Identification of weak signals to prevent emergent system failures in process industries

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Outline

- Motivation
- Challenges
- What has been done
- Objective & Methodology
- Modeling of complex systems
- Conclusions
- References

Motivation

- Existence of Weak Signals
- BP Texas City Explosion and Fire (2005)
  – Delayed maintenance
  – Operator overtime shift
  – Inadequate staffing and supervision
  – Practice of overfilling during start-ups

Image Source: Chemical Safety and Hazard Investigation Board.

Challenges to Catch Weak Signals

- Nature of Weak Signals

- Few studies have been conducted
  - to identify weak signals or evaluate effectiveness of weak signal management in organizations

Challenges to Catch Weak Signals

- Complex Socio-technical System
  - Emergent failures

- Traditional Hazard Identification Techniques
  - Fault Tree Analysis/Event Tree Analysis
  - Hazard and Operability Analysis (HAZOP)
  - Failure Modes and Effects Analysis (FMEA)
  - Human Reliability Analysis (HRA)

Efforts that Have Been Done

- System-based techniques
  - Acci-Map
  - System-Theoretic Accident Model and Processes (STAMP)
  - Functional Resonance Analysis Method (FRAM)

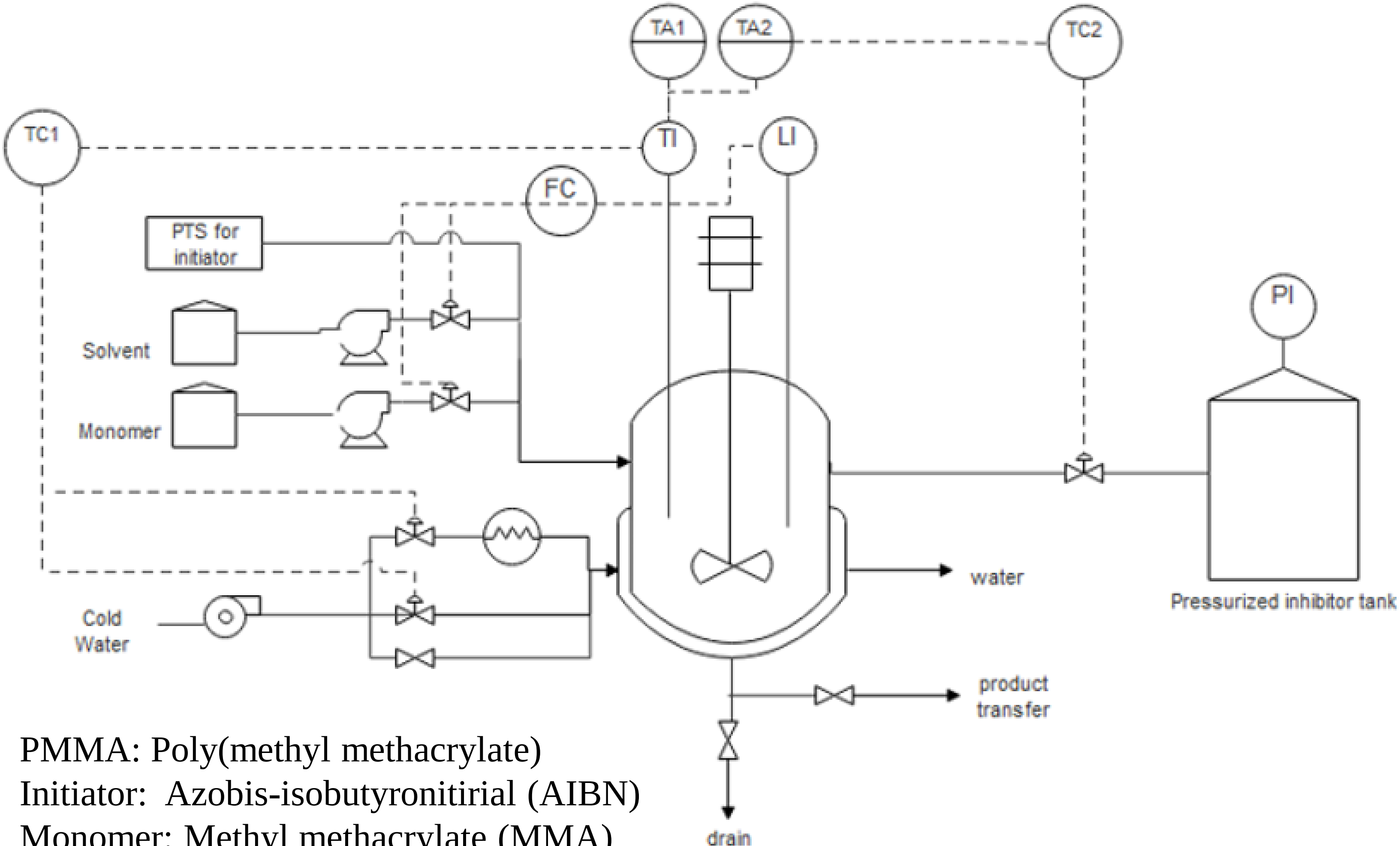
Objective & Methodology

- Develop a framework to identify weak signals to prevent emergent system failures

FRAM → Simulation →
- Identify emergent failures
- Identify weak signals

FRAM:
- Chemical Process
- Equipment
- Human

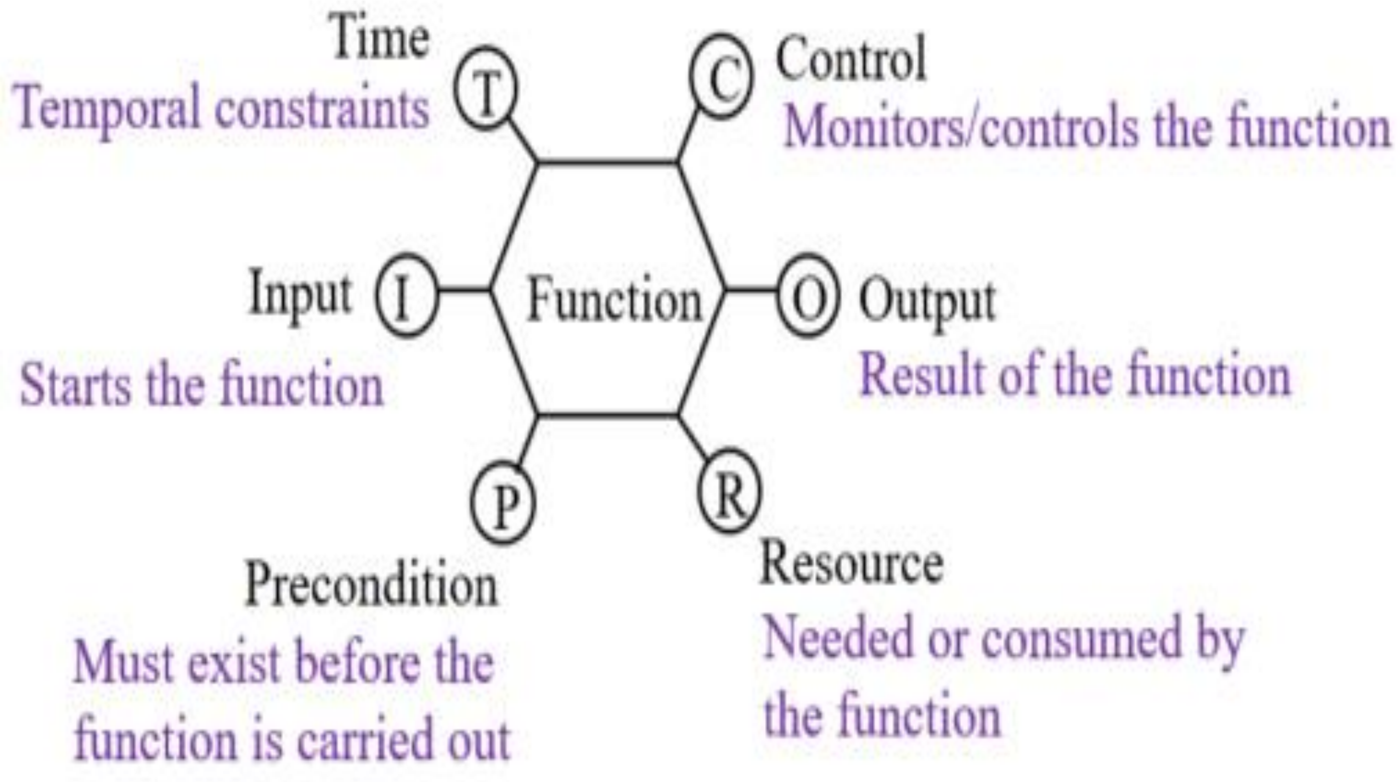
Process - PMMA Polymerization



PMMA: Poly(methyl methacrylate)
Initiator: Azobis-isobutyronitirial (AIBN)
Monomer: Methyl methacrylate (MMA)
Solution: Toluene

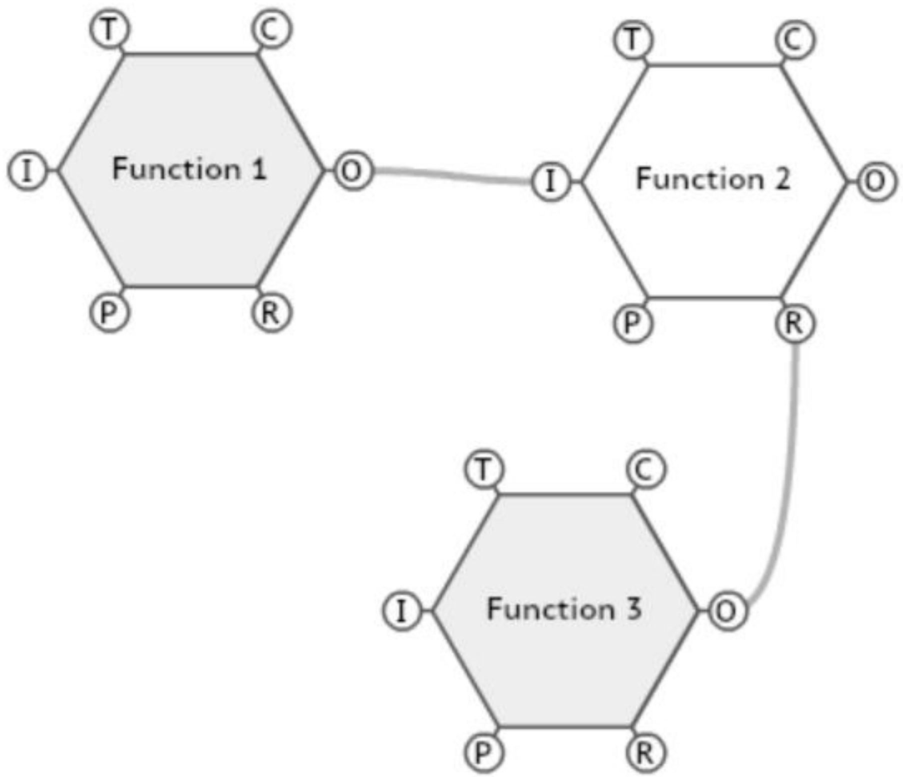
Functional Resonance Analysis Method (FRAM)

- Identify the functions that are involved in a system

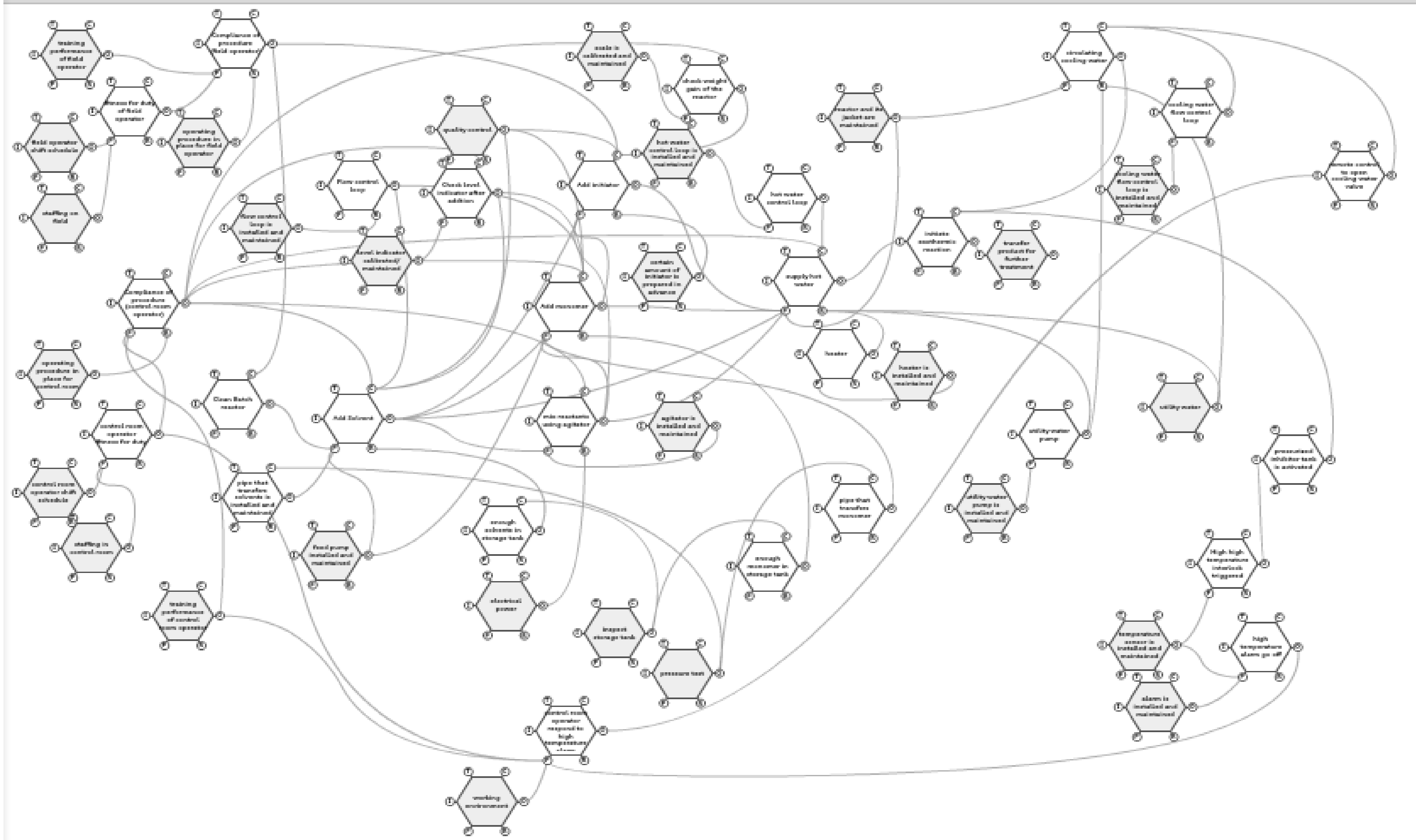


Functional Resonance Analysis Method (FRAM)

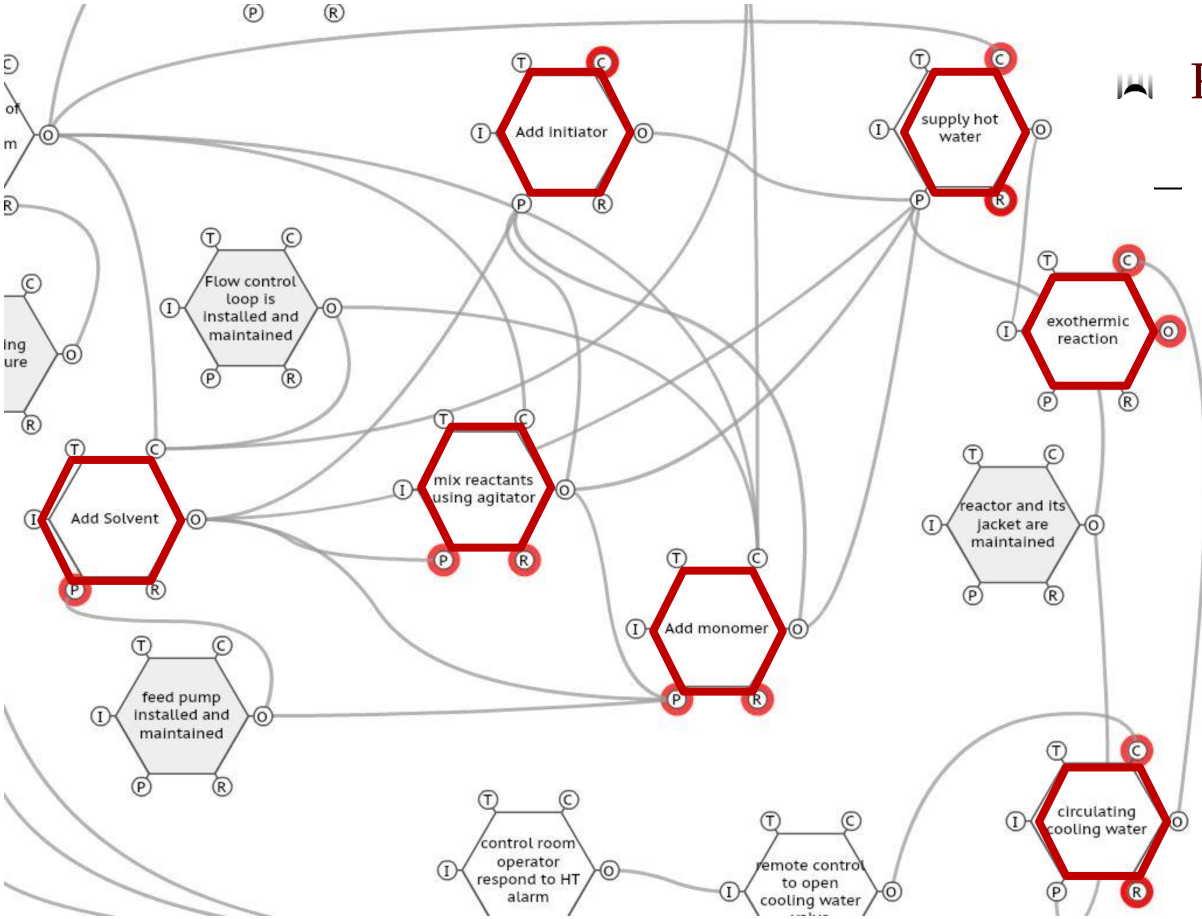
- Identify how functions interact



Overview of FRAM

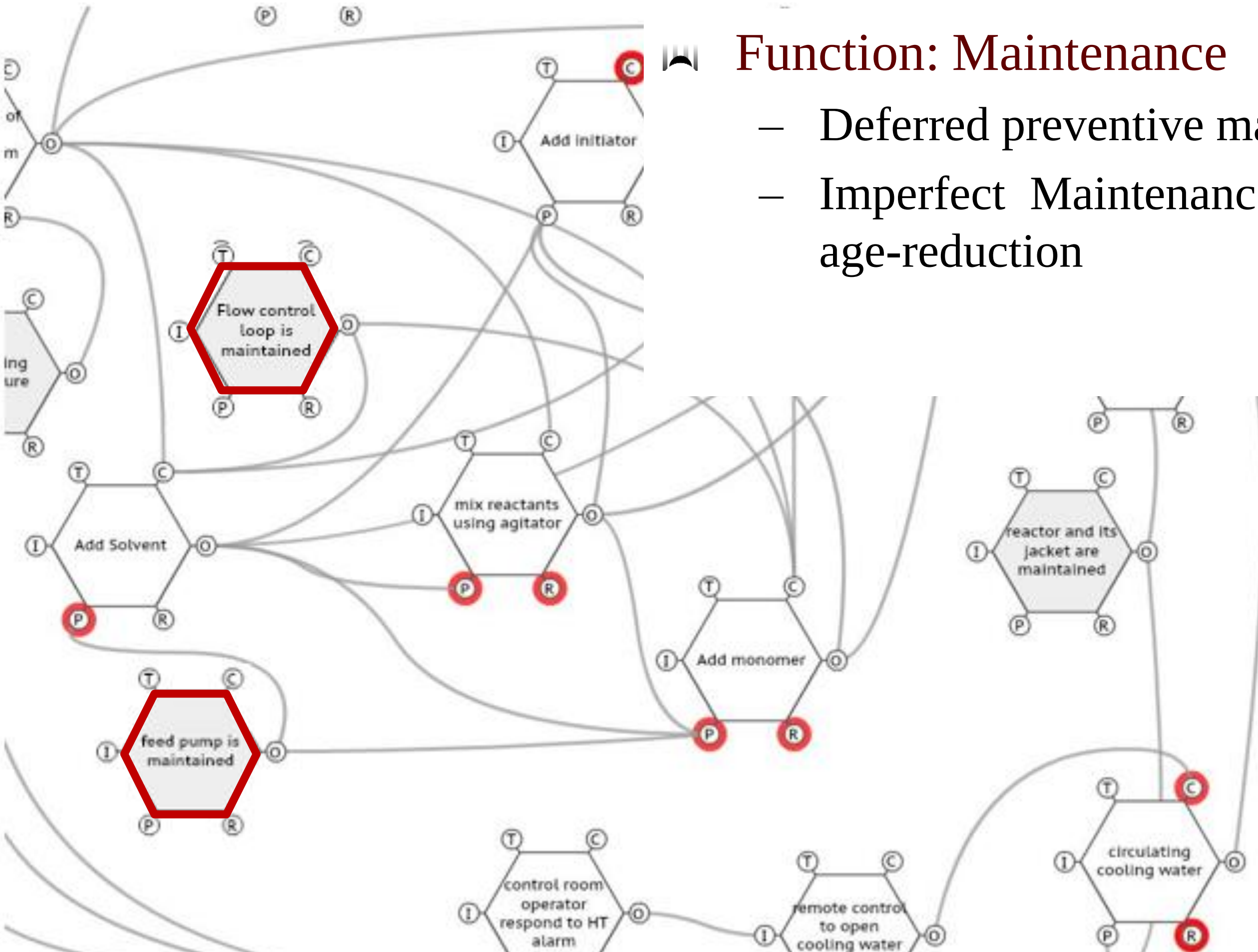


Model Interactions-Process Parameters



- Function: Exothermic Reaction
  - Kinetics and thermodynamics

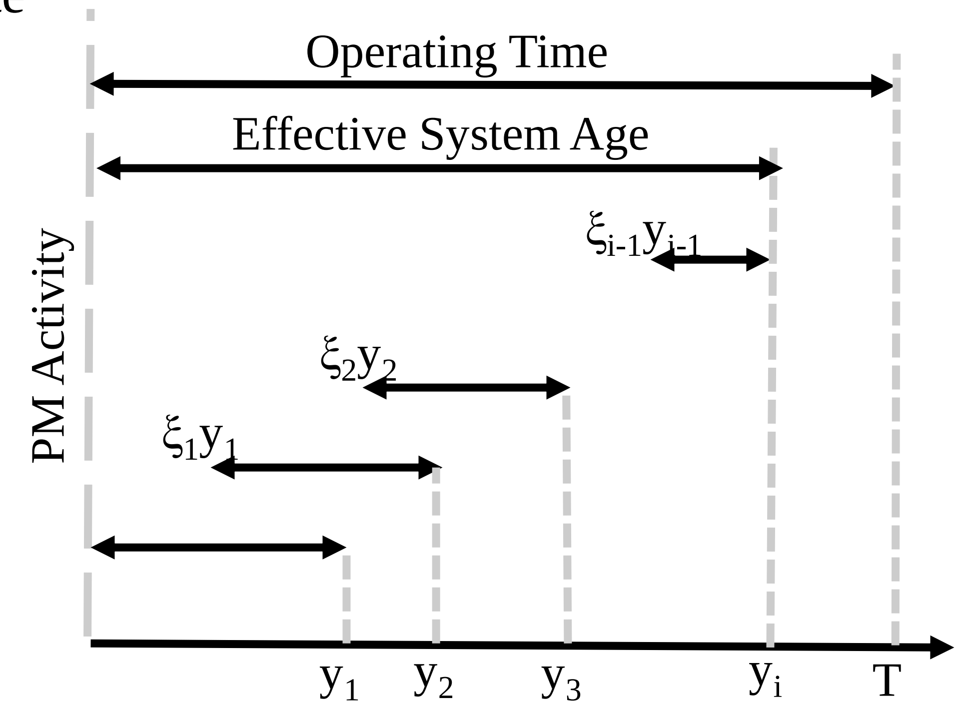
Model Interactions-Equipment Reliability and Preventive Maintenance (PM)



- Function: Maintenance
  - Deferred preventive maintenance (PM)
  - Imperfect Maintenance Model based on age-reduction

Imperfect Maintenance Model

- Model Assumptions
  – PM is scheduled based on a predetermined reliability threshold
  – PM reduces the effective age of a system, but not affects the deterioration rate



y_i = effective age before the ith PM

ξ_i = age reduction factor due to ith PM [0,1]

Imperfect Maintenance Model Cont.

- Cumulative probability of failure after (i-1)th PM:

  $F^{(i-1)}(t) = \text{function}(\alpha, \beta, j, \xi_j, y_j, t)$

  $j=1,2,\ldots(i-1)$

  y_j = effective age before the ith PM

  α, β : parameters of deterioration rate distribution

  ξ_j = age reduction factor due to jth PM [0,1]

- Influence of PM on reliability

Model Interactions - Human Function and Human/Organizational Factors

- During normal operation
  - What is the probability of control room operator to make mistakes?
  - What are possible failure modes of operator behavior?

- During abnormal situation
  - How much time will it take for an operator to provide proper response?

Human Reliability Analysis (HRA) Techniques

HRA Techniques

- SLIM-MAUD
- THERP
- JHEDI
- HEART
- SPAR-H
- CREAM
- HCR

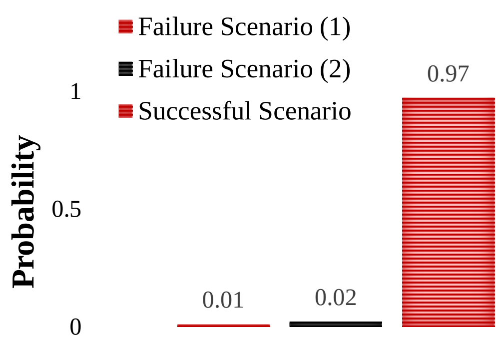
Selection Criteria

- Performance Shaping Factor (PSF)
- Flexibility
- PSF Dependency
- Application field

Cognitive Reliability and Error Analysis Method (CREAM)

CREAM - during normal conditions

Human Action	Cognitive Activity	Cognitive Demands	Failure Scenario	Failure Type	Nominal Probability
Check level indicator after addition	Verify	Interpretation /Observation	(1) Not check	Delayed Interpretation	0.01
			(2) Check but make a wrong decision	Decision Error	0.02
			Comply with procedure		0.97



→ The distribution is adjusted by influencing index of 9 PSFs

Human Cognitive Reliability (HCR) Model

- HCR- during abnormal situation
- $(T_{0.5})_{modified}$

  $= (T_{0.5})_{simulation}(1+ K_1)\ (1+ K_2)\ (1+ K_3)\ldots(1+K_i)$

  K_i Coefficient of performance shaping factor i

Conclusions

- Complexity of socio-technical system and tremendous amount of information stored in plants make it difficult to recognize emergent failures
- The study is aimed to develop an integrated framework to identify emergent failures in process industries
- Weak signals of the emergent failures will be further identified
- Model validation by using real plant data is needed in future work

Collaborations with industries are needed

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Thanks!
Questions and Comments?

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