Flexible Manufacturing Line with Multiple Robotic Cells

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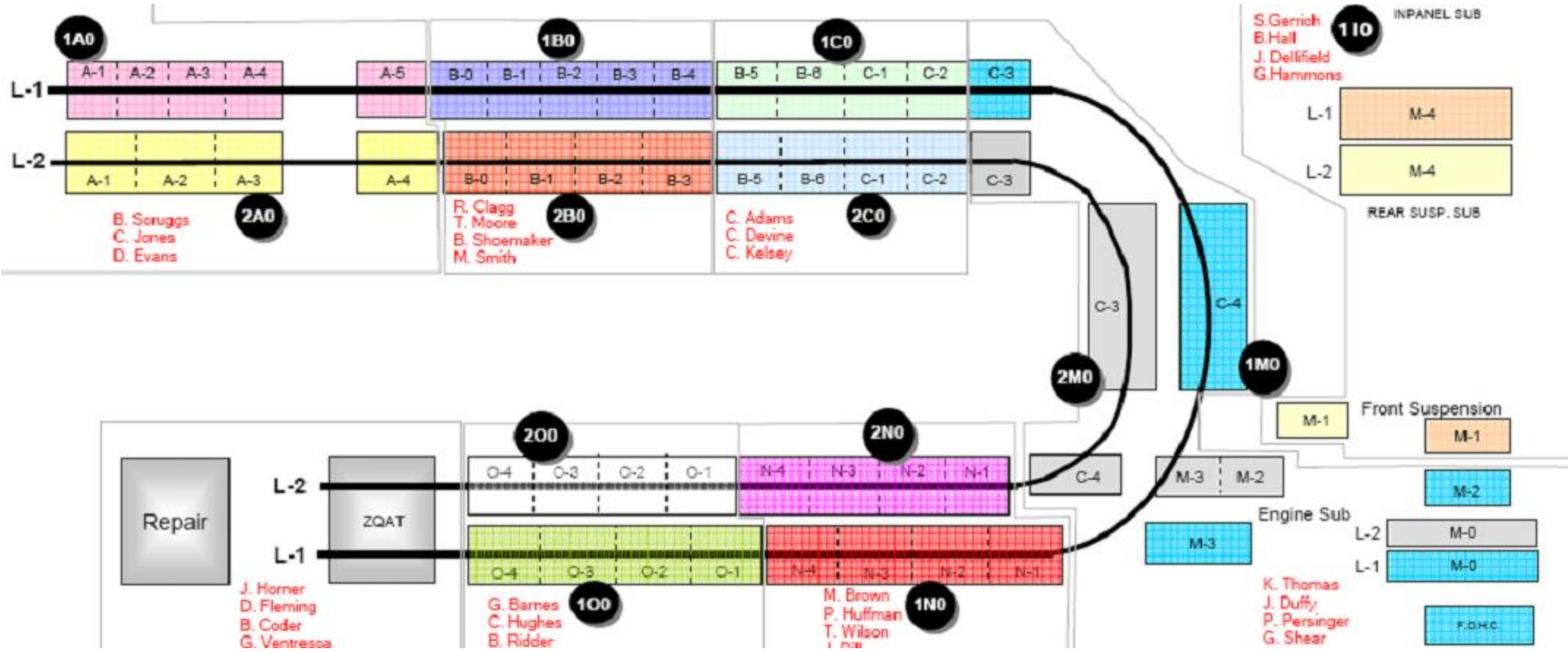
OUTLINE

- Introduction
- Autonomous Robot Teaching
  - POMDP based learning algorithm
- Performance Optimization
  - Single cell optimization
  - Multi cell Optimization
- Discussion

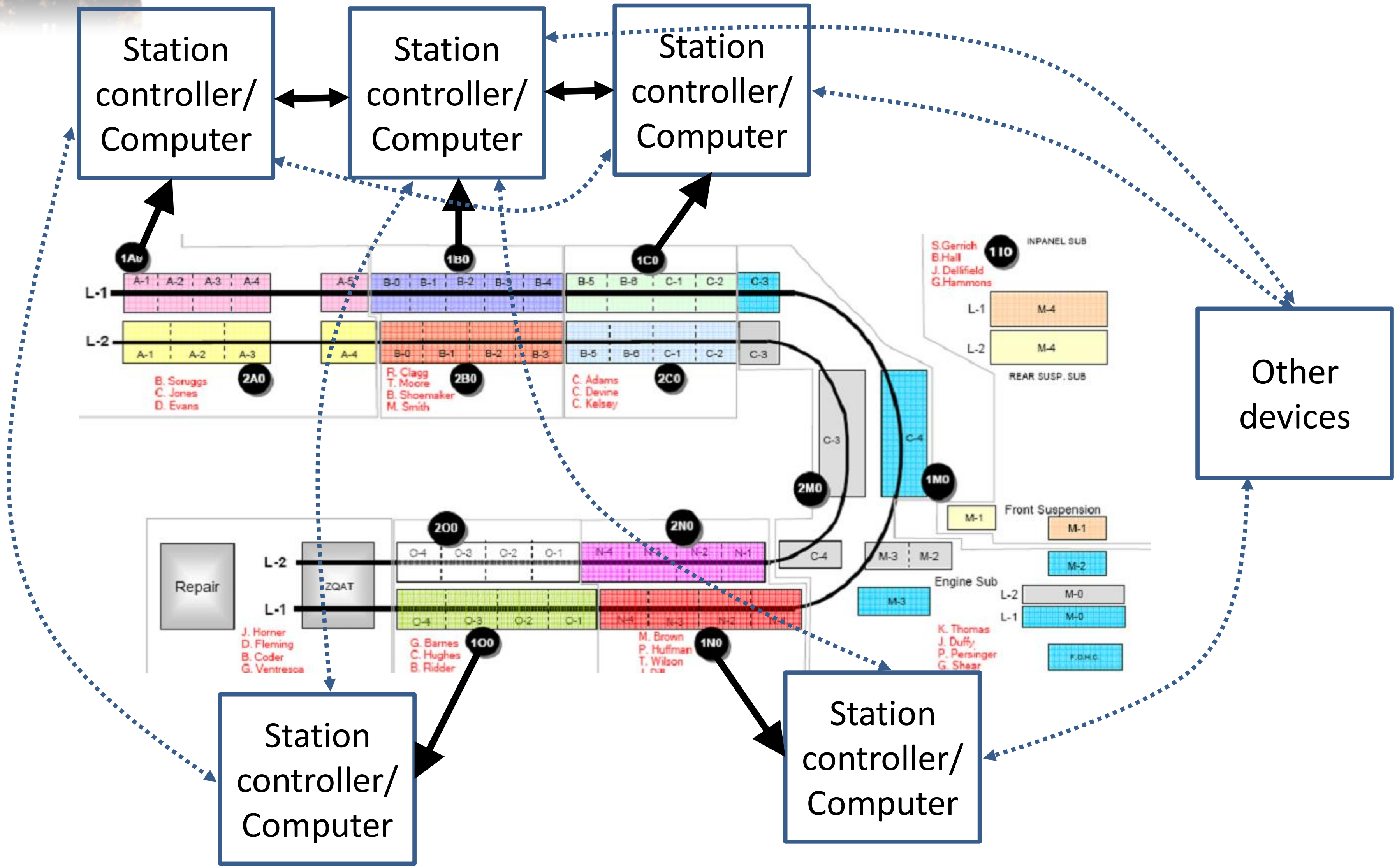
Trim and Final Assembly Line



Problems in Production Line

- When one work station fails, the production line has to be stopped
  - Low efficiency
  - High cost
- For complex manufacturing processes, is it possible to optimize the system performance?
  - Single work station optimization?
  - Multi work station optimization?

Proposed Solution



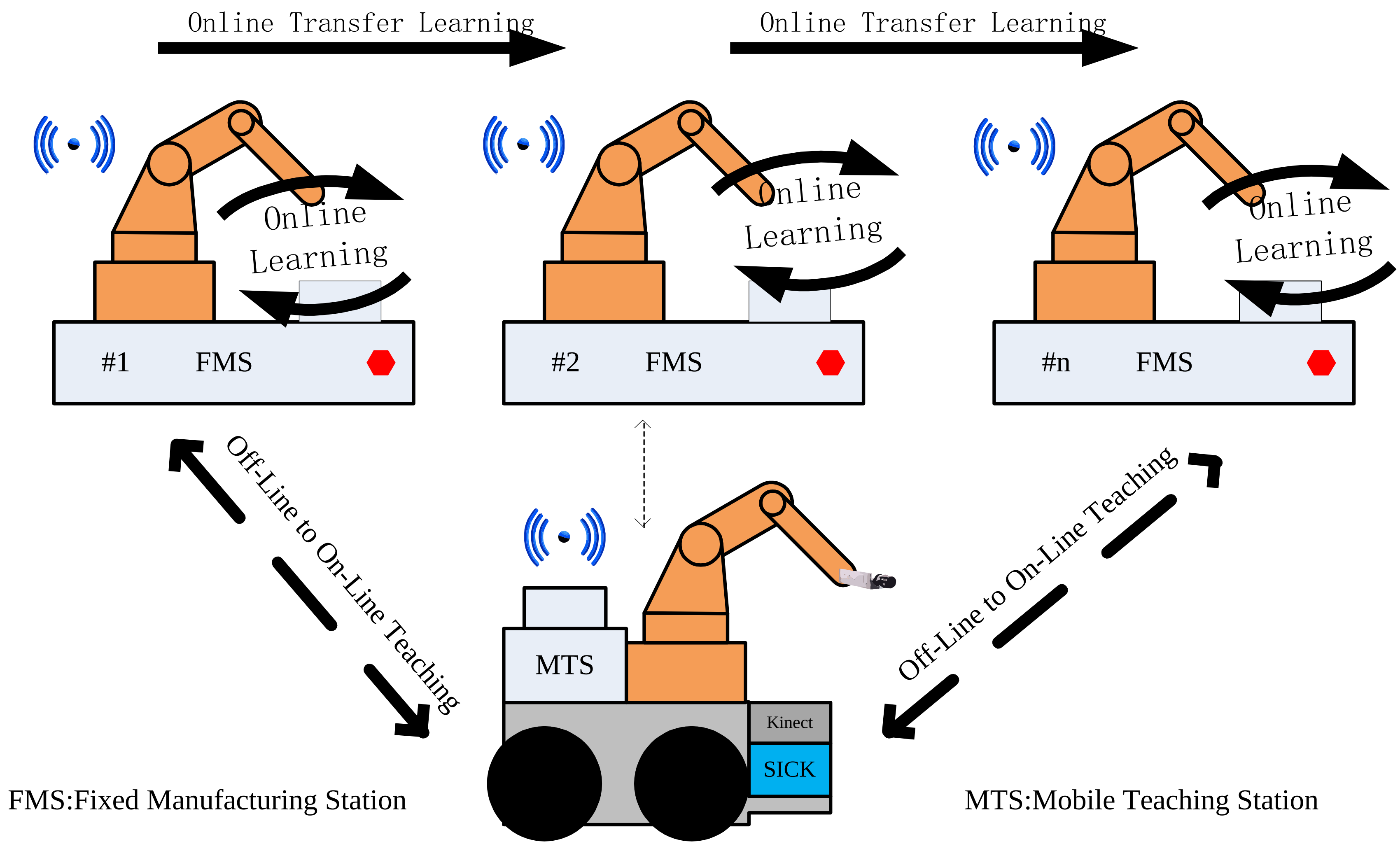
Problems

- Big part location errors
  - Can happen after a new batch is launched
  - Parts could come from different suppliers

- Typically manual teaching methods are used to adjust the parameters
  - Production line has to be stopped

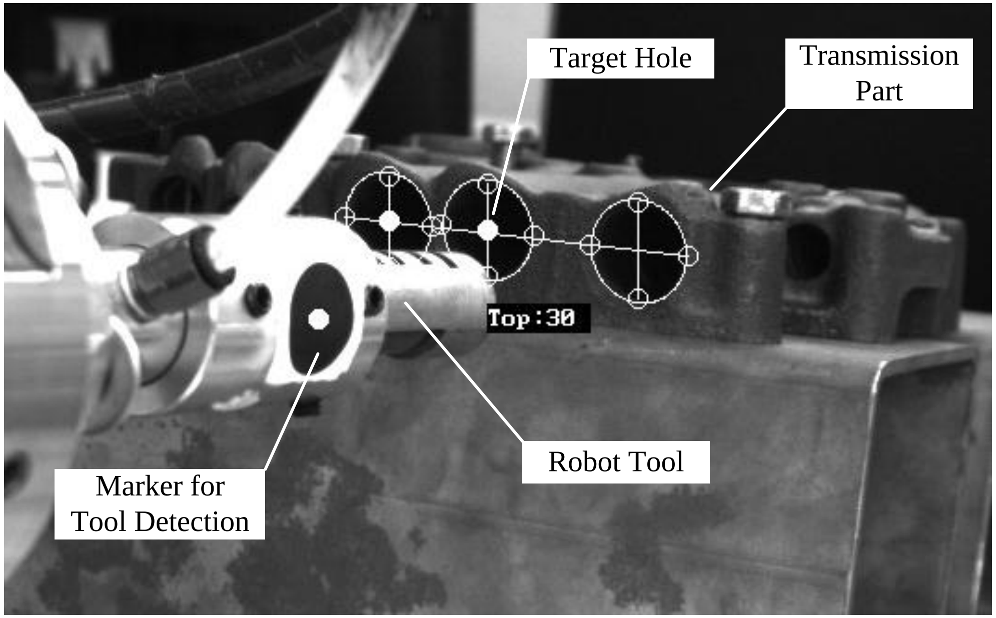
- Installing additional sensors generates new problems
  - System upgrading cost
  - Maintenance issues
  - Sensor failure

Failure Correction

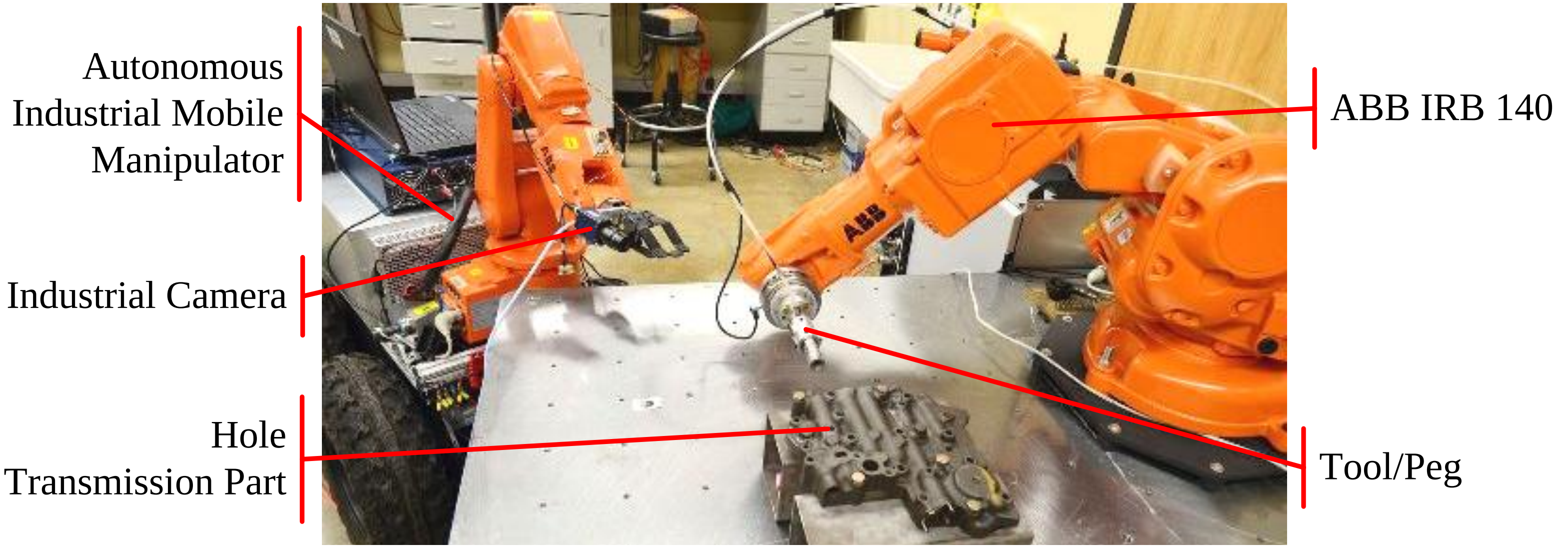


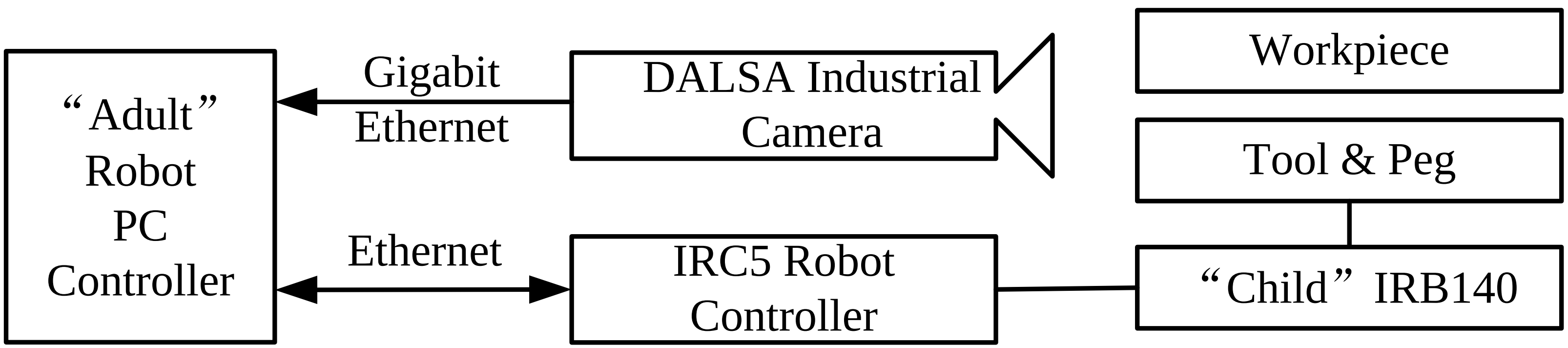
Autonomous Robot Teaching

- Reducing the operational cost
- Sensor accuracy problem
- Calibration is difficult
- Noise



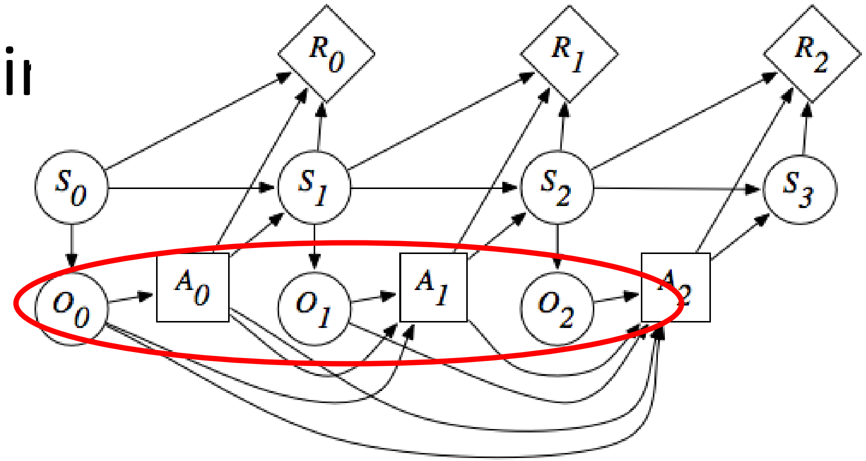
Autonomous Robot Teaching





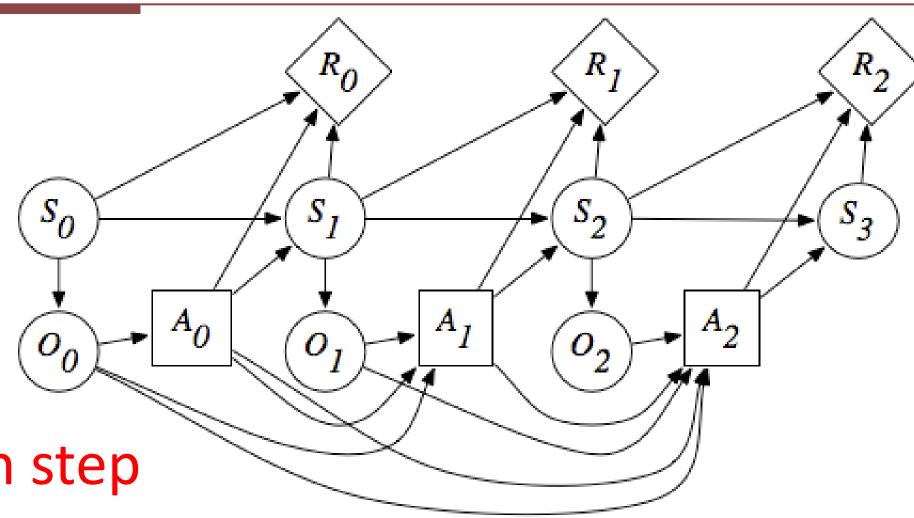
POMDP

- Partial Observable Markov Decision Process
  - State Transition is Uncertai
  - Observation is uncertain
  - State is partial observable



- Why POMDP?
  - Using POMDP to estimate the underlying errors through executing actions and receiving observations

POMDP Method



- Belief State $\sum_s b(s) = 1$
  - Real state is unknown
  - How to make decision?
  - Assign a belief b over state S
  - Update the belief state in each step

$$b'(s'|b,a,o) = \frac{O(o|s')\sum_s b(s)T(s'|s,a)}{\sum_{s'} O(o|s')\sum_s b(s)T(s'|s,a)}$$

  - Defining Value Functions

$$J^{\pi}(b_0) = \sum_{k=0}^{\infty}\gamma^k r(b_k,a_k) = \sum_{k=0}^{\infty}\gamma^k E[R(s_k,a_k)|b_o,\pi]$$

$$\begin{aligned} V^*(b) &= J^{\pi^*}(b) \\ &= \max_{a\in A}\left[r(b,a) + \gamma \sum_{o\in O} z(o|b,a)V^*(\tau(b,a,o))\right] \end{aligned}$$

  - Approximating Value Functions
    - Alpha Vector $V(b) = \max_{\alpha\in\Gamma} V^{\alpha}(b)$ $\quad V^{\alpha}(b) = \langle\alpha\cdot b\rangle = \sum_i \alpha_i b_i$

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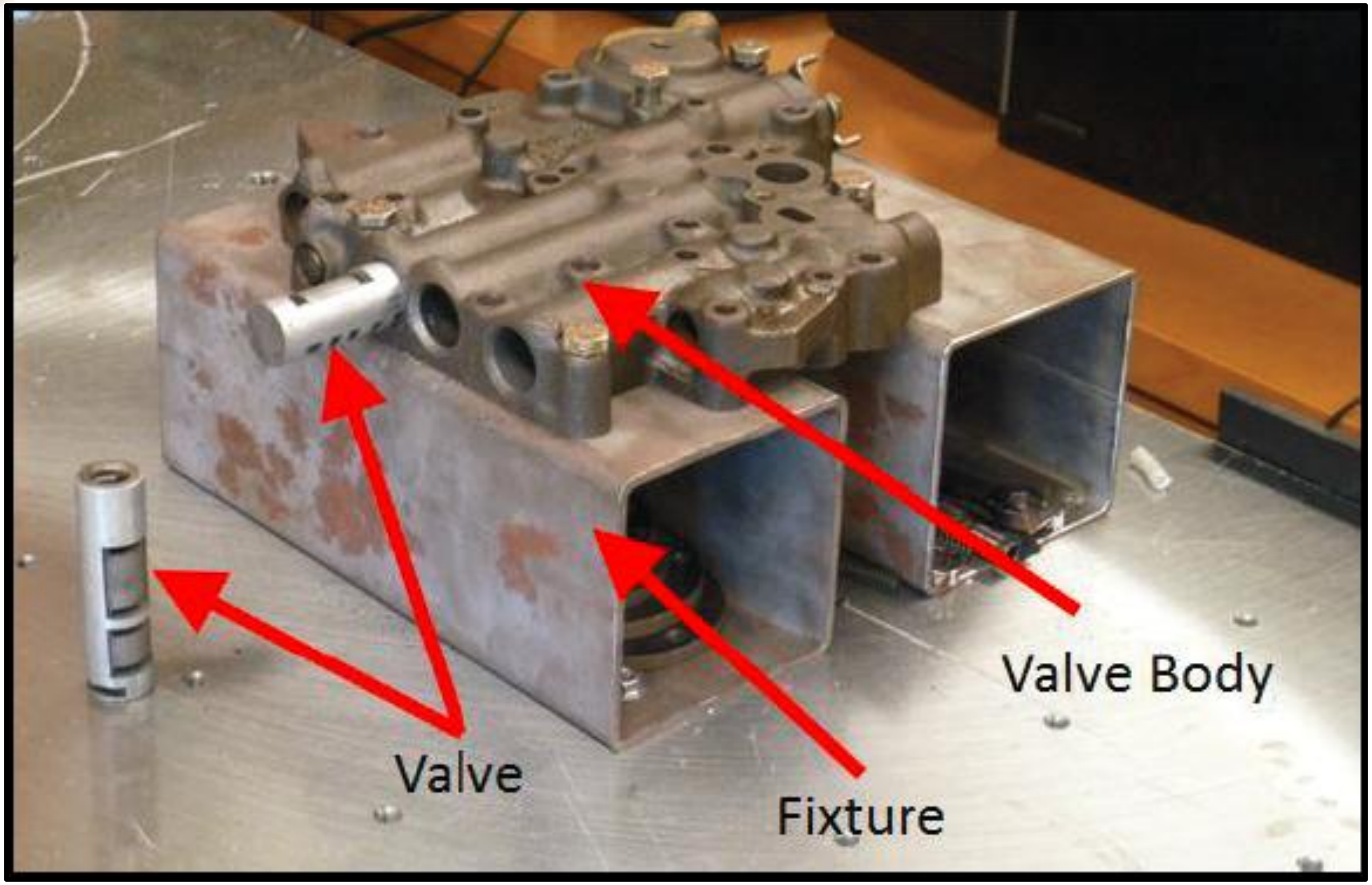
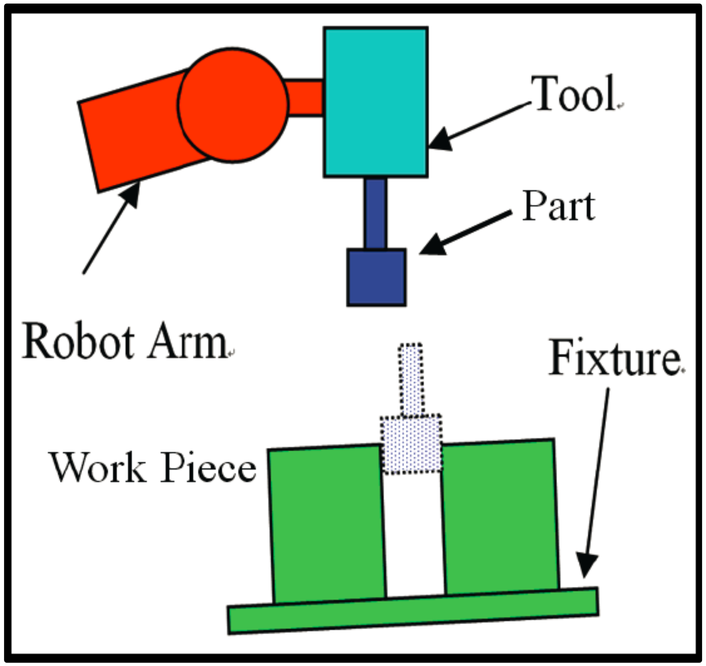
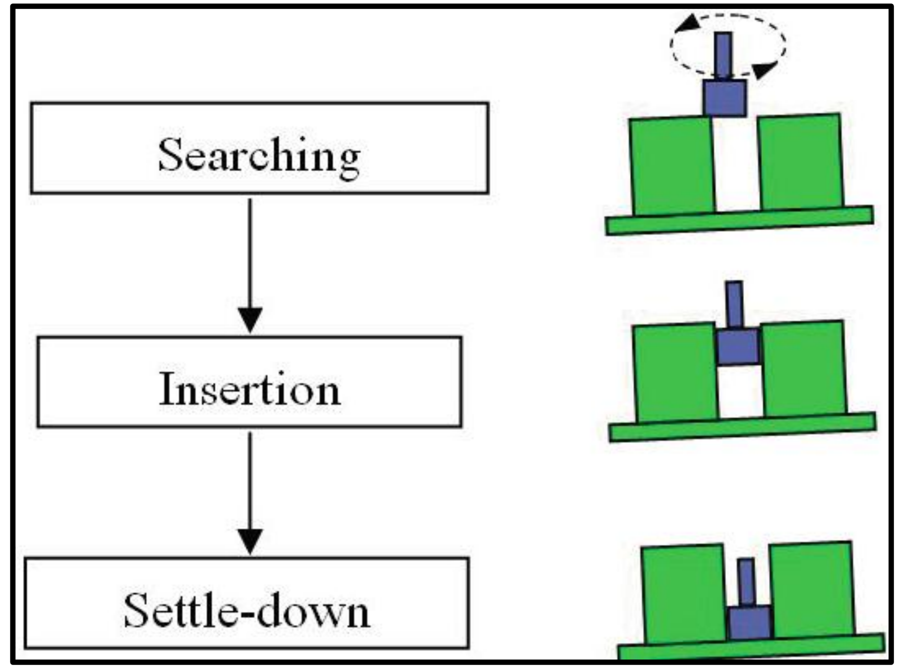
Example: Single Stage Assembly



Assembly Process



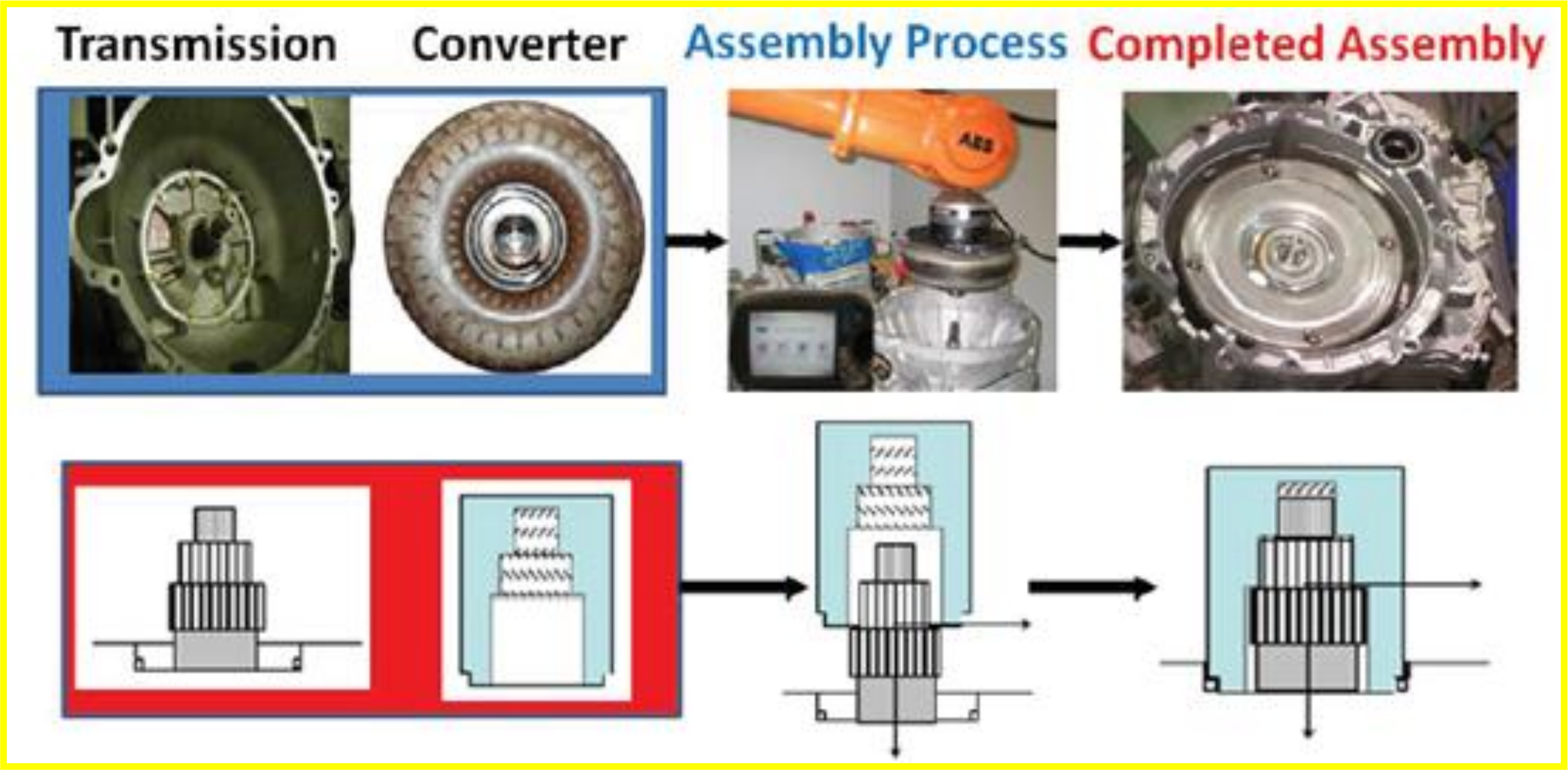


Parameters:

search force, search radius, search speed, insertion force

How to tune the Assembly Parameters?

Example: Multi-Stage Assembly



Problems

- Design of Experiment (DOE)
- Genetic Algorithm (GA)
- Genetic Algorithm (GA)+ANN

- Model Free
- Offline
- Manufacturing line has to be stopped
- Cannot deal with variations, including part location errors, part geometry errors and environmental errors.

Low Efficiency
Low Accuracy

Single Work Station Optimization

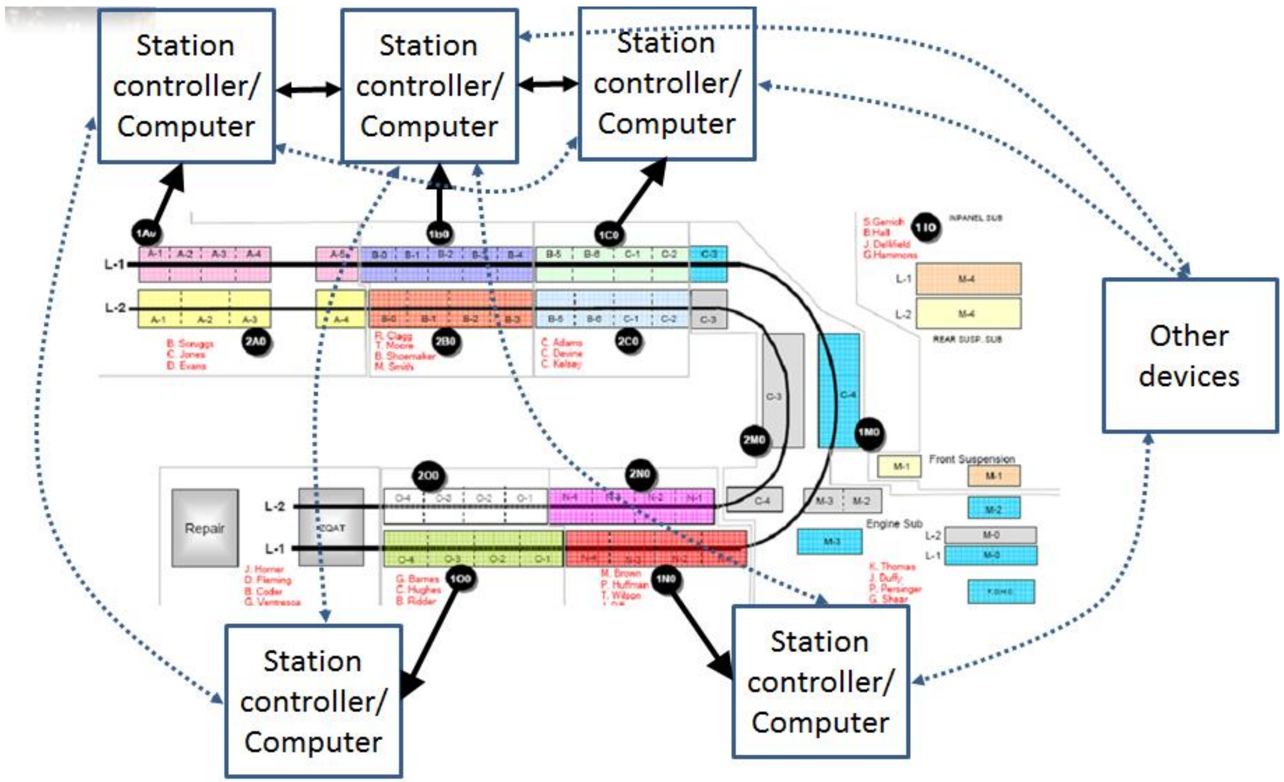
- First Time Through (FTT) rate

$$\bar{r}_f(\mathbf{x}, \mathbf{T_c}) = \frac{1}{\mathbf{n}} \sum_{\mathbf{i}=1}^{\mathbf{n}} \rho(\mathbf{t_i}, \mathbf{T_c}); \quad \rho(\mathbf{t_i}, \mathbf{T_c}) = \begin{cases} 1 & t_i \leq T_c \\ 0 & otherwise \end{cases}$$

- How to balance FTT rate and cycle time?
  - FTT rate is calculated statistically.
  - Cycle time is recorded each assembly
  - Modeling?
  - Optimization methods?
    - FTT prediction? Cycle time estimation?

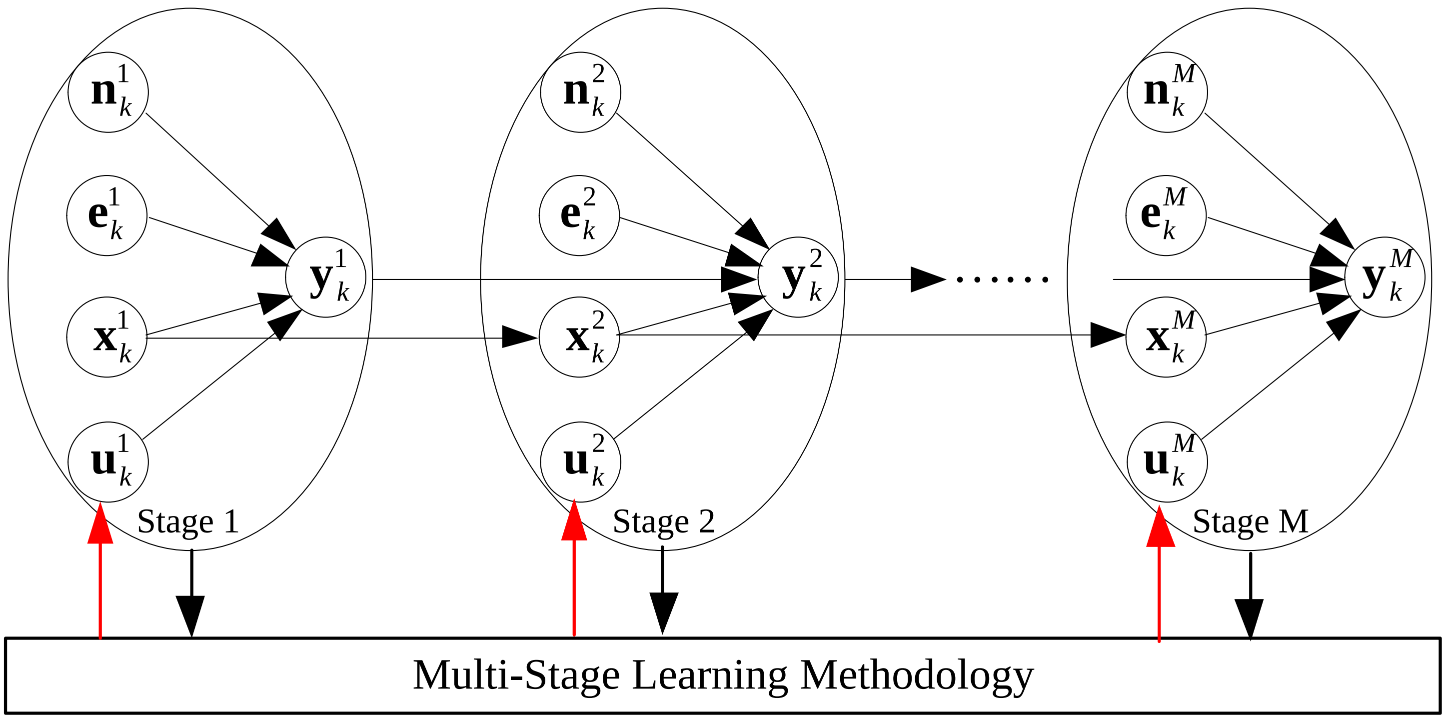
Multi Work Station Optimization

- FTT rate of the whole system
- Cycle time of the production line



Performance Optimization

- Performance optimization
  - Knowledge transfer
    - What can we transfer? How to transfer?



Discussions

- Comments
  - Robot teaching
  - System optimization
- Interesting topics?
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