Enabling Facility-Level Interoperability Between Robot Teams and Machine Cell Devices

Improved Interoperability

- Building on 2013 work to create "generic bridge" between MTConnect and ROS

- Break down the well-documented language barrier in factories

- Enable for industry-wide adoption of open-source technologies
  - Providing a use-case(s) and testbed showcasing lower cost solutions for comprehensive factory floor integration for small- and medium-sized manufacturers

https://youtu.be/hnDKqr-g3t4
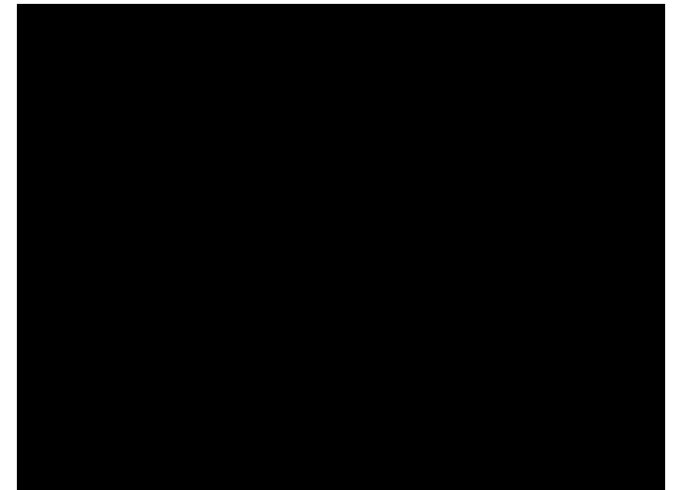
ROS: Robot Operating System – Why?

- **Research Robotics**
  - Reinvention of the Wheel
  - Little Commonality
  - Short Lifespan
  - Inability to Compare Results

ROS

ROS Solves These
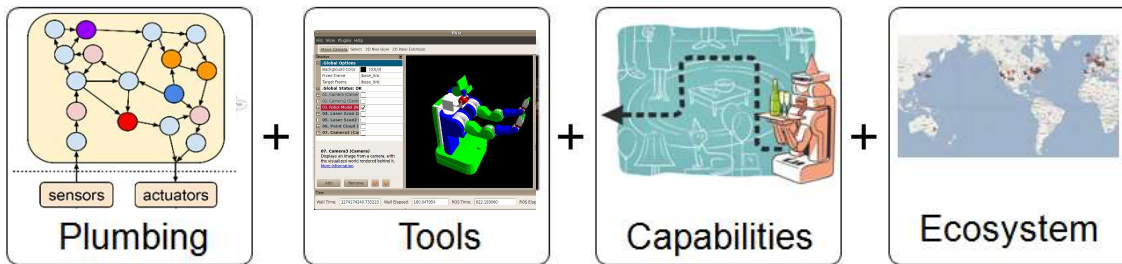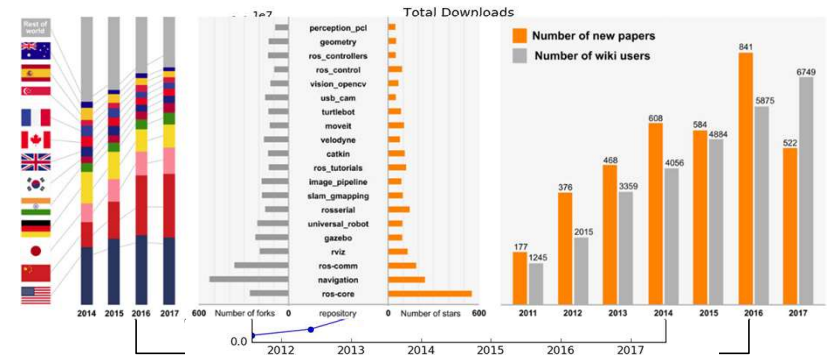
- Open source (BSD)
- Established to keep robotics researchers from "re-inventing the wheel"
- Maintained by OSRF – 10 years strong!
- Reusable software components
- >1,000,000 users downloaded/mo. [1]

Plumbing + Tools + Capabilities + Ecosystem

1. http://download.ros.org/downloads/metrics/metrics-report-2017-07.pdf

2018: ROS-I
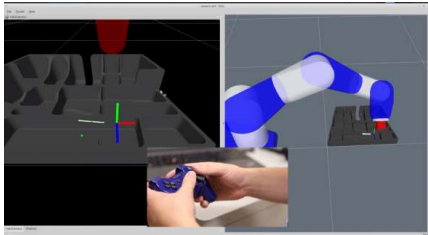
Human Interfaces

Calibration

Industrial 3D Sensors

Developer Tools

Qt Creator ROS Plug-in
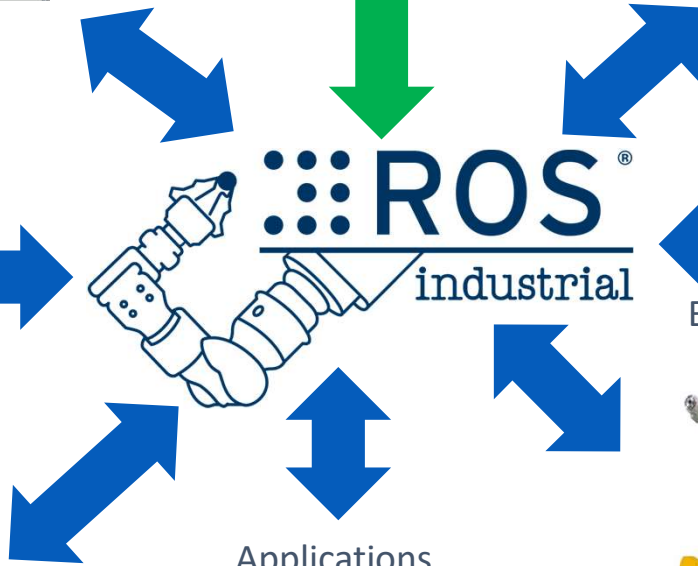
Applications

Mobile Manipulator

Sorting
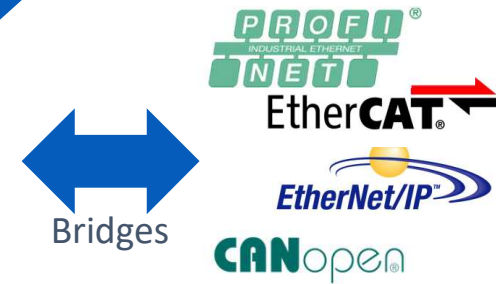
Bridges

Hardware Interfaces

ROS-I Timeline

2010 SwRI Adopts ROS	2011 ROS-I Inception	2012 ROS-I Repo Launch	2013-2016 RIC Launch & Growth

SwRI Unmanned Ground Systems

Robotic Automated Coating Stripping Sys
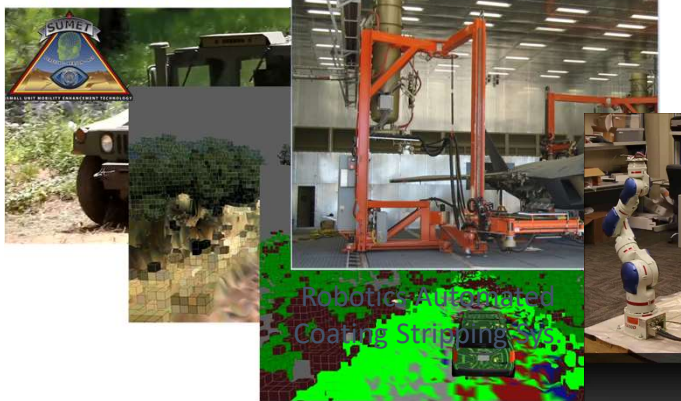
Networking & Strategy Events

Hardware Interfaces | Human Interfaces | Motion/Path Planning
Mobility | Perception | Developer Tools

Mobile Manipulator

Custom Kinematics

2013 RIC Kickoff Meeting

2014 – RIC-EU Launch

2016 – RIC-AP Launch

What Can ROS-I Do?
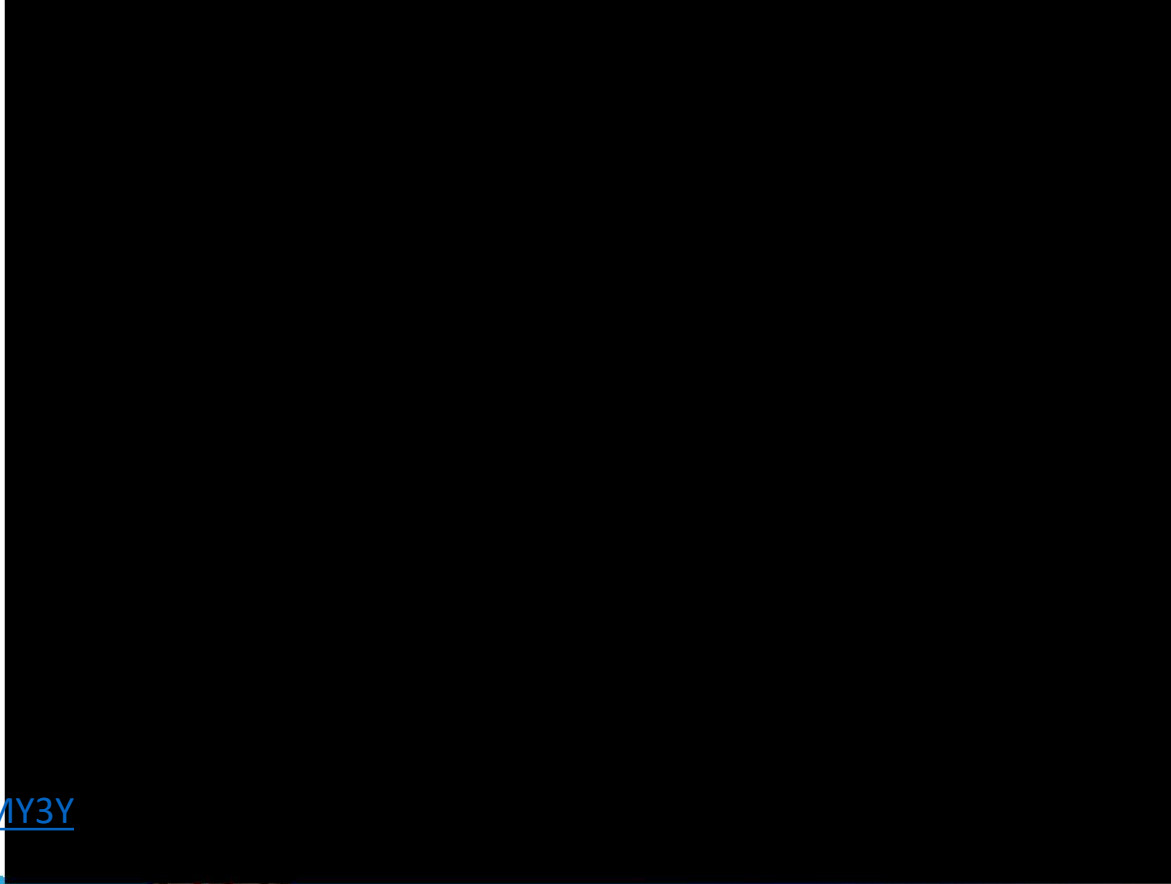
Tech Vision Supported by Industry

ROS-Industrial Technical Vision
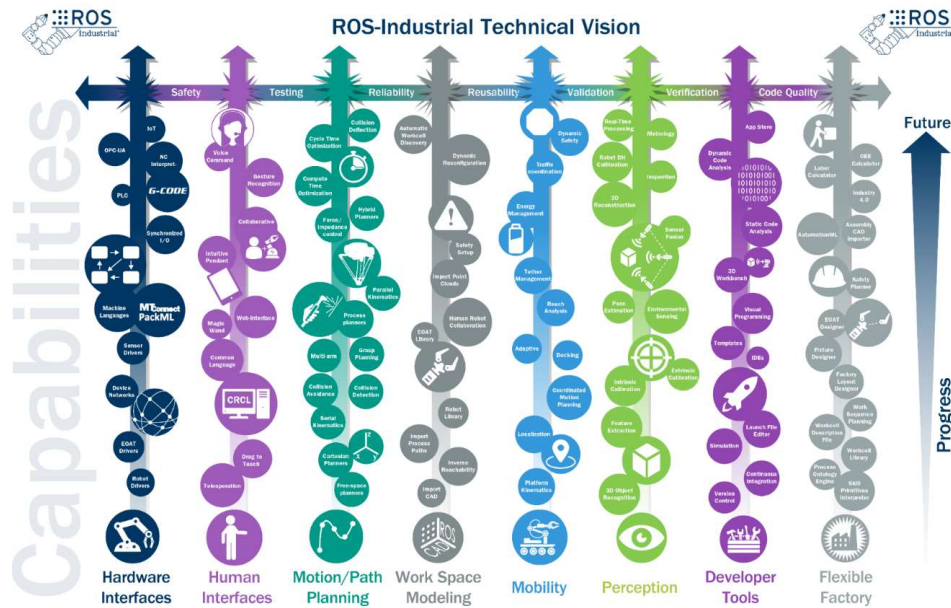
Blending – A Stepping Stone to Intelligent Agility

Scan-N-Plan Foundation
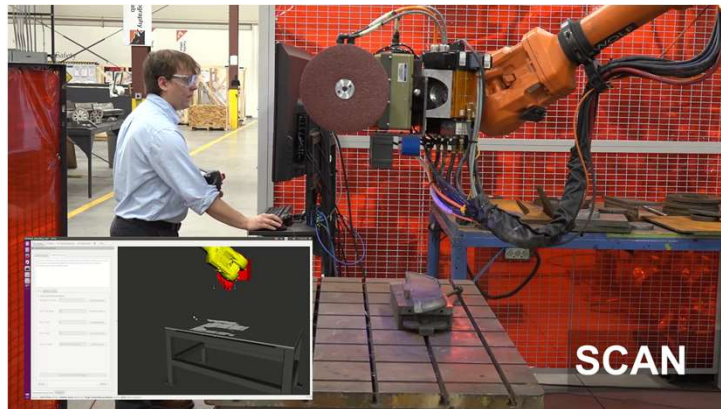
Tech Demonstration of Robotic Blending Milestone 4
https://youtu.be/PWCpehyKnTY
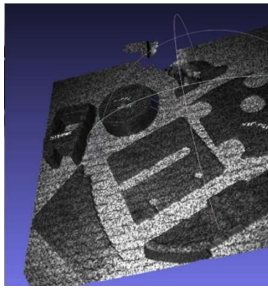
Target Adopter is a Low-Lot High Mix Manufacturing Site
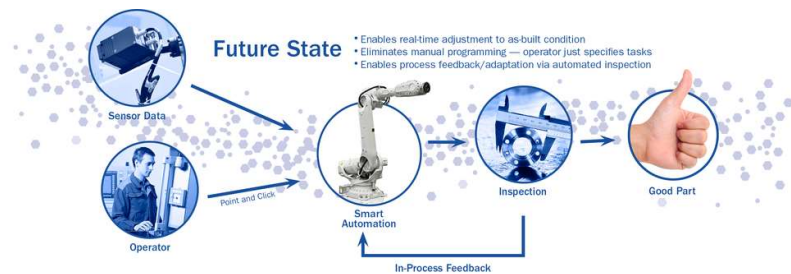
Opportunity 73% ROI based on overall part processing area efficiency improvements via reduction in variable labor
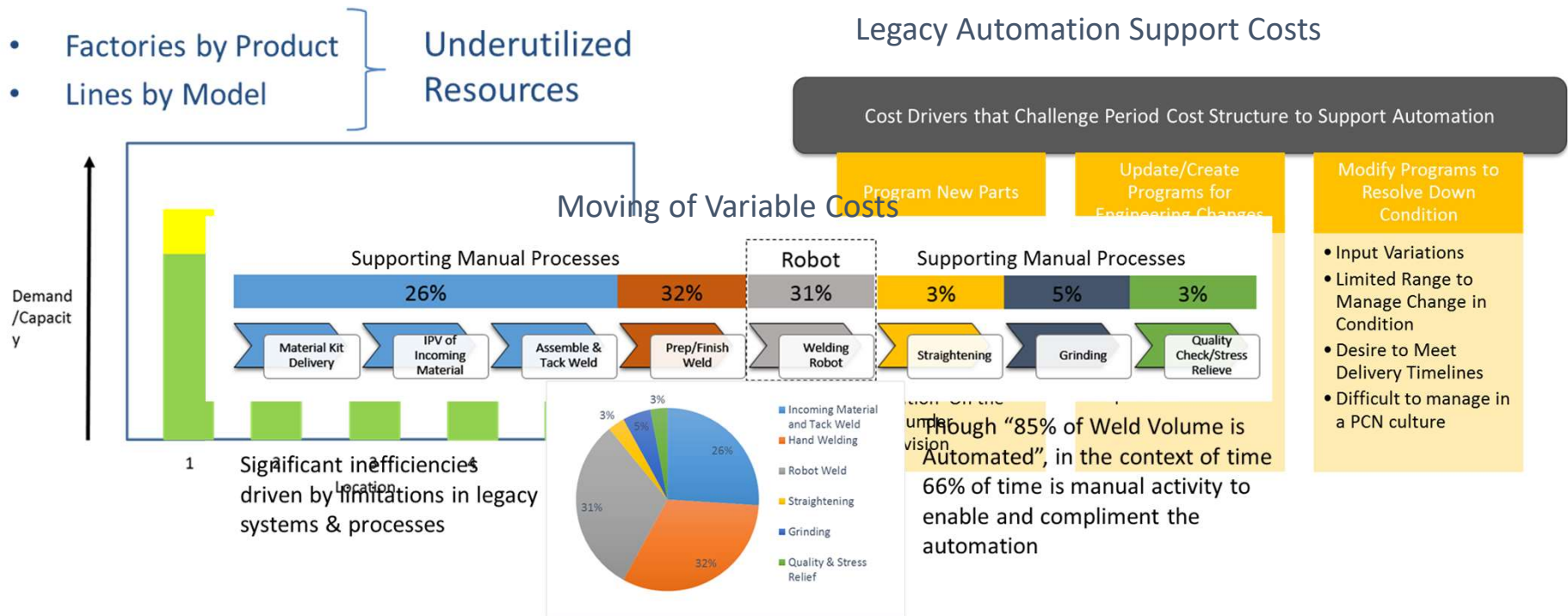
Attacking End-User Opportunities

- Factories by Product
- Lines by Model

Underutilized Resources

Legacy Automation Support Costs

Moving of Variable Costs

Demand/Capacity

Significant inefficiencies driven by limitations in legacy systems & processes

Supporting Manual Processes

| 26% | 32% | Robot 31% | 3% | 5% | 3% |

Material Kit Delivery | IPV of Incoming Material | Assemble & Tack Weld | Prep/Finish Weld | Welding Robot | Straightening | Grinding | Quality Check/Stress Relieve

Though "85% of Weld Volume is Automated", in the context of time 66% of time is manual activity to enable and compliment the automation

Pie chart legend:
- Incoming Material and Tack Weld — 26%
- Hand Welding — 32%
- Robot Weld — 31%
- Straightening — 5%
- Grinding — 3%
- Quality & Stress Relief — 3%

Cost Drivers that Challenge Period Cost Structure to Support Automation

| Program New Parts | Update/Create Programs for Engineering Changes | Modify Programs to Resolve Down Condition |

- Input Variations
- Limited Range to Manage Change in Condition
- Desire to Meet Delivery Timelines
- Difficult to manage in a PCN culture

Evolution of Automation

- Recent reports highlight evolution of automation

- Perception is that Manufacturing Work is nearer to complete automation

- For larger fabrication scenarios this work may be more appropriately defined as 'Unpredictable Physical Work'

- This is where the development of ROS-Industrial plays a key role

Source: http://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/where-machines-could-replace-humans-and-where-they-cant-yet
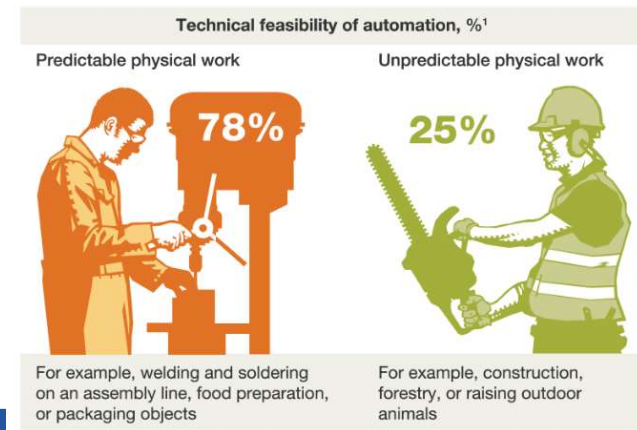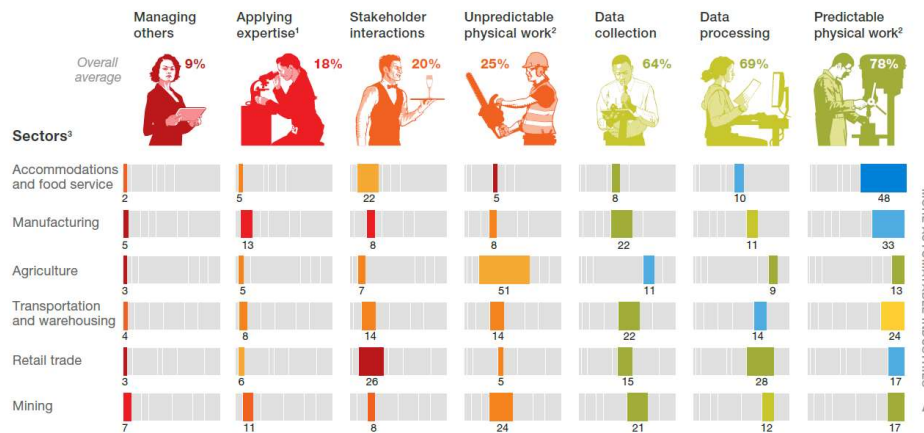
Value Stream Optimization

- The automated solution is only as successful as its inputs, supporting process steps, reliability, and quality of output

- Merging ROS-Industrial and the initiatives around Digital Manufacturing/IoT, improved efficiencies in operations can be realized

Only Processing what is Needed

Completed Assembly

Every Step Every Time

Op 10   Op 20   Op 25   Op 30   Op 35
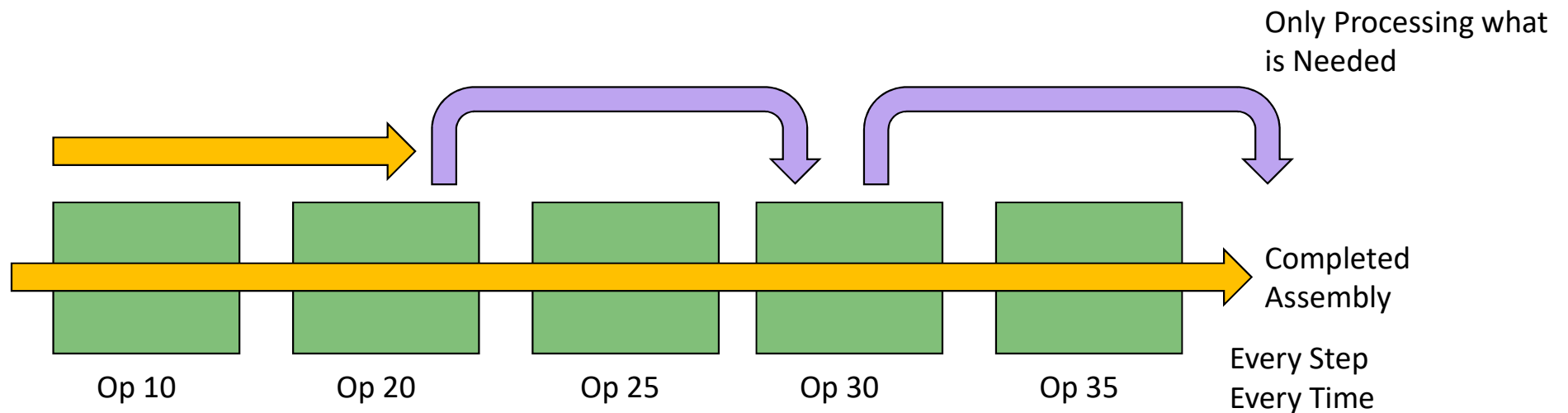
Closed Loop Agile Process

- CAD+Scan to Path

- Closed Loop QA

- Improved Order to Delivery

- Improved Product to Market

- Reduced Losses during Product Change

- Enables ability to apply novel optimization and deep learning techniques for dynamic continuous improvement

PLM – Model with Embedded Features – Modeled Welds; Machine Features

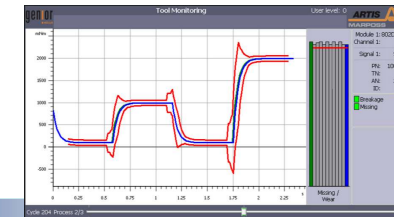MRP and Work Orders/Execution Systems

Point Cloud of 'to be processed' assembly
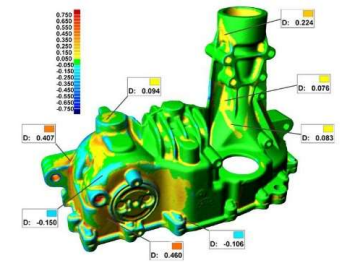
Source: creaform3d.com

Organization's manufacturing IP/Process Data

Process Data to Drive Optimization

Source: AdvancedManufacturing.org

Coordinated Cooperative Use-Case

- 2 Mobile Industrial Robots need to work in a coordinated fashion to load a large CNC
  - Reference case – large spline shaft loaded into CNC lathe

https://youtu.be/MNvh03xYDIs

Photo courtesy of GE Power

Photo courtesy of motorman.com Y-blog

Profitability through Flexibility

- Demonstrated Cases of Impact on Improved Utilization of Assets
  - New Capability in Legacy Assets
  - Increased Flexibility
- Reduction in Non-Value/Low-Value Added Variable Labor
  - Often high risk jobs
  - Typically tasks subject to over-processing/little control
- Flexibility to be able to shift production closer to Market as demand shifts geographically; optimize outside the four walls
- Reduced overhead to support due to greater capability in variation management
- Improved accessibility to technology for the SME

Capabilities and Composition

Part
Archetype
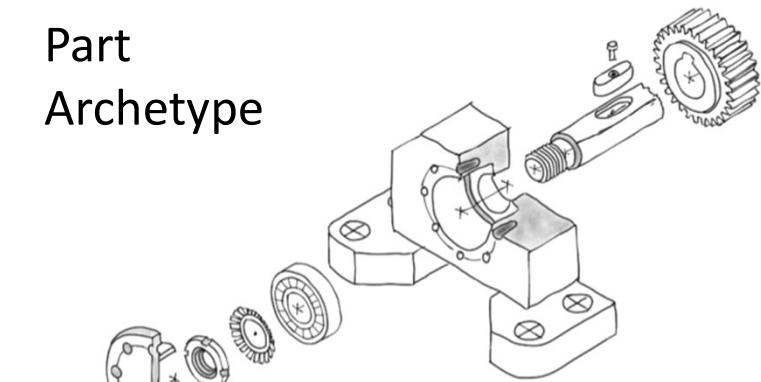
Alternatives
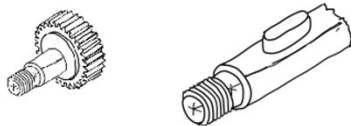
Requirements
Process Primitives
eg. Tooling

requires

Capabilities

Matches

Capabilities
Capacity
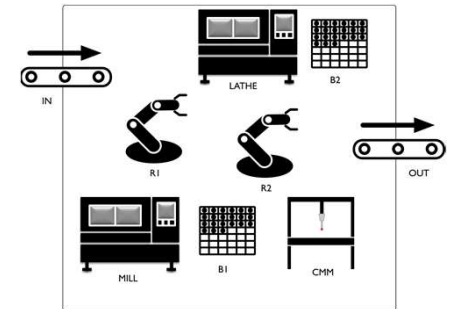
Capabilities

Capabilities	
Payload	Max 150 KG
Reach	5000 mm
End Effector	Gripper

Capabilities	
Payload	Max 50 KG
Reach	2000 mm
End Effector	Gripper
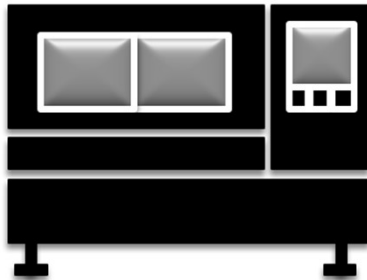
Capabilities	
Enclosure	Max 150 KG
Spindle	200 HP
Kinematics	bXYtZb
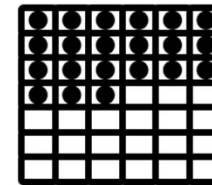
Capabilities	
Capacity	Max 36
Capacity	21

Workflow
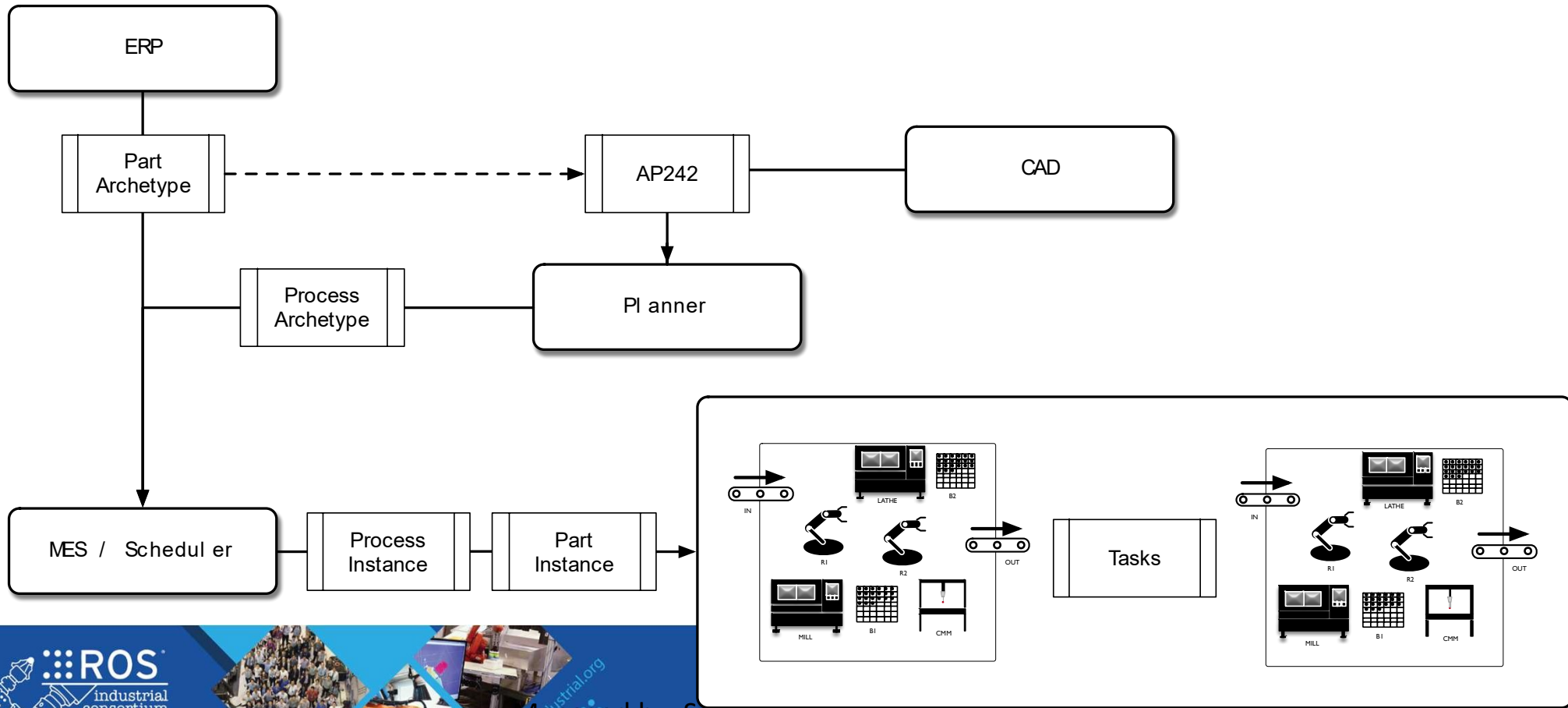
Abstractions

Example: Move Material

```
┌─────────────────────────────┐ (1)
│          Conveyor           │
│      Move Material          │
│       Robot, CNC            │
└─────────────────────────────┘
            │
     ┌──────┴──────┐
     ▼             ▼
┌──────────────┐(2) ┌──────────────────┐(3)
│   Conveyor   │    │       CNC        │
│Material Unload│   │  Material Load   │
│    Robot     │    │     Robot        │
└──────────────┘    └──────────────────┘
                          │
          ┌──────┬────────┼────────┬────────┐
          ▼      ▼        ▼        ▼
    ┌─────────┐(4)┌─────────┐(5)┌──────────┐(6)┌──────────┐(7)
    │  Robot  │   │  Robot  │   │  Robot   │   │  Robot   │
    │Open Door│   │Open Chuck│  │Close Chuck│  │Close Door│
    │   CNC   │   │   CNC   │   │   CNC    │   │   CNC    │
    └─────────┘   └─────────┘   └──────────┘   └──────────┘
```
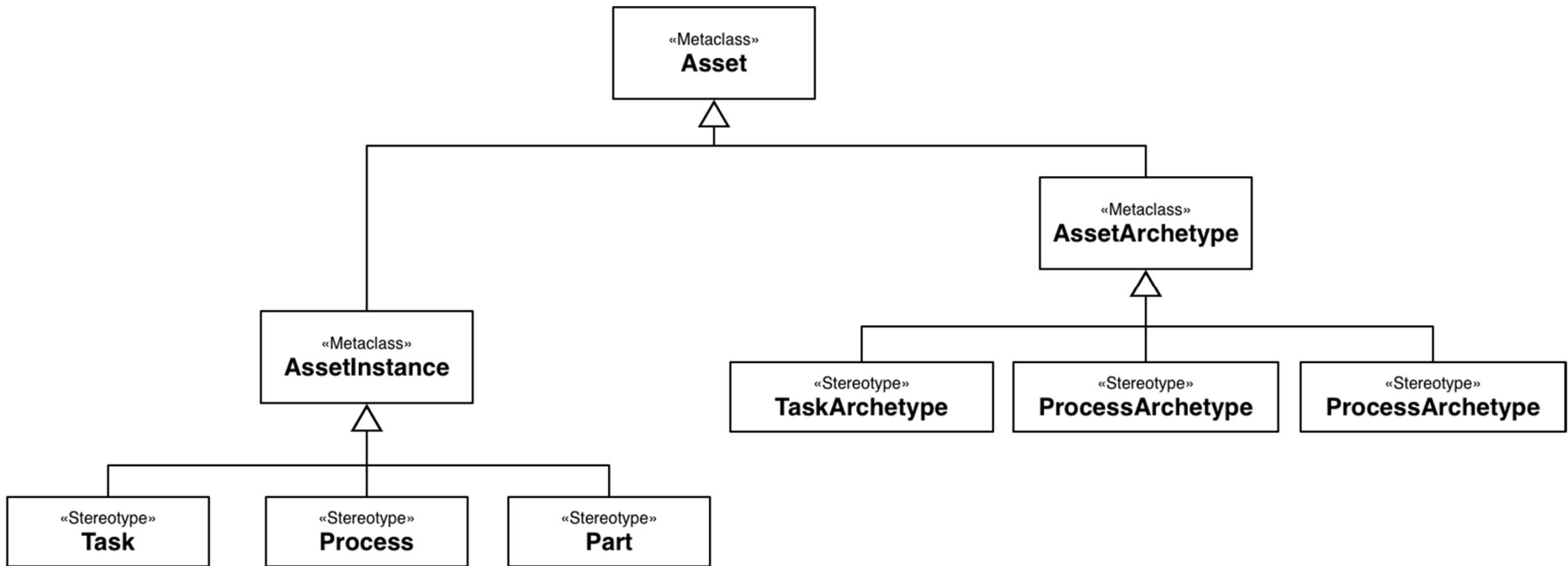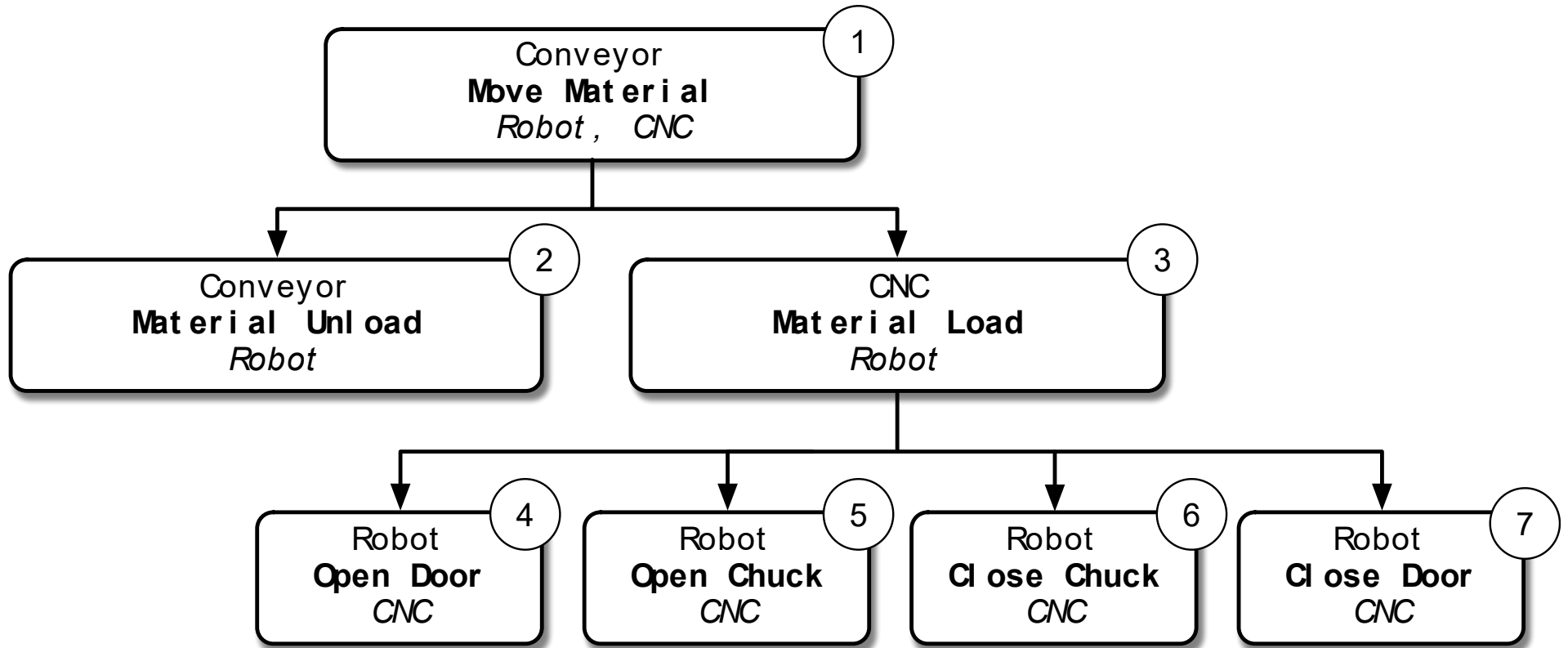
Overview of Orchestration
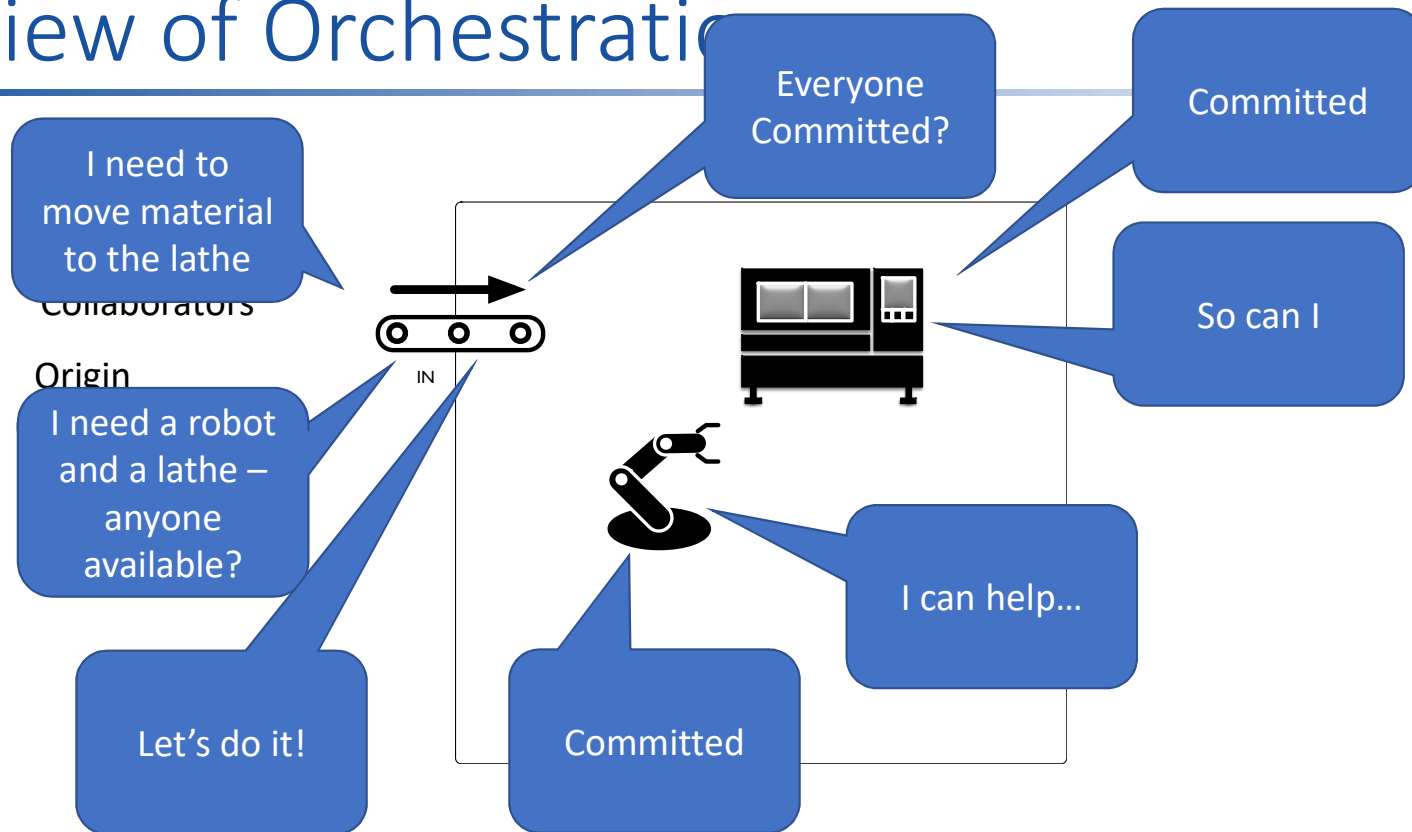
Cell

Coordinator Task Asset

Task

INACTIVE	**PREPARING**	**COMMITTING**	**COMMITTED**	**COMPLETE**
Wait for activation from Coordinator	Wait for collaborators to state they are participating *quorum/committing*	If all commit/COMMITTED If not commit/PREPARING If task failed/FAIL	**Begin Task** On completion: *Success/Complete Failure/Fail*	Success / Remove task

Create → INACTIVE → (Activated) → PREPARING → (Quorum) → COMMITTING → (All Commit) → COMMITTED → (Success) → COMPLETE → Removed

No Commit · Fail · Failure

FAIL — Failure / Remove task

Binding States

Collaborator

● Unavailable

Coordinator

● Unavailable

INACTIVE

Machine becomes available but has no work to do

Creates Task
Binds to Task

Completed or Failed

COMMITTED

Stays Committed until complete.

INACTIVE

Wait for task that requires collaboration

Task created

PREPARING

State interest in collaborating in all tasks that require our capability

One ore more tasks change to COMMITTING state. If > 1, choose a task

Could not complete committing

COMMITTED
Once task is complete, return to INACTIVE state

Task is completed

Types of Tasks

- Material Handling
- Tool Change
- Maintenance
- Part Cleaning
- Welding
- Additive Processes
- Taking out the Garbage
- Making Coffee

DEMO

Resources

- ROS-Industrial
  - Home: rosindustrial.org
  - Documentation: wiki.ros.org/industrial
  - Code: https://github.com/ros-industrial
  - Training: rosindustrial.org/training
- Upcoming Events
  - ROS-I Americas Training – April 10-12
  - Register! https://rosindustrial.org/events/2018/04/10/ric-americas-spring-ros-i-training

- MTConnect
  - Home: http://www.mtconnect.org/
  - Documentation: http://mtcup.org/wiki/Main_Page
  - Code: https://github.com/mtconnect