

The 14th International Workshop on the Functional Resonance  
Analysis Method (FRAM)

# System Analysis and Improvement Methodology with WDA and FRAM, A Win-Win Combination

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Hideki Nomoto<sup>3</sup>, and Tetsuo Sawaragi<sup>1</sup>

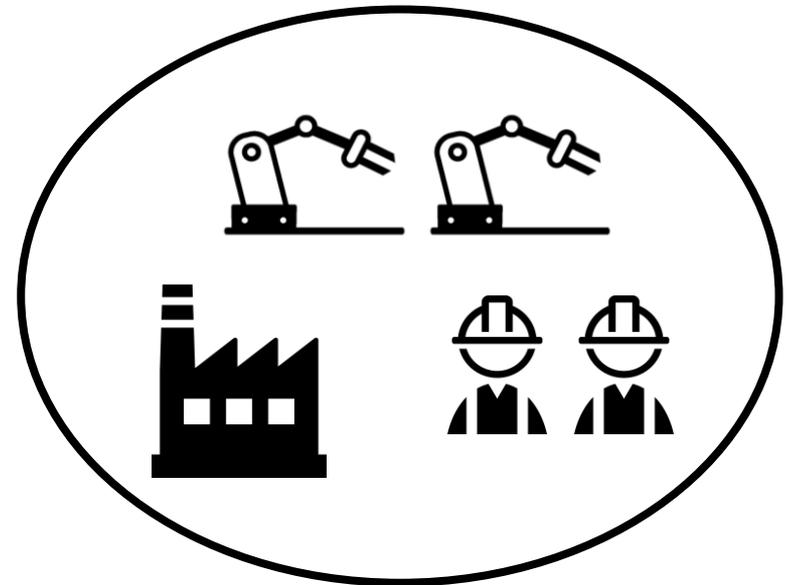
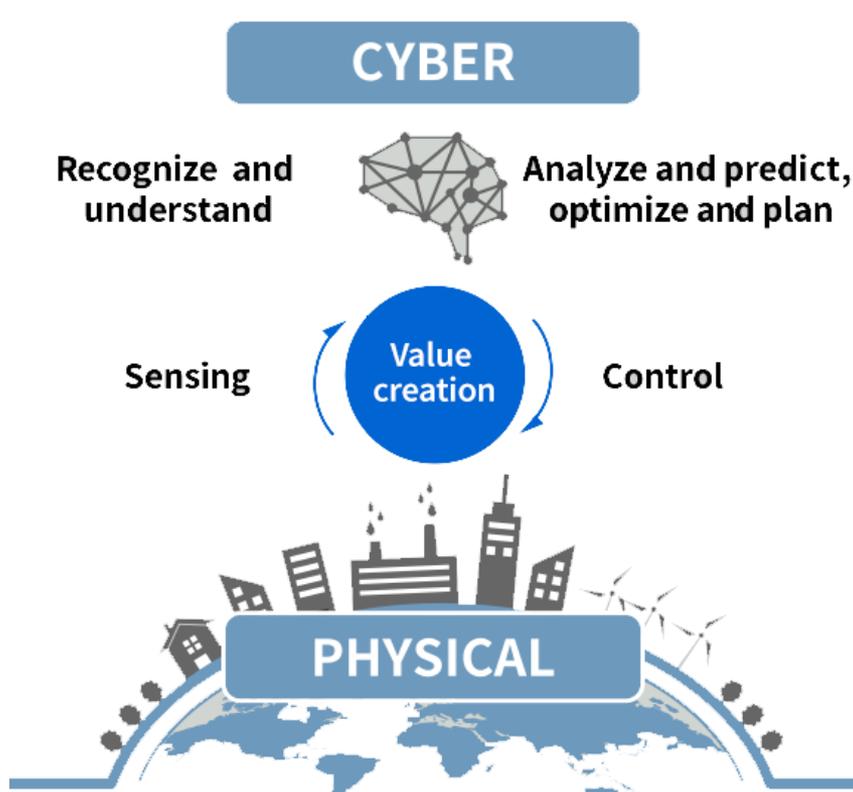
1: Kyoto University, 2: University of Skövde,  
3: Japan Manned Space Systems Corporation





*"It complements the existing "Industry 4.0" approach by specifically putting research and innovation at the service of the transition to a **sustainable, human-centric and resilient European industry.**"*

- Methods for system analysis and improvement are required.

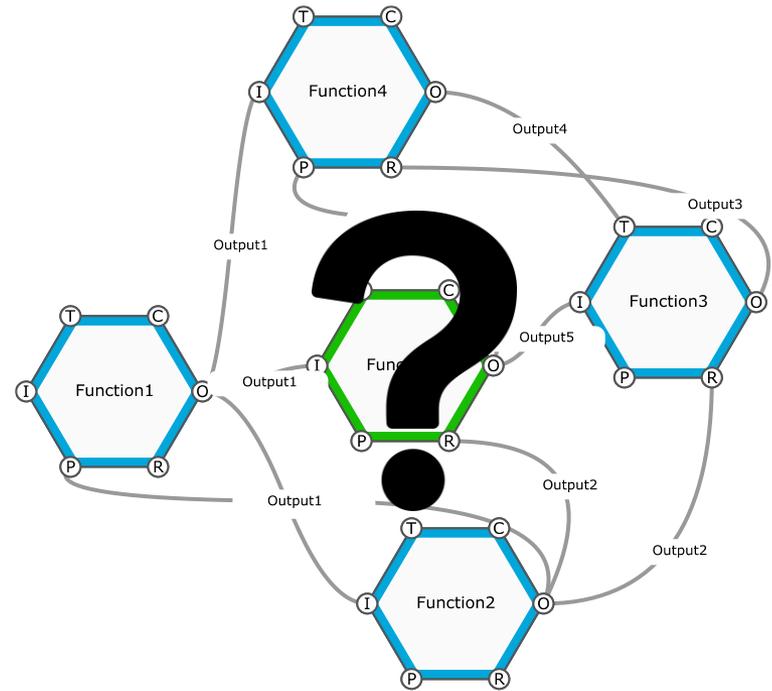
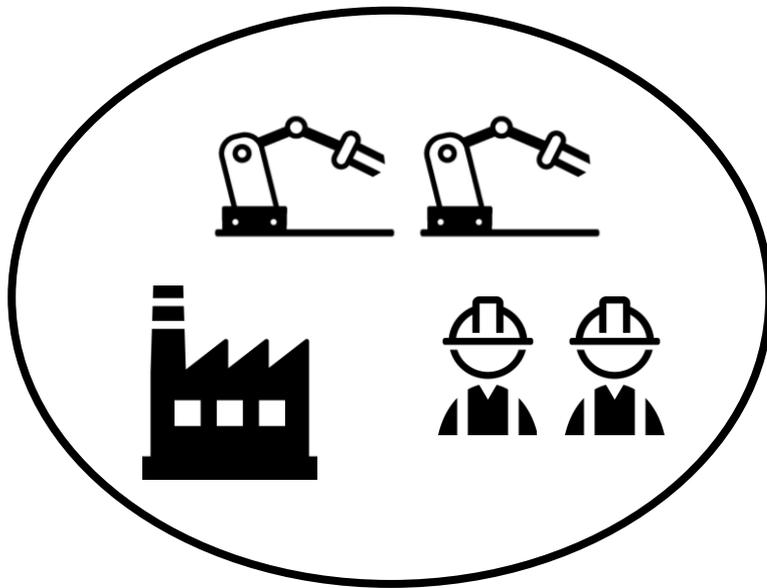


Increasing complexity of systems

- FRAM: Functional Resonance Analysis Method
  - **Originally** proposed for Accident Modeling and Safety Analysis.
  - **Recently** also used in various fields including **Complexity Management** in socio-technical systems.
- For example...
  - **Maritime domain**: Understanding socio-technical work of pilots and Vessel Traffic Services (VTS) operators (de Vries, 2017).
  - **Healthcare domain**: Improving the primary care management of possible sepsis (McNab et al., 2018).
  - **Aviation domain**: Assessing operational impacts of automation in Air Traffic Control (ATC) (Ferreira and Cañas, 2019).

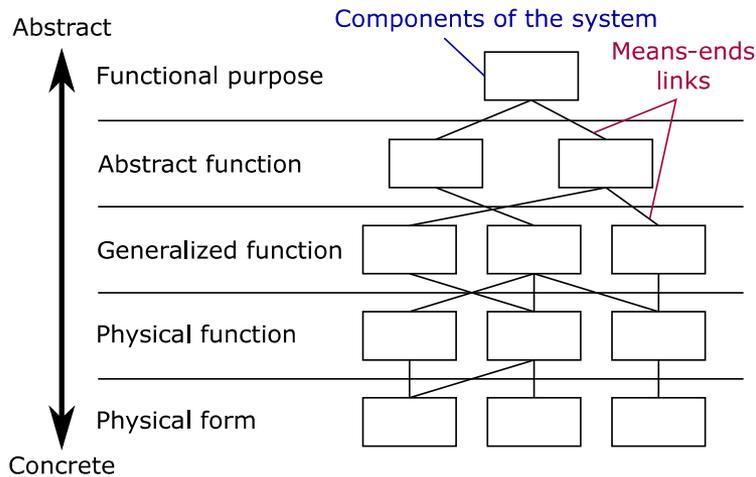
# Difficulties to Conduct FRAM Analysis

- Still some difficulties to build a FRAM model
  - Systematic process to conduct a FRAM analysis is required.

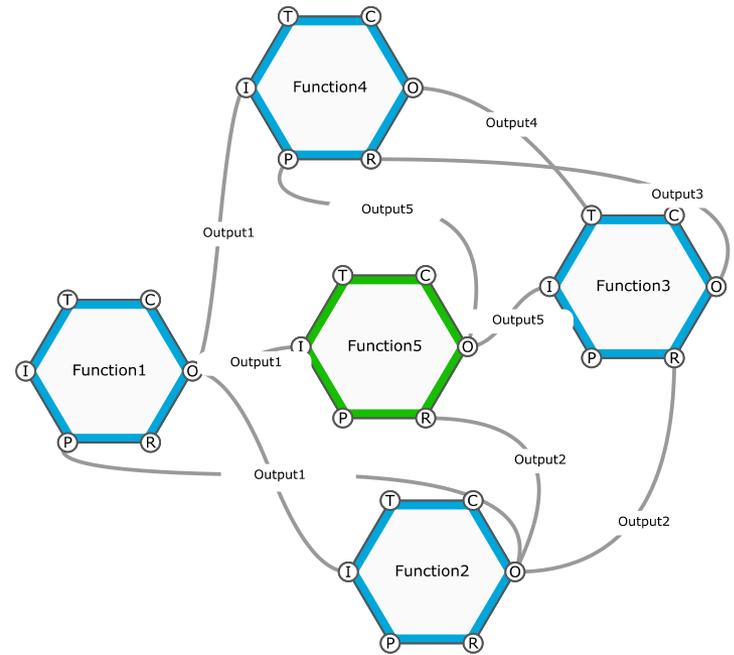
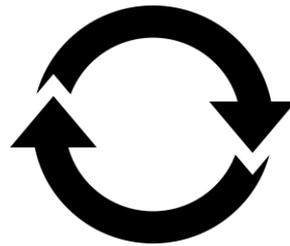


# Our Proposal: A Win-Win Combination

- We propose a new framework combining two methods.
  - **WDA**: Work Domain Analysis
  - **FRAM**: Functional Resonance Analysis Method

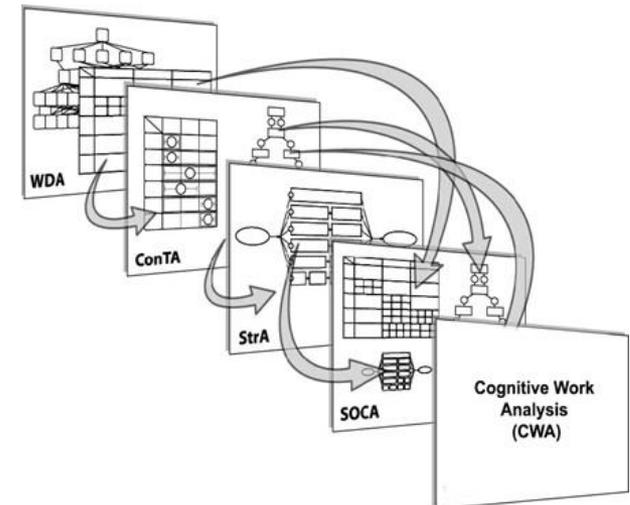


WDA

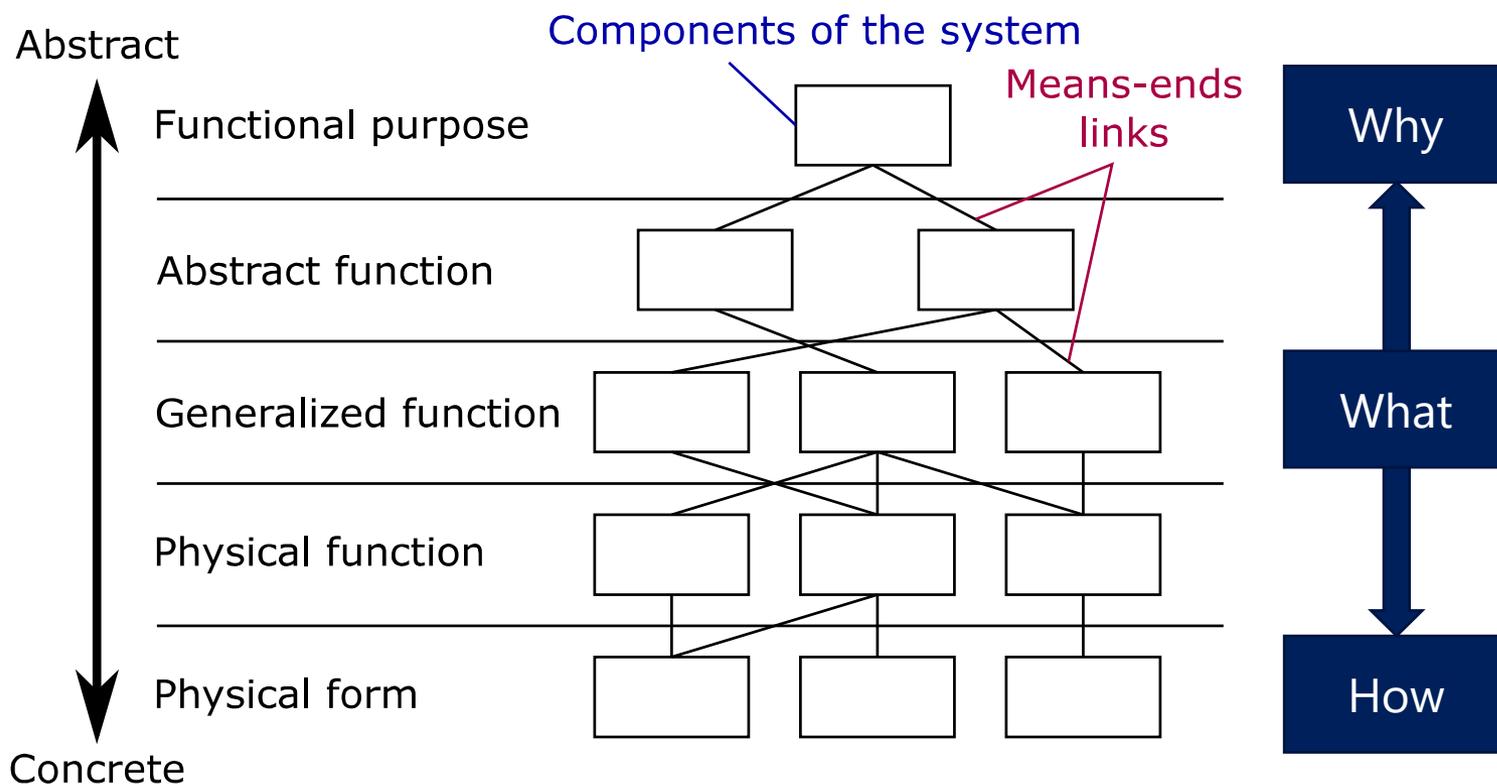


FRAM

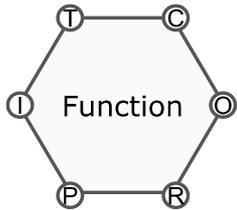
- Cognitive Work Analysis (CWA): A framework to model and analyze complex socio-technical work systems (Vicente, 1999).
- Five steps of CWA
  1. Work Domain Analysis (WDA)
    - Providing a general overview of the entire system.
  2. Control Task Analysis
  3. Strategies Analysis
  4. Social Organization and Co-operation Analysis
  5. Worker Competencies Analysis



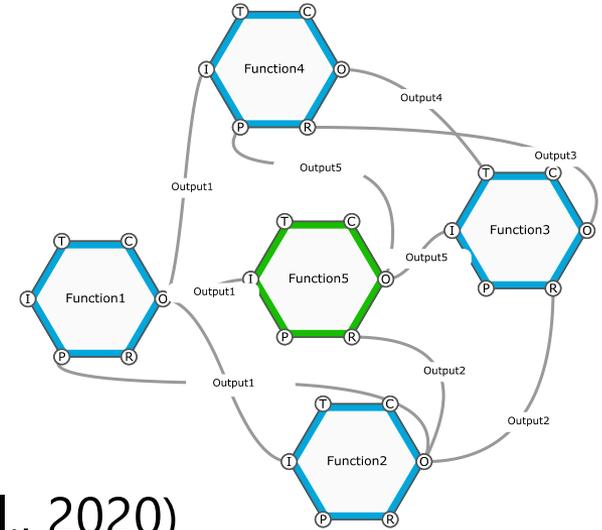
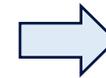
- Abstraction Hierarchy: Illustrating functional structure of target system.
  - Connecting layers with means-ends links.
  - Providing a general overview of the entire system.



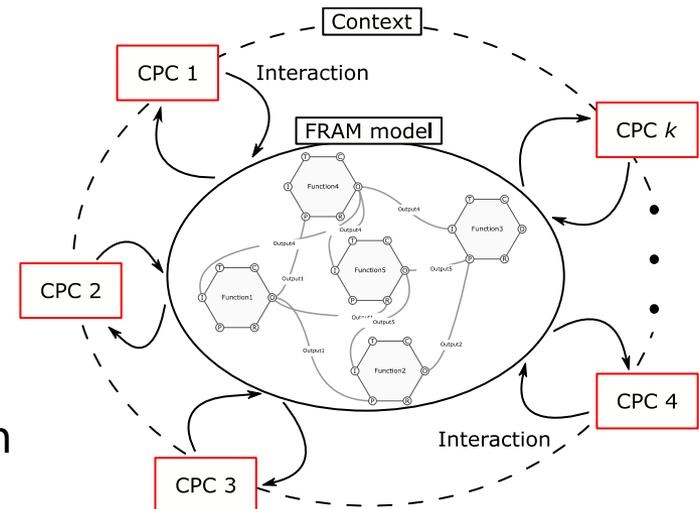
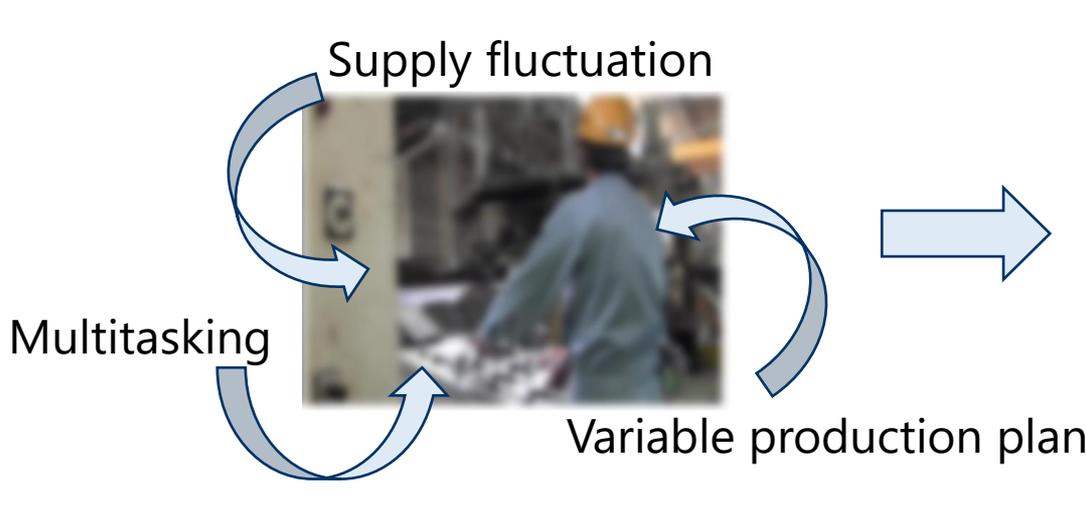
- Analysis method for complex socio-technical systems (Hollnagel, 2012)



Input	Input/Trigger of a function
Output	Outcome of a function
Precondition	Conditions that must be satisfied
Resource	What is consumed by a function
Control	What supervises or restricts a function
Time	Time constraints for a function



- Simulation method based on FRAM (Hirose et al., 2020)
  - Modeling complex interactions in the working environment

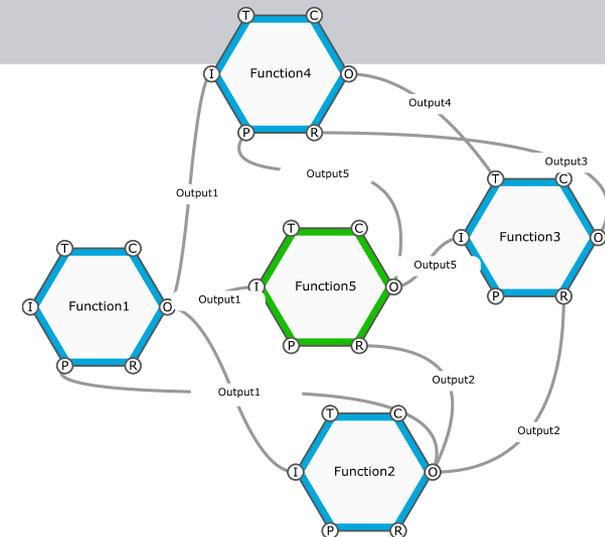
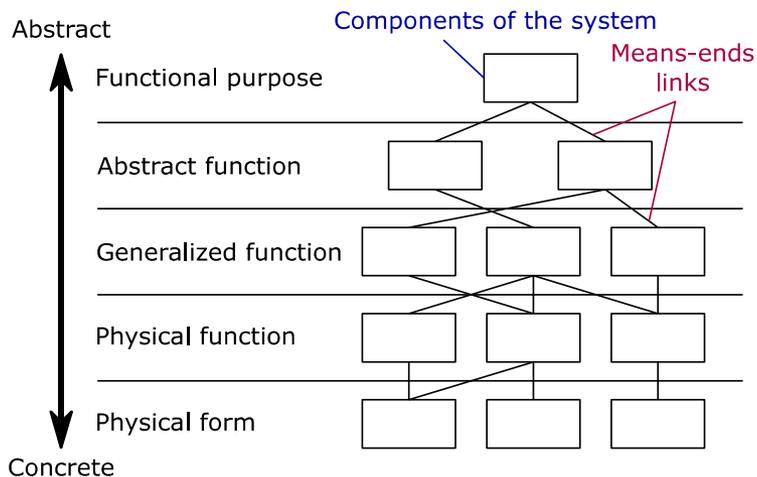


- Similar points of the two methods

## WDA

## FRAM

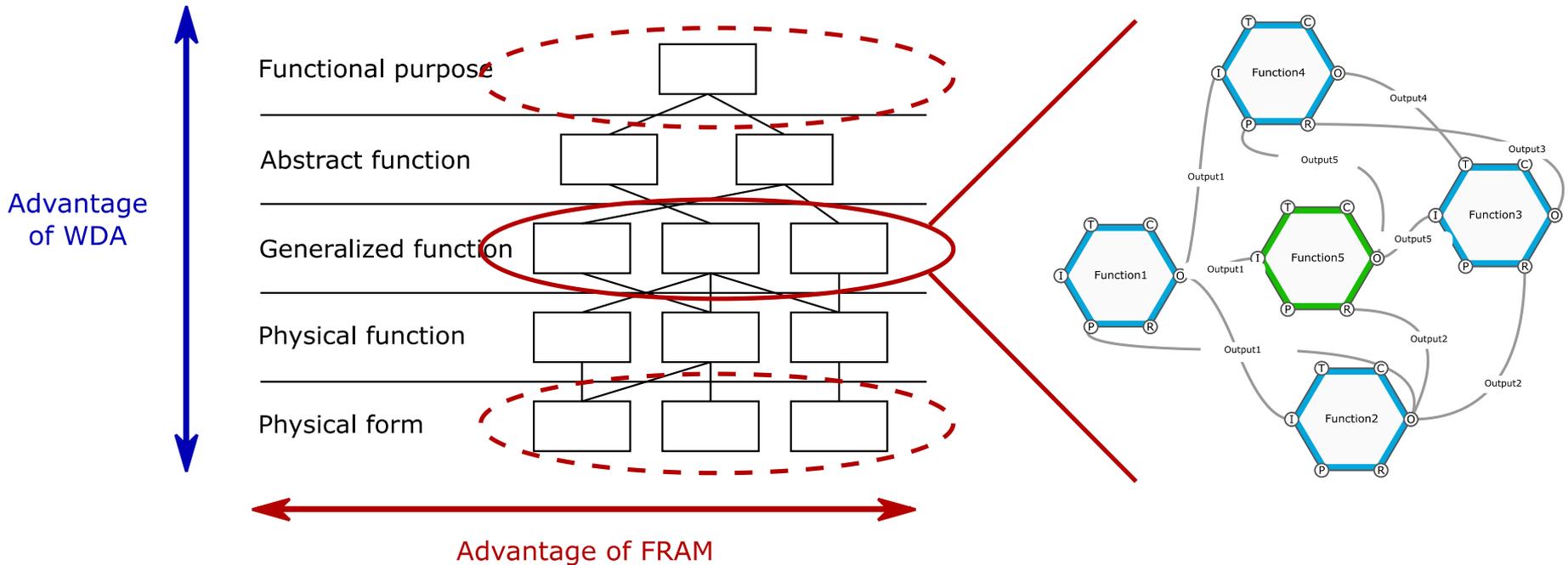
- ✓ Modeling method for socio-technical systems involving human workers.
- ✓ Modeling the system by a network of functions.
- ✓ Managing the complexity of the target system.



- Different points of the two methods

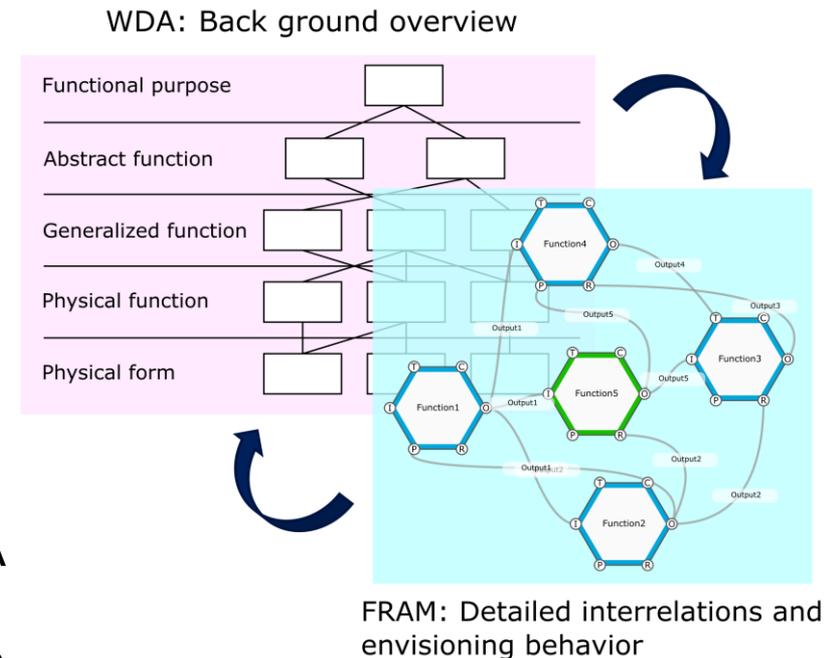
WDA	FRAM
<ul style="list-style-type: none"><li>✓ Global view of the system</li></ul> <p><b>Win</b></p> <ul style="list-style-type: none"><li>✓ Visualizing the overview of the system's functions</li></ul> <ul style="list-style-type: none"><li>✓ Visualizing information processes of human workers (with Control Task Analysis)</li></ul>	<ul style="list-style-type: none"><li>✓ Specific model of the system</li></ul> <p><b>Win</b></p> <ul style="list-style-type: none"><li>✓ Visualizing interrelations between functions clearly</li></ul> <p><b>Win</b></p> <ul style="list-style-type: none"><li>✓ Envisioning the effect of variability propagations</li></ul>

- Graphical representation of the comparison of the two methods
  - The two methods can compensate each other
  - General overview by WDA / Model in specific context by FRAM



- System analysis and improvement using combined framework

1. Document review and basic interviews
2. **WDA**: Describing functions in hierarchy
3. Detailed interviews
  - More detailed information
4. **FRAM**: Key function identification
  - Building FRAM model based on WDA
5. (Go back to No.2 and modify functions)



- Exploring the feasibility of the proposed framework in two case studies
- Case study No.1: Steel plate production process
  - Speaker: Naruki Yasue

Worker's view



Bird's-eye view



Yasue & Sawaragi, 2022

- Case study No.2: Boat production process
  - Speaker: Enrique Ruiz Zúñiga



## Data collection

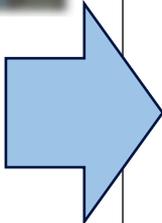
### ➤ Steel plate production system

Worker's view

Bird's-eye view

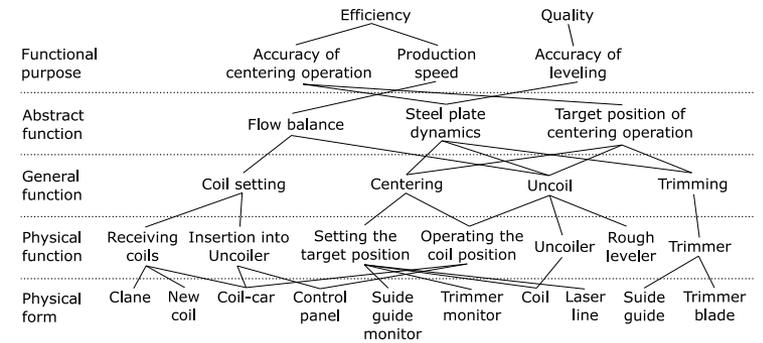


### ➤ Interview analysis

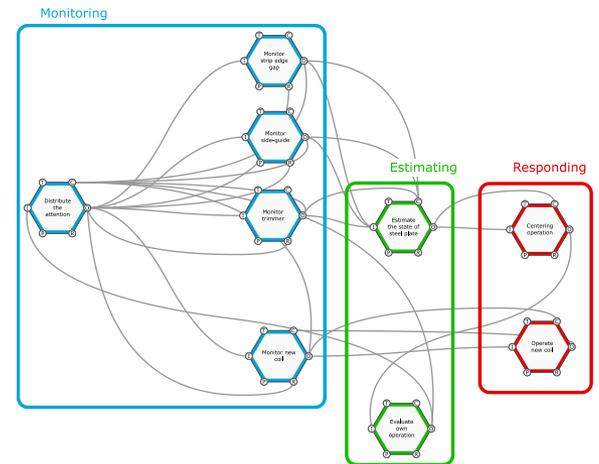


## WDA and FRAM

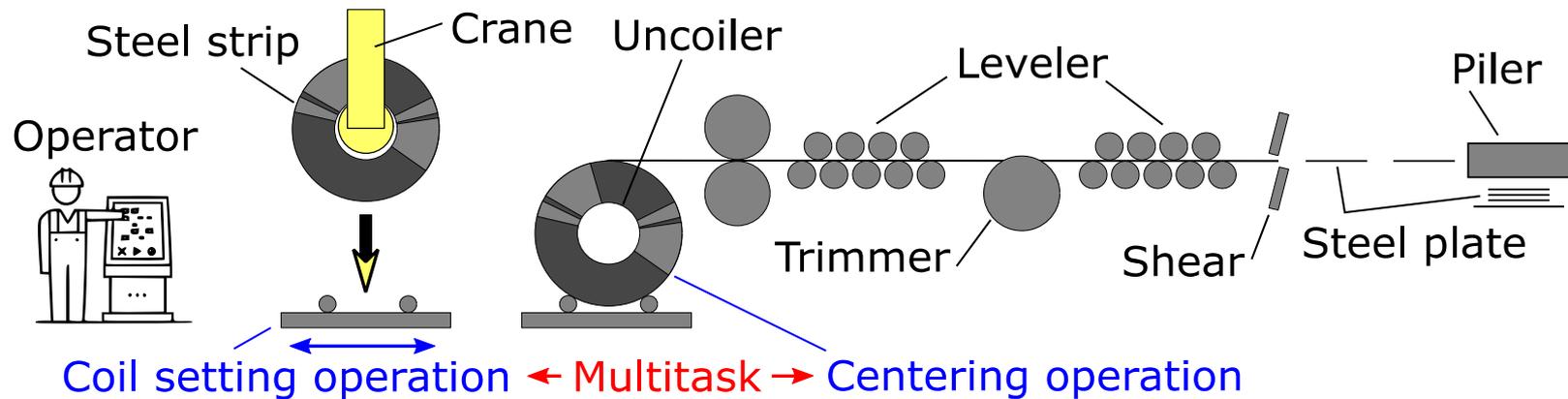
### ➤ WDA: Abstraction Hierarchy



### ➤ FRAM analysis



- Focusing on multitasking of two operations
  - Centering operation
  - Coil setting operation



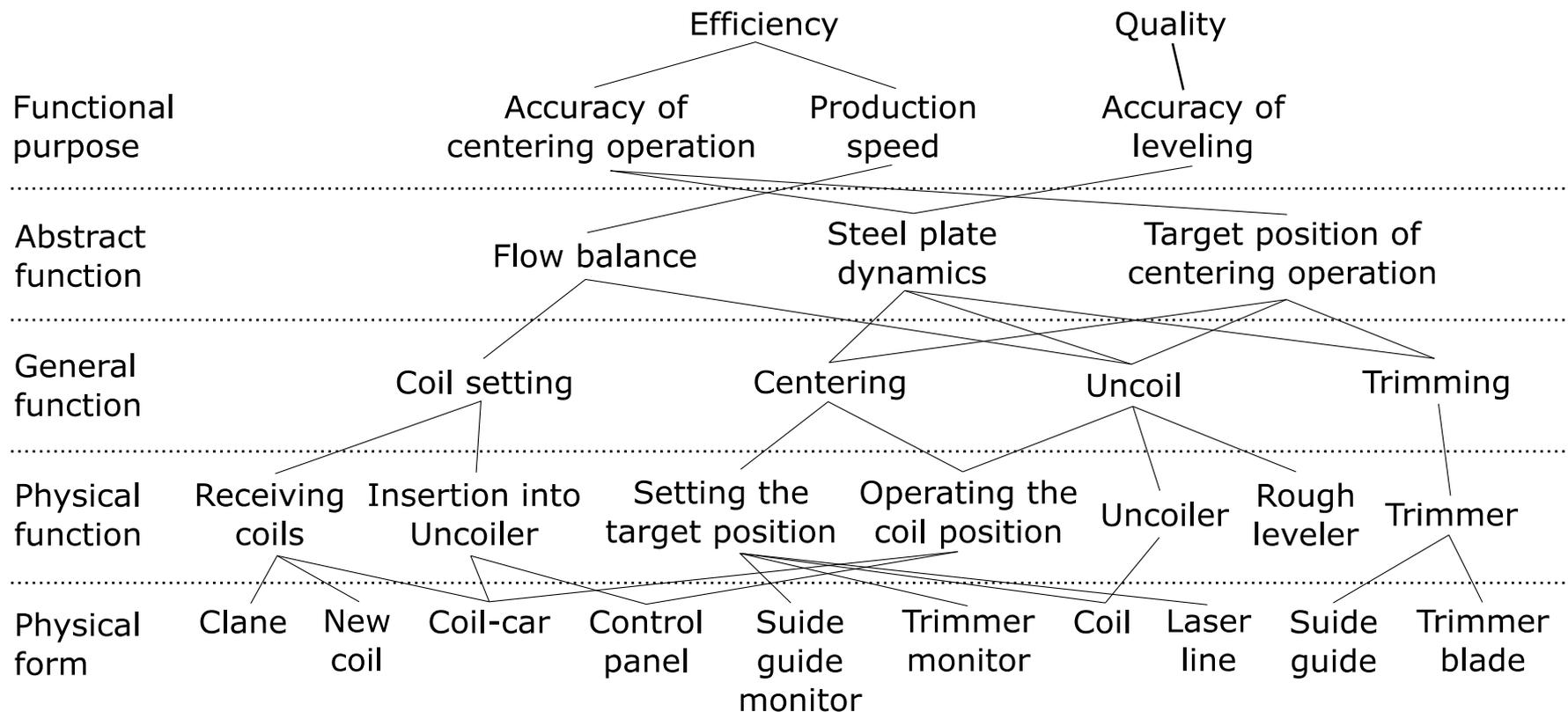
Worker's view



Bird's-eye view



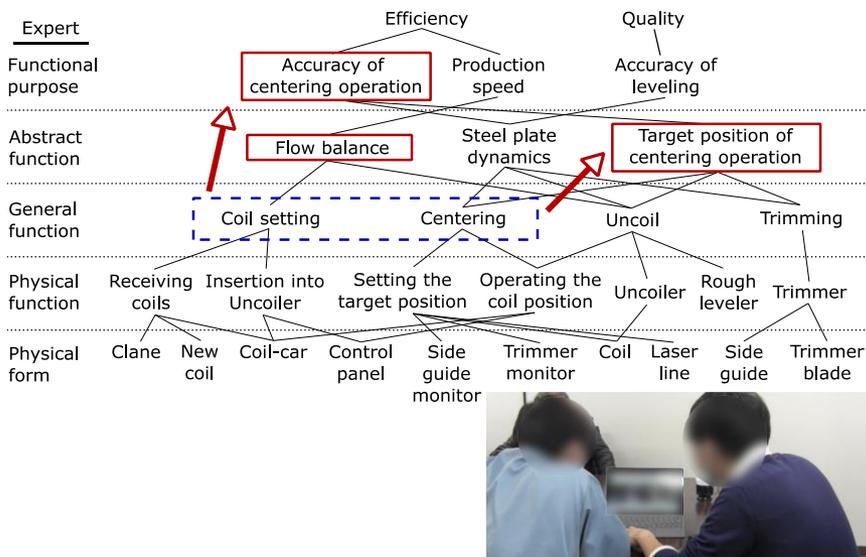
- Based on document review and basic interviews
  - Ginzburg, V. B. (2009). Flat-rolled steel processes: advanced technologies. CRC Press.



- Work Domain Analysis: Mapping the functional relationships of the system into a hierarchy
- Visualize the typical answers during interviews using this hierarchy

## Expert

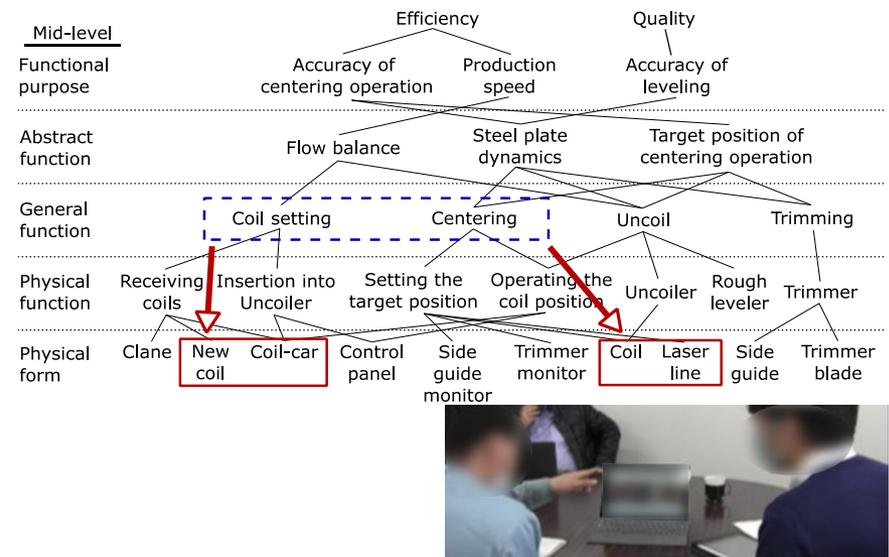
- Abstract answers
- Focus on relation between components
- Upward transitions in the hierarchy



More aware of abstract relations

## Mid-level

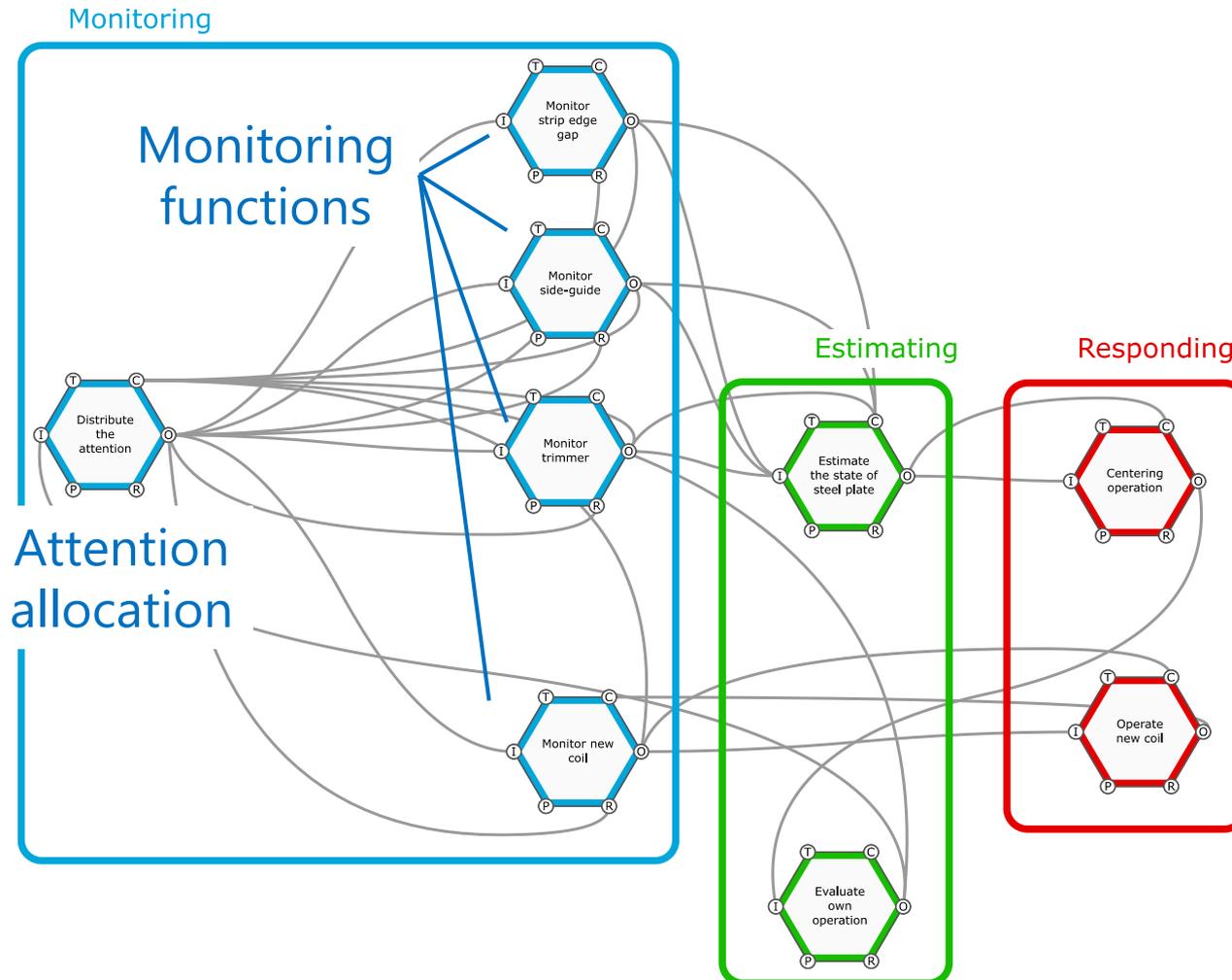
- Concrete answers
- Focus on each specific components
- Downward transitions in the hierarchy



Focusing on specific equipment

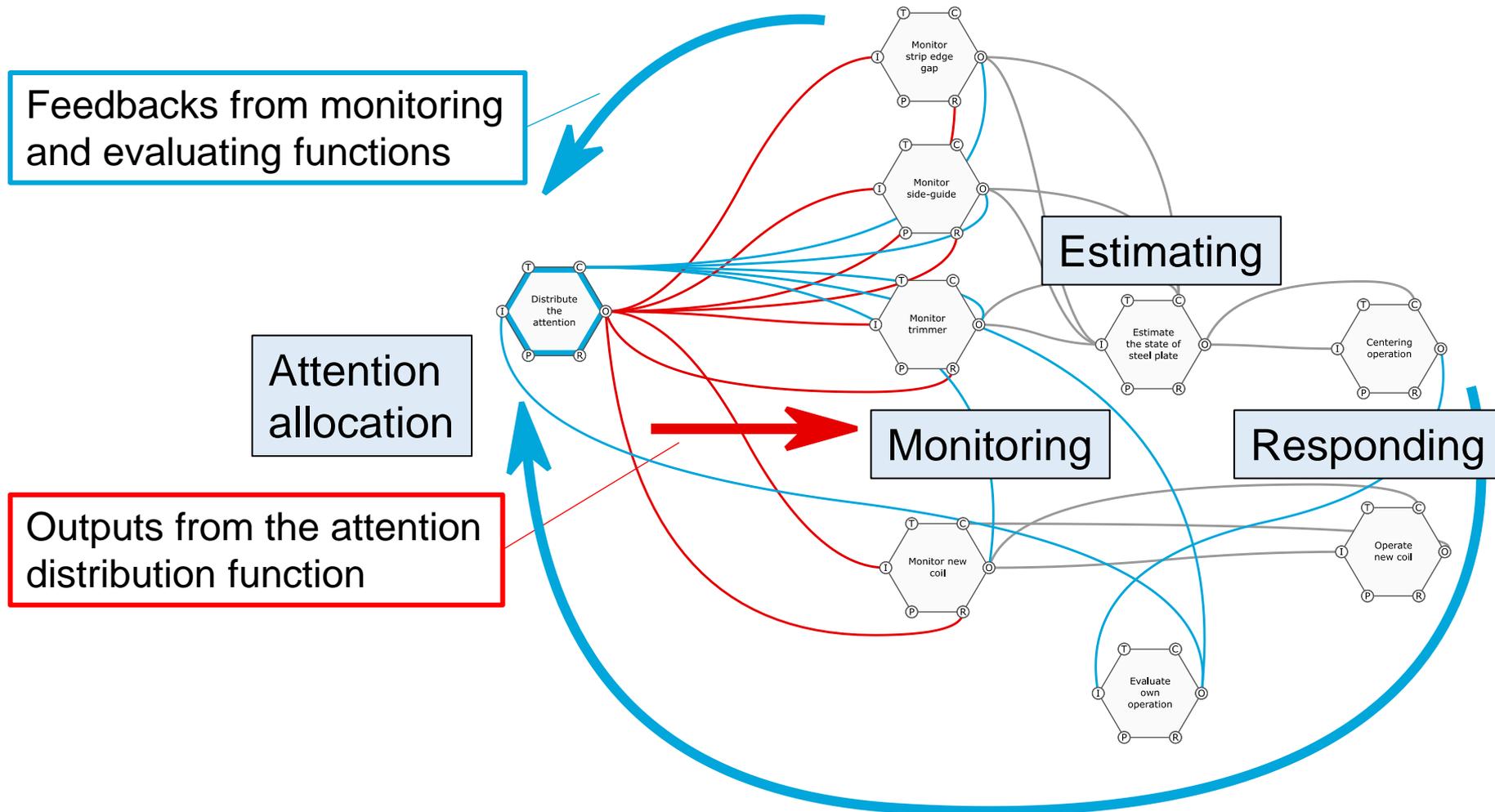


- Grouping the functions based on four resilience abilities (Hollnagel, 2017)
  - Monitoring, Estimating, Responding, (Learning)



# Analyzing Operator's Skill

- The FRAM model has a perception-action cycle



- Nimbus – JAMSS bottleneck and capacity analysis
- Aim: Increase the capacity and resilience of a leisure-boat manufacturing company of highly-customized large-size products

Increase flexibility and resilience of the production  
Different levels of abstraction: strategic, tactical, operational

Two main stages: composite (plastic) and assembly. Focus narrowed down to painting process.

Constraints: Space, skills, molds, and transports

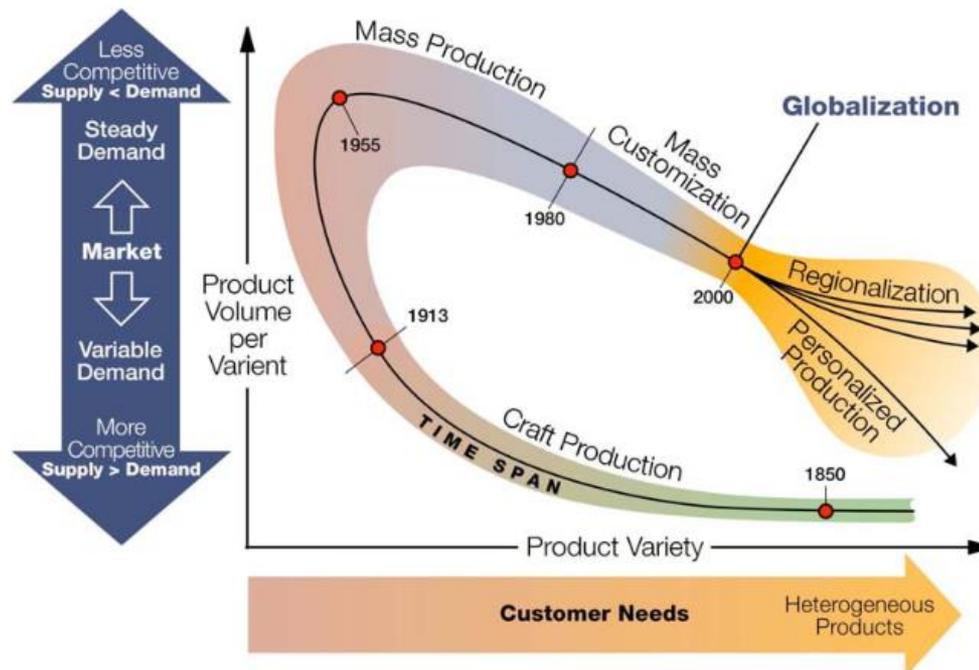
Methods: Theory of Constraints, Discrete-Event Simulation, Functional Resonance Analysis Method, Work Domain Analysis



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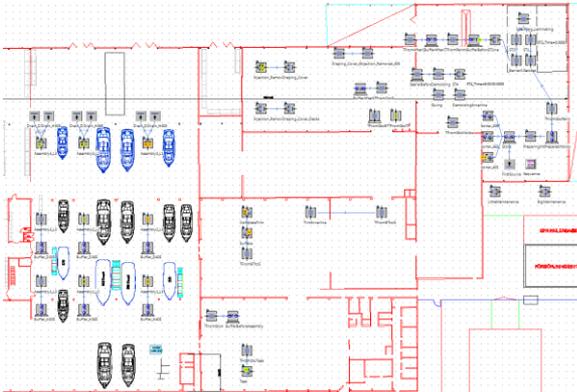


- Competition and offshoring
- Complexity
- Flexibility and adaptation required for mass customization
- High levels of uncertainty associated with the introduction of new production processes or products
- Resilience of the system

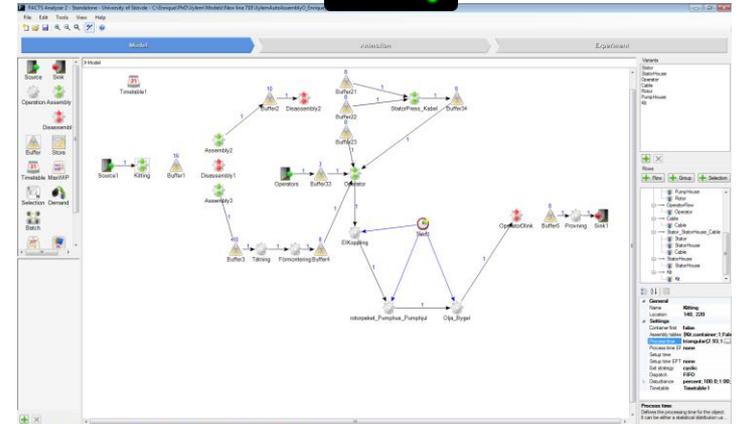
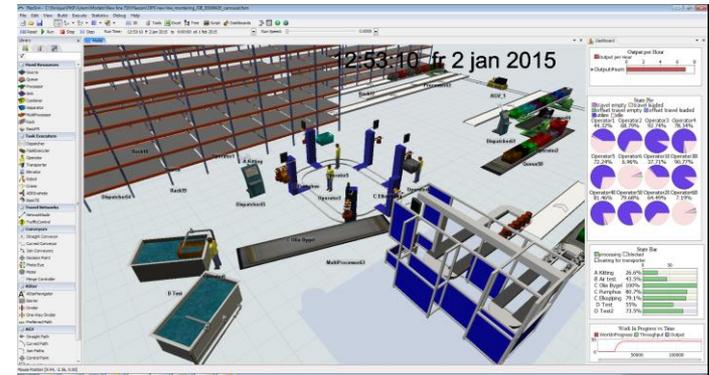


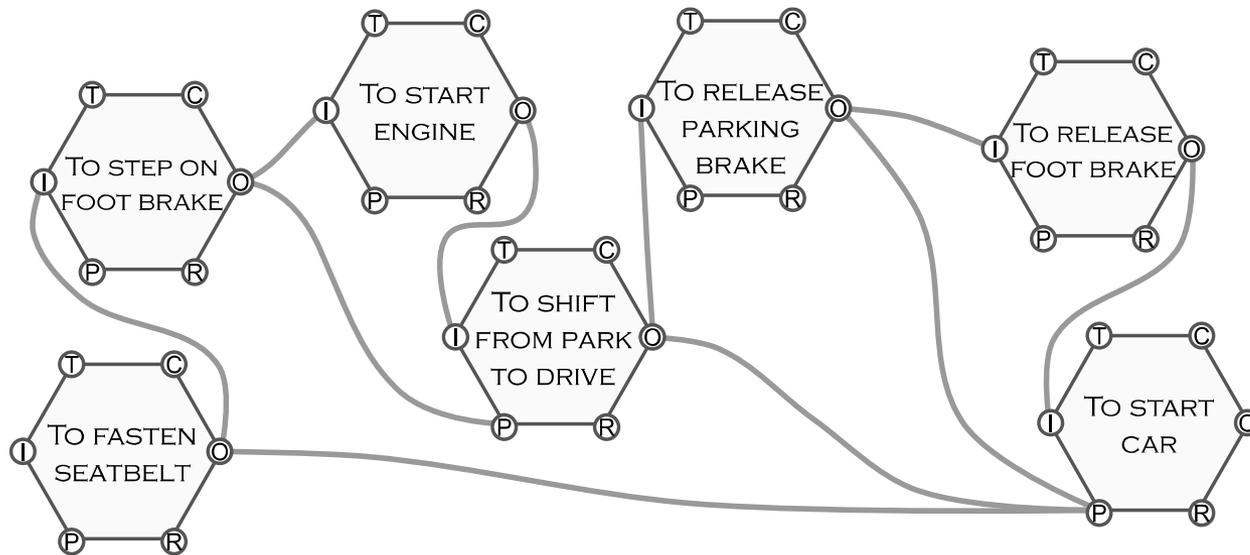
# Discrete-Event Simulation (DES)

SIEMENS TECNOMATIX  
Plant Simulation



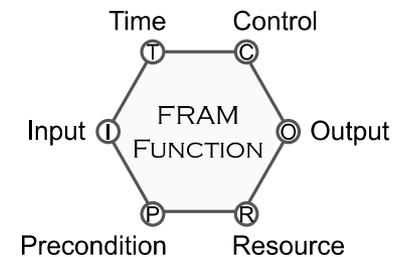
FLEXSIM



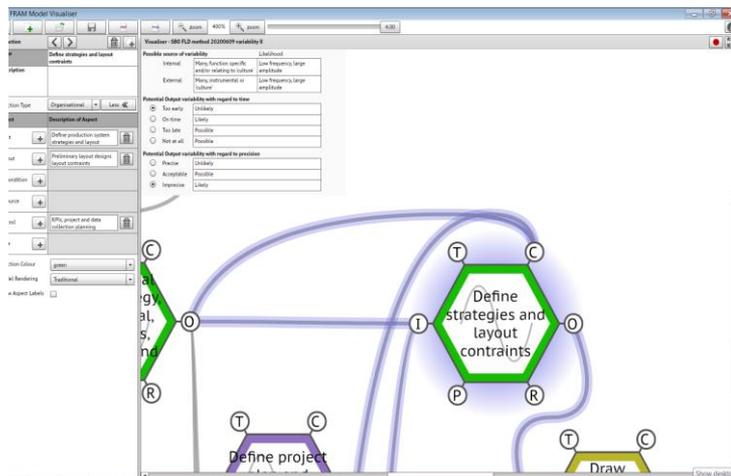


Hirose and Sawaragi (2019)

**FRAM Functions**  
 Tasks/Activities to achieve specific goals  
 ➤ Defined with six aspects



Hollnagel (2012)



Possible source of variability	Likelihood
Internal	Many, function specific and/or relating to 'culture'
External	Many, instrumental or 'culture'

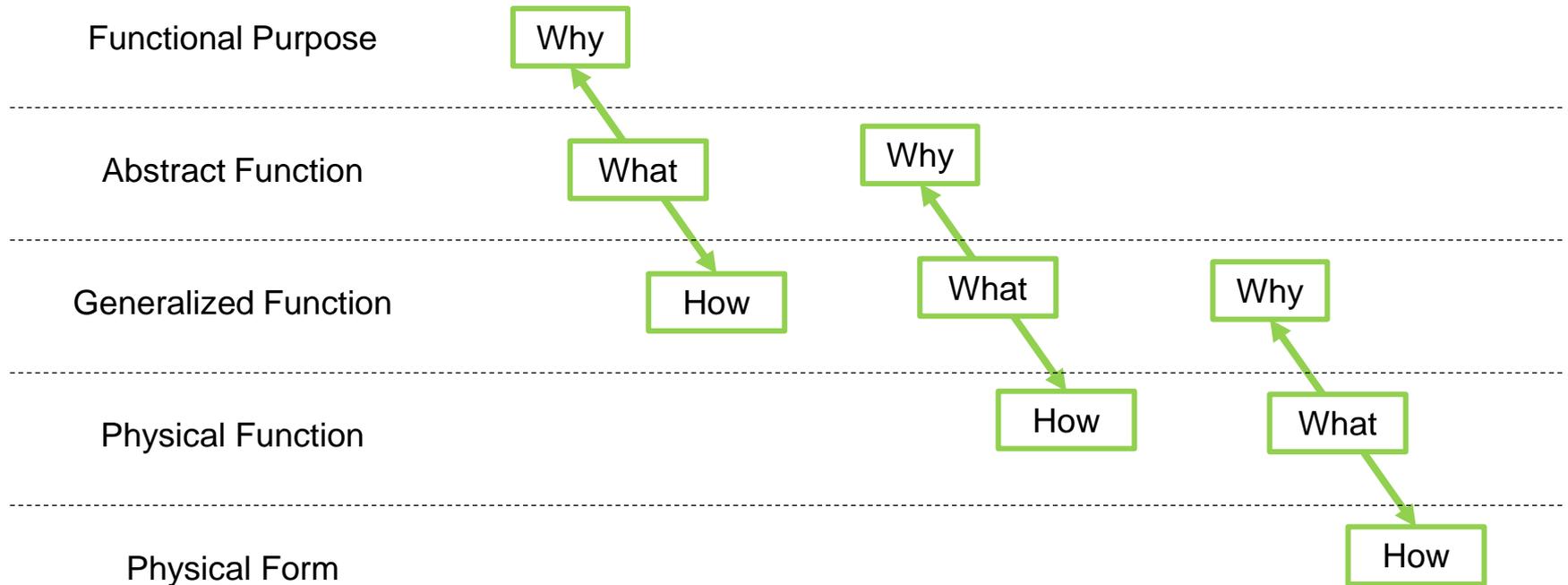
  

Potential Output variability with regard to time	
<input checked="" type="radio"/> Too early	Unlikely
<input type="radio"/> On time	Likely
<input type="radio"/> Too late	Possible
<input type="radio"/> Not at all	Possible

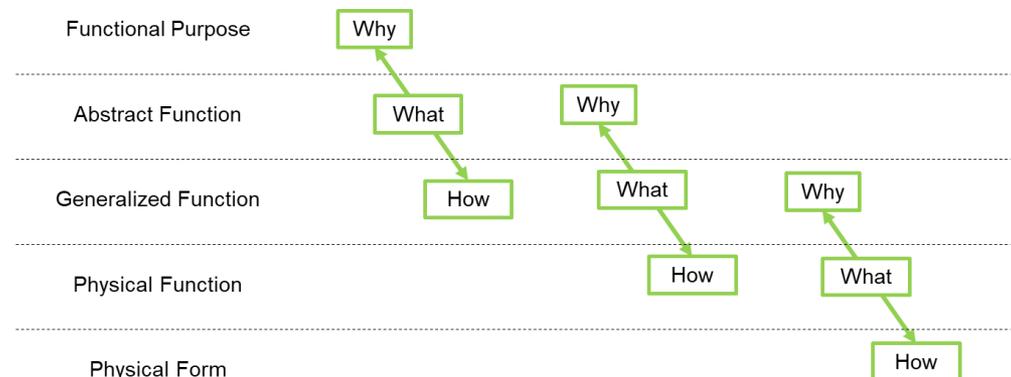
  

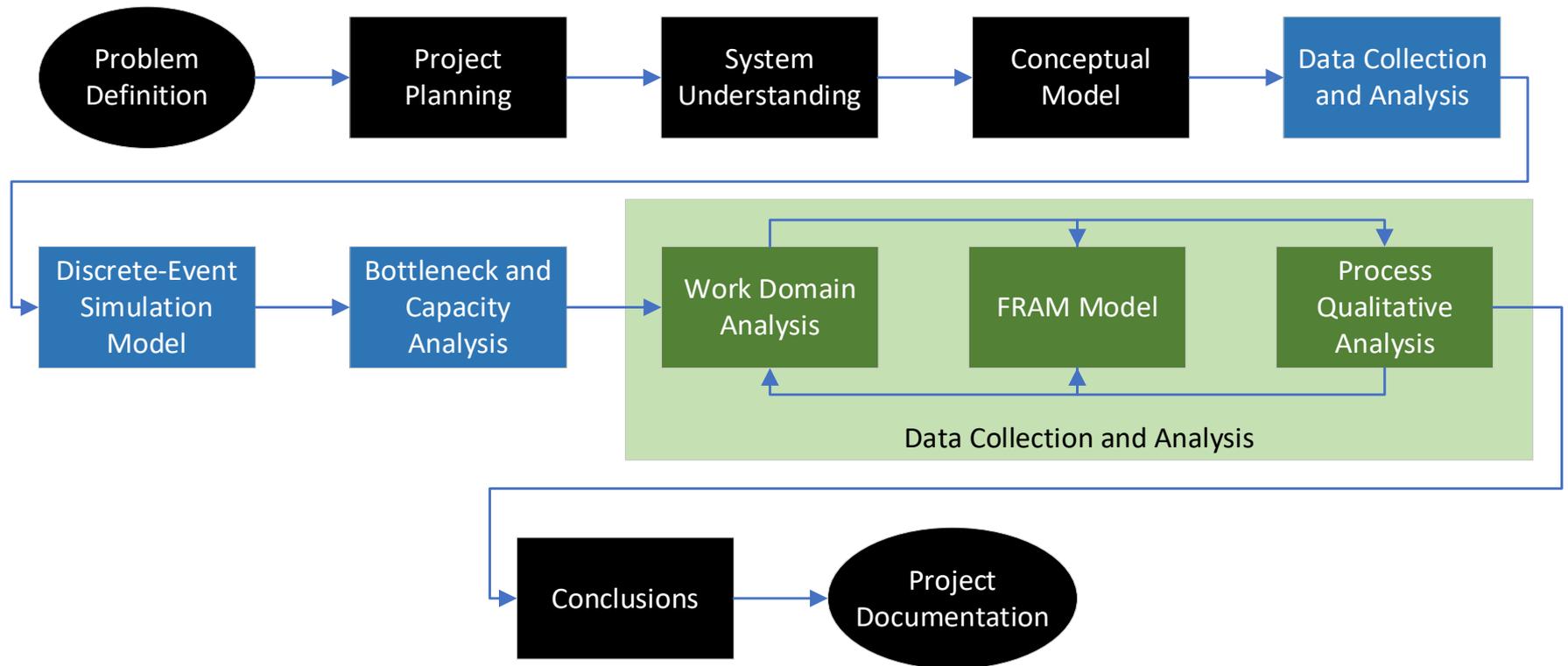
Potential Output variability with regard to precision	
<input type="radio"/> Precise	Unlikely
<input type="radio"/> Acceptable	Possible
<input checked="" type="radio"/> Imprecise	Likely

- Work Domain: System controlled by human or automations
- Investigate its entire picture, based multiple abstraction layers of purpose and functions

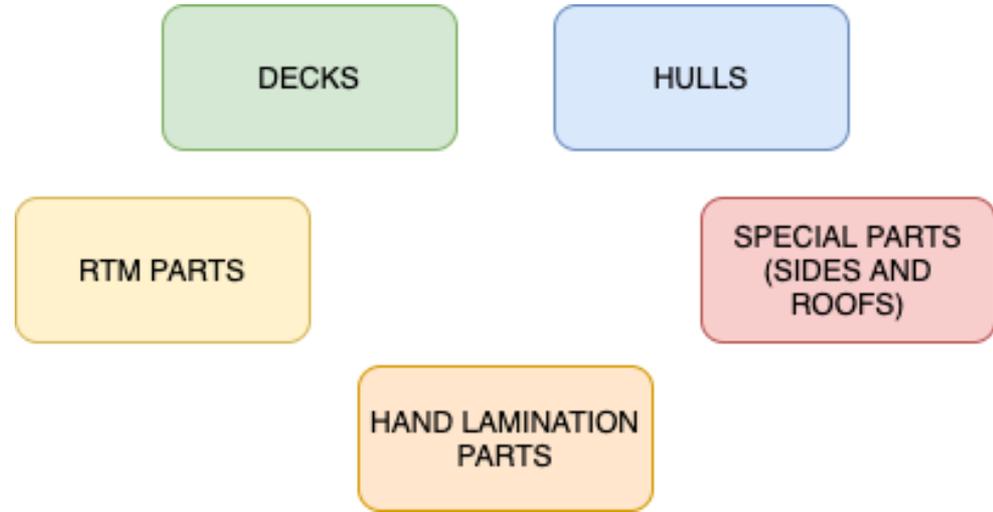


- Work Domain: System controlled by human or automations
- Investigate its entire picture, based multiple abstraction layers of purpose and functions
  - Step 1: Establish the purpose and use of the WDA.
  - Step 2: Establish abstraction levels (abstraction-decomposition space (ADS)):
    - Abstraction levels: Functional purposes - Values and priority measures - Purpose-related functions - Object related processes - Physical objects
    - Decomposition levels(total system, subsystem, function unit, subassembly, component):  
Painting process
  - Step 3: Determine WDA boundaries.
  - Step 4: Identify the Nature of Constraints.
  - Step 5: Identify the Potential Sources of Information
  - Step 6: Construct ADS – First Iteration
  - Step 7: Construct ADS – Second Iteration
  - Step 8: Construct ADS – Third Iteration
  - Step 9: Validate the ADS

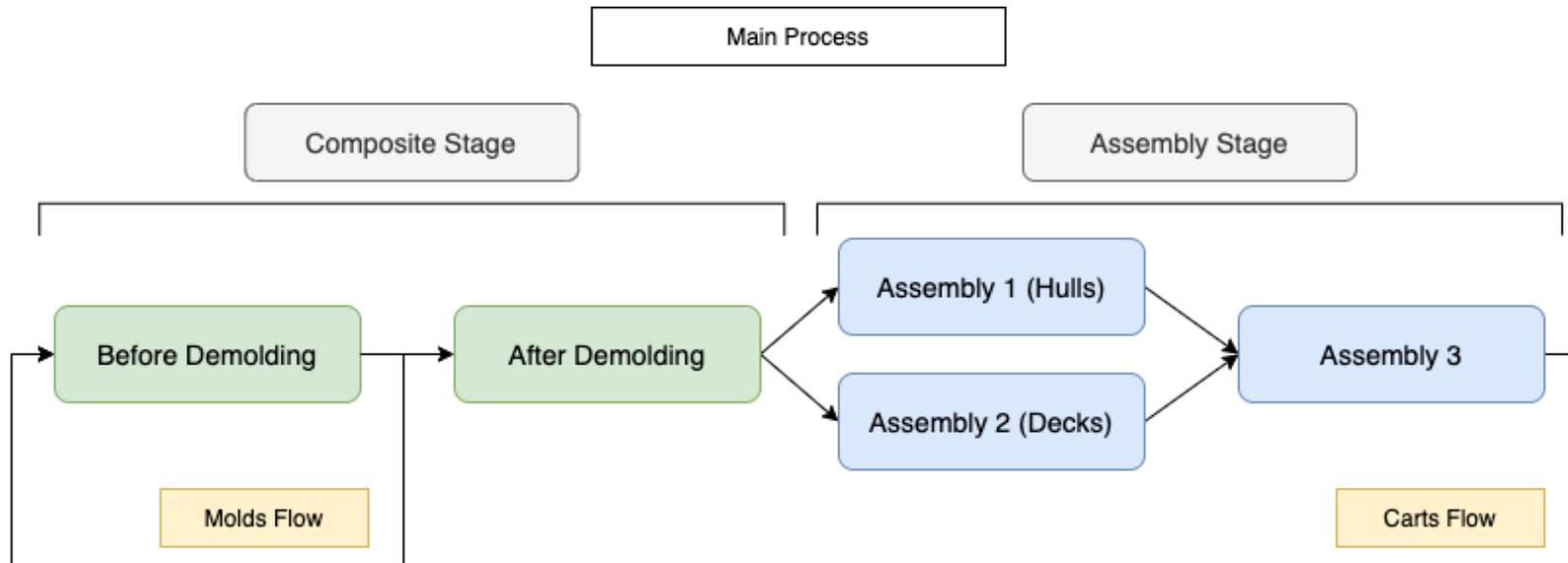




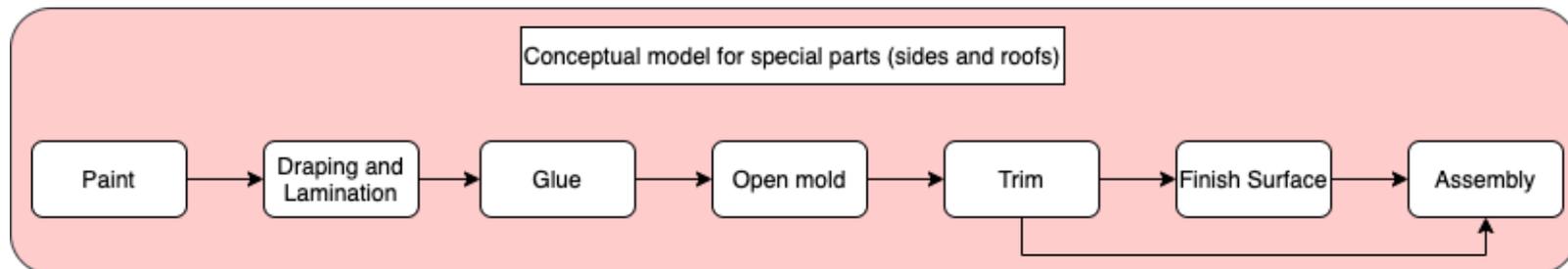
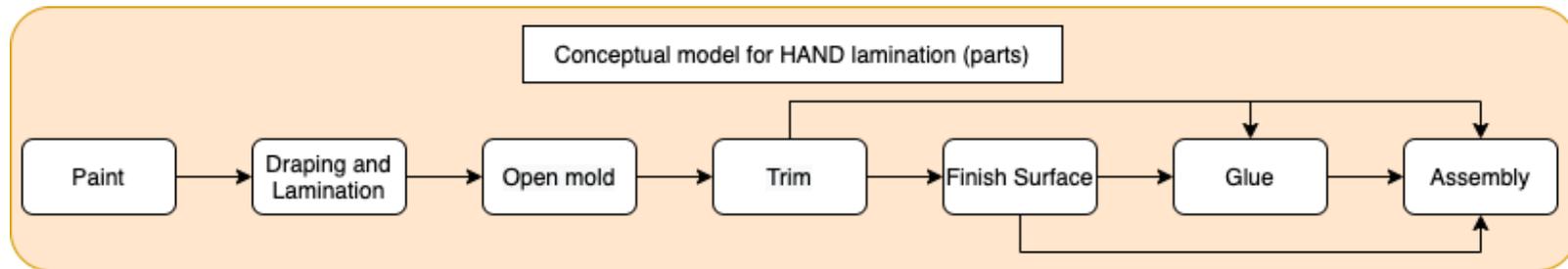
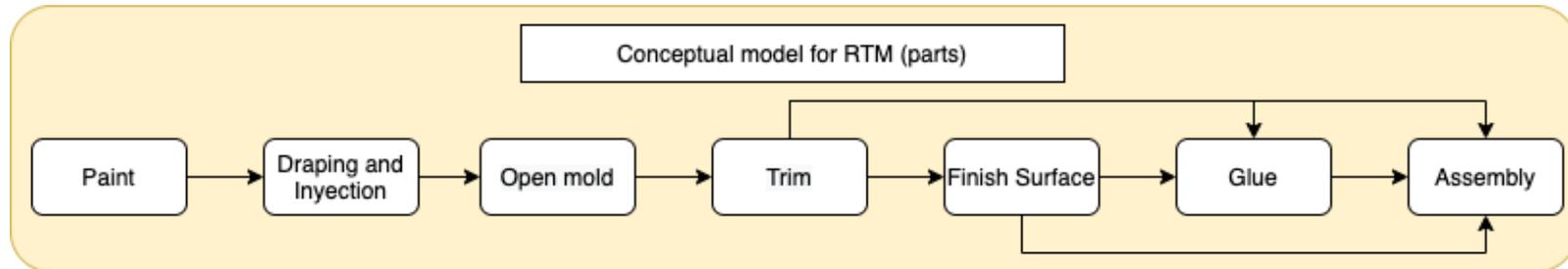
- In order to better analyze the different steps that make up the process, all parts have been categorized into 5 main types:



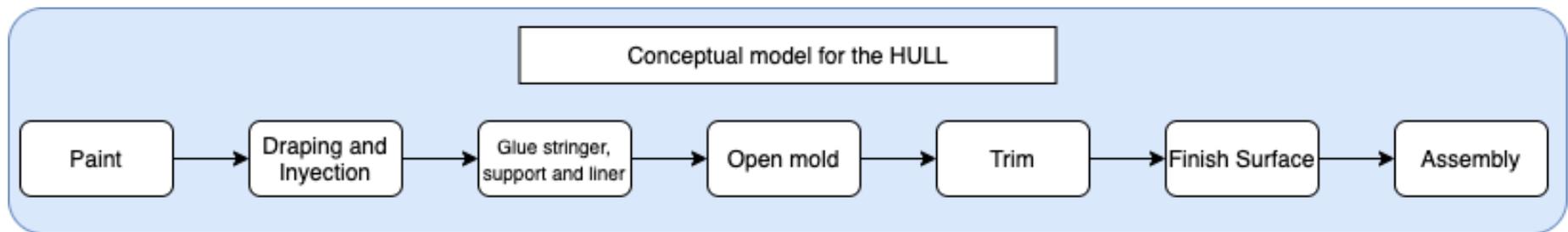
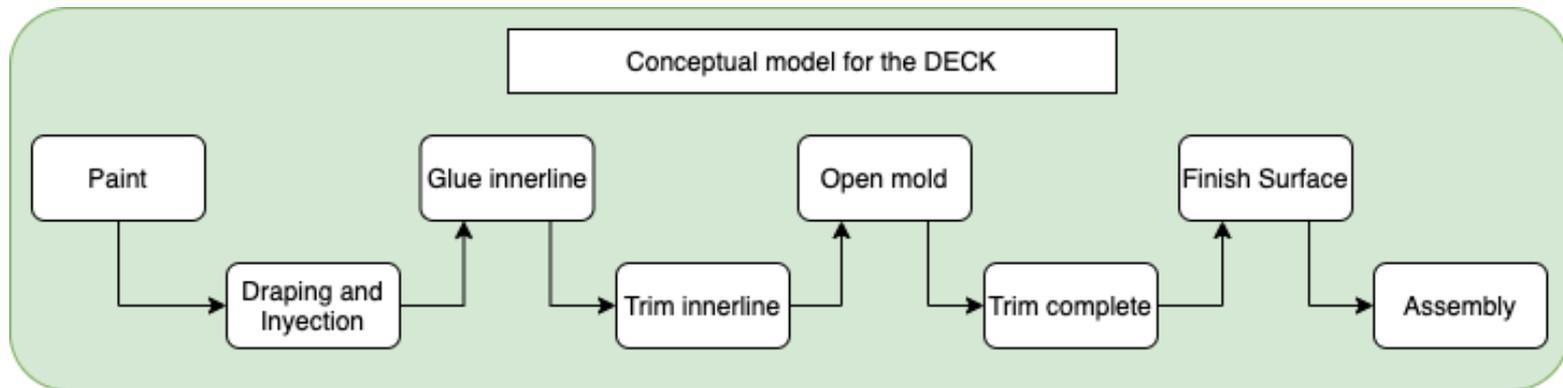
- Conceptual modelling, 1st level:



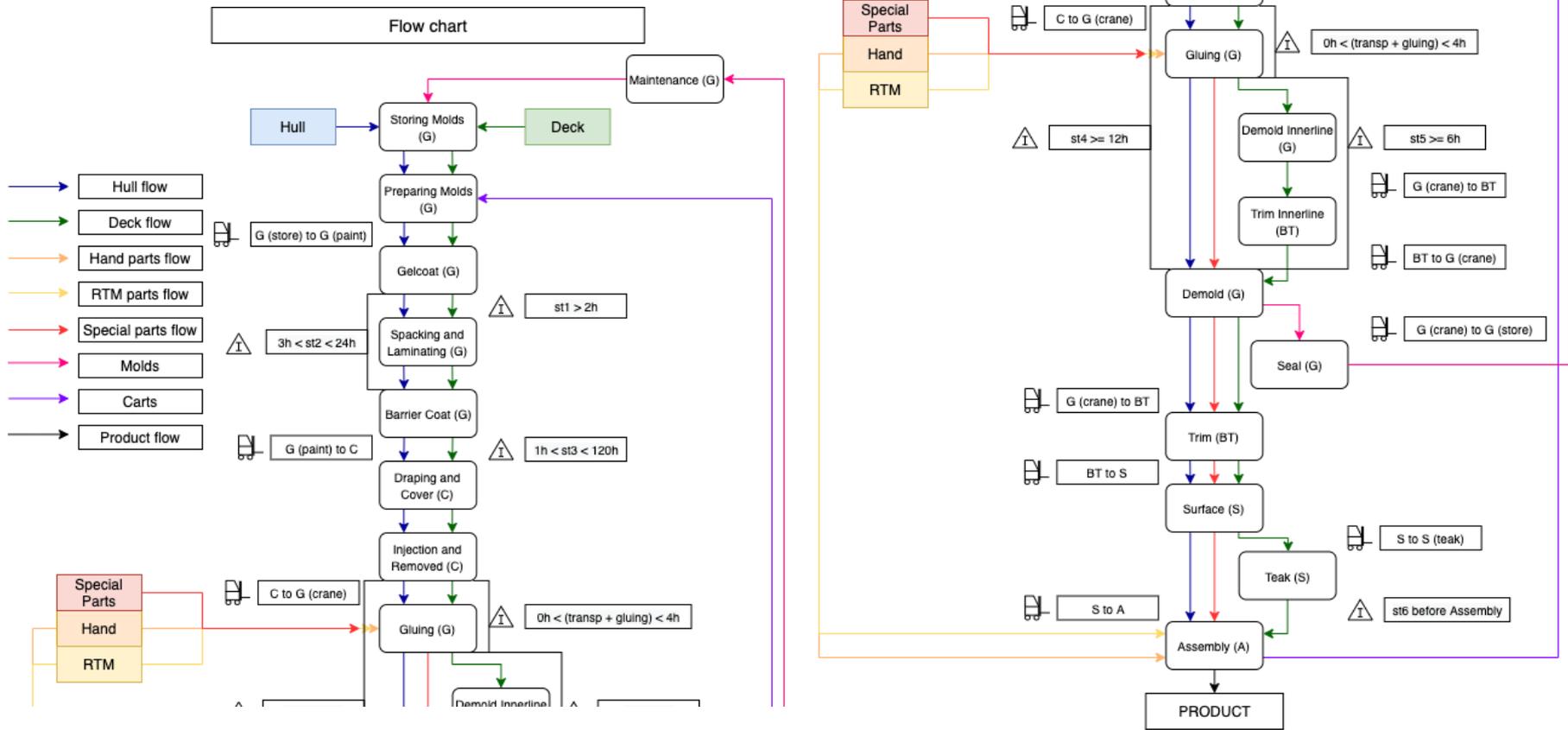
- Conceptual modelling, 2nd level:



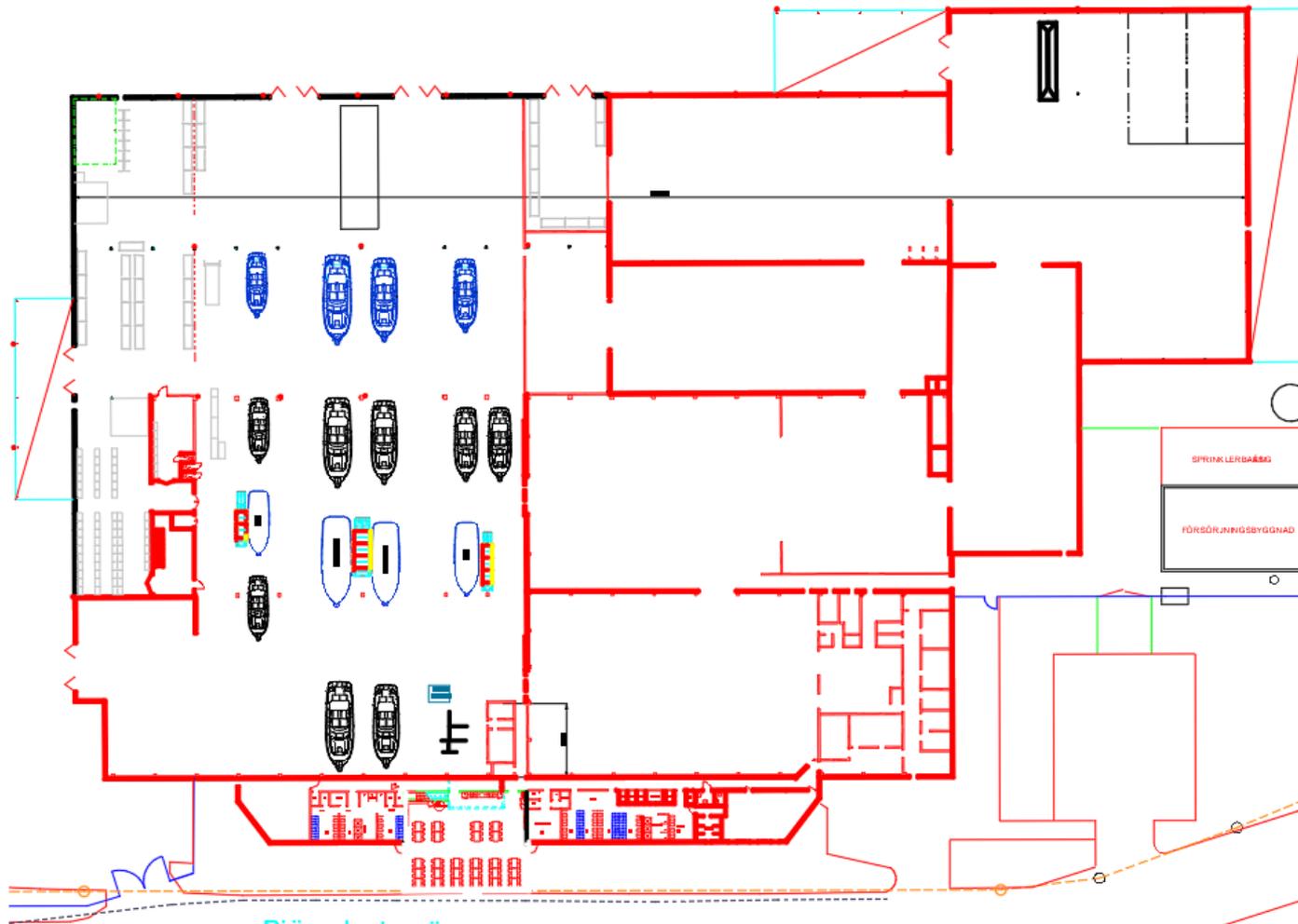
- Conceptual modelling, 2nd level:



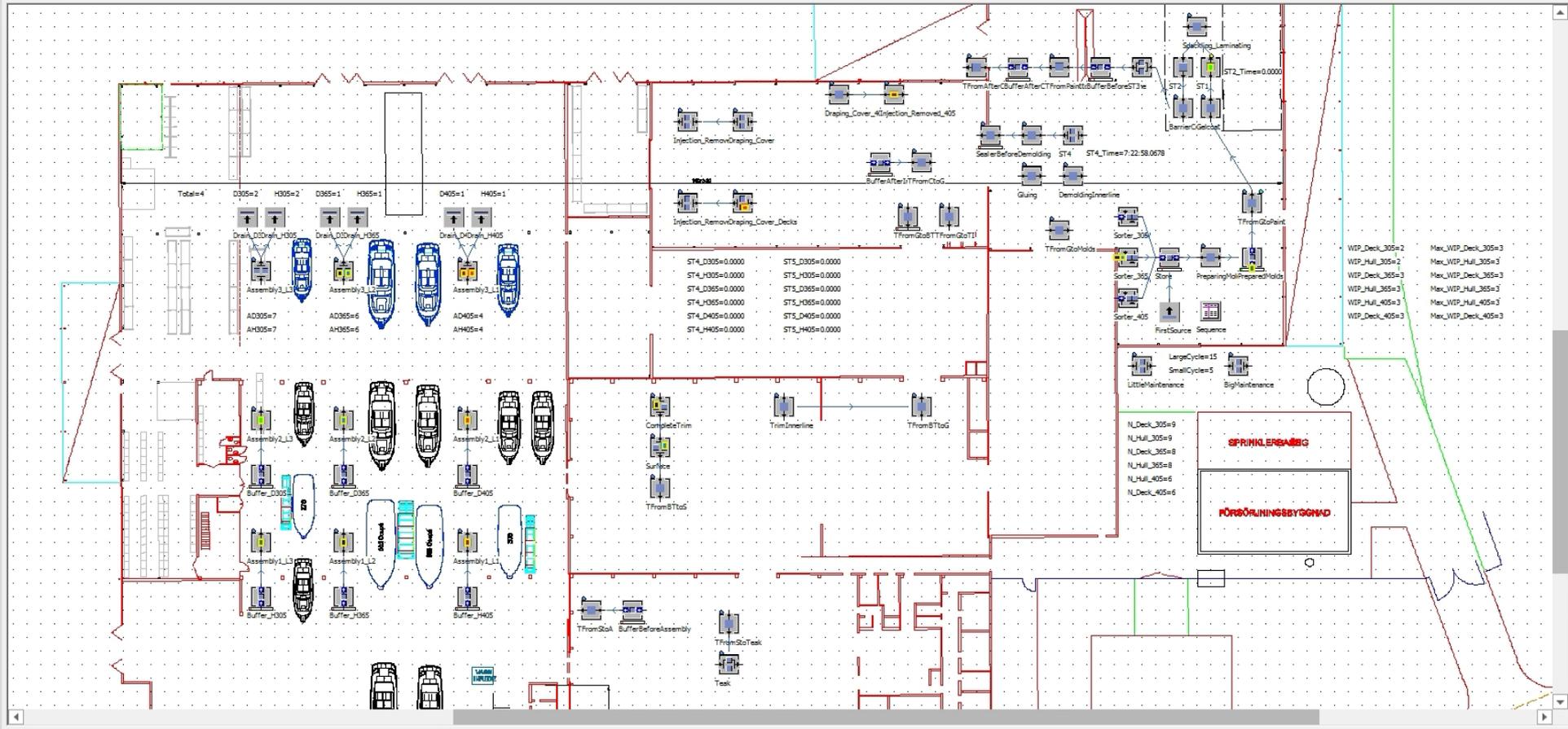
- Conceptual modelling, 3rd level:



- Data collection:



- Model translation:



- Simulation model validation
- Simulation model verification

To validate the simulation model, the outputs obtained in the model are compared with the plant's production throughput over a period of 1 year.

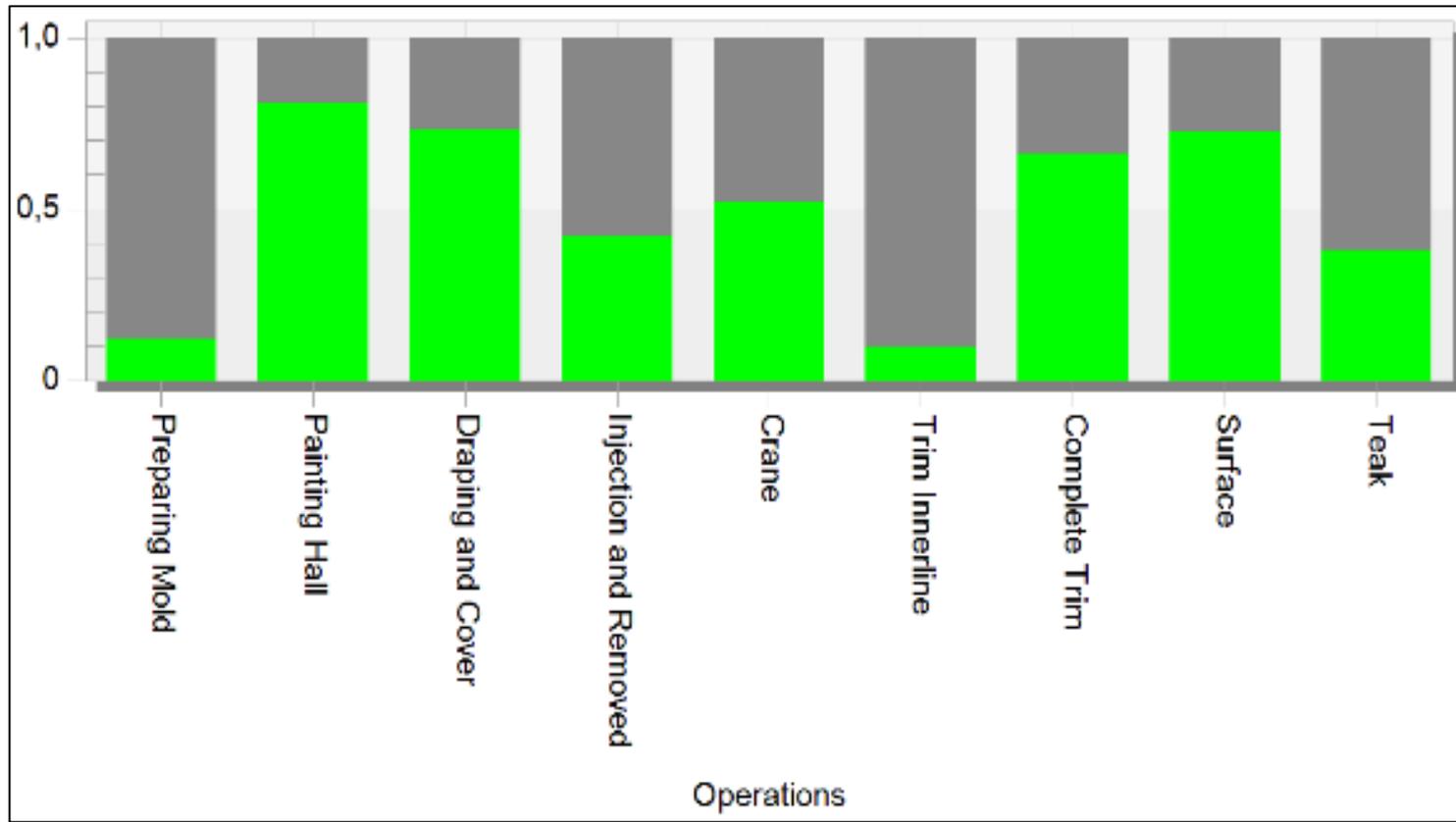
Product Family	Throughput (products/year)		Lead Time (days)		Work in Progress (products)	
	Factory	Model	Factory	Model	Factory	Model
A	45	42	25	22	12	8
B	35	32	29	31	6	6
C	20	22	44	45	6	6

Throughput Per Year: Number of boats produced in 1 year.

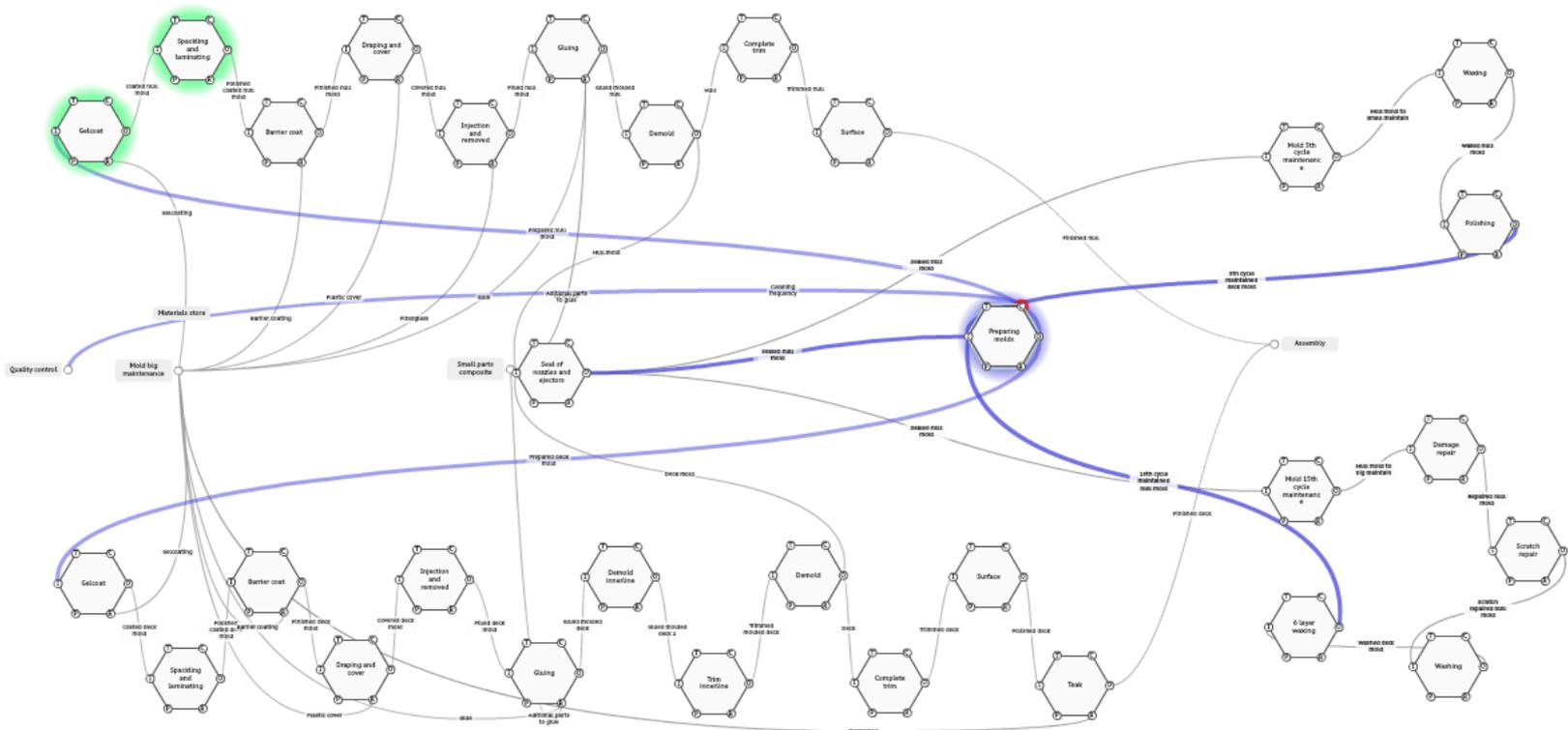
Av. Lead Time: Average time to manufacture a complete boat from launch to finished boat.

WIP: Max work in progress (WIP) level reached during the process.

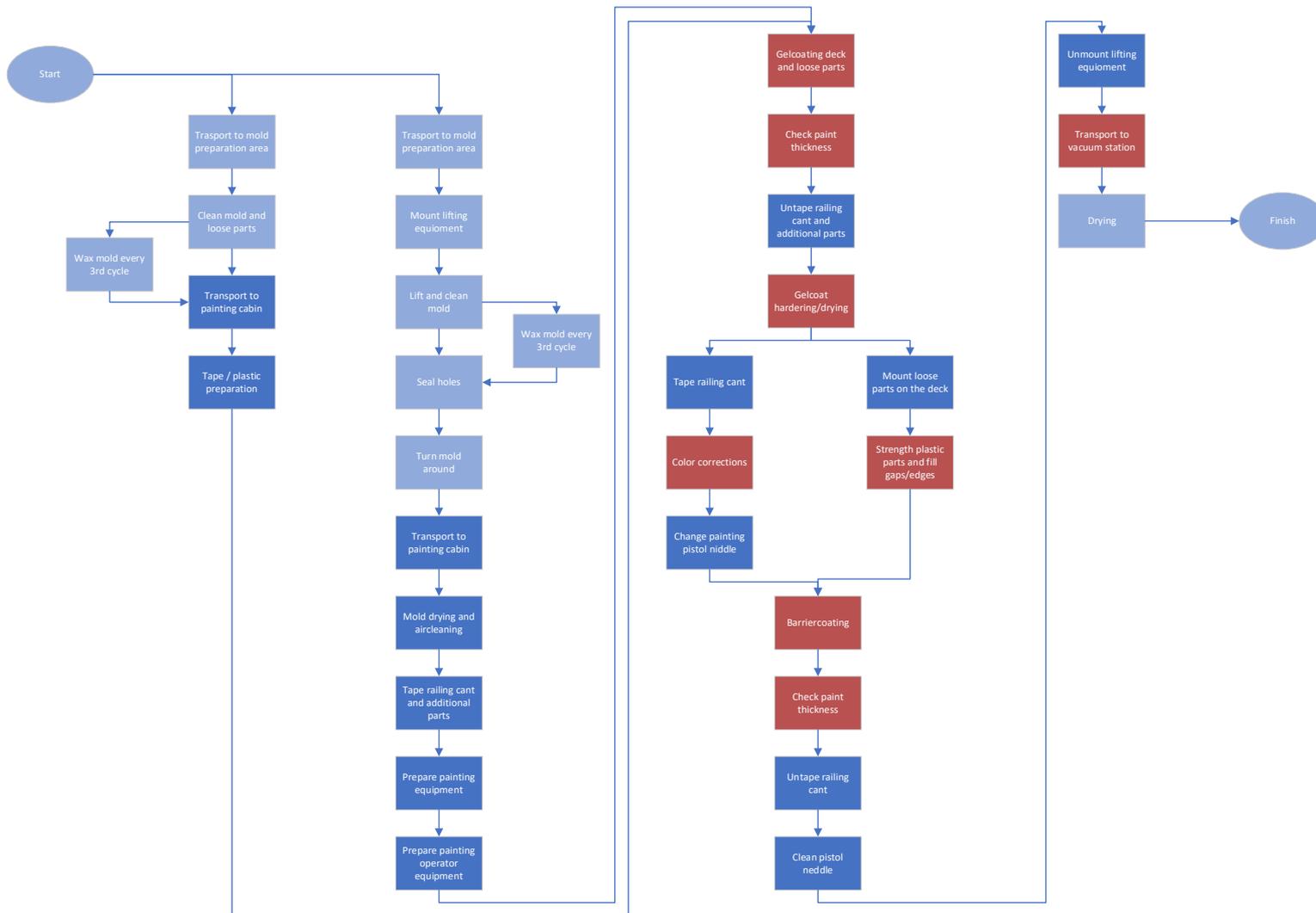
- Bottleneck analysis results



- FRAM representation of the system

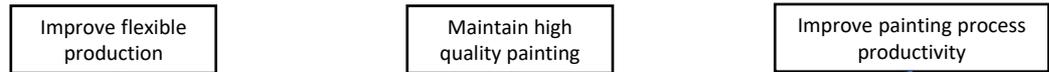


- Quantitative data analysis of the bottleneck

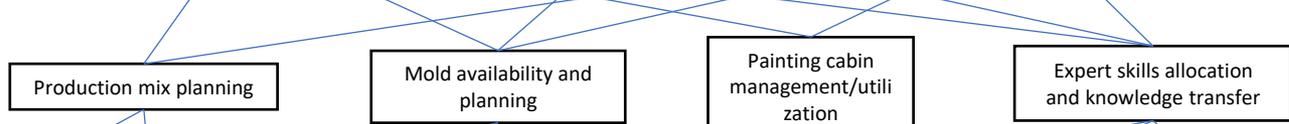


- Work Domain Analysis

Functional Purpose



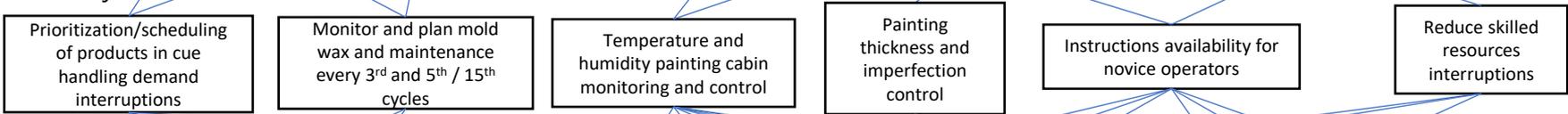
Abstract Function



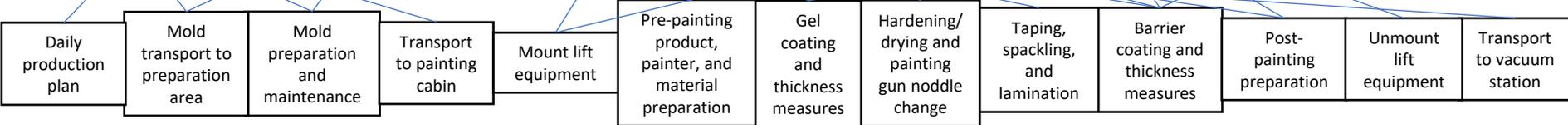
Generalized Function



Object Related Function

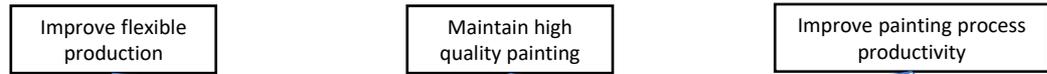


Physical Function

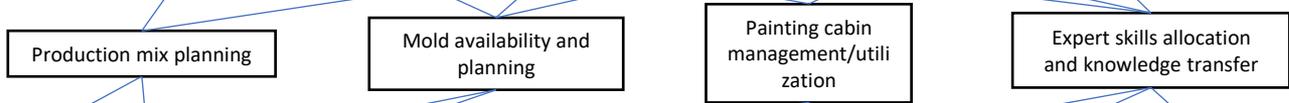


- Work Domain Analysis

Functional Purpose



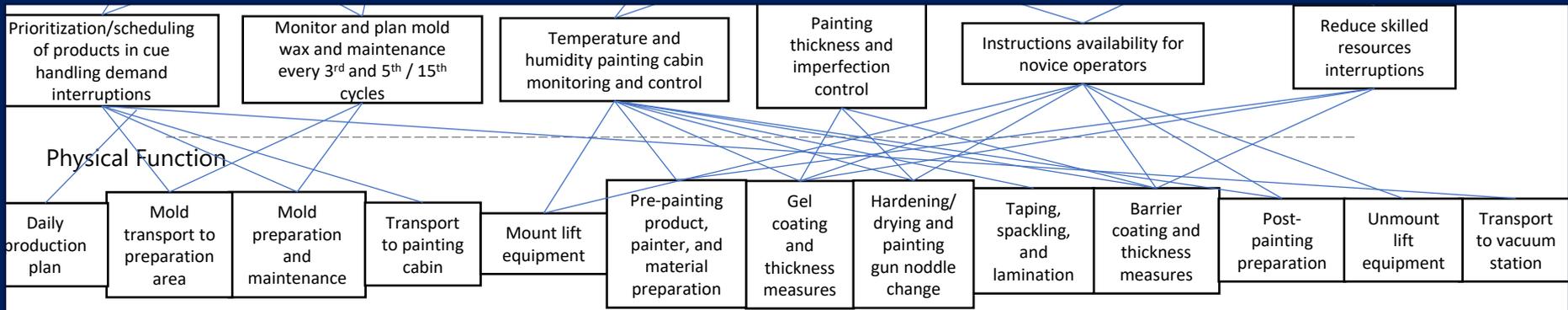
Abstract Function



Generalized Function



Physical Function



- Object Related Function critical points:

Object Related Function critical points:

- Prioritization/scheduling of products in cue handling demand interruptions
- Monitor and plan mold wax and maintenance every 3rd and 5th / 15th cycles
- Temperature and humidity painting cabin monitoring and control
- Painting thickness and imperfection control
- Instructions availability for novice operators
- Reduce skilled resources interruptions

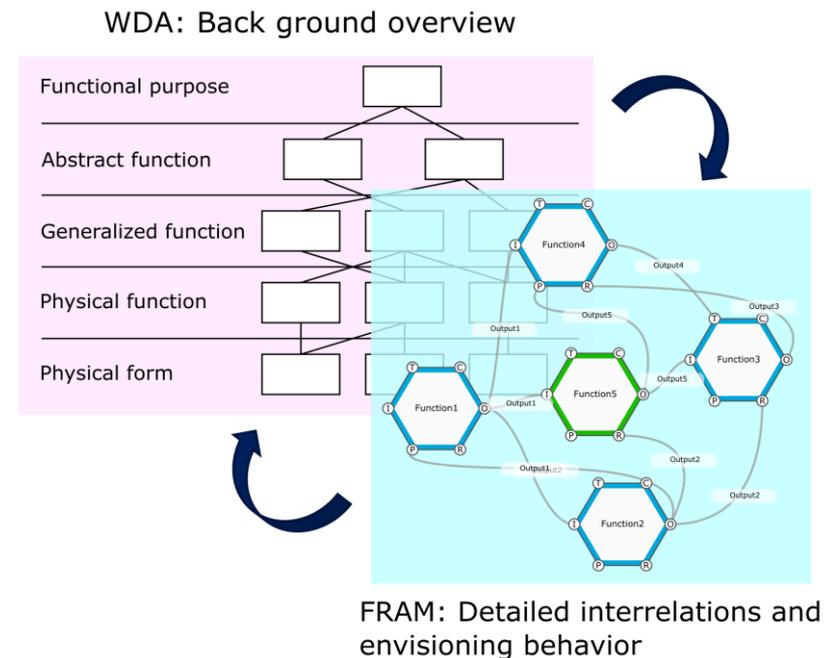


- A win-win combination method of WDA and FRAM

- WDA provides a general overview of the target system
- FRAM gives a more detailed model in a specific situation and envisions the behavior of the complex socio-technical system
- Interactive method of these two methods were proposed

- Two case studies

- In steel plate production process
- In boat production process



- de Vries, L. (2017). Work as done? Understanding the practice of sociotechnical work in the maritime domain. *Journal of Cognitive Engineering and Decision Making*, 11(3), 270-295.
- McNab, D., Freestone, J., Black, C., Carson-Stevens, A., & Bowie, P. (2018). Participatory design of an improvement intervention for the primary care management of possible sepsis using the Functional Resonance Analysis Method. *BMC medicine*, 16(1), 1-20.
- Ferreira, P. N., & Cañas, J. J. (2019). Assessing operational impacts of automation using functional resonance analysis method. *Cognition, Technology & Work*, 21(3), 535-552.
- Hollnagel, E. (2017). *FRAM: the functional resonance analysis method: modelling complex socio-technical systems*. Crc Press.
- Hollnagel, E. (2017). *Safety-II in practice: developing the resilience potentials*. Routledge.
- Hirose, T., & Sawaragi, T. (2020). Extended FRAM model based on cellular automaton to clarify complexity of socio-technical systems and improve their safety. *Safety science*, 123, 104556.
- Yasue, N., & Sawaragi, T., Functional Resonance Analysis of Experts' Monitoring Features in Steel Plate Processing. *IFAC-PapersOnLine*, 55(29), 126-131, 2022.

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Thank you!