

Knowledge Management of Workers by Comparing WAI and WAD Using FRAM

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This presentation is based on the results obtained from a project, JPNP20006, commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

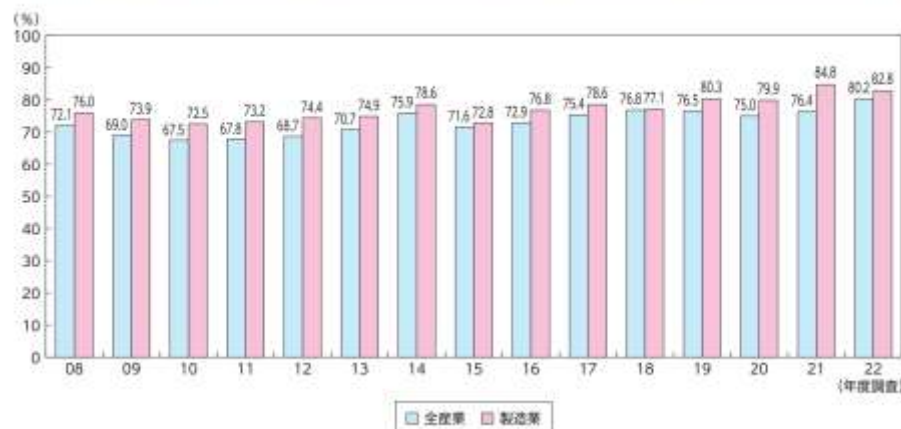
Skill transfer problem

- Declining working age population, Aging working force
- Percentage of companies with issues in human resource: 82.8% (2022)

図 212-3 高齢就業者（65歳以上）数の推移



図 222-1 能力開発や人材育成に関する問題がある事業所の割合の推移



- Especially, the problem is serious for skilled workers
- Requiring long period to acquiring skills through OJT (On the Job Training)
- Current countermeasures
 - Translating knowhow into guidelines, documents, and databases
 - Still challenging to transfer skills efficiently

Routine expertise

Executing tasks quickly and accurately

Automation and mechanization has been introduced in this area

Documentation has been applied to this type of knowledge

Adaptive expertise

The ability to **respond flexibly to unexpected situation and recover to a high level of performance**

Variable production and diverse market needs ⇒ Importance of Adaptability

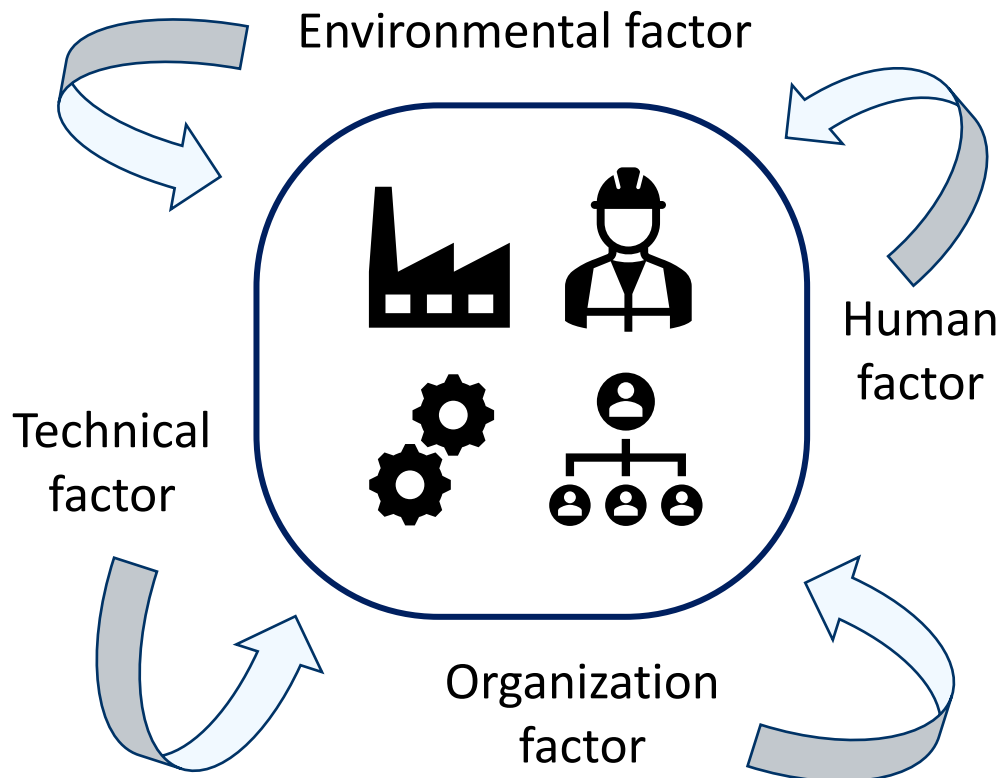
To establish tacit knowledge in workers
Longer period is required

Research objective:

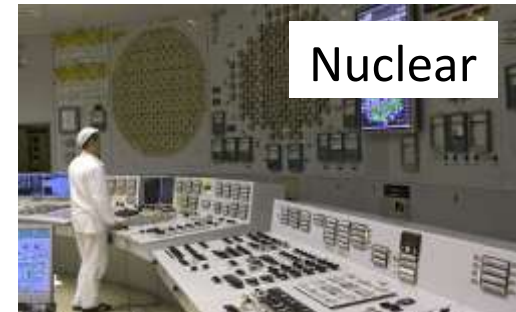
Unraveling the process of adaptive expertise to promote skill transfer

- This study adopts an approach based on **resilience engineering**
 - Modeling and analyzing socio-technical systems
 - Focusing on **adaptive behavior** of human operators

Socio-technical systems



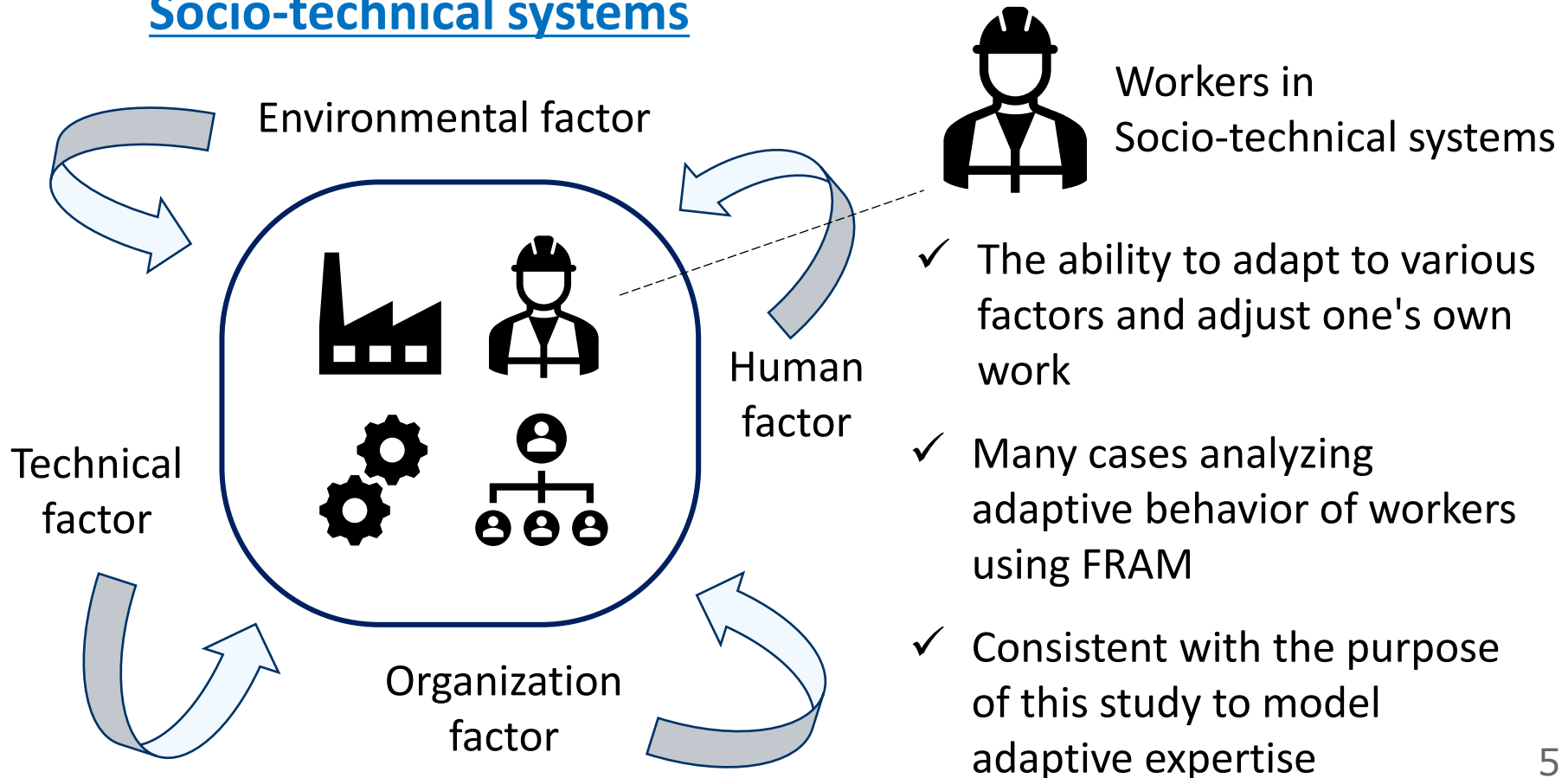
Examples



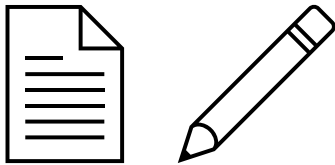
Pictures
from
Wikipedia

- This study adopts an approach based on **resilience engineering**
 - Modeling and analyzing socio-technical systems
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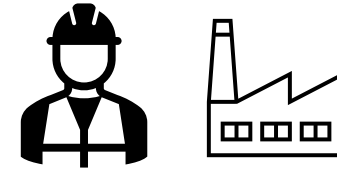
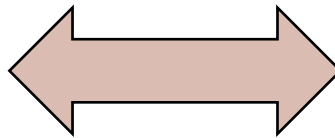
Socio-technical systems



- **Objective:** Development of a practical method for organizing the adaptive knowledge
 - Traditional knowledge management is limited in managing adaptive knowledge
- Background: Risk assessment by comparing WAI and WAD [Clay-Williams et al., 2015]
 - **Work-As-Imagined** : How the system was designed
 - **Work-As-Done** : How the system is actually operated



Work according to the procedure manual



Actual work

Question: How often do you see the gap between WAI and WAD in your own field?

We can often see the gap between WAI and WAD in manufacturing worksites...

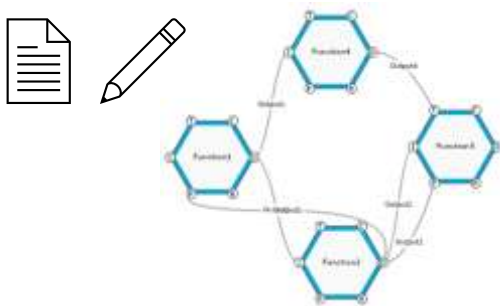
- Concept: Manage the gap between WAI and WAD for **knowledge management**

Clay-Williams, R., Hounsgaard, J., & Holnagel, E. (2015). Where the rubber meets the road: using FRAM to align work-as-imagined with work-as-done when implementing clinical guidelines. *Implementation Science*, 10(1), 125.

Yasue, N., Sato, G., & Sawaragi, T. (2026). Extracting knowledge of workers by identifying performance variability using functional resonance analysis method. Submitted to *Reliability Engineering & System Safety*.

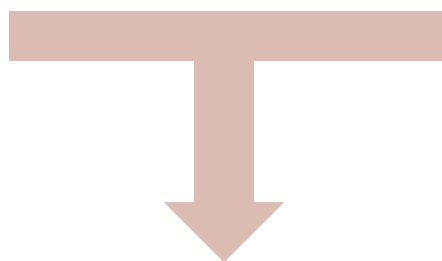
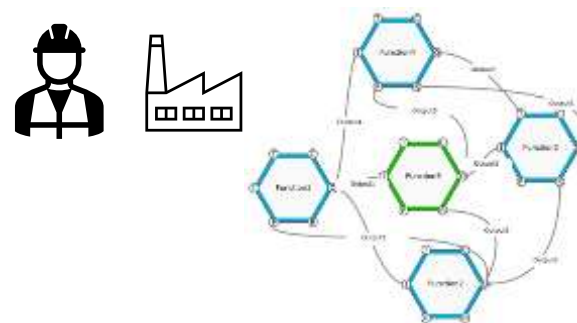
Step 1

FRAM model of Work-as-Imagined



Step 2

FRAM model of Work-as-Done



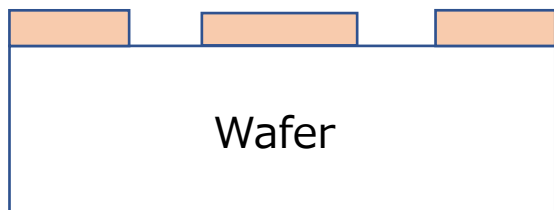
Step 3

Simulation study: Investigating the effect of differential functions on work performance

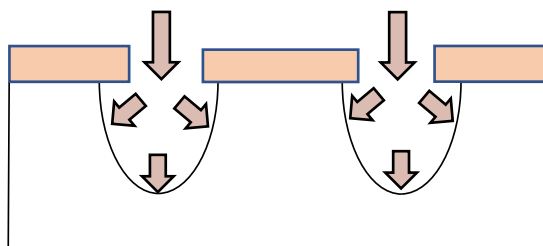
Case study

Compounded semiconductor, Wet-etching work

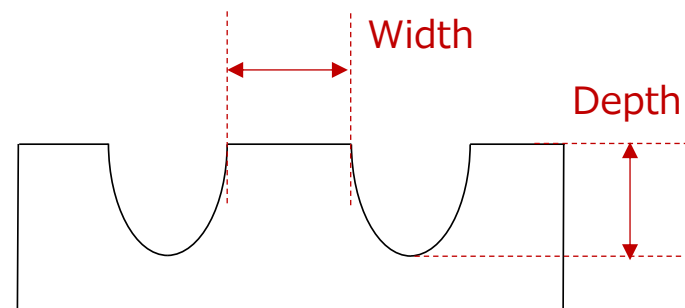
Place the wafer on the jig and immerse them in the chemical solution



After resist development



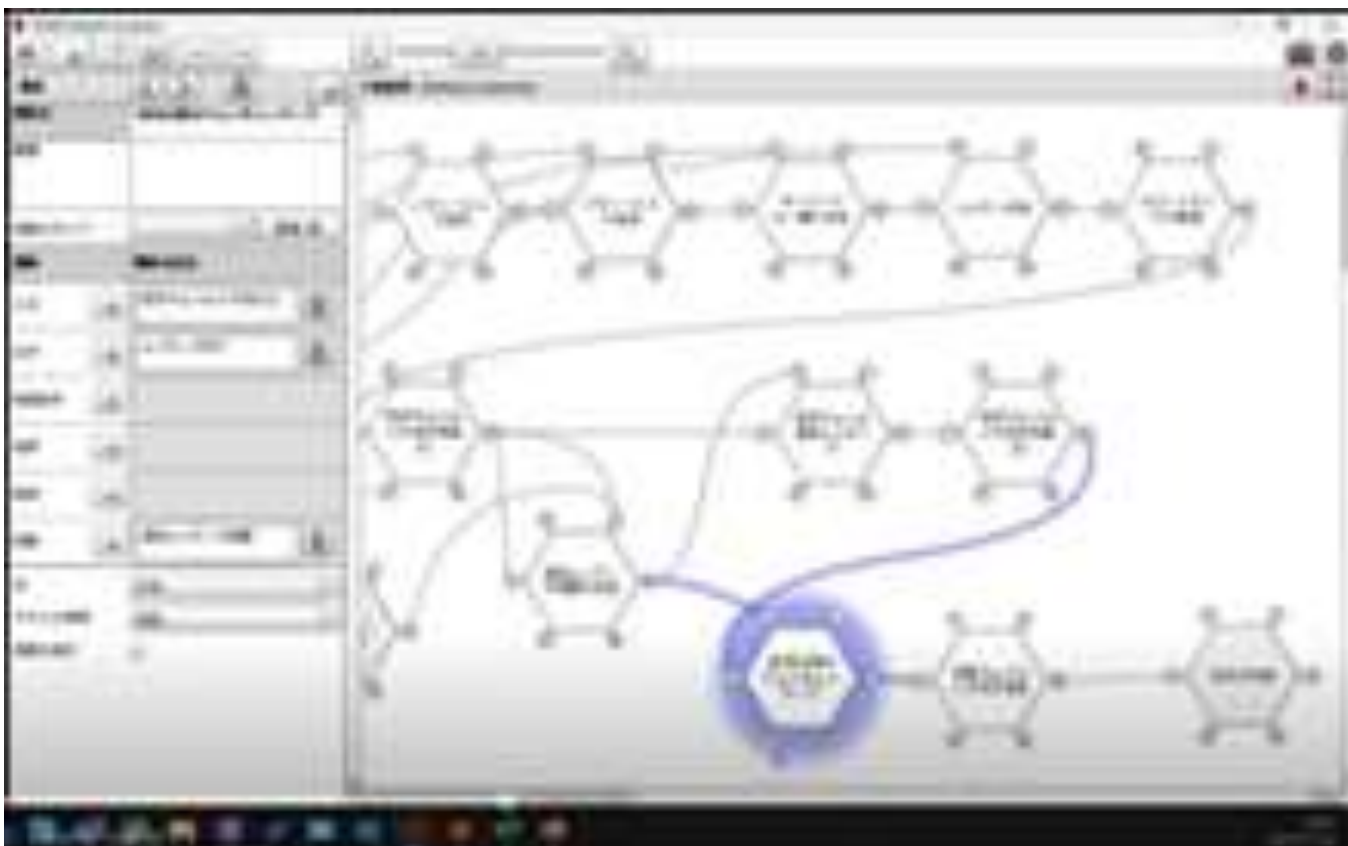
Wet etching



Removing photoresist

Step 1: WAI model

1. Identifying basic work steps from work procedure document
2. Modeling FRAM model jointly with the manager in charge of the work procedure document



Snapshot of the screen during the joint FRAM model building

Step 1: WAI model

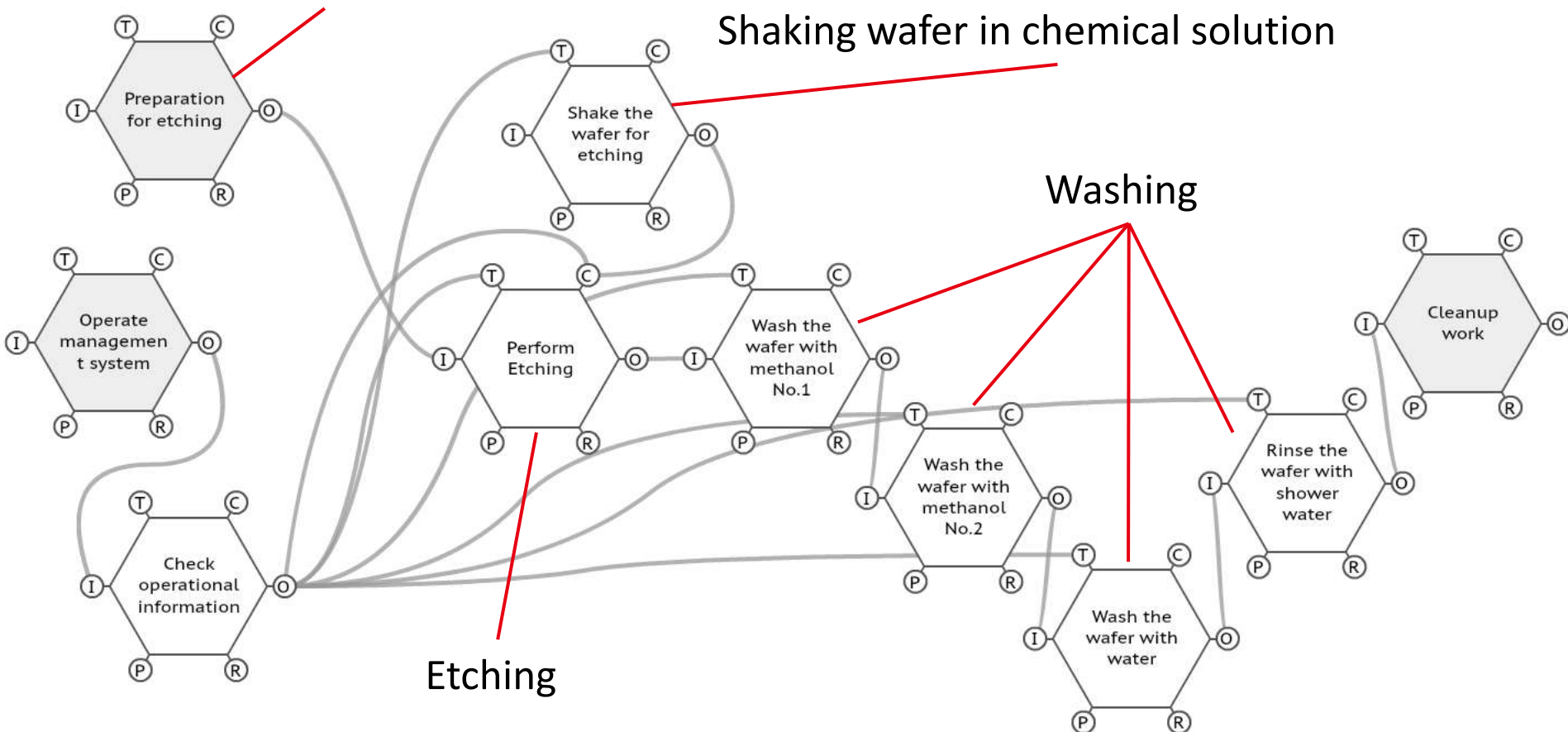
1. Identifying basic work steps from work procedure document
2. Modeling FRAM model jointly with the manager

Preparation

Shaking wafer in chemical solution

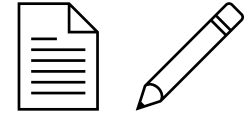
Washing

Etching



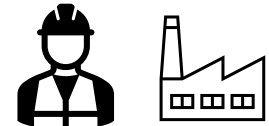
Question: What kinds of differences do you think might appear in Work-as-Done?

1. Recording etching work → Interview with workers
2. Identifying discrepancies between work procedure and actual work
3. Building WAD FRAM model based on WAI model



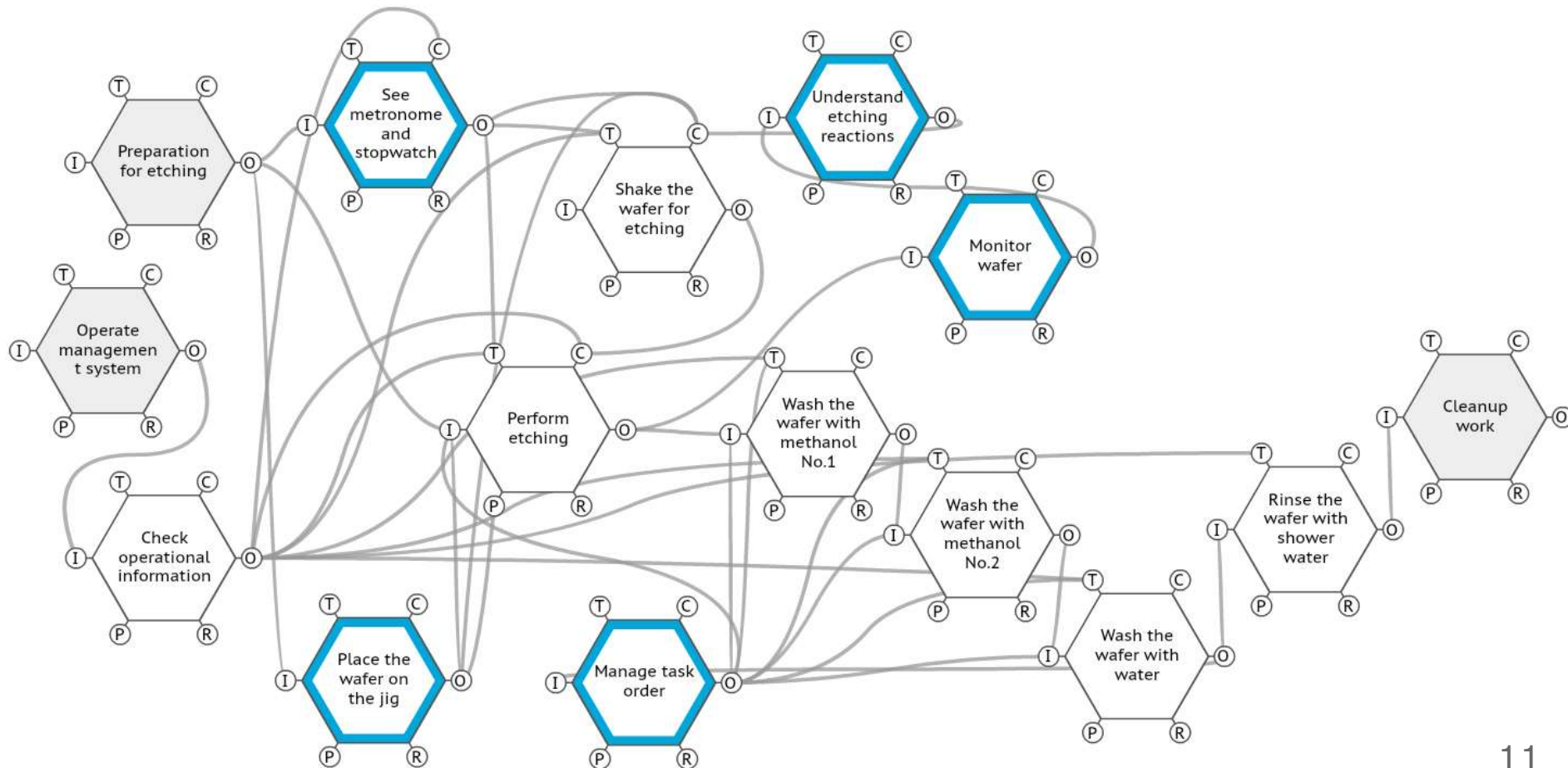
Participants

- Five workers in charge of the target work (B、C、F、G、H)
 - Experienced (Work experience > 10 years) : 2 (B、C)
 - Mid-level (Work experience > 3 years) : 2 (F、G)
 - Novice (Work experience < 3 years) : 1 (H)
- Also focusing on groups in the working schedule
 - Group X: B, F, and H
 - Group Y: C and G



WAD model

- List up the activities that were not included in the work procedure
- Select five activities that were common to the multiple workers
- Visualize those five points with five blue functions



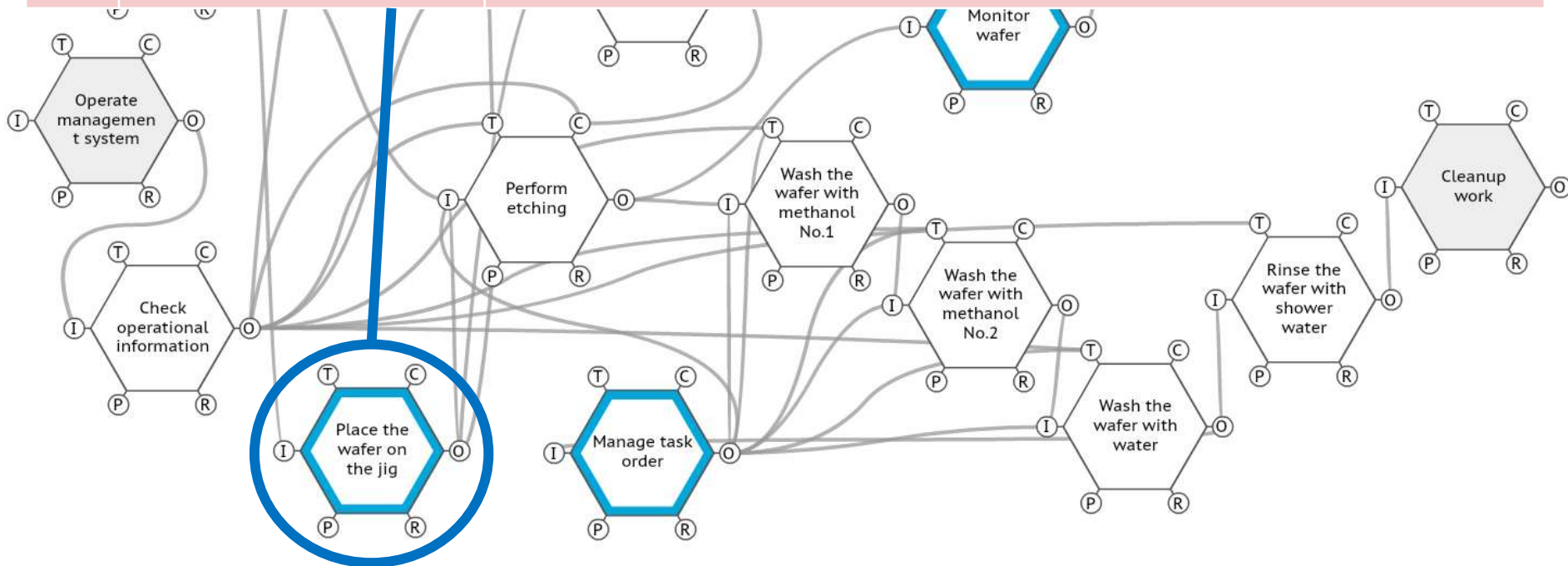
- Visualize five points in WAD with five **blue functions**



1

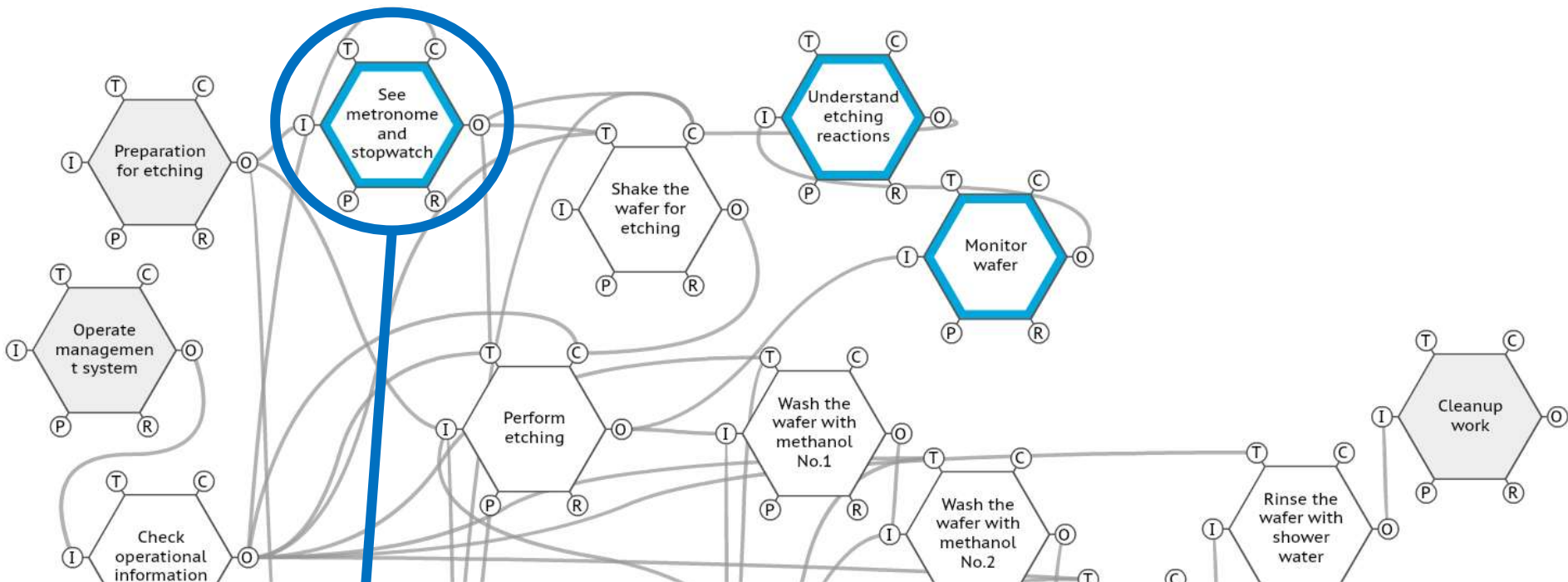
Orientation for placing the wafer on the jig (BCFH)

Align the wafer orientation with the jig
The wafer orientation affects the uniformity of the etching



WAD model

- Visualize five points in WAD with five **blue functions**



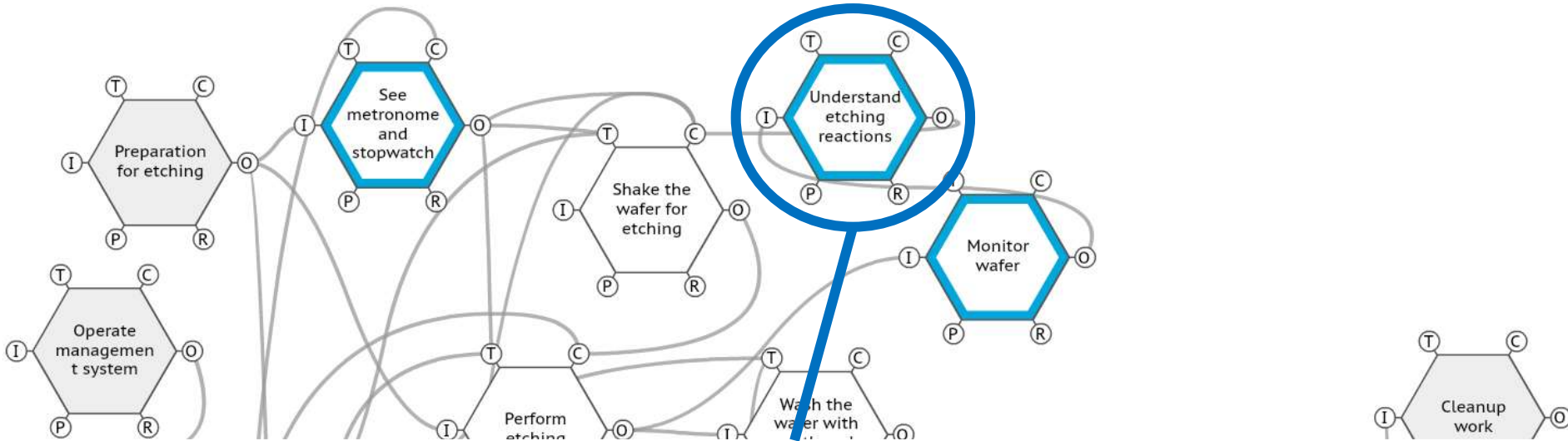
2

Managing the
etching time (BCG)

Use a **metronome** to keep time with the swinging rhythm
Use a **stopwatch** to fine-tune the timing of the pull-up

WAD model

- Visualize five points in WAD with five blue functions



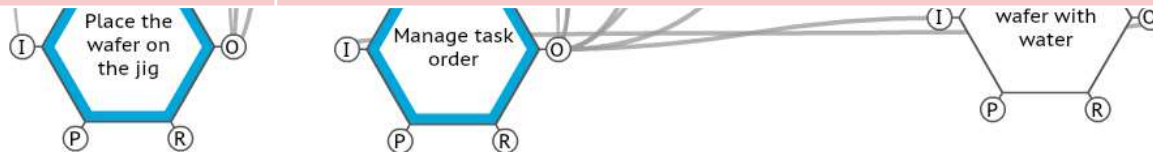
3

Attention to shaking the jig (CFG)

Shaking the wafer surface with an awareness of the flow of the chemical solution

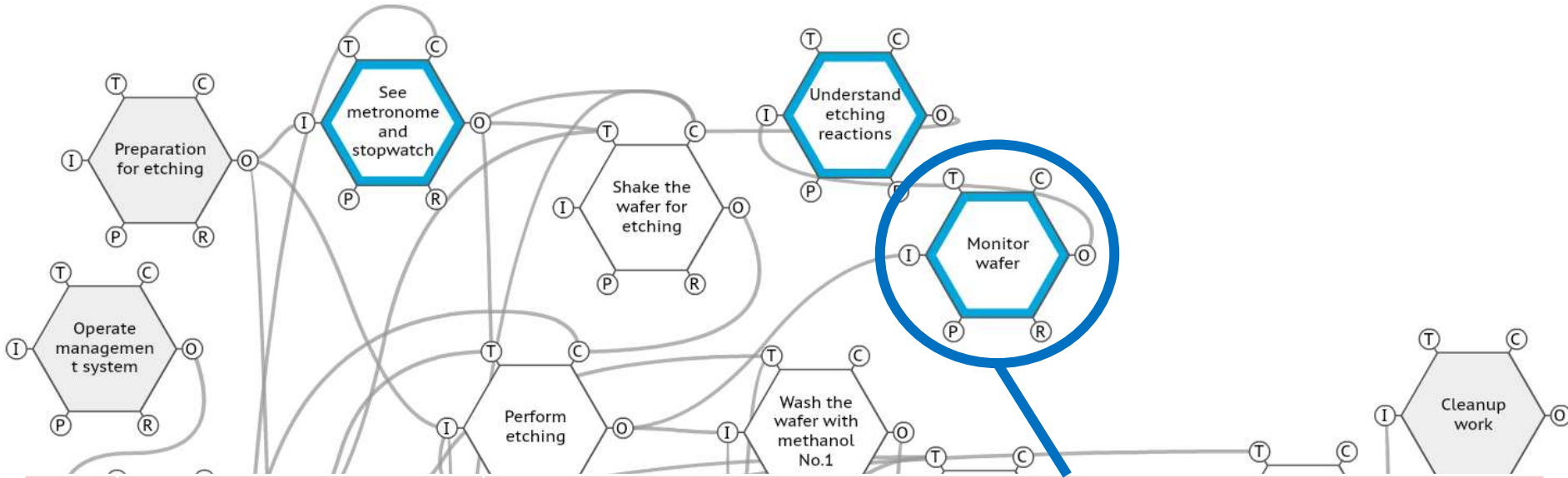
Understanding the chemical reaction

⇒ Adjusting the wafer shaking



WAD model

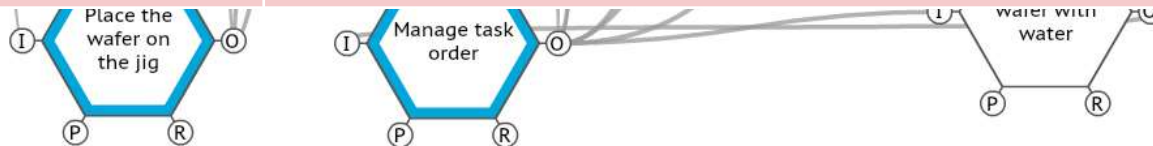
- Visualize five points in WAD with five **blue functions**



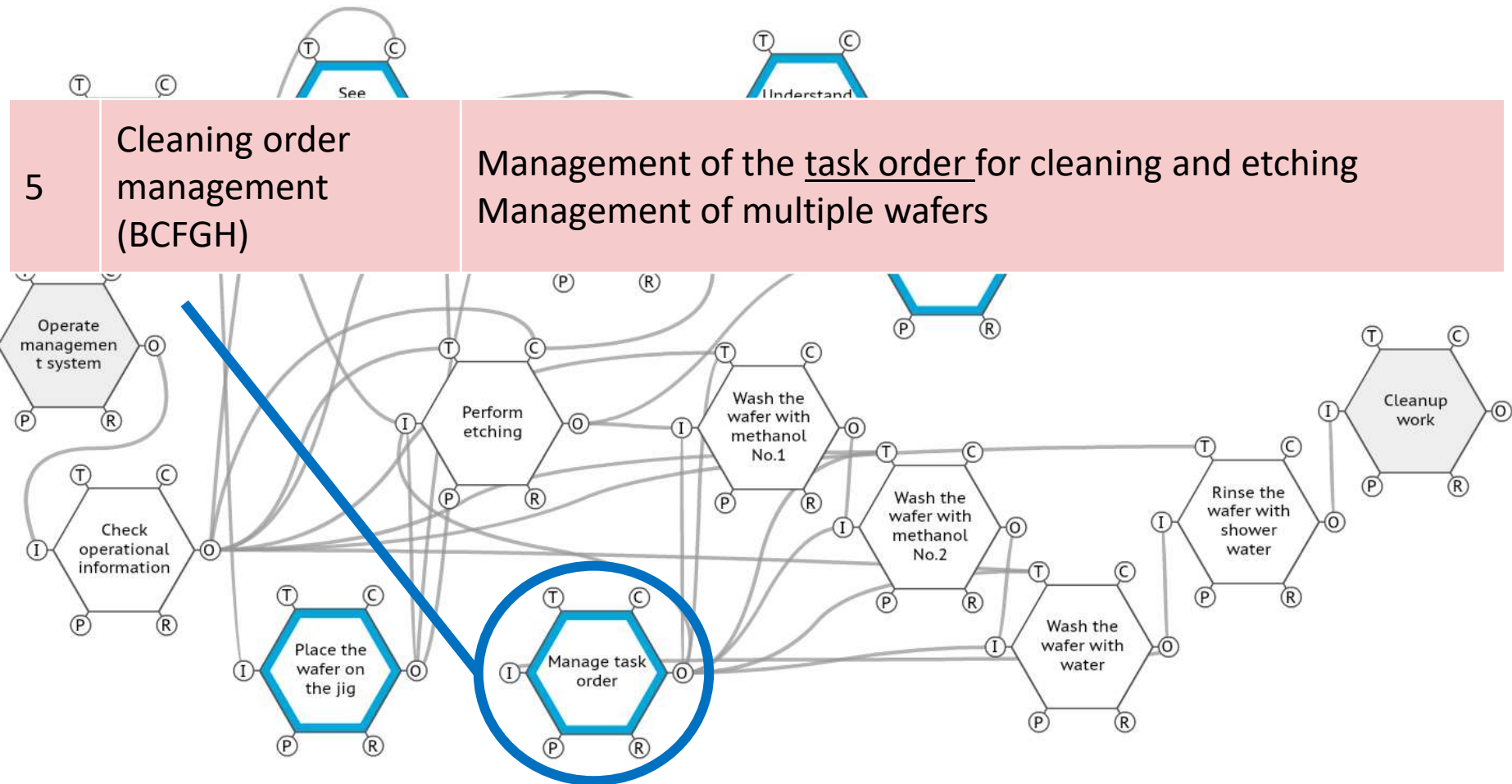
4

Observing the wafer surface (CF)

Evaluating whether the etching has been successful by observing the wafer surface
⇒ Enhancing understanding of wafer surface etching



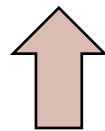
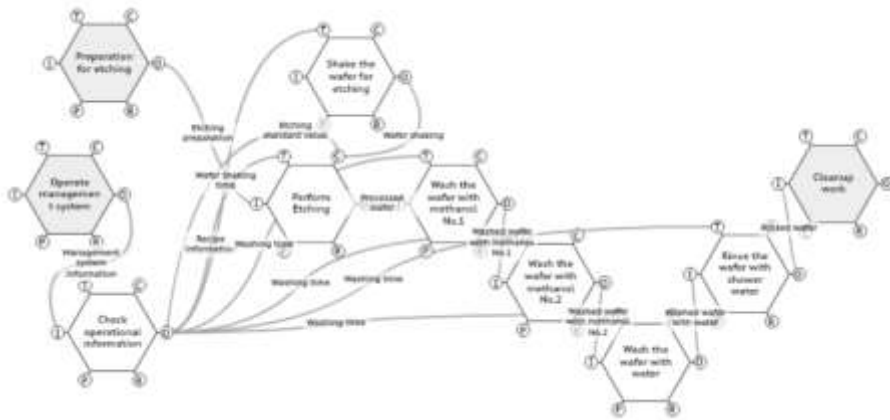
- Visualize five points in WAD with five **blue functions**



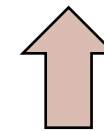
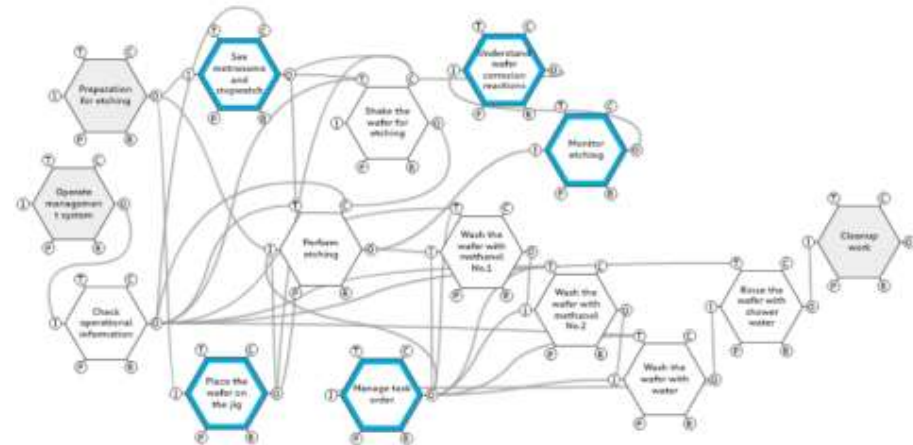
Step 3: Simulation study

- Simulation method :
Envision the work performance after the variability was introduced
- Considering the variability of time constraint
Represented by: CPC No.8 “Available time”

Work-as-Imagined model

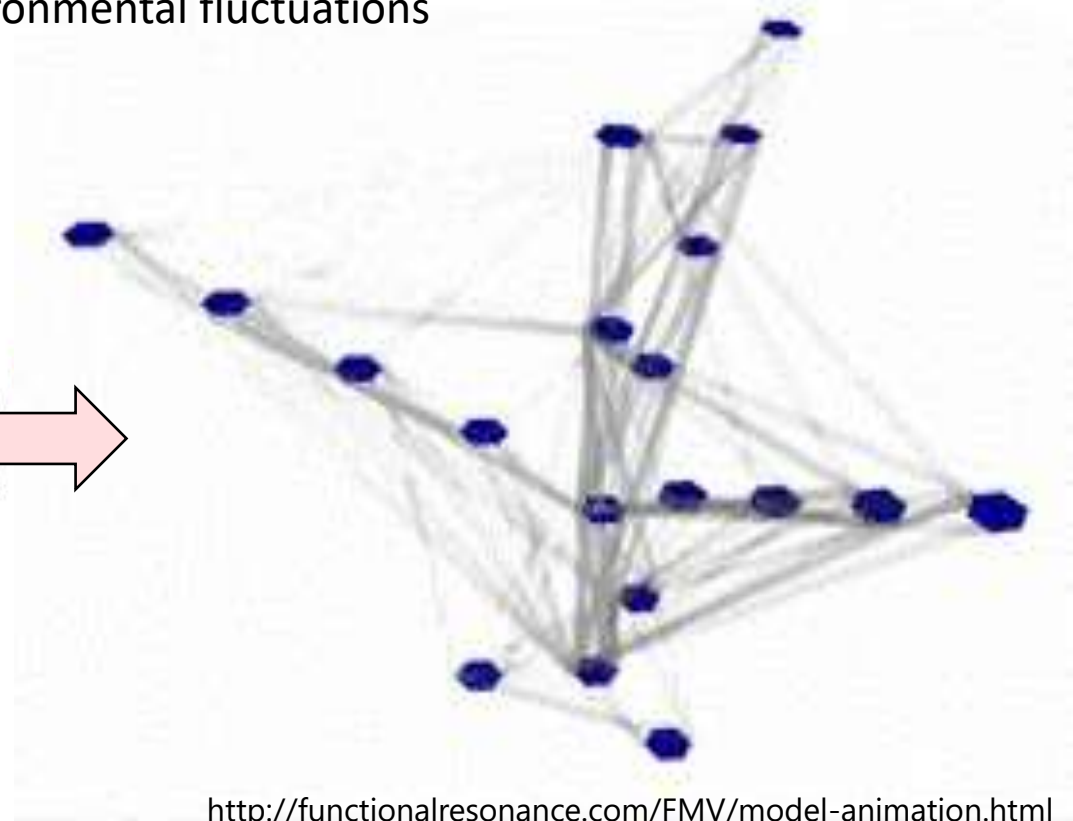
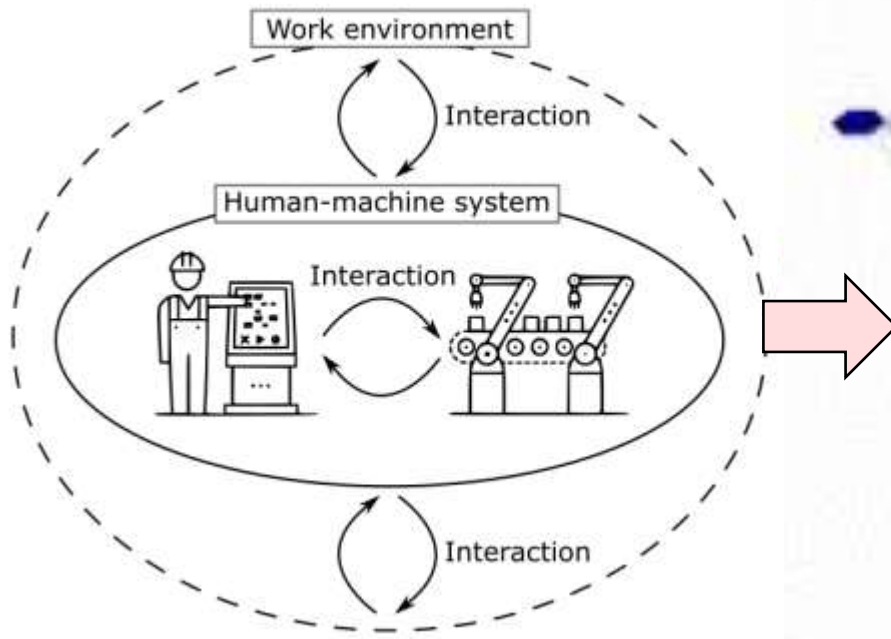


Work-as-Done model



Considering same variability in the simulation scenario

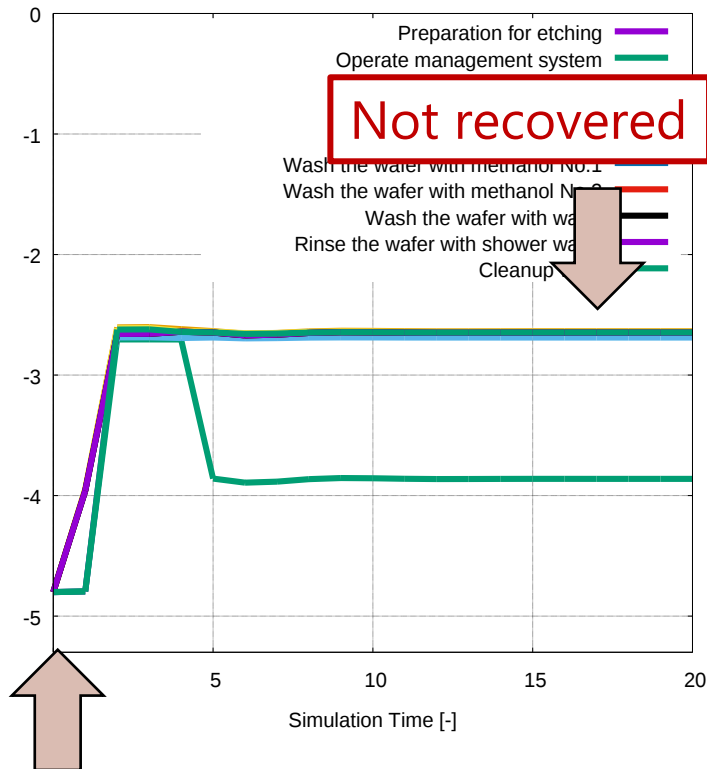
- Analyzing the Effects of “**Variabilities**” in Complex Socio-Technical Systems[Hirose, 2020]
 - **Variability**: Factors affecting system performance
- Difficult to extract by decomposing into knowledge elements:
Model the behavior of dynamic complex adaptive systems in which workers interact with the environment and adapt to environmental fluctuations



<http://functionalresonance.com/FMV/model-animation.html>

Work-as-Imagined model

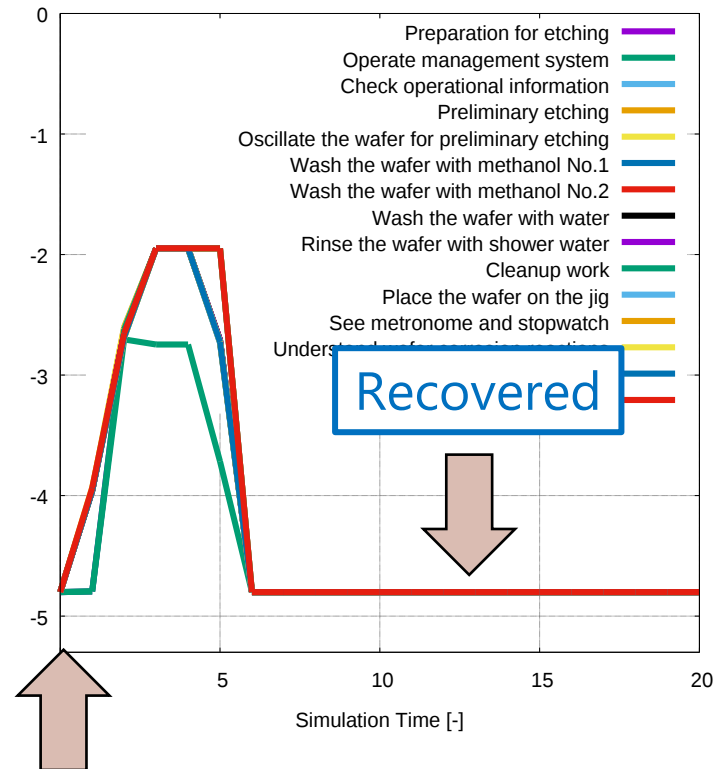
Not recovered from variability



Variability introduced

Work-as-Done model

Recovered from variability

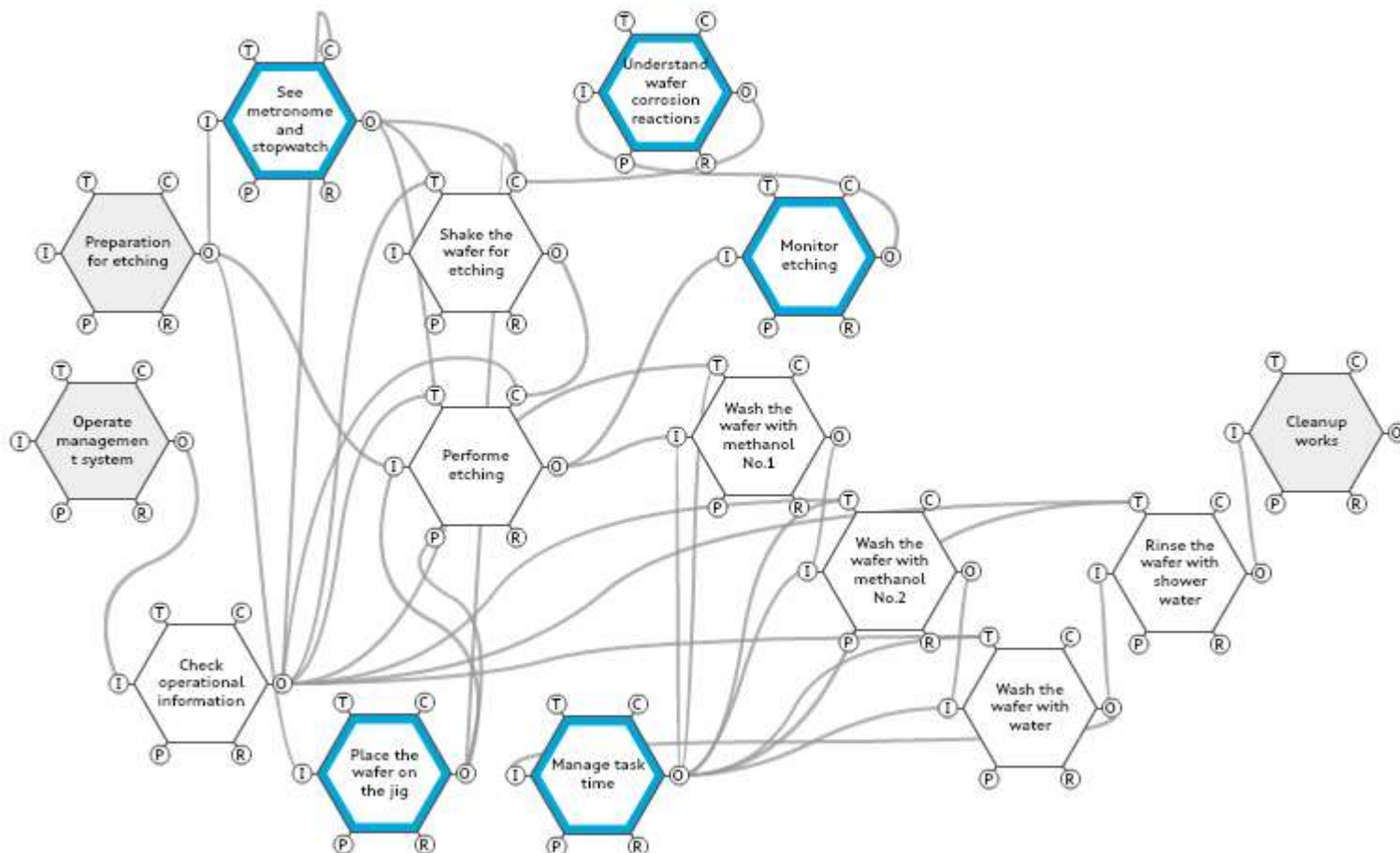


Variability introduced

Functions in WAD contributed to the resilient performance

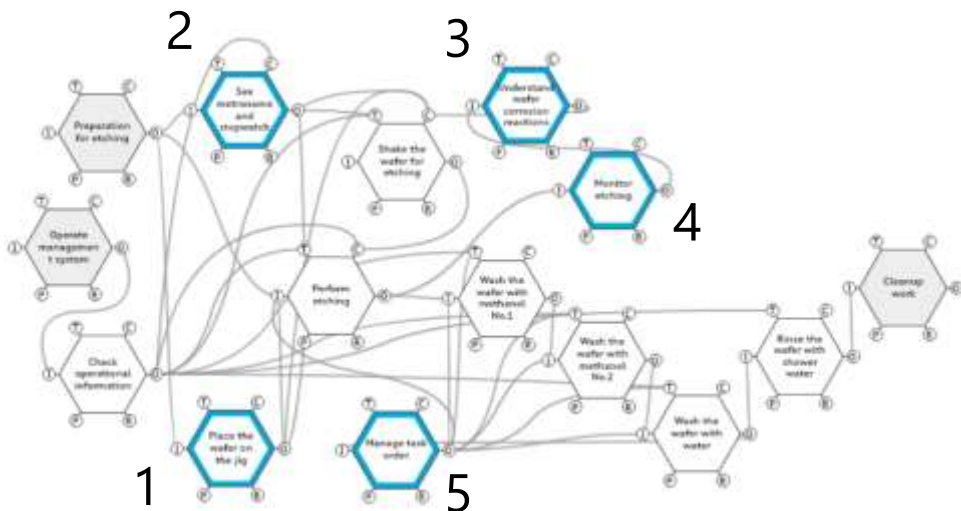
Identifying critical functions with QCA approach

- Qualitative Comparative Analysis (QCA) approach
Systematically investigates similarities and differences among cases



Exploring important functions (combinations)

1×	1-2	○
2×	1-3	×
3×	1-4	○
4×	1-5	○
5×	2-3	×
	2-4	○
	2-5	○
	3-4	×
	3-5	×
	4-5	×



Numbers show the function IDs in WAD model
 ○ : Recovered from variability
 × : Not recovered

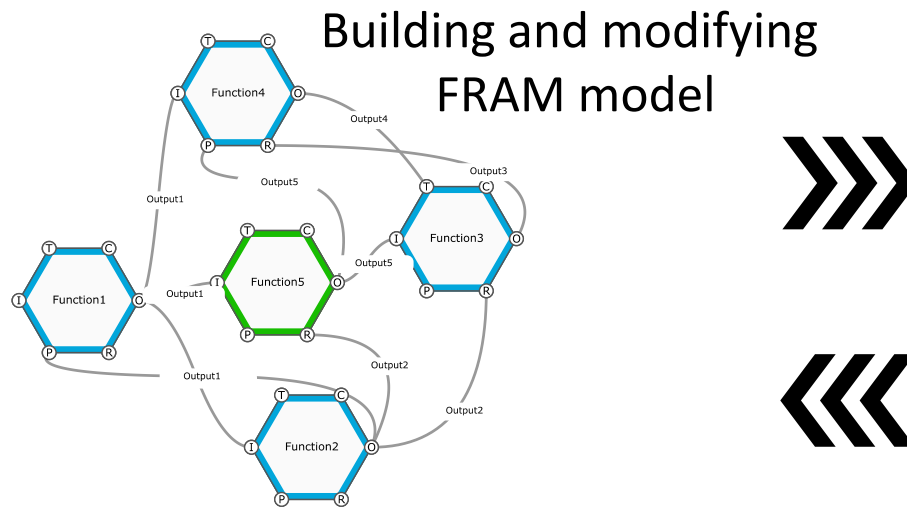
FRAM model gets resilient when
 two functions from ID 1, 2, 4, 5 were activated

Except ID 4 and 5

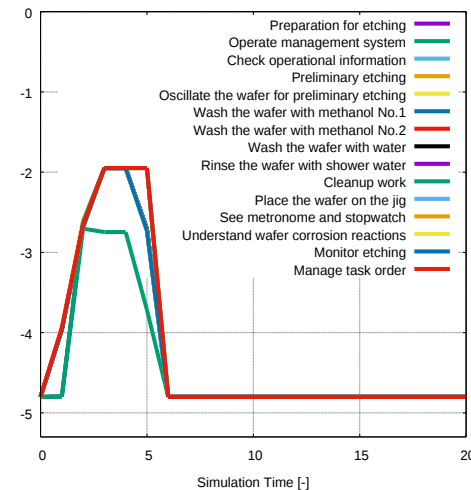
1	Wafer orientation on the jig	Align the wafer orientation with the jig The wafer orientation affects the uniformity of the etching
2	Managing the etching time	Use a metronome to keep time with the swinging rhythm Use a stopwatch to fine-tune the timing of the pull-up
5	Cleaning order management	Management of the task order for cleaning and etching Management of multiple wafers

- Focus group: Discussion with the work managers
- Functions of the expert workers: ID 1 and 2
 - Both of them contribute to the **Quality** of the etching work
 - Experienced workers enhance etching quality with these functions
- Functions of the work group X : 1, 5
- Functions of the work group Y : 2, 5
 - Functions 1 and 2 = **Quality**, Function 5 = **Efficiency**
 - Resilient work performance under the time related variability with the combination of those functions (ETTO principle)

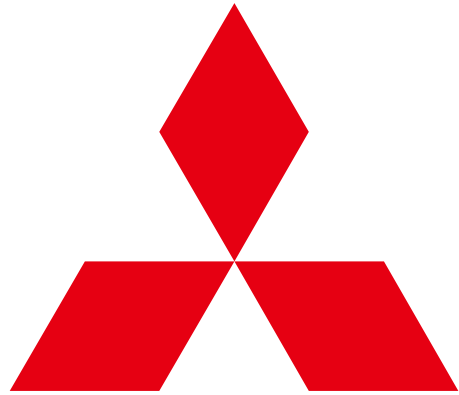
- Developing a practical method to systematically extract knowledge
- Comparing [WAI](#) and [WAD](#) using FRAM
 - Identifying critical functions and functional couplings
- Adaptive skills: Workers adapt to the situation with [functional resonance](#) of multiple functions
 - Difficult to extract with conventional knowledge management



Simulations



Question: If these WAD functions are important for resilience, how should organizations treat them?



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