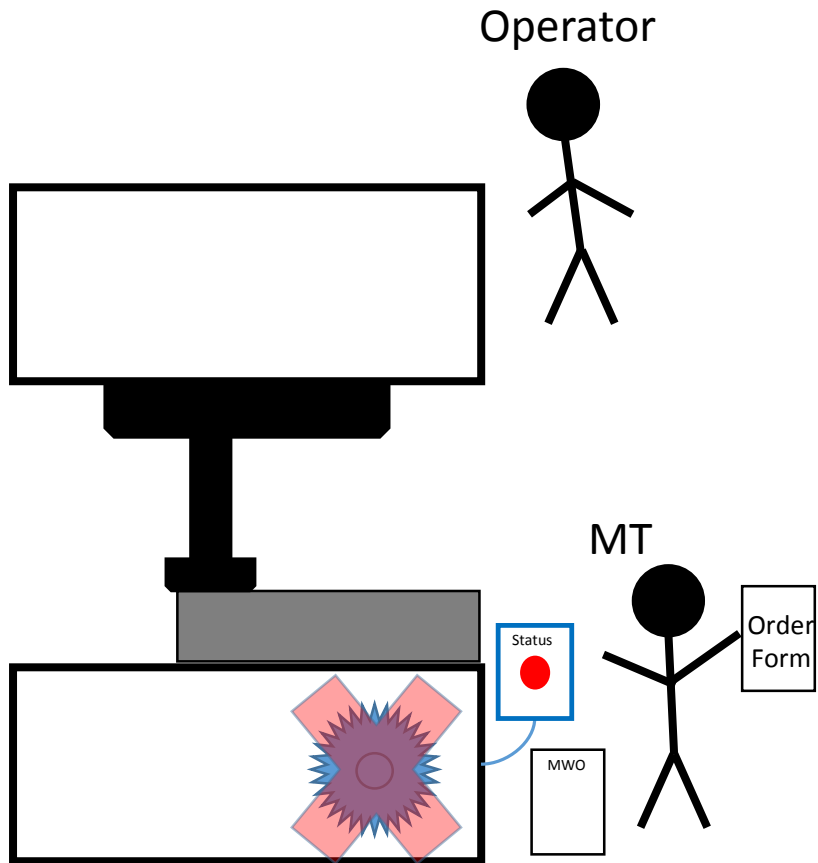
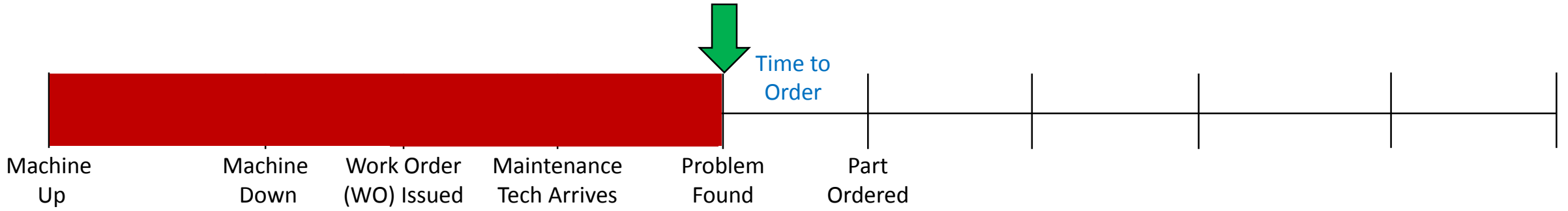


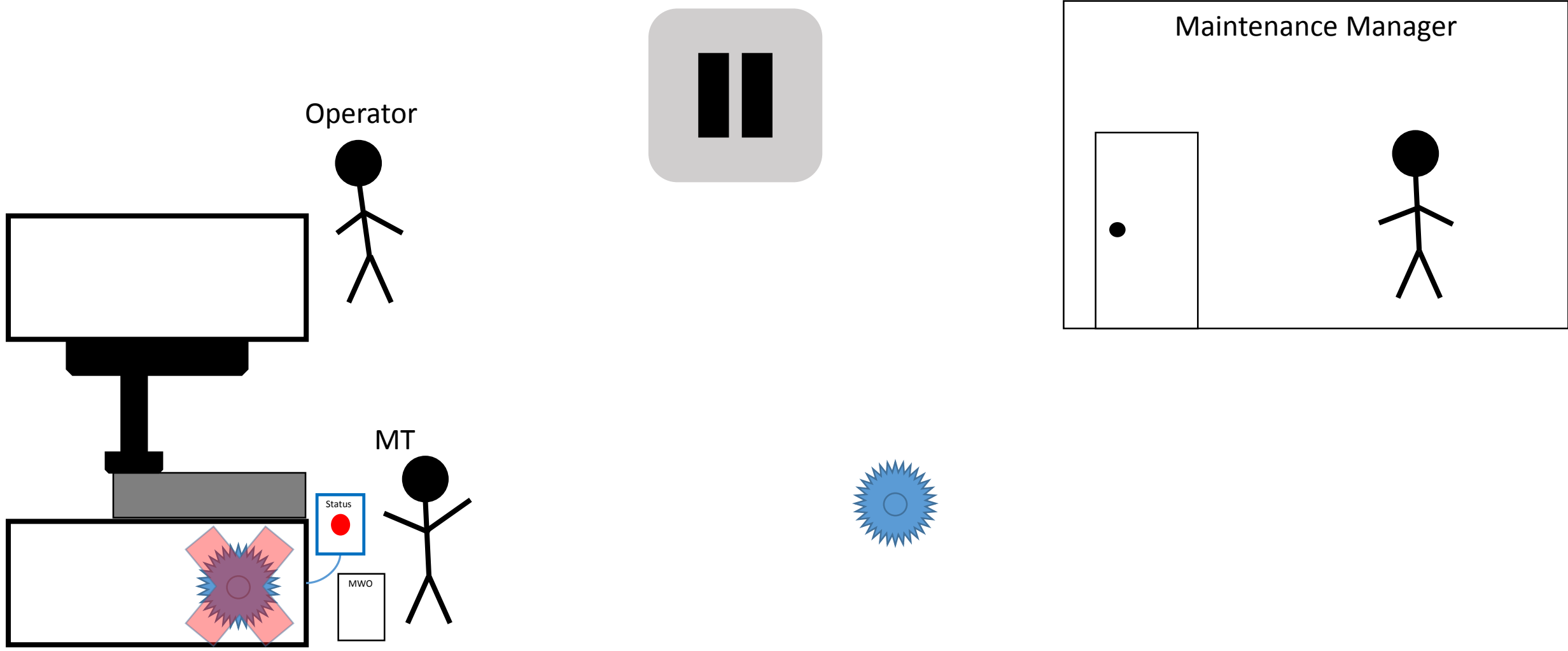
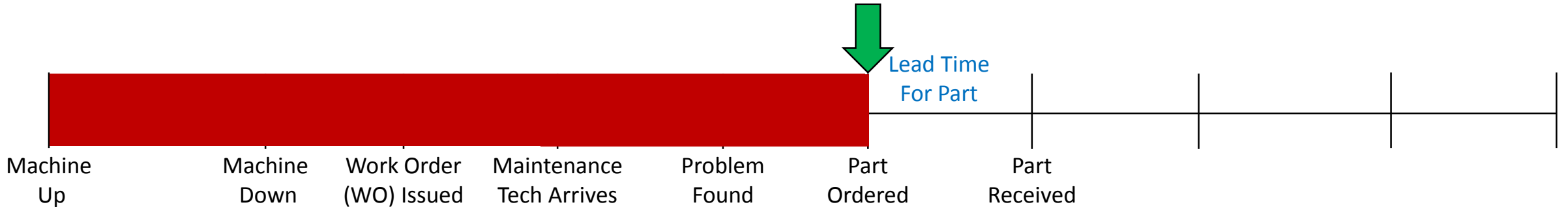


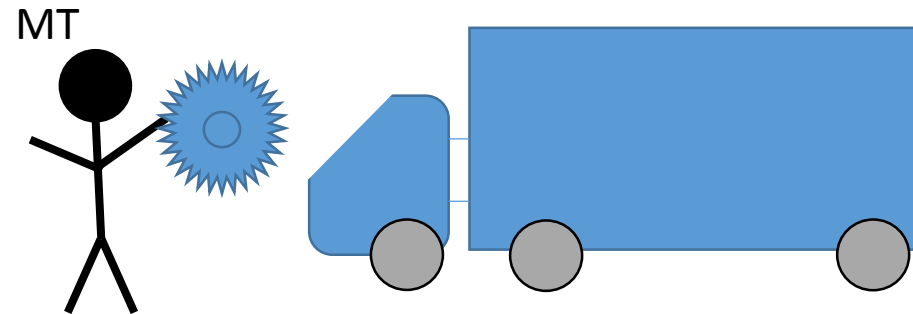
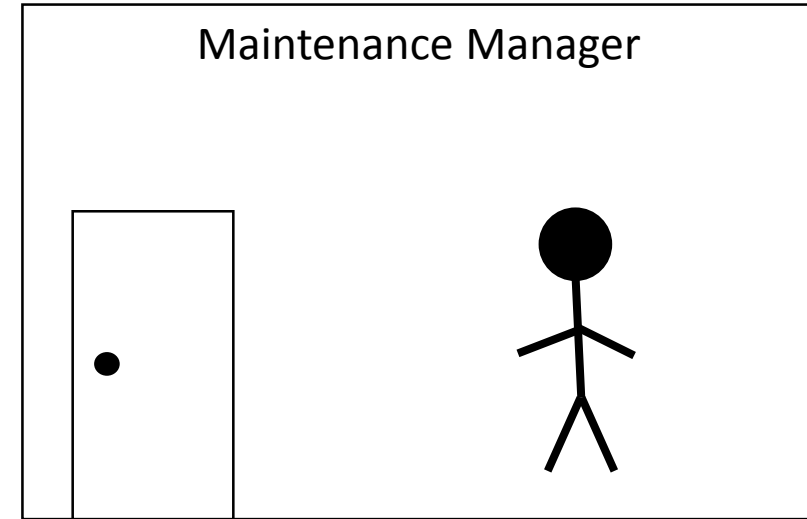
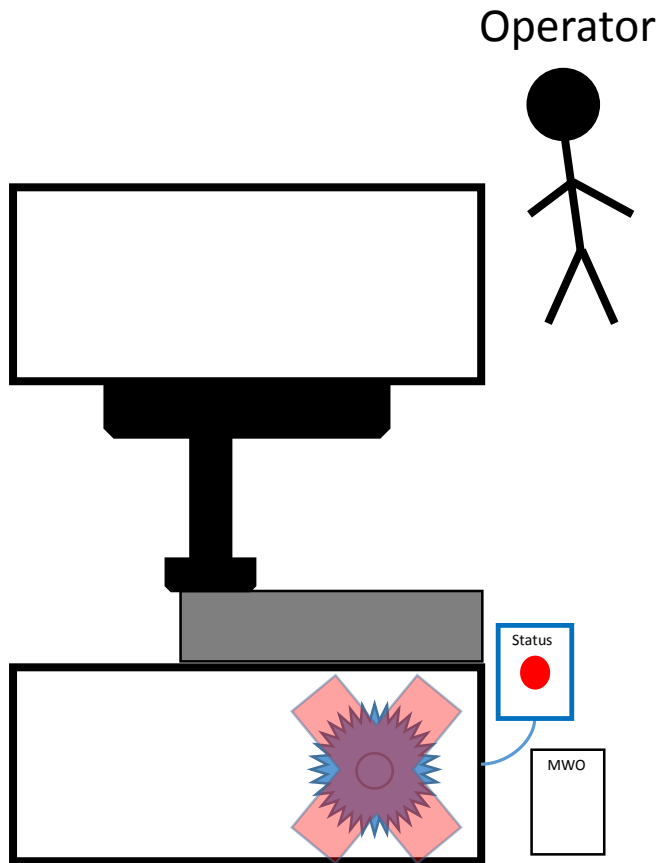
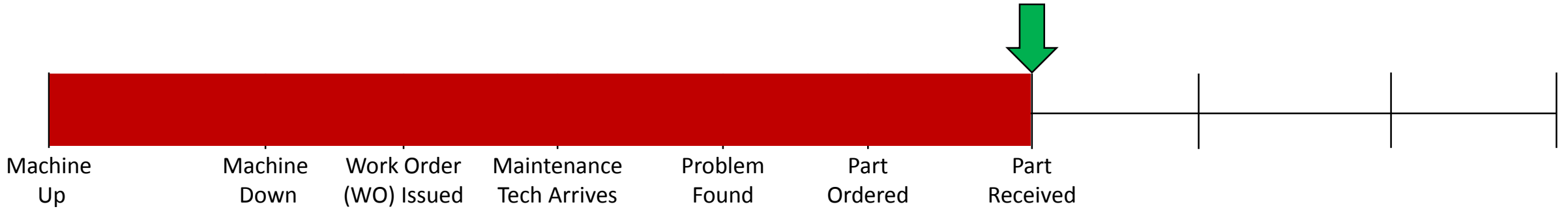


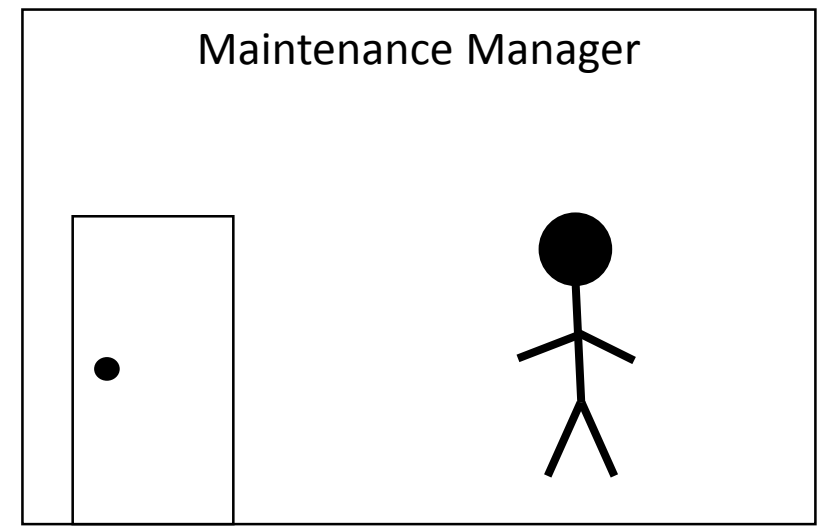
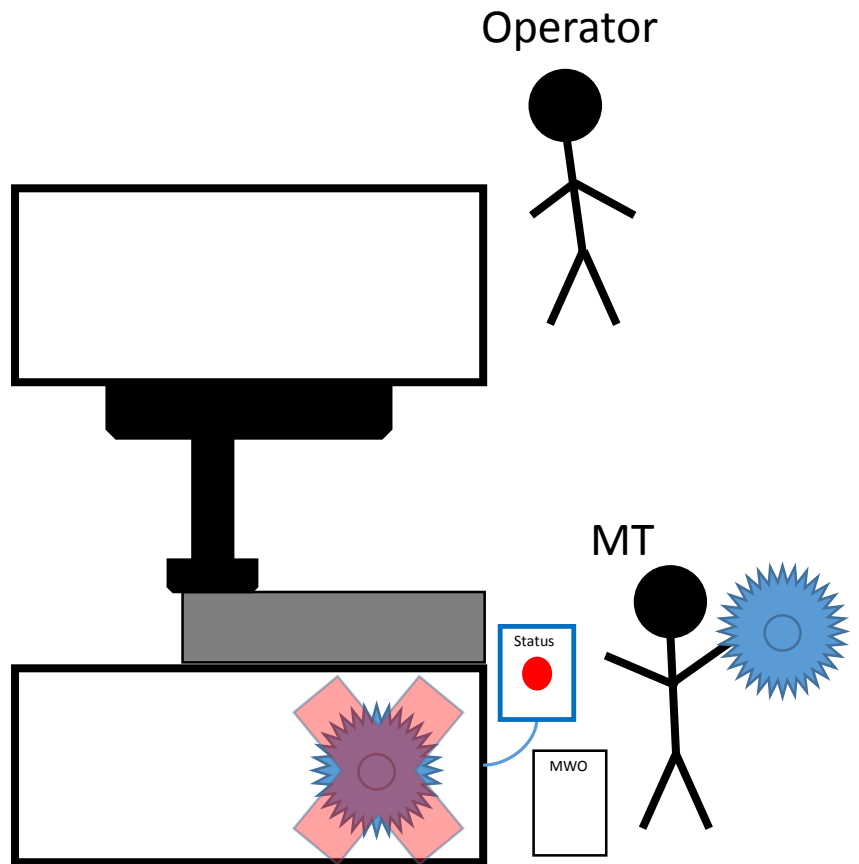
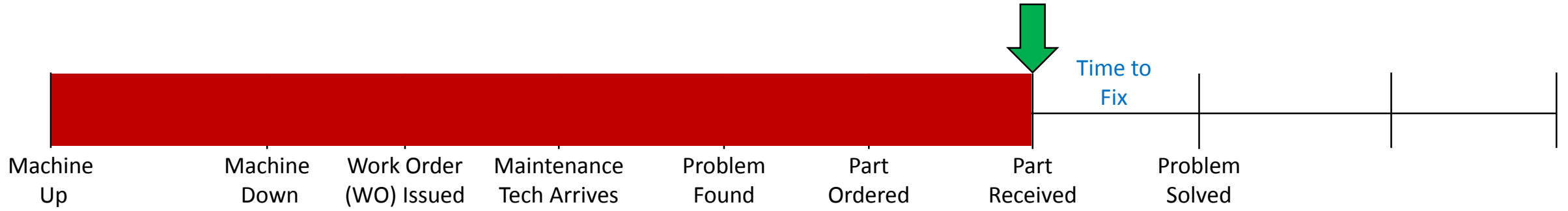


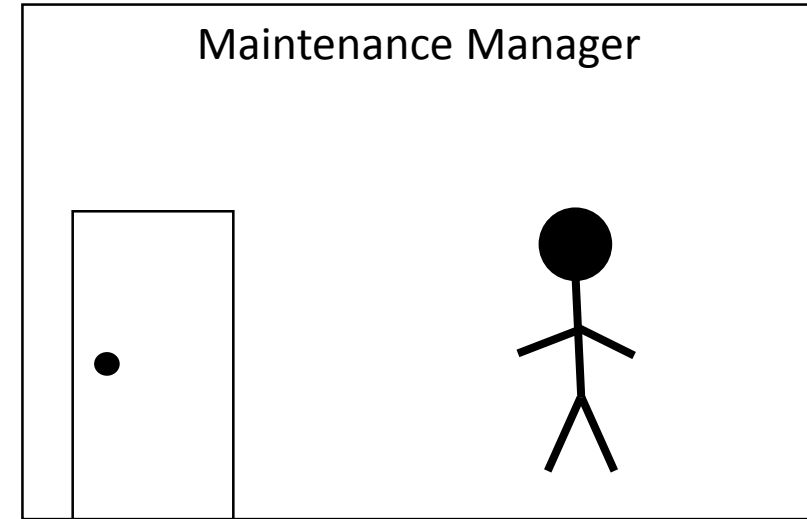
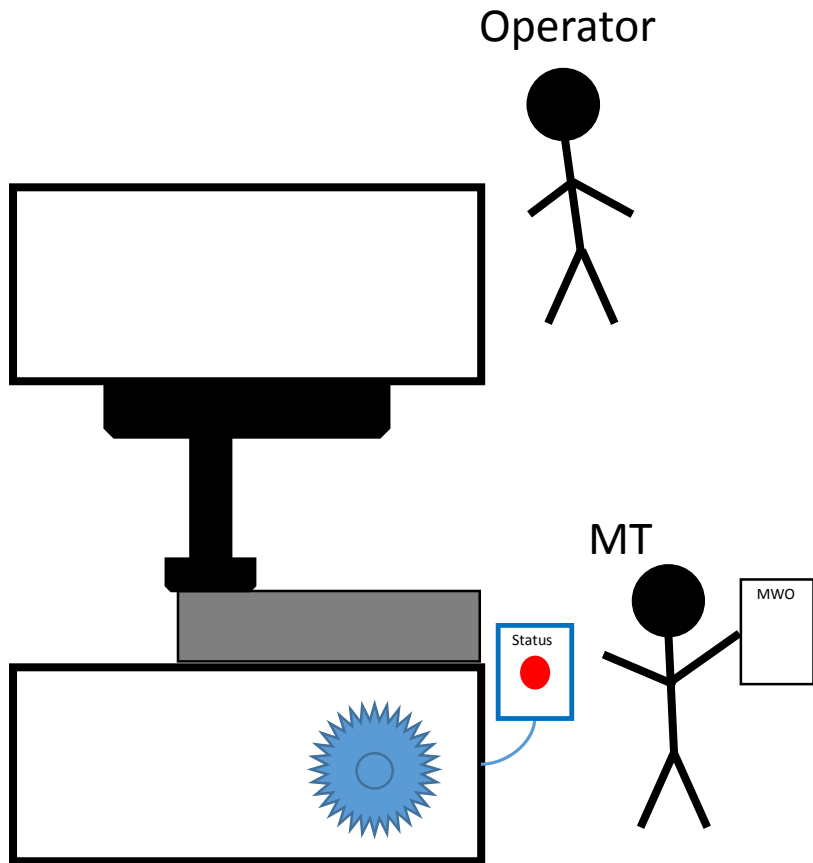
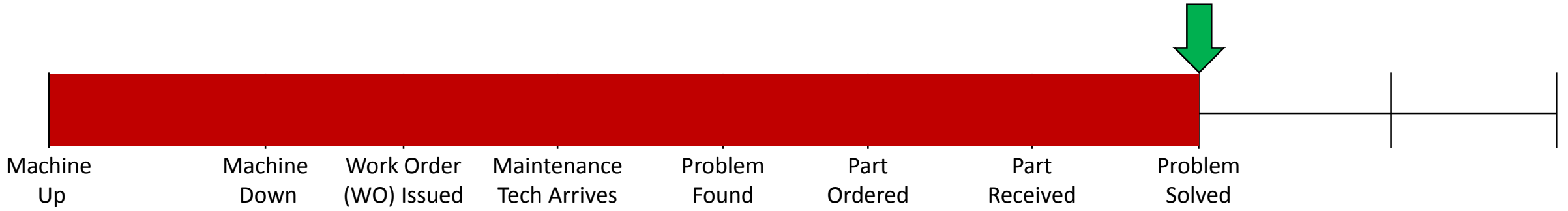


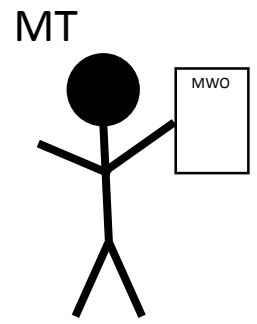
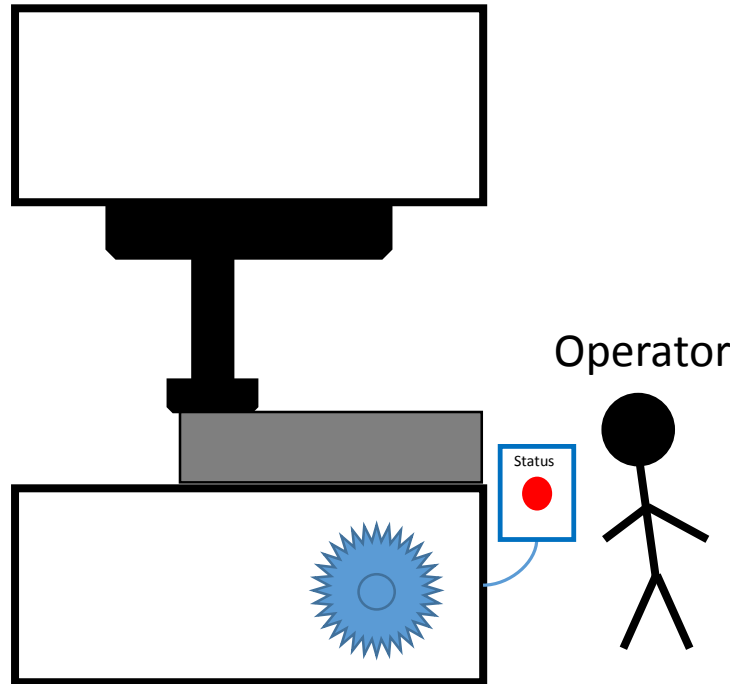
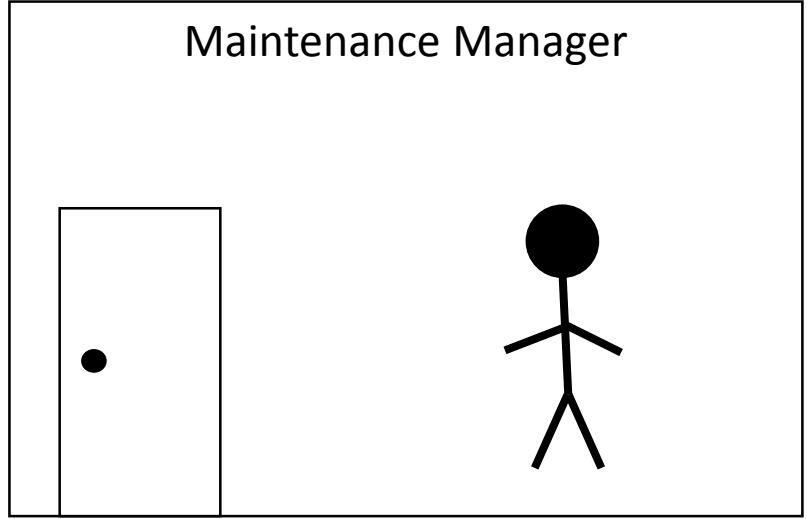
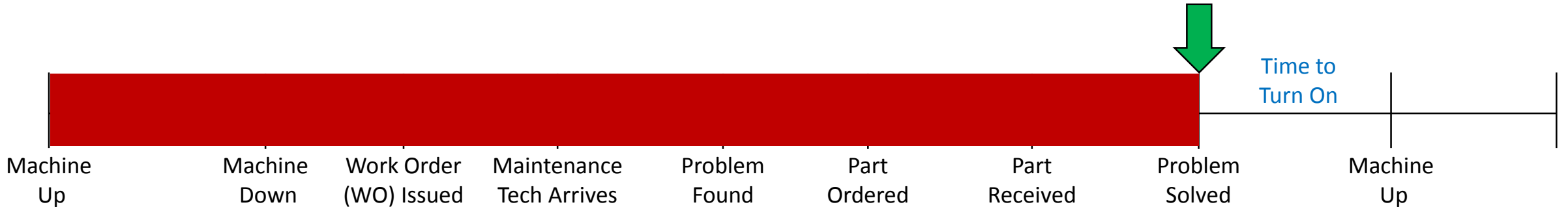


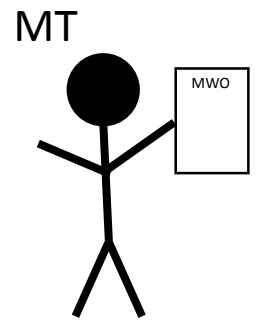
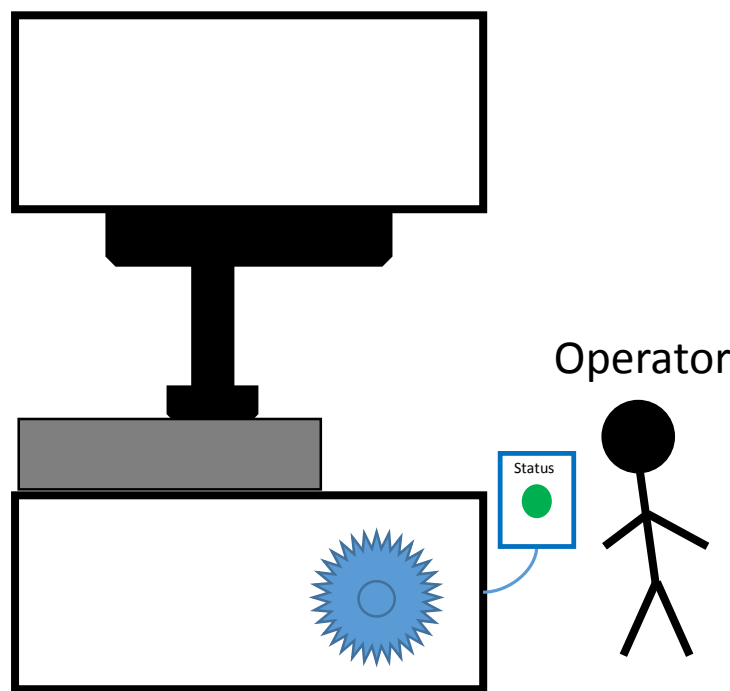
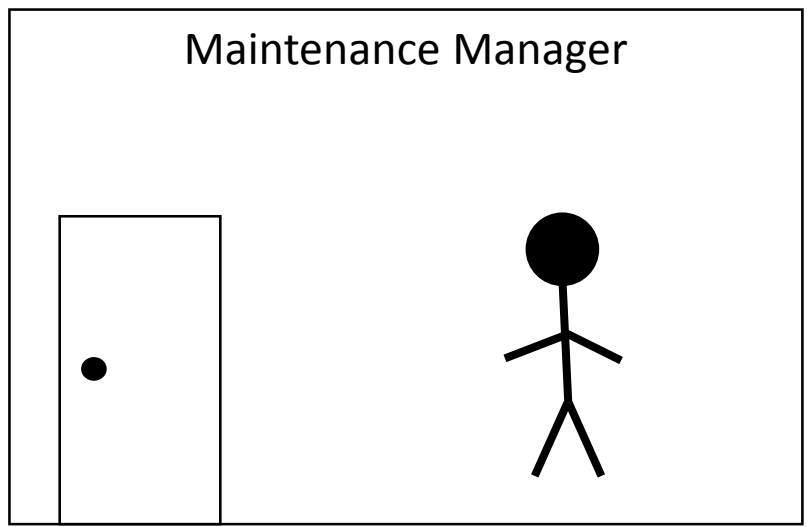
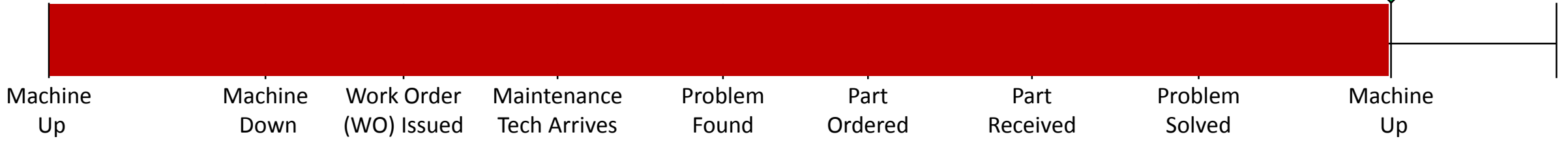


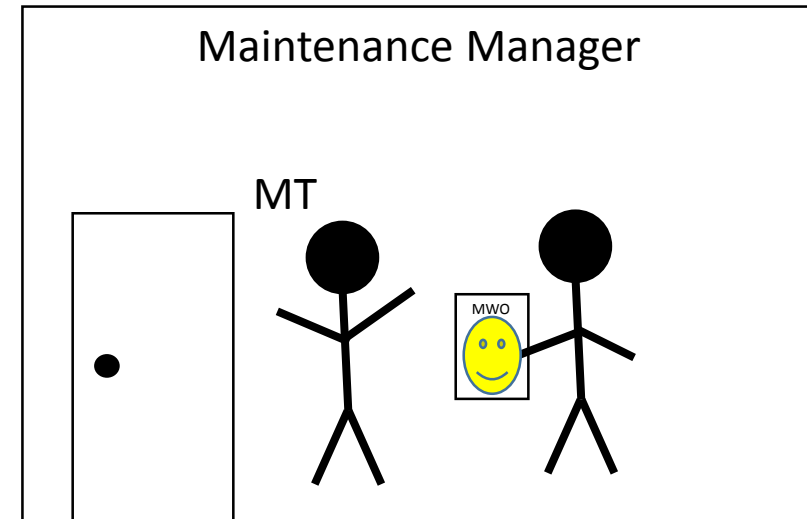
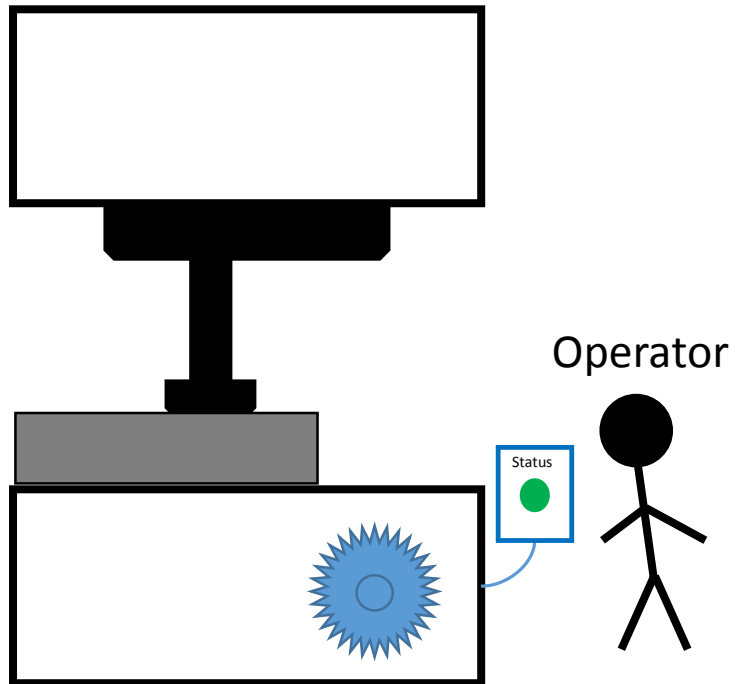
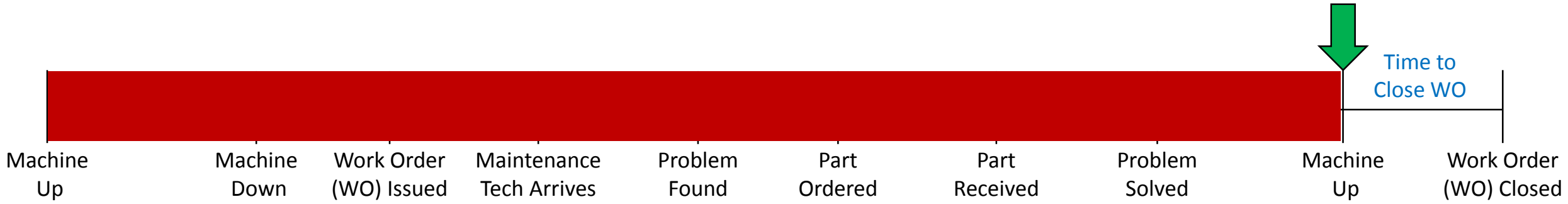













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MWO Data “Pipeline”

- **Extract**
 - **Transform**
 - **Load**
- 
- Collection and Storage
 - Cleaning and Parsing
 - Analysis and Visualization

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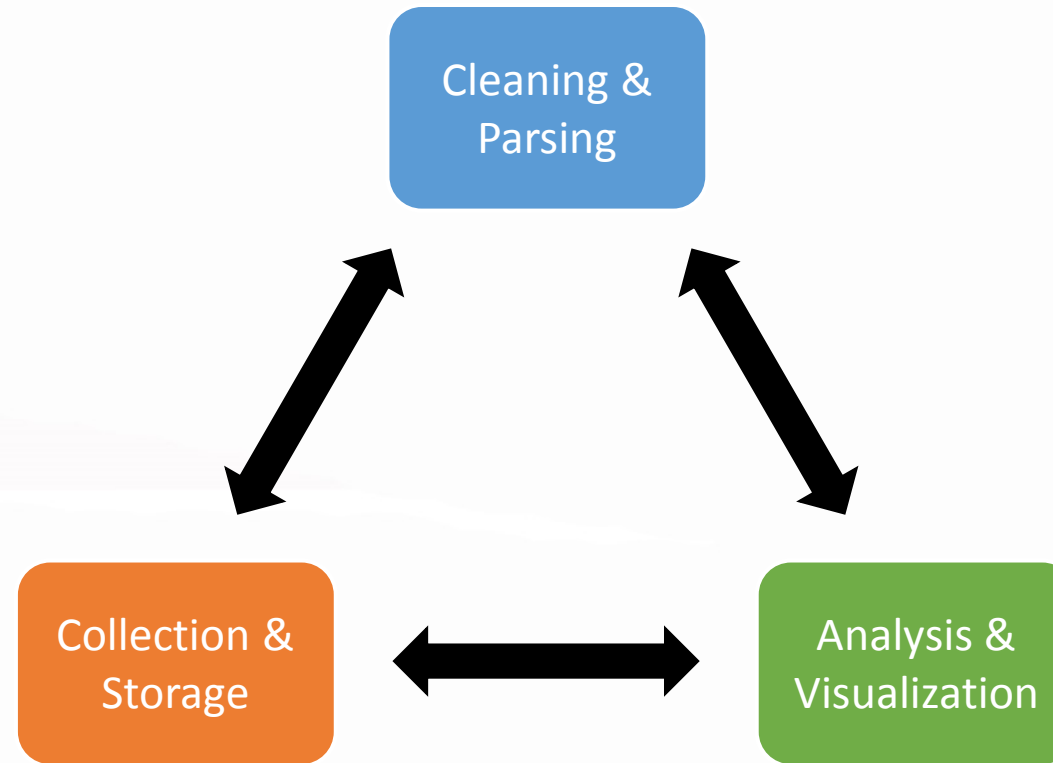


MWO Data “Pipeline”

Decisions made at each stage **will impact** the strategies that are

- Available
- Efficient

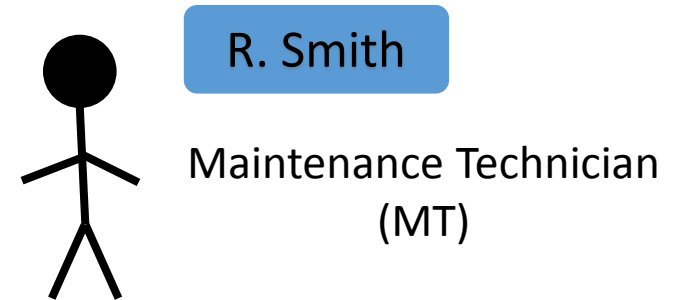
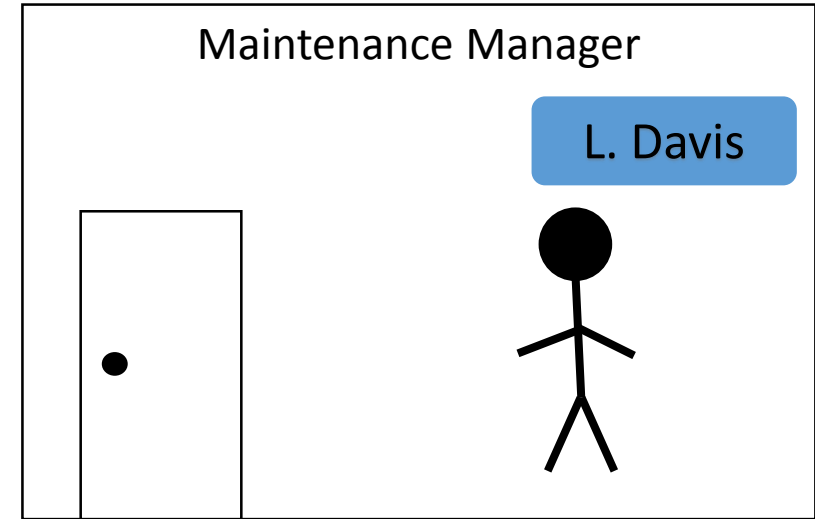
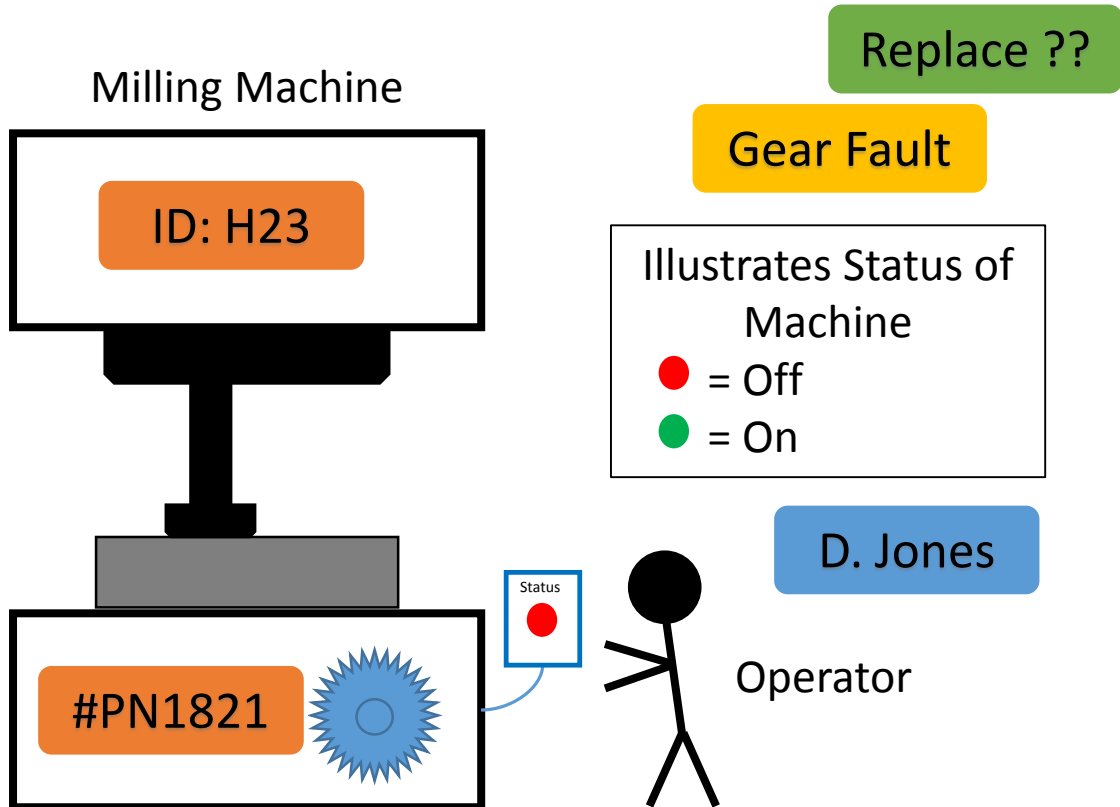
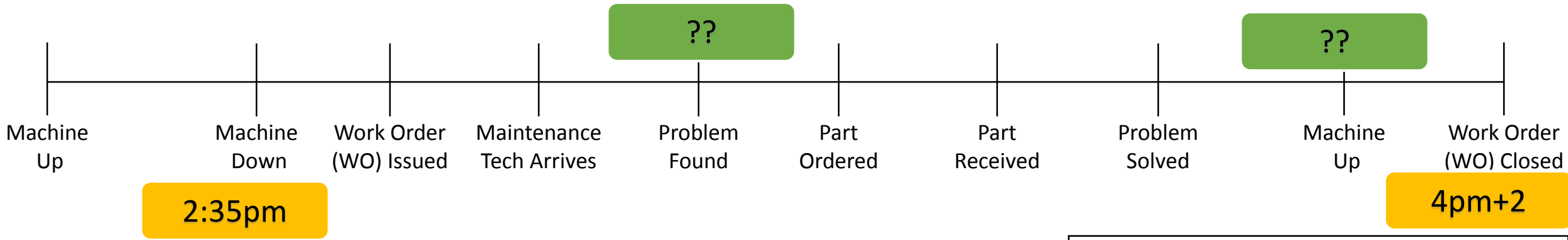
at each other stage.



Keep in mind while we address needs...

Data Collection and Storage

Recall the CNC video...



Data Collection and Storage

- Needs

- MWO Terminology Definitions

- What defines its components? Who is involved? What is it recording?*

- Atomic data types and formats for information flow in MWOs

- Issue meta-data (dates, descriptions, etc.), personnel, asset IDs*

- Adaptive database schemas for storing varied MWO data

- Desirable information will shift over time—what are the core invariable relations?*

- Mapping from disparate CMMS solutions into standard data types

- Current software uses proprietary/custom schemas—unification?*

Data Collection and Storage

- Granularity can directly impact willingness to participate...*buy-in is imperative*. Culture shifts are hard!
- How will this data benefit the shop-floor...analysis? How will it interfere with their primary responsibilities?
- Some parts of the maintenance management workflow will benefit from data more than others...how to bootstrap cost-vs-benefit estimate?

Data Cleaning and Parsing

Raw Data

| Effect | Average of Time to Complete (hrs) | Number of Instances | Total Time to Complete (hrs) |
|------------------------------------------------------|-----------------------------------|---------------------|------------------------------|
| Accumulator check requested | 1.4590 | 14 | 16.05 |
| Vogel lube faults | 1.5875 | 7 | 6.35 |
| Base cleaning requested | 13.575 | 4 | 27.15 |
| Table index O/T faults | 2.7 | 3 | 2.7 |
| lemca will not load in Auto | 313.2 | 3 | 939.6 |
| Chip conveyor INOP | 1.075 | 3 | 2.15 |
| Chip conveyor jammed | 3.725 | 3 | 7.45 |
| St#2 drill detector INOP | 0.15 | 2 | 0.15 |
| Table drifting at 1/2 table setting | 47 | 2 | 94 |
| Motor thermal overload fault -Hydraulic | 24 | 2 | 24 |
| Machine will not run in Auto | | 2 | |
| Part not loading into collet | | 2 | |
| St#8 Hyd flange not repeating | 0.15 | 2 | 0.15 |
| Power pack leak | | 2 | |
| Table index O/T at 1/2 table -Turning off Hydraulics | | 2 | |

Clean Data

| Effect | Average of Time to Complete (hrs) | Number of Instances | Total Time to Complete (hrs) |
|-----------------------------|-----------------------------------|---------------------|------------------------------|
| Hydraulic Leak | 40.8775 | 39 | 817.55 |
| Accumulator check requested | 1.690 | 26 | 35.5 |
| Coolant Leak | 122.47 | 17 | 1347.2 |
| Bearings check | 16.835 | 16 | 168.35 |
| Chip conveyor INOP | 5.8 | 15 | 63.8 |
| Broken screw | 3.8722 | 14 | 34.85 |
| Table index faults | 24.08 | 13 | 120.4 |
| Brush unit stuck forward | 4.744 | 10 | 42.7 |
| Vogel lube fault | 2.27 | 9 | 11.35 |
| Coolant Pressure Low | 3.26 | 9 | 16.3 |
| Oil leak | 39.2375 | 8 | 156.95 |
| Base cleaning requested | 13.575 | 4 | 27.15 |
| lemca will not load in Auto | 235.9 | 4 | 943.6 |
| Bearings noise | 79 | 4 | 79 |
| Inverter failing to return | 0.3 | 4 | 0.3 |

| Effect | Total Time to Complete (hrs) | |
|-----------------------------|------------------------------|-------|
| | Raw | Clean |
| Accumulator check requested | 16.05 | 35.5 |

Raw Data

| |
|----------------------------------------------------------|
| Hyd leak at Bar stop pre load position |
| Major Hydraulic leak at Bottom XD head |
| Hydraulic leak at cutoff unit |
| “Hyd leak at St#2 chip breaker valve” |
| Hydraulic return line leak |
| Hyd leak from behind collet #6 |
| Hydraulic leak turret 2 |
| Hydraulic leak actuator or horseshoe |
| “Iemca hydraulic pump leaking -Full tank per day” |
| Hydraulic leak |
| Hyd leak at locking pin assy |
| Iemca hydraulic pump leaking -Full tank per day |
| Hydraulic leak on Side A |
| “Hydraulics leaking from dressing unit” |
| Hydraulic leak at St#4 |
| Hyd leaks at valve below #7 / Lid leaks at loader |
| St#8 valve spraying hydraulic fluid |
| Hyd leak at Iemca pumps tank |
| Hvd leak from dressing unit |
| “Hydraulic Leak reported - One tank per day” |
| Major hydraulic leak |
| Major Hydraulic leak at rotator -Rotator rack is broken |
| Hydraulic oil getting into Vogel waste oil |

Clean Data

Hydraulic Leak

Data Cleaning and Parsing

- Needs

- Guidance on strengths and limitations of specific data cleaning methods

What assumptions does each type of automation make?

- Guidance on how to select data cleaning methods

How well do the pros/cons of a method align with your context and strategic goals?

- Metrics to determine validity of data cleaning methods for use in PHM

Objective measure for relative usefulness of each method type.

Data Cleaning and Parsing

- The investment/payoff of solving problems through analysis will directly impact *how much annotation* you're willing to do.
- How rapidly are the states/behaviors of a system changing? Data Schema's will likely need ability to adapt rapidly.
- Can data annotation be outsourced (e.g. local university, etc.?) to be used for analysis? Kaggle competitions.... Is "PII" a problem?

Data Analysis and Visualization

What can we do now?

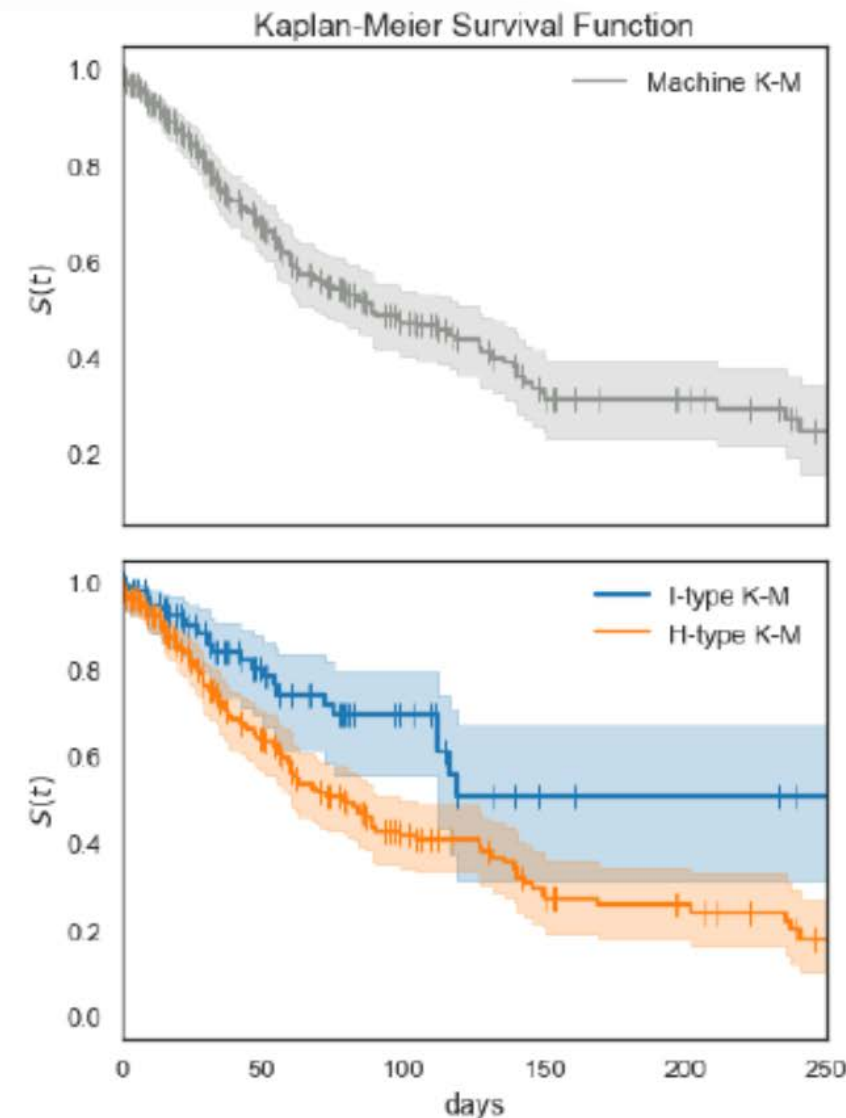
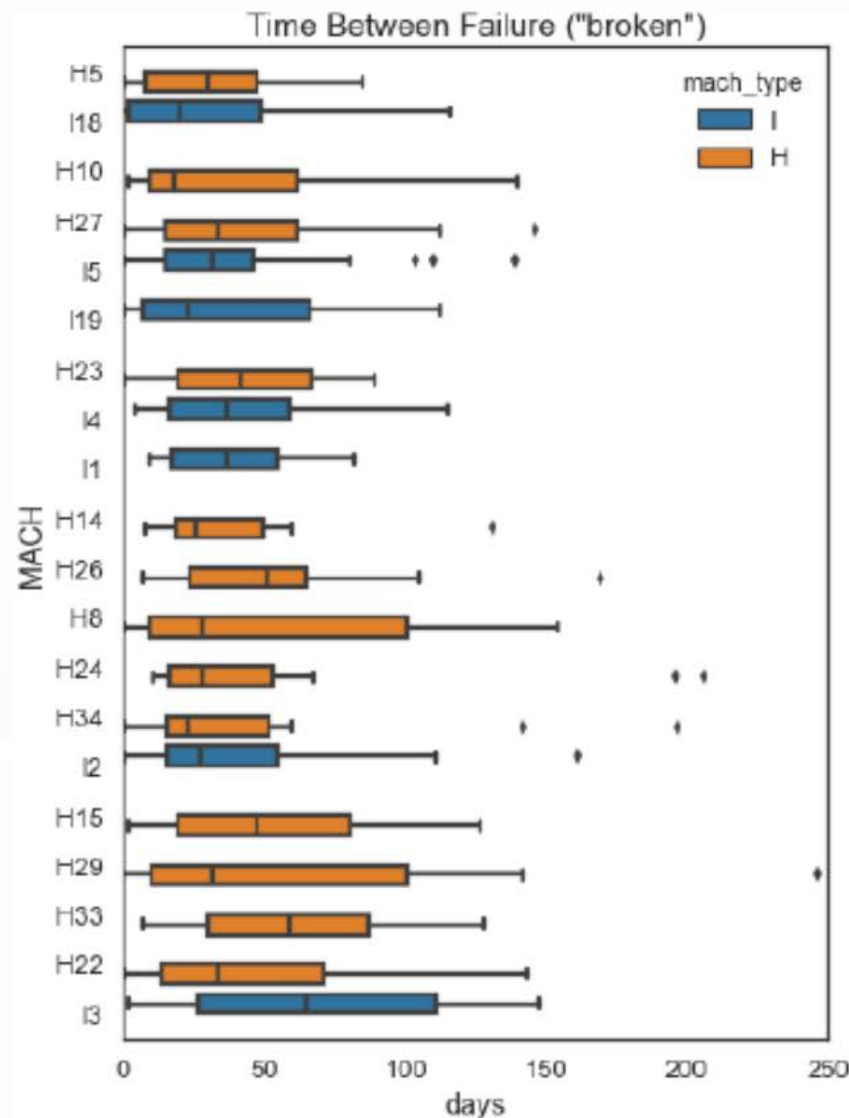
Data Analysis and Visualization

Example:

Once occurrences of “broken” were aggregated, patterns emerge:

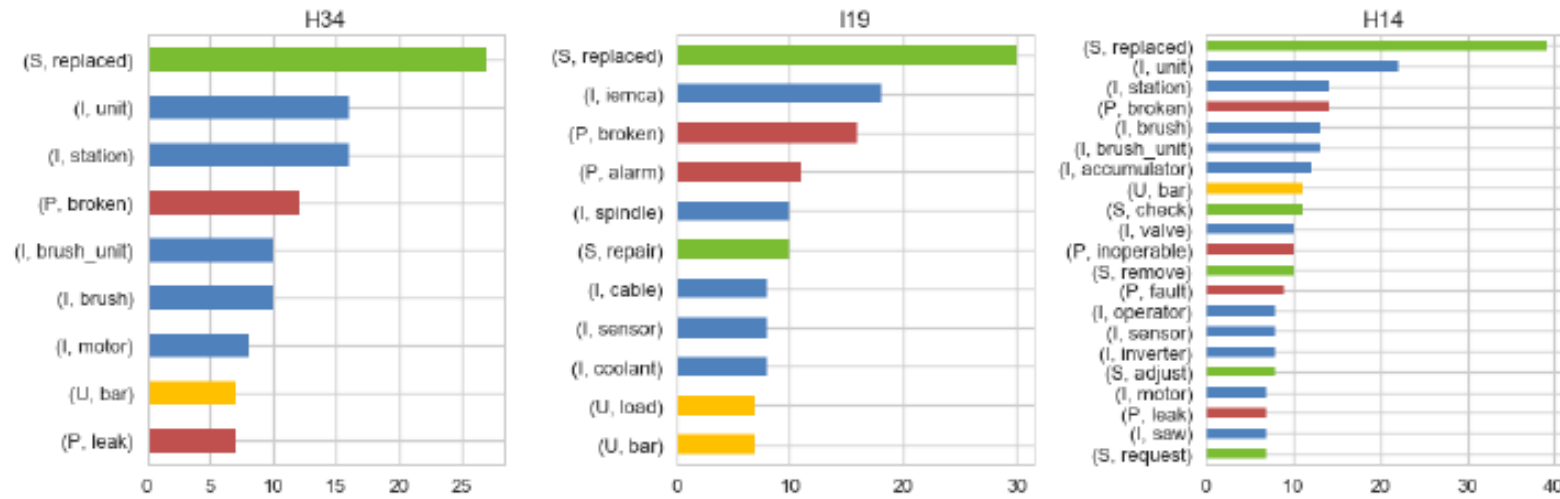
- Some machines “reliably” fail significantly more often
- Unusual dip in survival at the 100-day mark...PM-induced corrective work?

→ Investigate!

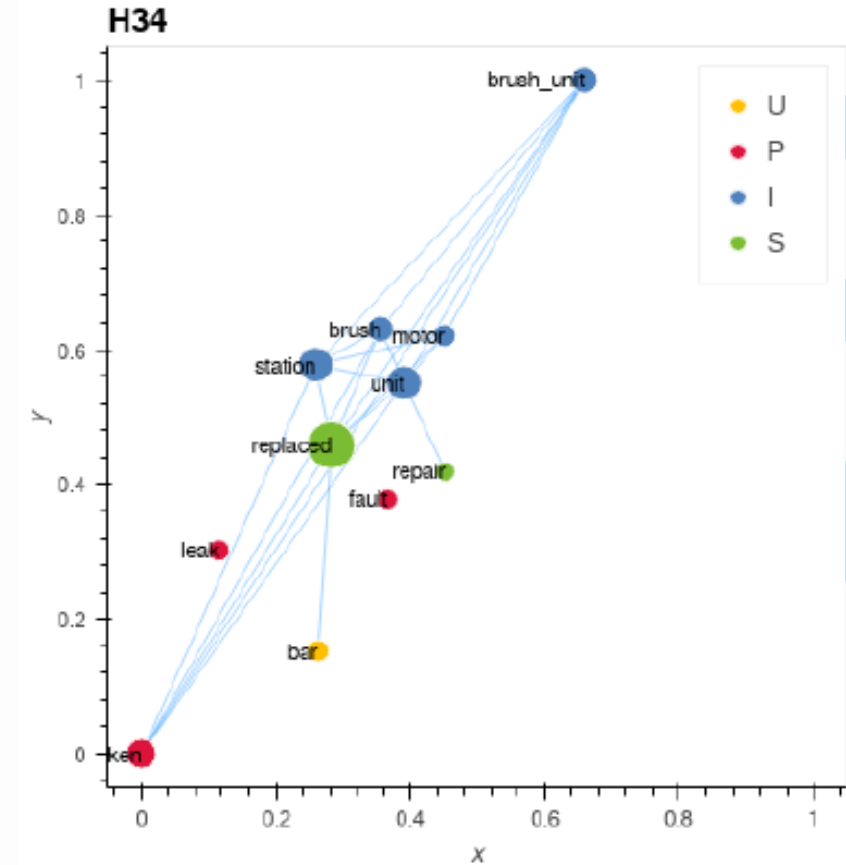


Data Analysis and Visualization

Top Tag occurrences, by Machine



- H34 issues with `motor`, `brush_unit`
- I19 alarms and/or sensors, potentially coolant-related
- H14 wide array of issues, including `operator` (!?)



Data Analysis and Visualization

- Needs

- Guidance on available analyses, and how they tie to maintenance decisions
Trends, diagnostics, RUL/MTTF, scheduling down-time, replacement part storage, etc.
- Guidelines on how to perform analysis techniques
What kinds of inputs are needed for desired output? What time-investment is involved?
- Validation methods and benchmarking for MWO analysis
How to know if the technique I choose “did a good job” on my data? What does that mean?
- Guidance on multi-modal data fusion
e.g. Merging MWO descriptions with sensor data? With energy cost?

Data Analysis and Visualization

- It's dangerous to predict behaviors under “new” conditions without a *theory* (limitations of techniques)
- How will this analysis get used? Is it easy for the decision-maker to access/apply it within the maintenance workflow?
- Is required data already in-place? If not, *where* would the analysis be most beneficial?

Future Work

- NIST Workshop to gather standards requirements for Natural Language Document Analysis in Manufacturing – **May 21, 2019**
- Tagging UI refinement and industry user studies
- Visualization UI
 - Explore alternative visualizations
- Improve tagging tool: <https://github.com/usnistgov/nestor>
- Develop standard guidelines through ASME PHM Subcommittee
 - Meeting at NIST – **May 22-23, 2019**

May 21, 2019 Workshop

- Focus on gathering standards requirement for natural language document analysis
 1. Data Collection and Storage
 2. Data Cleaning and Parsing
 3. Data Analysis and Visualization
- Each topic area will have short presentations and brainstorming sessions
- Website:
- If you are interested in presenting, email Michael.Brundage@nist.gov by April 19, 2019 with your title and topic of presentation

Questions?

Thurston Sexton

Thurston.sexton@nist.gov

Michael Brundage

michael.brundage@nist.gov