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Numerical Safety Analysis of Complex Supply-Chain Systems Integrating Functional Resonance Analysis Method and Cellular Automaton

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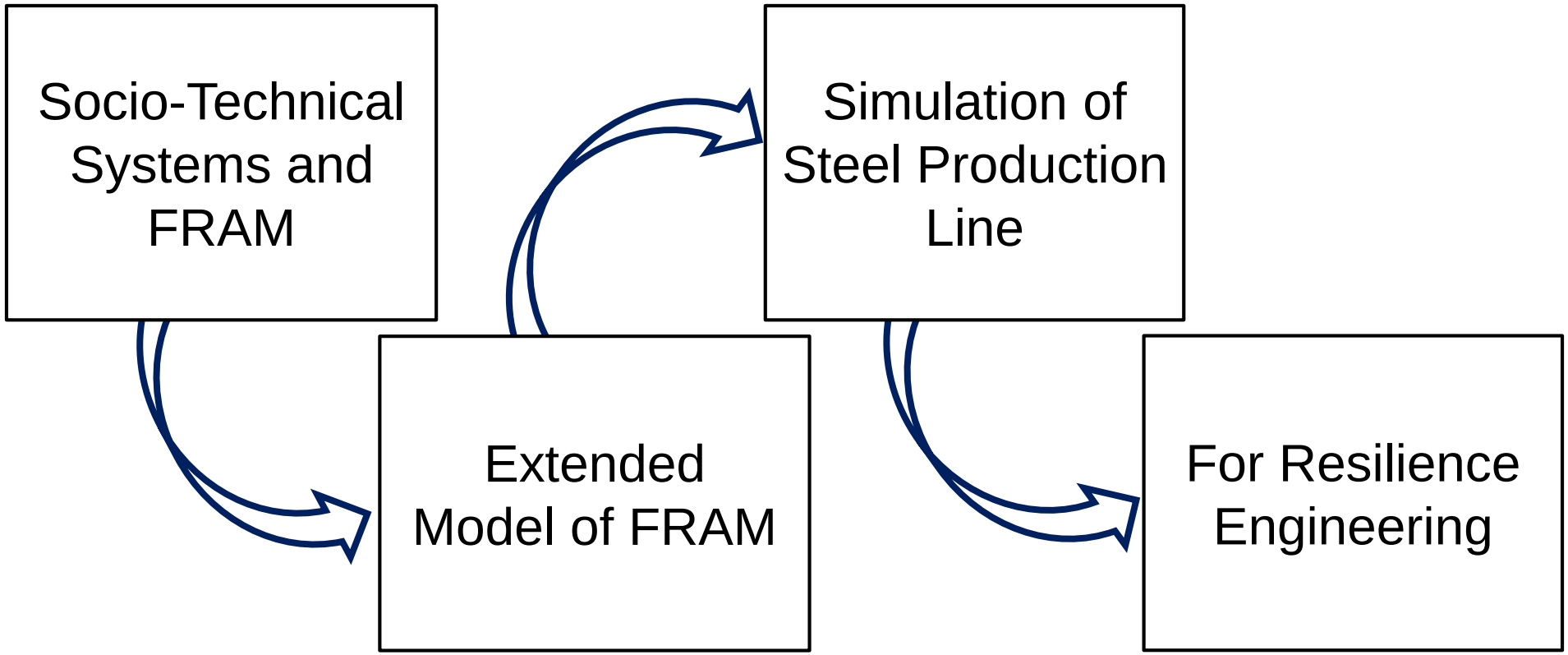
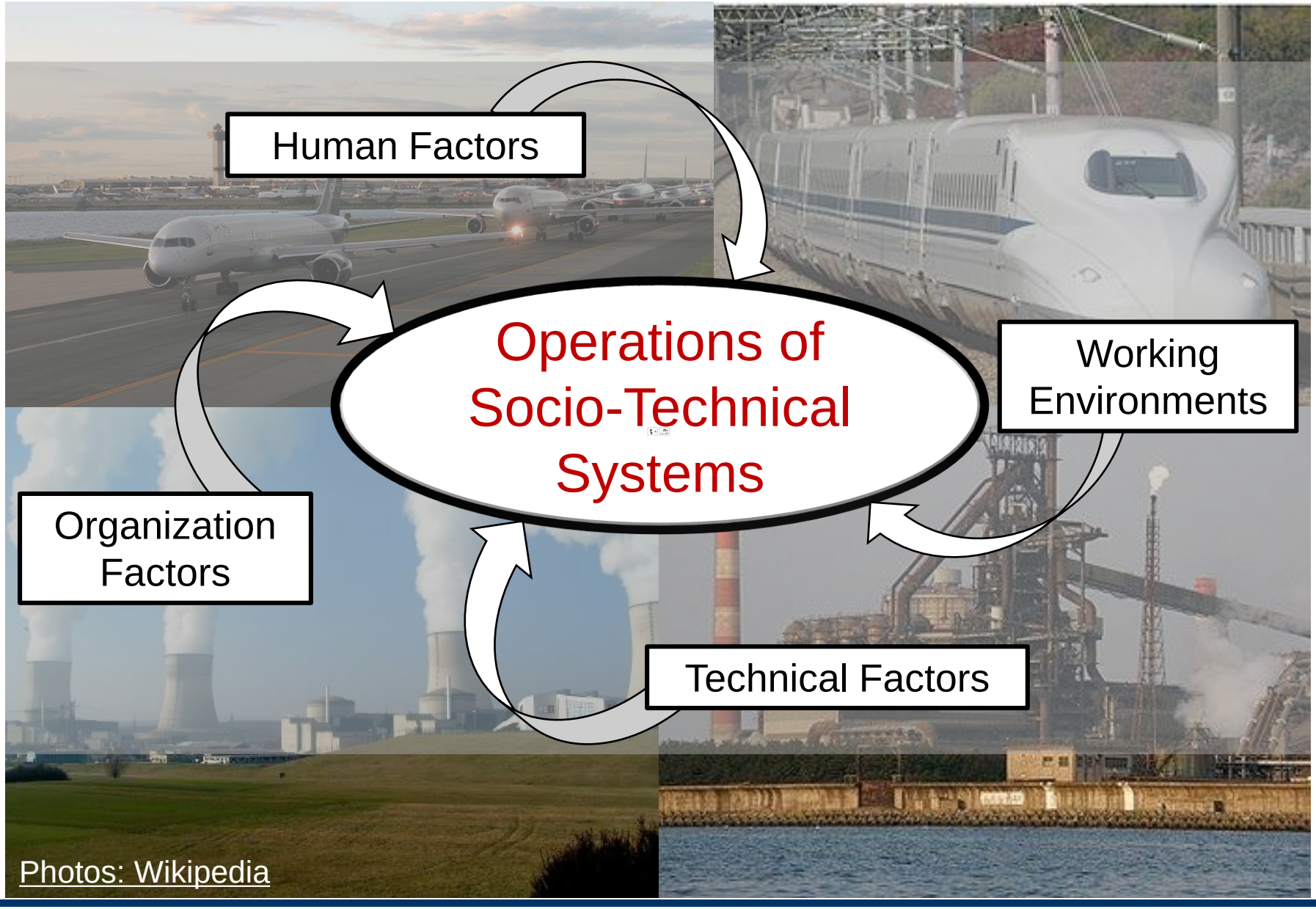
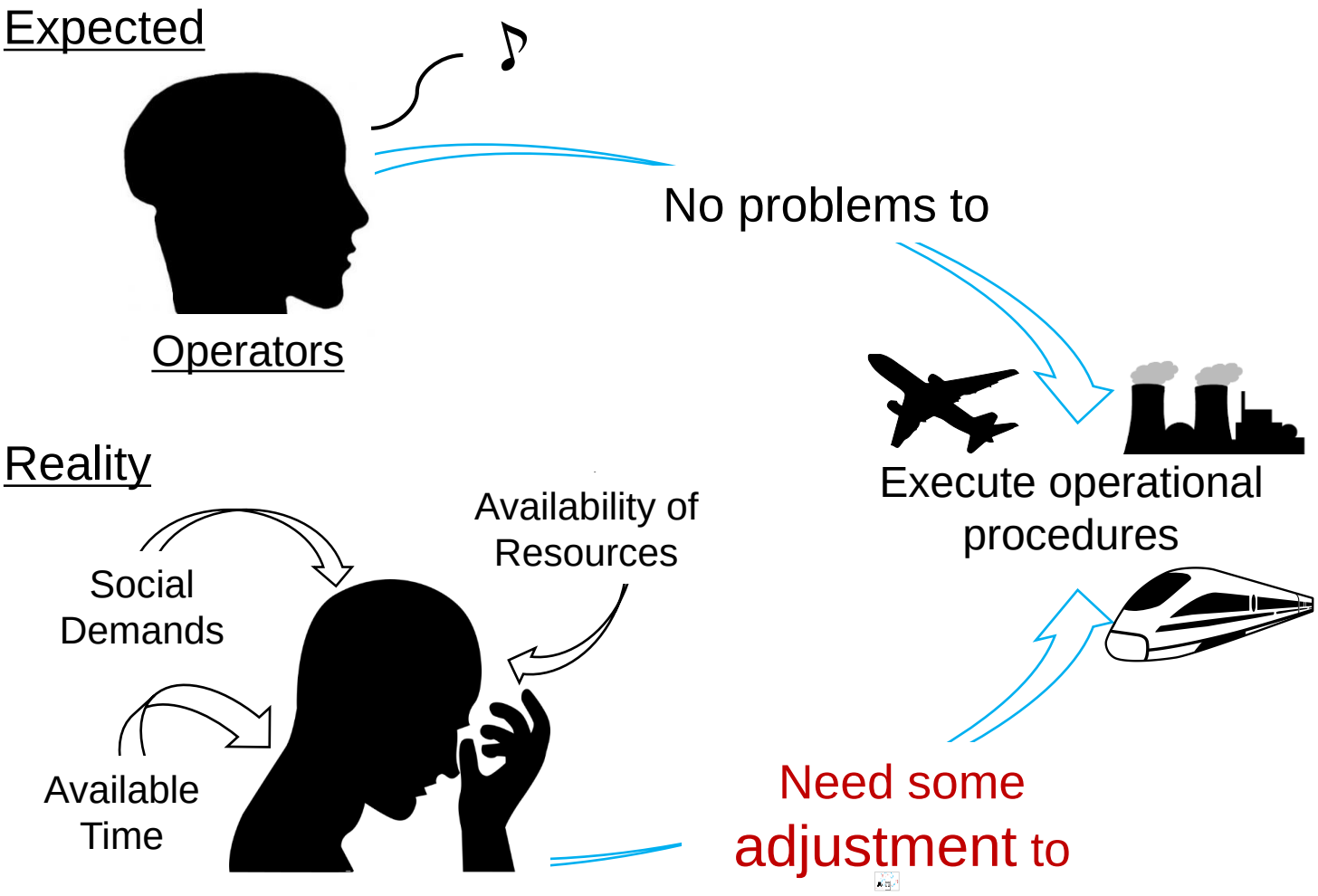


Socio-Technical Systems and FRAM



Variabilities Existing in Operations

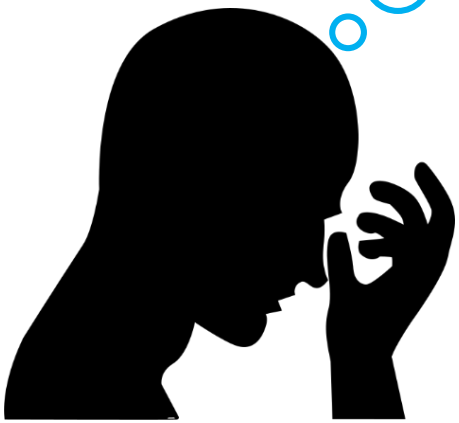


- ✓ Variability: Fluctuation from the expected conditions
  - ➢ Variabilities of working environment and task performance (functions)

This procedure is…

- ✓ Irrational/Inefficient
- ✓ Troublesome
- ✓ Impossible

in this situation



Dilemma:

Efficiency vs. Thoroughness

Procedure

1. ○ ○ ○
2. × × ×
3. △ △ △
4. □ □ □

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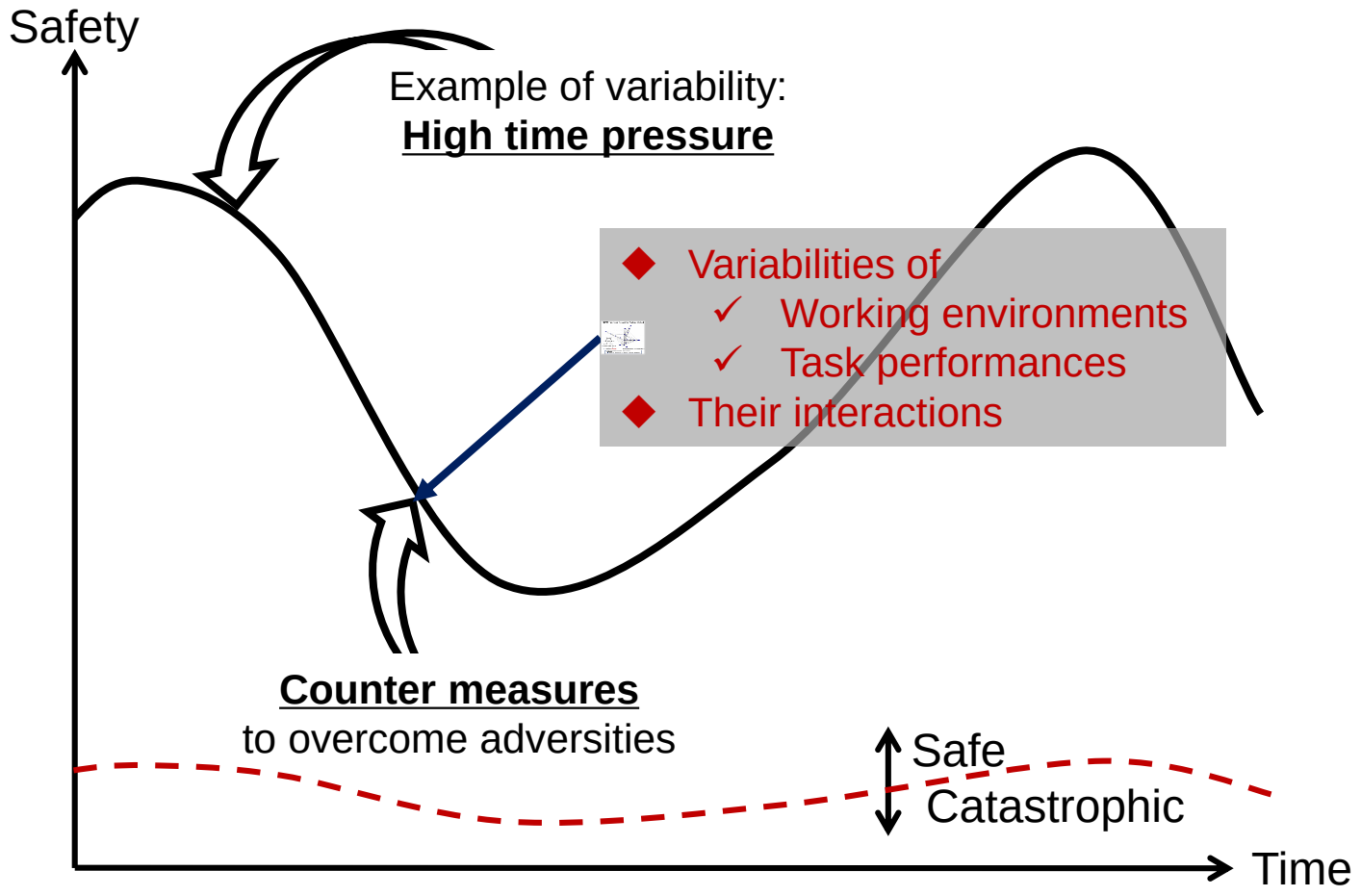
Modification

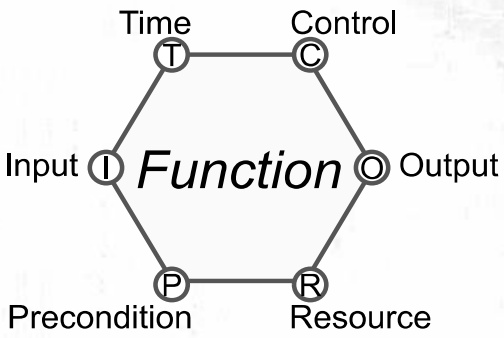
Actual Work

Safety of Socio-Technical Systems



- Safety of the systems emerges from interactions of variabilities
  - Visualizing and managing it to avoid catastrophic conditions is more important than eliminating malfunctions of machines or human errors
  - ※Traditional approaches (e.g. why-because analysis) are not available

FRAM: Functional Resonance Analysis Method

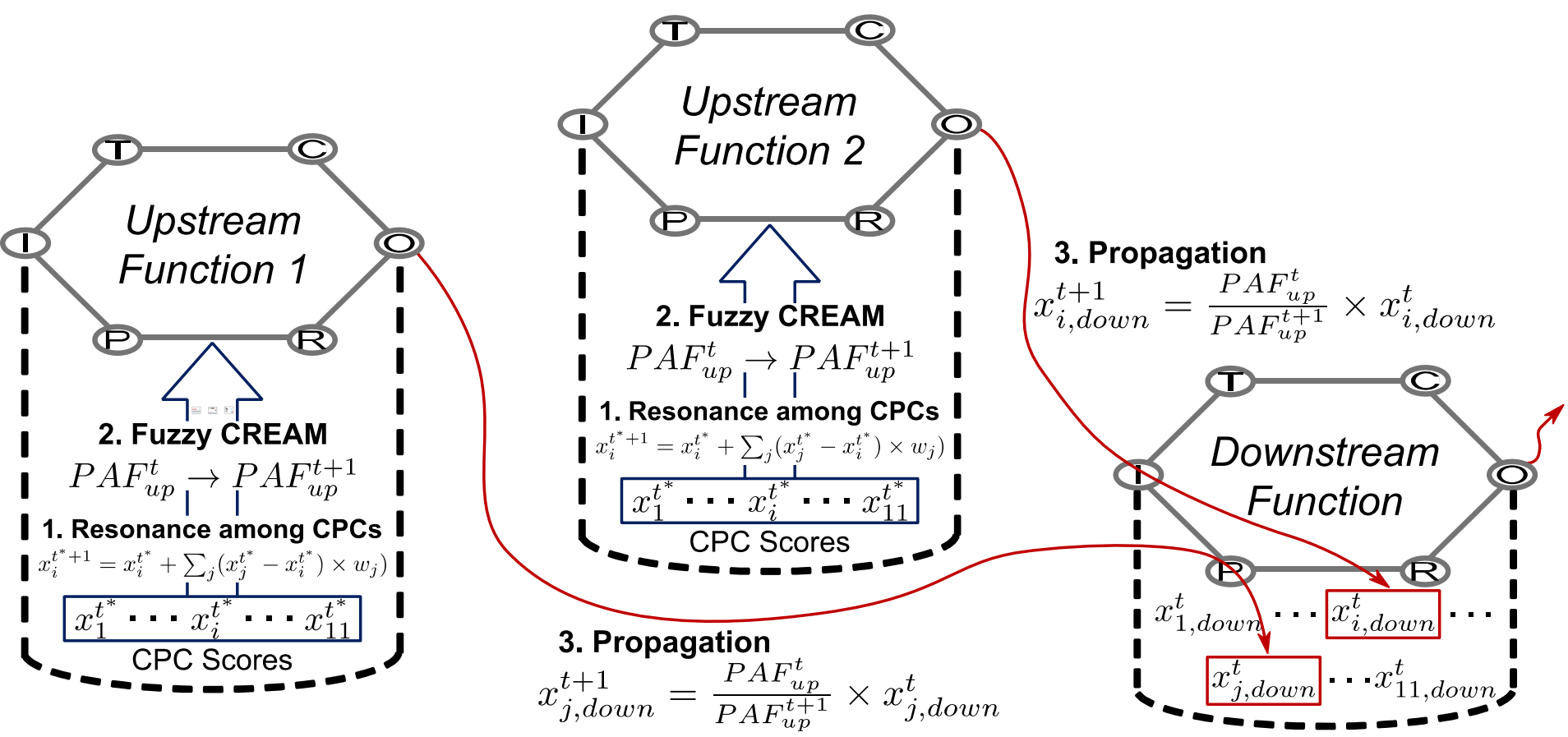


- ✓ Function: Entities required to achieve specific goals
  - ➢ Defined with 6 aspects

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

- ✓ Problems: Unclear definition of parameters
  - ➢ Variability, propagation, interaction, functional resonance…

Extended Model of FRAM



- ✓ Working environment variabilities: Change of CPC scores
- ✓ Function variabilities: Change of PAF
  - ➢ Formulating propagations of function variabilities
- ✓ Result of FRAM: Change of PAF in each functions

CREAM: Cognitive Reliability And Error Analysis Method

[Erik Hollnagel, 1998]

◆ Identifying Control Mode based on status of CPCs

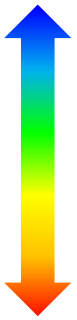
✓ CPC: Common Performance Condition: Factors influencing progressions

- ✓ Organization Factor
- ✓ Working Condition
- ✓ Man-Machine Interaction (MMI)
- ✓ Available Time
- ✓ Access to Procedures
- ✓ Available Resources
- ✓ Number of Simultaneous Goals
- ✓ Circadian Rhythm
- ✓ Adequacy of Training & Experience
- ✓ Crew Collaboration Quality
- ✓ Quality of Communication

✓ Control Mode: Index which represents progression of a task

➢ Defined with intervals of PAF: Probability of Action Failure

Control Modes	Intervals of PAF
Strategic	$0.5 \times 10^{-5} < p < 0.01$
Tactical	$0.001 < p < 0.1$
Opportunistic	$0.01 < p < 0.5$
Scrambled	$0.1 < p < 1.0$



Fuzzy CREAM

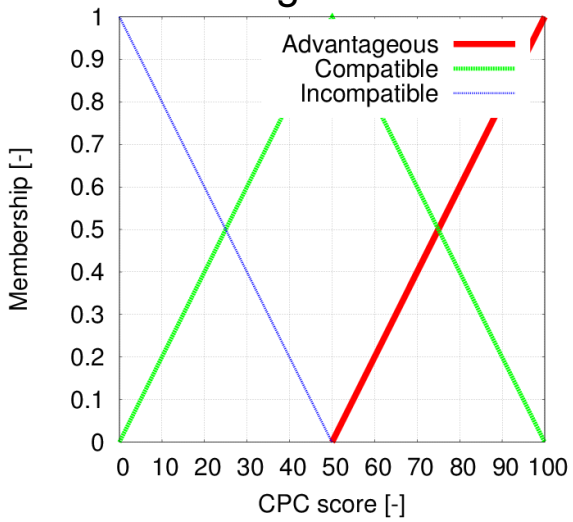
CPC	Level
Working Condition	Advantageous
	Compatible
	Incompatible

Control Mode	Intervals of PAF
Strategic	$0.5 \times 10^{-5} < p < 0.01$
Tactical	$0.001 < p < 0.1$
Opportunistic	$0.01 < p < 0.5$
Scrambled	$0.1 < p < 1.0$

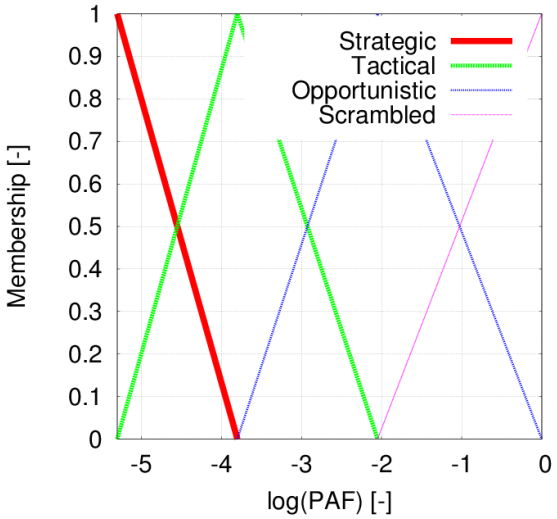
$$IF\ CPC\ 1 = Level\ 1$$
$$AND\ CPC\ 2 = Level\ 2$$
$$AND\ \ldots\ THEN$$
$$Control\ Mode = Tactical$$

In Fuzzy CREAM

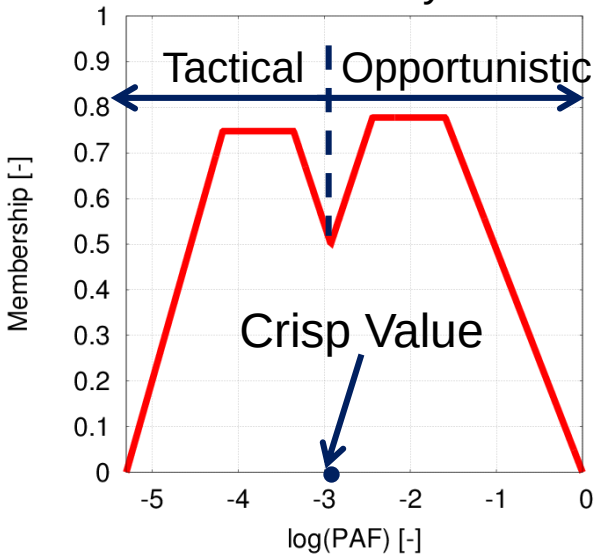
"Working Condition"



Control Mode and PAF



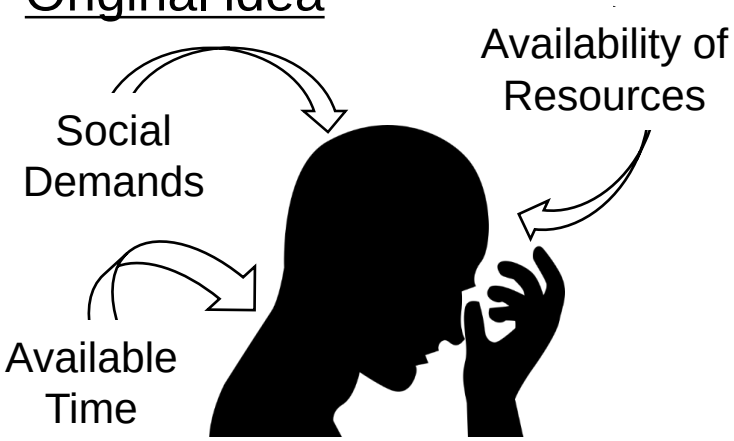
Conclusion Fuzzy Set



※ Several methodologies of Fuzzy CREAM are proposed
- ➢ Weighted CREAM model [Ung, S-T., 2015] is used in this study

What I Wanted to Do With Fuzzy CREAM

Original idea



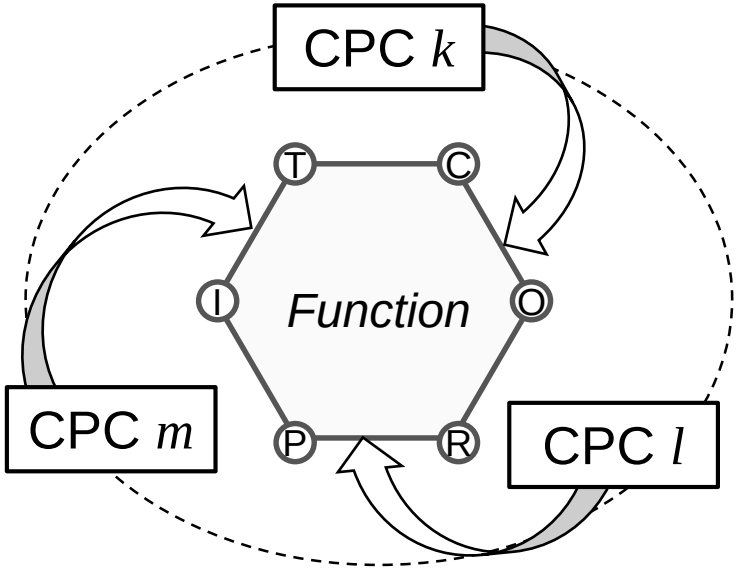
Dilemma:

Efficiency vs. Thoroughness

Resulting in

Variability of task performance

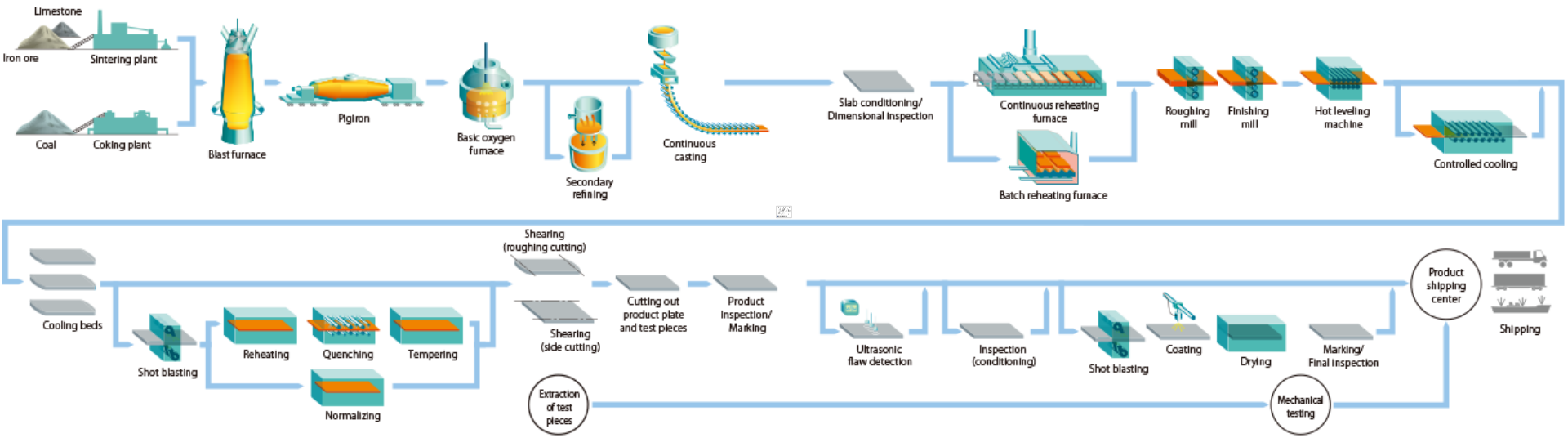
In this method



Resulting in

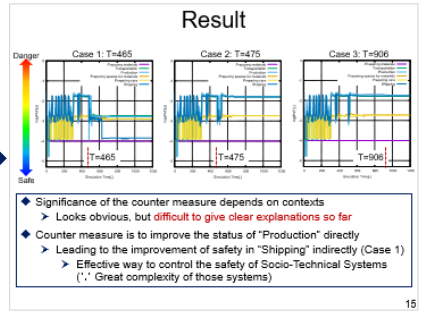
Variability (Change) of PAF

Simulation of Steel Production Line

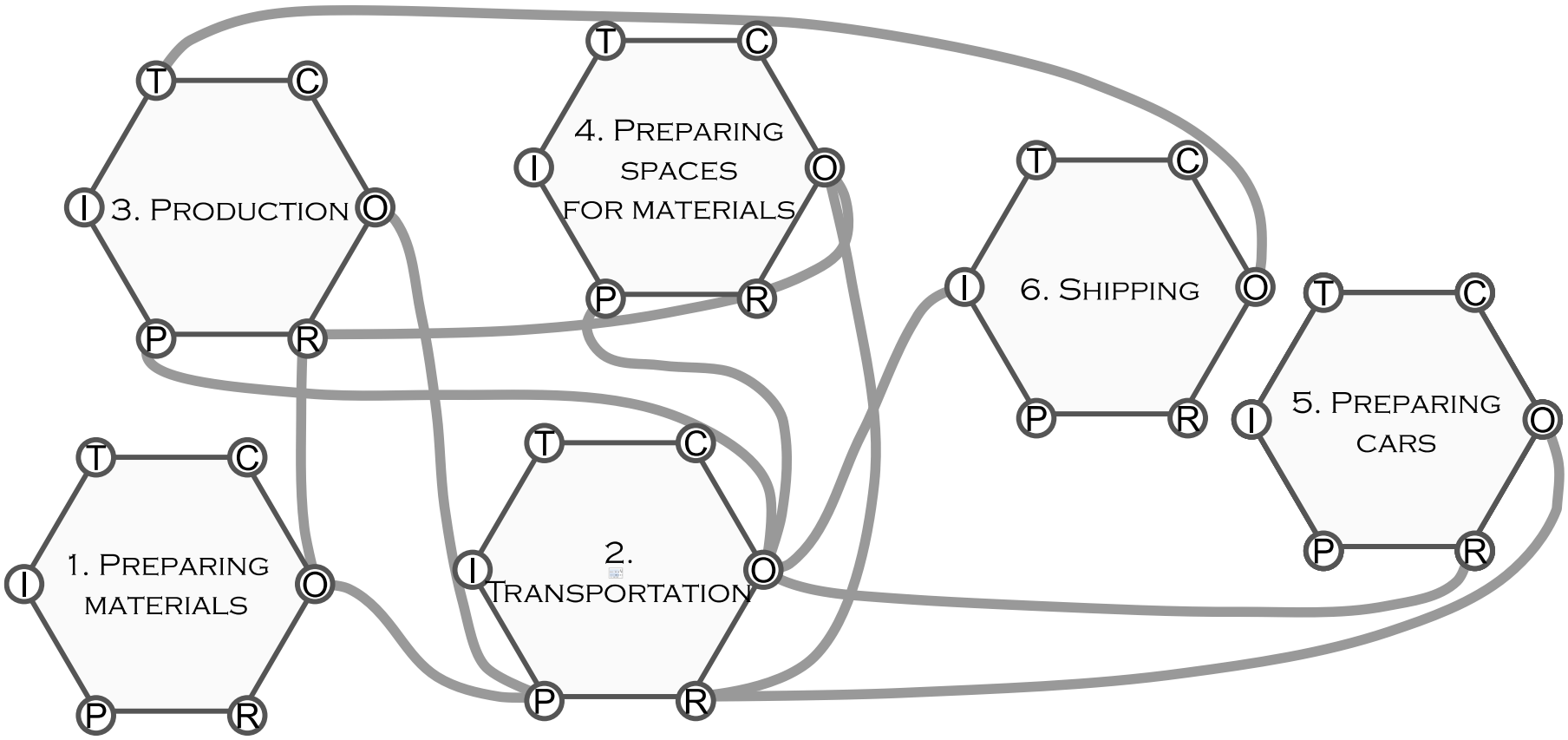


http://www.nssmc.com/en/product/plate/process

- ✓ Simulation Scenario
  - ➢ Variability: Arrival of excess materials
  - ➢ Counter measure: Adjusting rate of direct delivery with more lively communication among processes



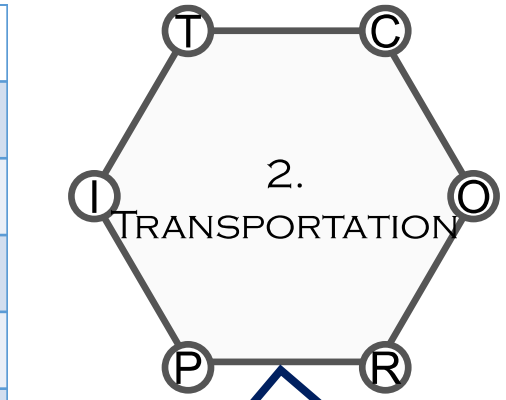
Steel Supply-Chain System in FRAM



- The processes were abstracted into functions
  - Identified through discussions with an engineer working for steel production industry

Setting of CPCs

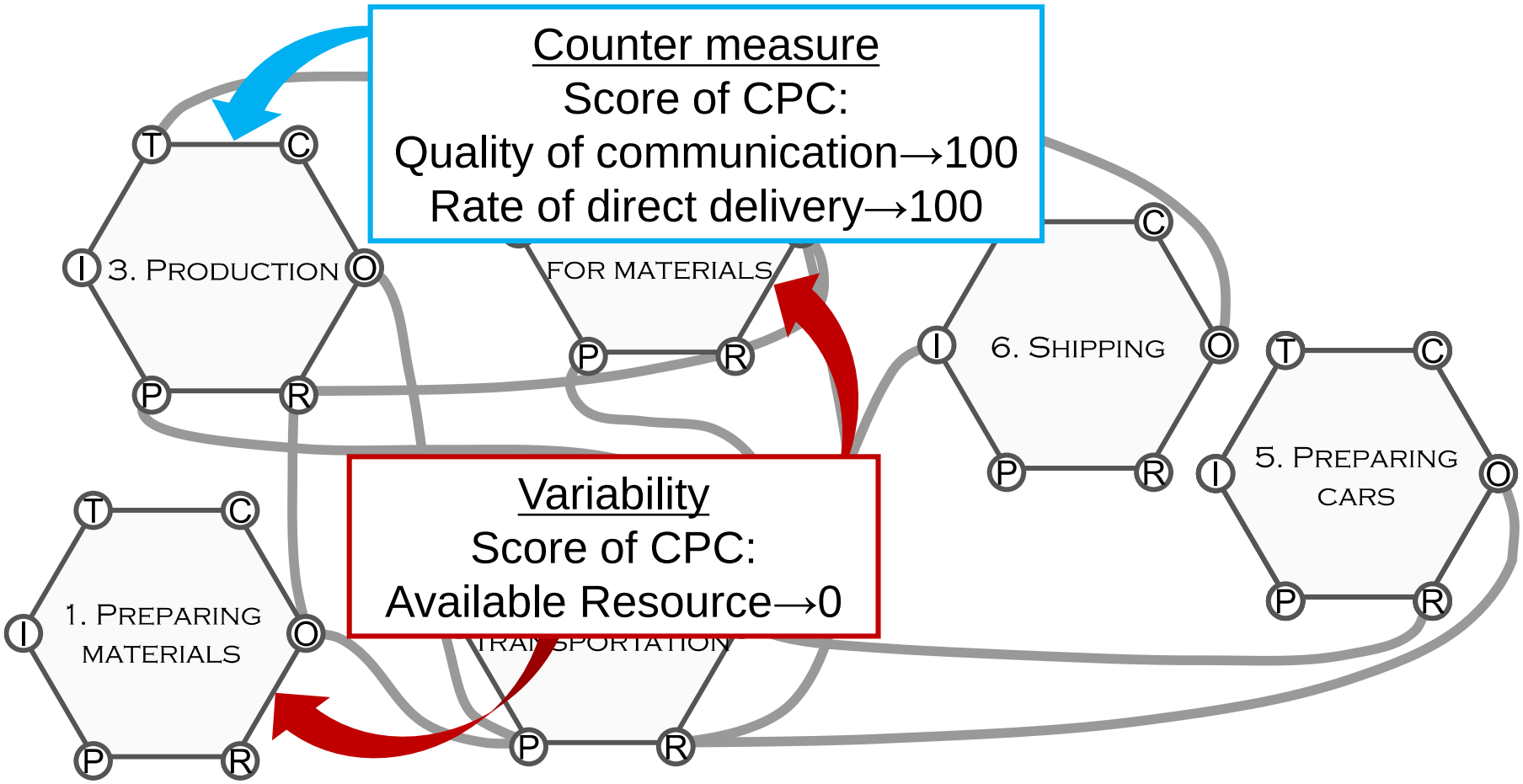
Original	Replaced with	Weight
Availability of resource		100
Training and experience	Quality of materials	5
Quality of communication		80
Man-Machine interaction	Lot size	80
Access to procedures		20
Condition of work		40
Number of goals to achieve		60
Available time		80
Circadian rhythm	Timeliness	80
Crew collaboration quality		5
Organization factor	Rate of direct delivery	80



"Shake" the function (Fuzzy CREAM)

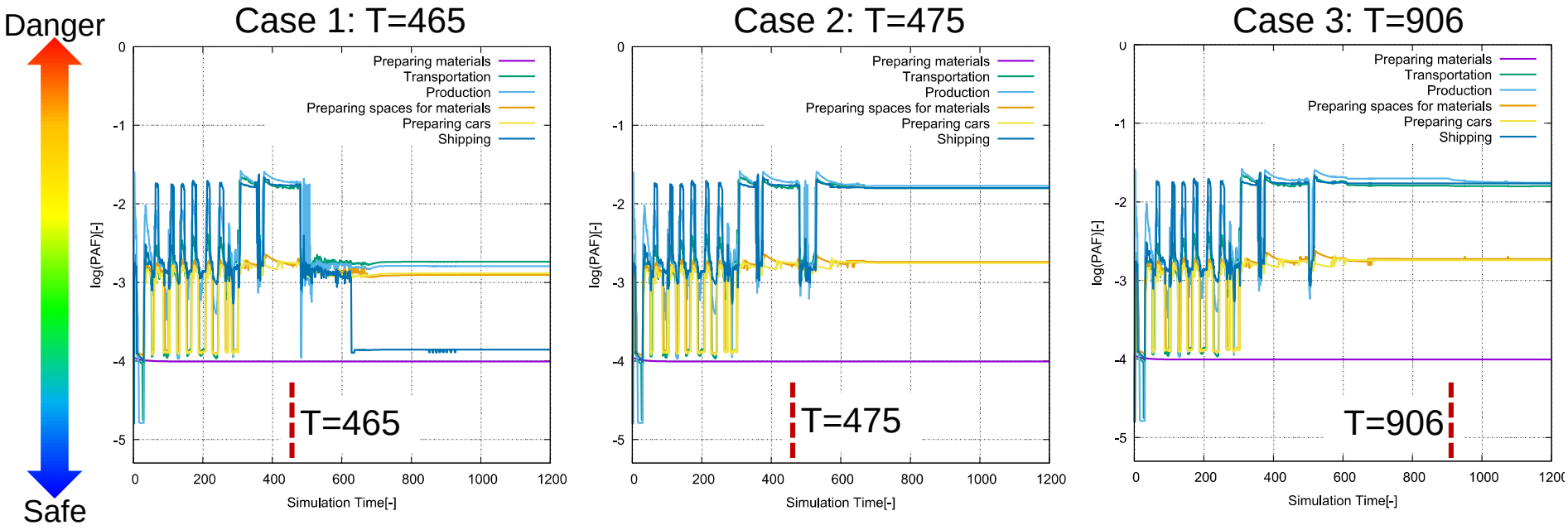
- ✓ CPC weight: Significance of a CPC for the function
  - ➢ Continuous values ranging from 0 to 100

Scenario in FRAM



- Variability occurs at Simulation Time: T=0
  - Counter measure will be taken at three different occasions

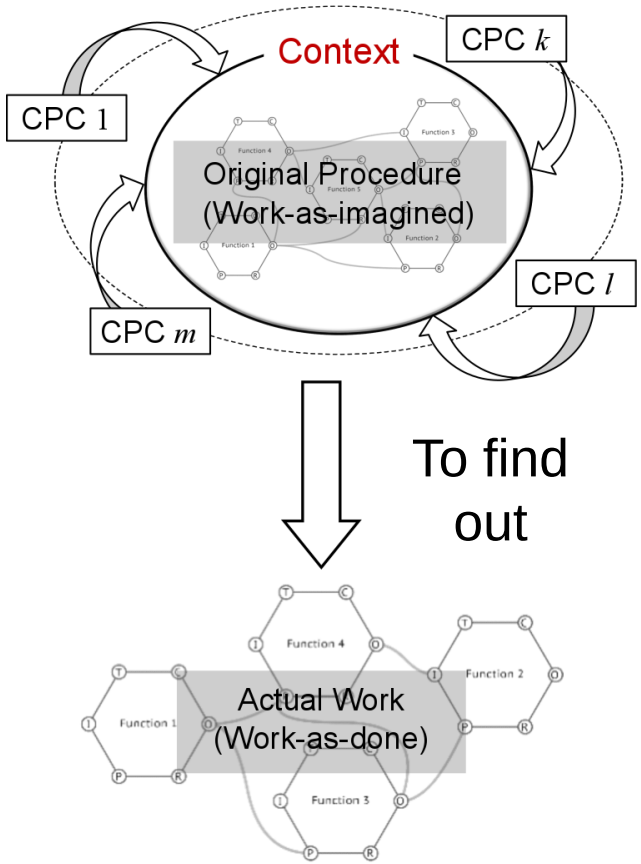
Result



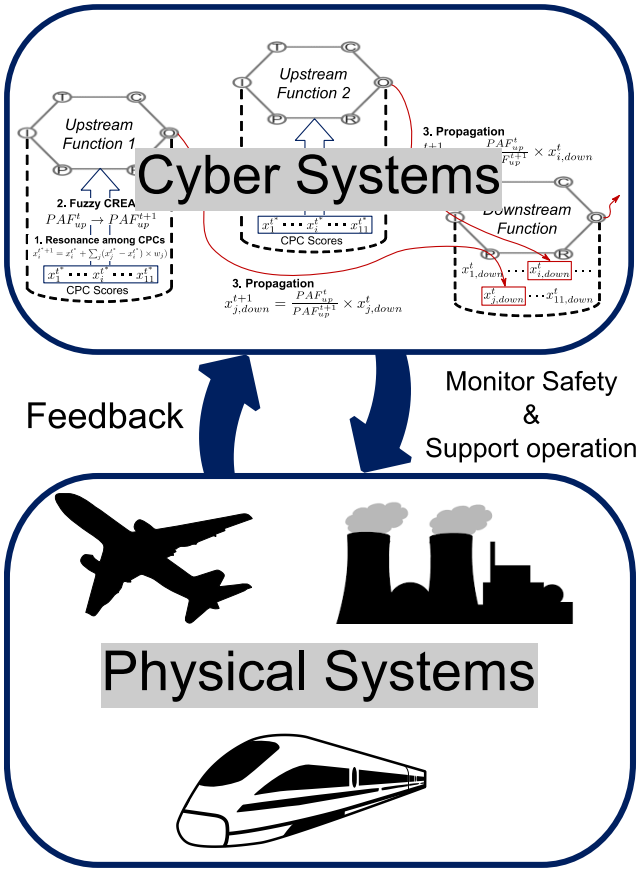
- Significance of the counter measure depends on contexts
  - Looks obvious, but difficult to give clear explanations so far
- Counter measure is to improve the status of “Production” directly
  - Leading to the improvement of safety in “Shipping” indirectly (Case 1)
    - Effective way to control the safety of Socio-Technical Systems (∵ Great complexity of those systems)

For Resilience Engineering

Stress test of procedures



Resilient Cyber Physical Systems



- FRAM can be utilized for the design of resilient systems as a
  - Stress test tool of procedures to know appropriate actual work
  - Cyber part of Cyber Physical Systems to support operation

Summary

- Safety of Socio-Technical Systems depends on variabilities
  - This is also the case with steel production industry
    - FRAM is an effective way to analyze the safety
- Extension of FRAM with Fuzzy CREAM and its implementation
- Case study: how the local variability and counter measure for it change the safety of the steel supply-chain
  - Effect of the counter measure depends on a specific context
  - Indirect intervention might be an effective way to improve the safety
- FRAM can be utilized for the design of resilient systems as a
  - Stress test tool of operation procedures
  - Cyber part of Cyber Physical Systems
    - Needs to make the result of FRAM more helpful