

Distributed Agents for Artificial Immunity in Modern Manufacturing

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Outline

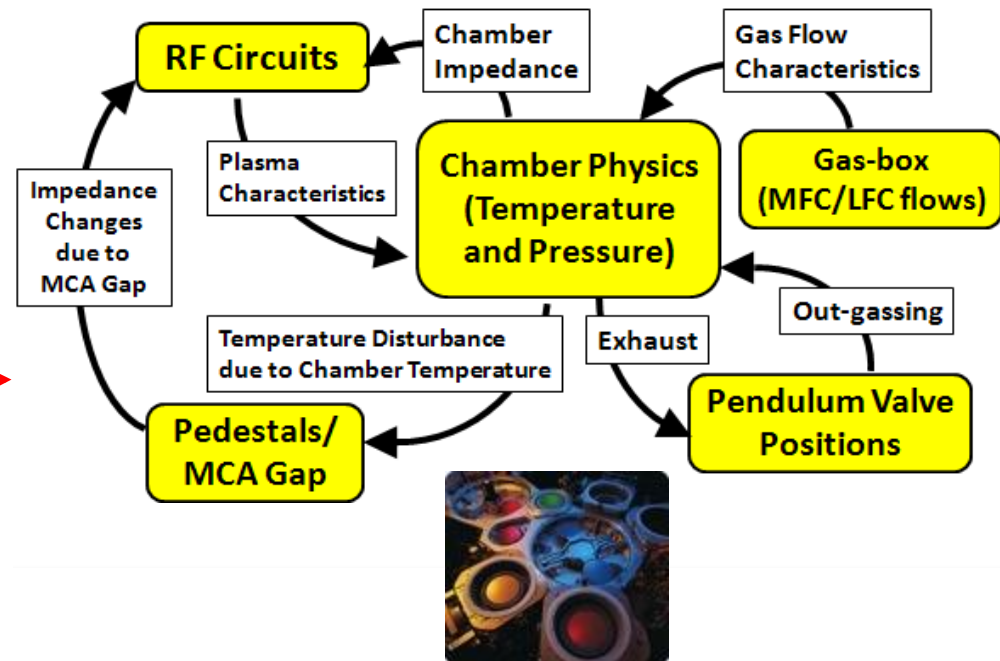
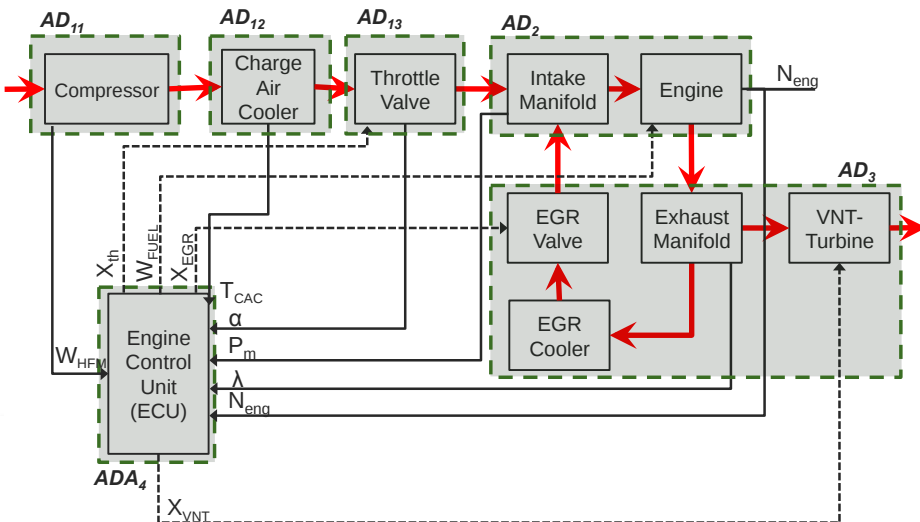
- **Introduction**
- **Coping with unprecedented conditions**
 - Concept of precedent free fault localization
 - Anomaly detection in complex manufacturing systems
- **Ongoing and future research**
 - Anomaly localization in complex manufacturing systems
 - Opportunities for operational decision-making in manufacturing systems



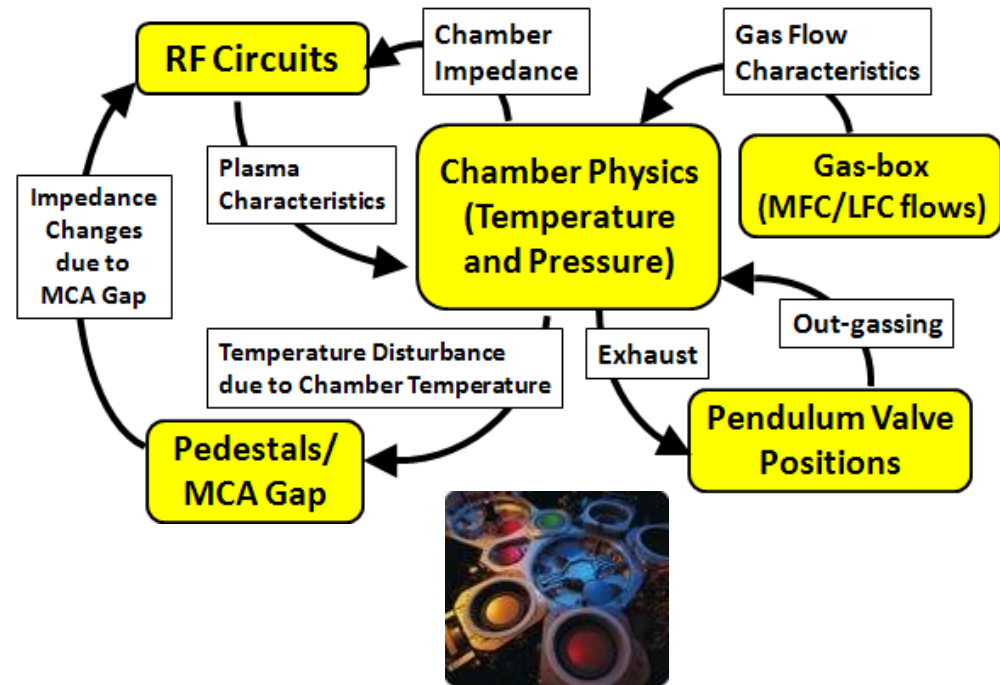
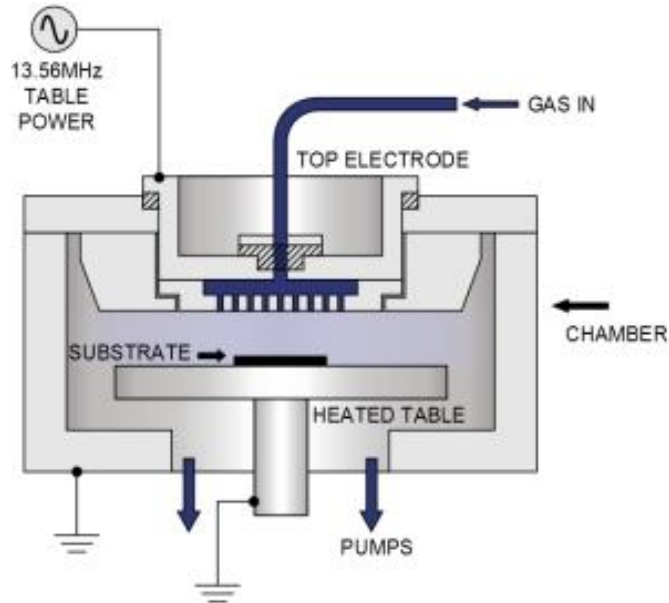
Motivation

“Operational safety, maintenance cost effectiveness and asset availability have a direct impact on the competitiveness of organisations and nations. Today’s complex and advanced machines demand highly sophisticated and costly maintenance strategies. Domestic plants in the United States spent more than \$600 billion to maintain their critical plant systems in 1981 and this figure doubled within 20 years [1]. An even more alarming fact is that one-third to one-half of this expenditure is wasted through ineffective maintenance. The trend is similar in many other countries including Australia [2]. Therefore, there is a pressing need to continuously develop and improve current maintenance programs. ”

Heng, Zhang, Tan and Matthew, 2009, Rotating machinery prognostics: State of the art, challenges and opportunities, Mechanical Systems and Signal Processing, Vol. 23,pp 724-739



Motivating Example



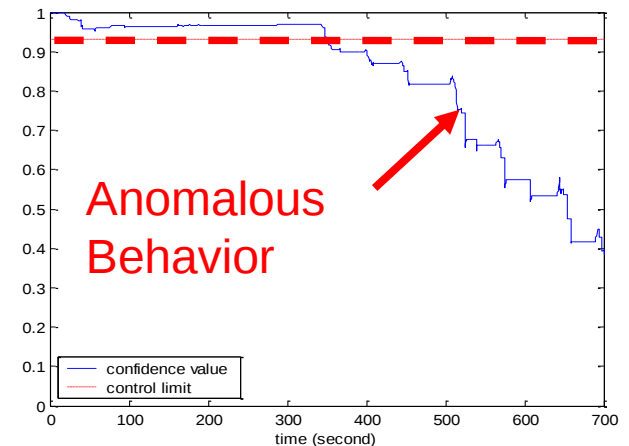
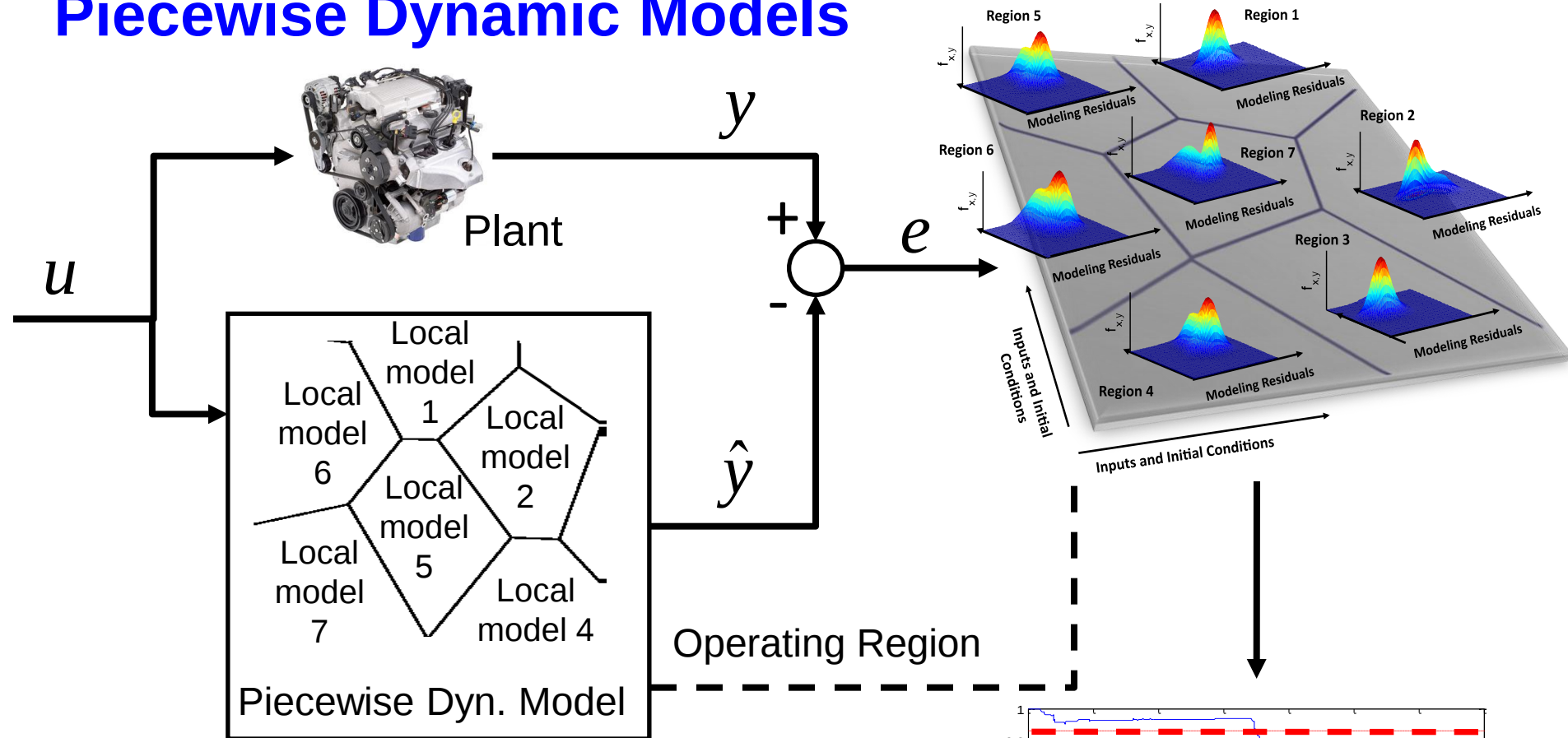
- **Source of the problem in the Plasma Enhanced Chemical Vapor Deposition tool was in the mass flow system (MFC).**
 - Highly integrated system (everything affects everything)
 - “Strange formations” observed in the chamber; Wafers had particles on them
 - After several days of hunting for the fault in the chamber, teleconference with a Ph.D. in quantum physics led to the source of the problem (“everybody knows these are Coulomb crystals”)
 - Hundreds of ruined wafers and thousands of wafers of lost production. Note that each patterned wafer is several thousand dollars worth.

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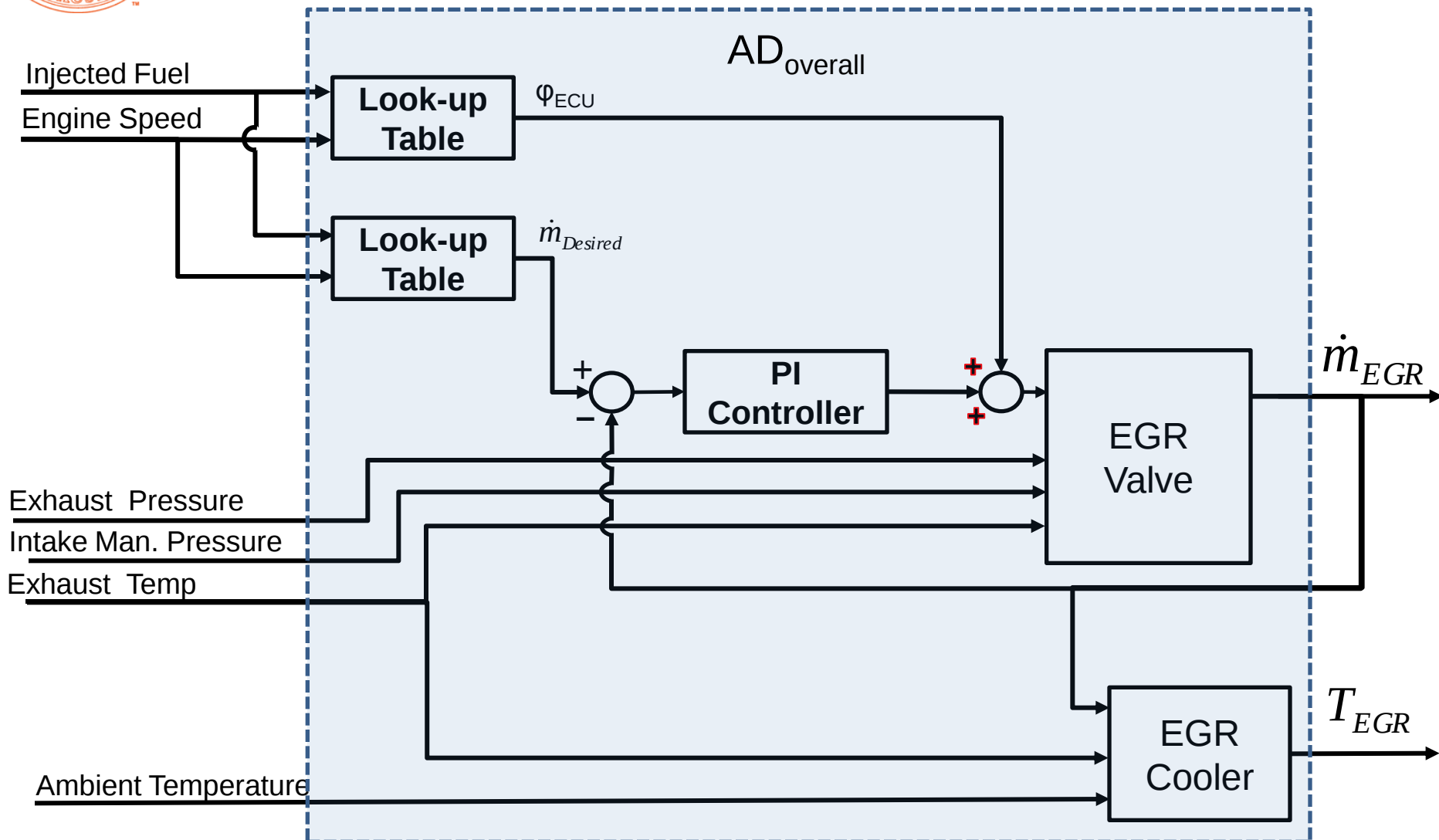
Anomaly Detection (AD) using Piecewise Dynamic Models



J. Liu, D. Djurdjanovic, K. Marko and J. Ni, "Growing Structure Multiple Model System for Anomaly Detection and Fault Diagnosis", *Transactions of ASME, Journal of Dynamic Systems, Measurements and Control*, Vol. 131, No. 5, pp. 051001-1 – 051001-13, 2009

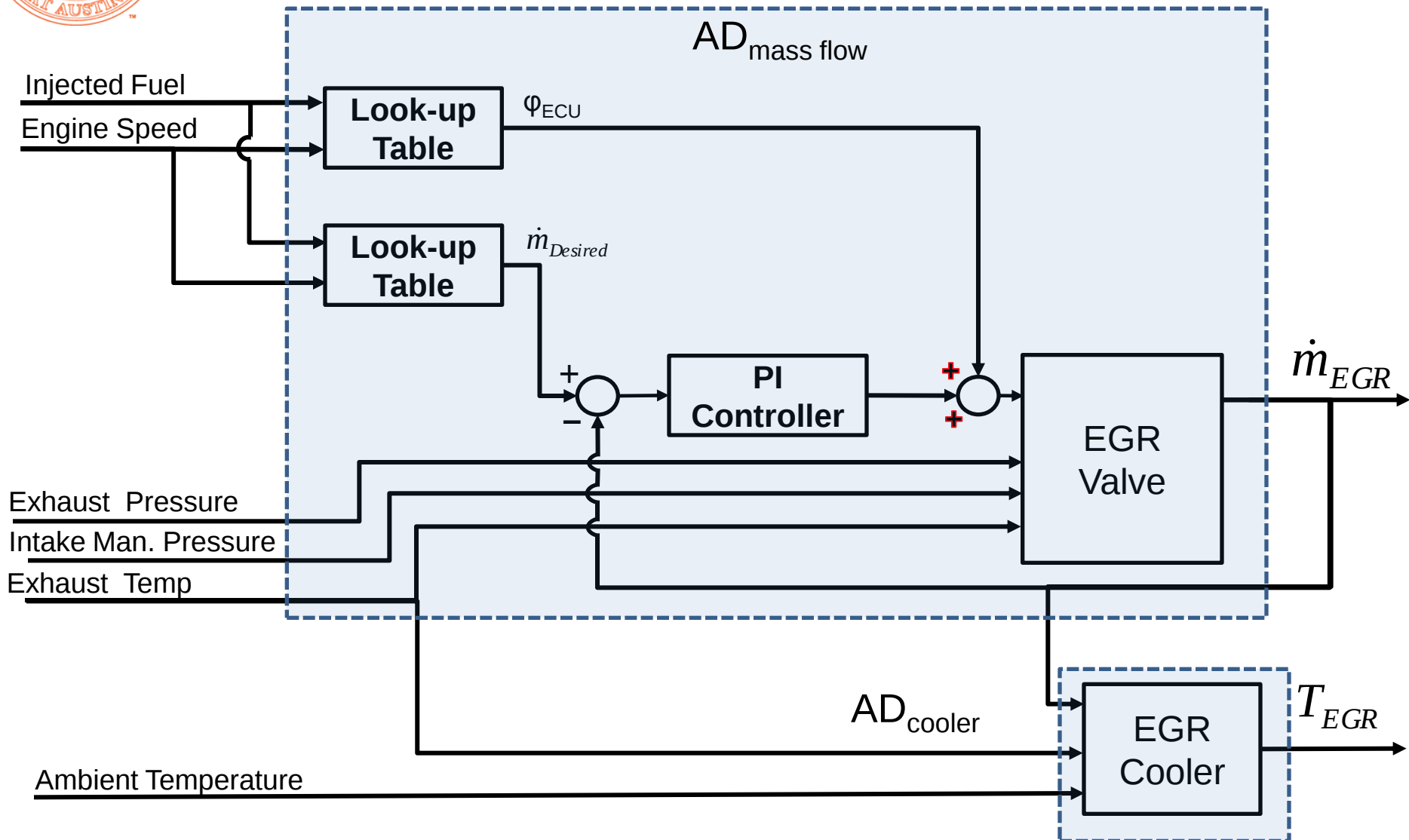


Precedent Free Fault Isolation in the Exhaust Gas Recirculation (EGR) System of a Diesel Engine



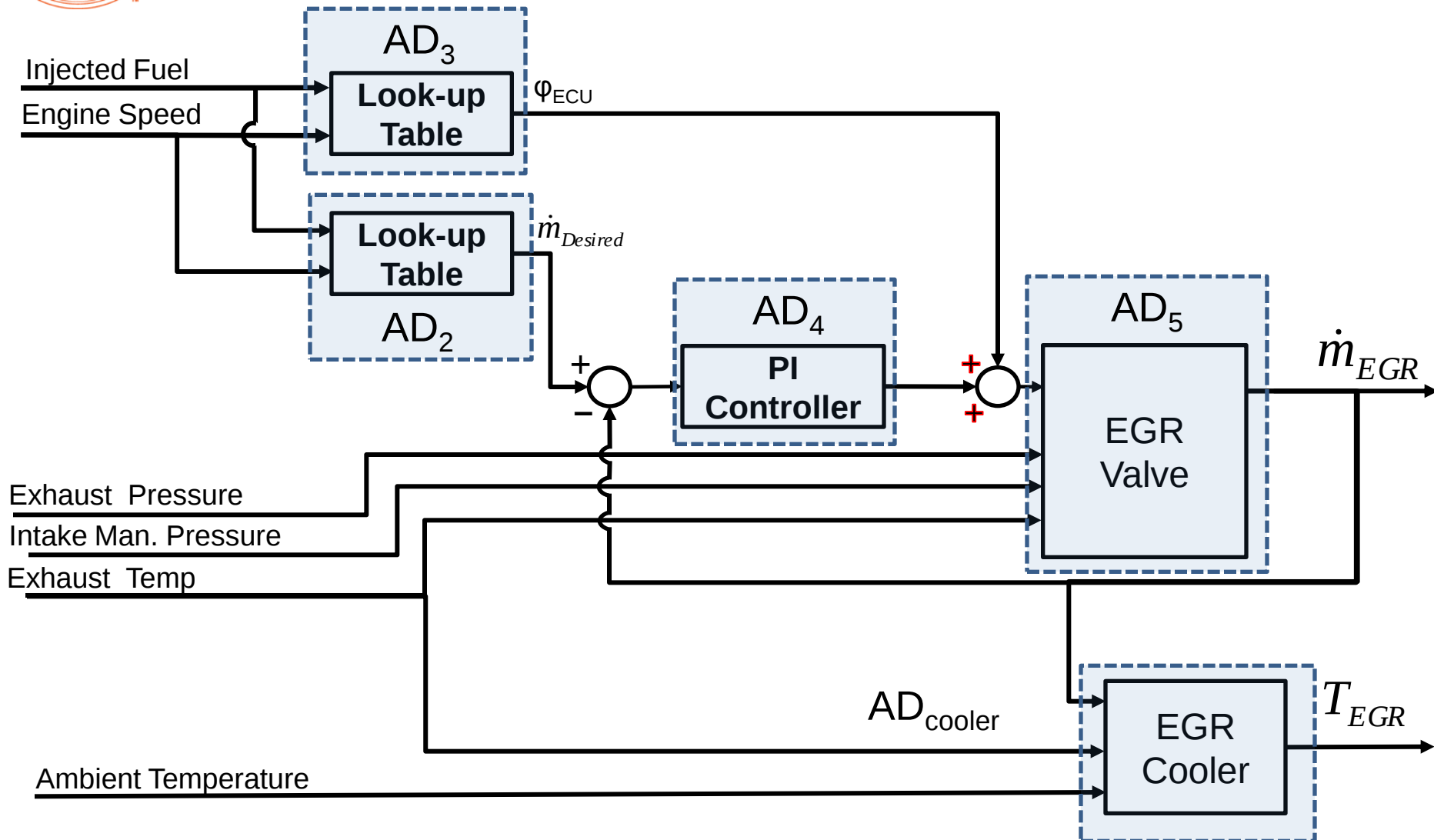


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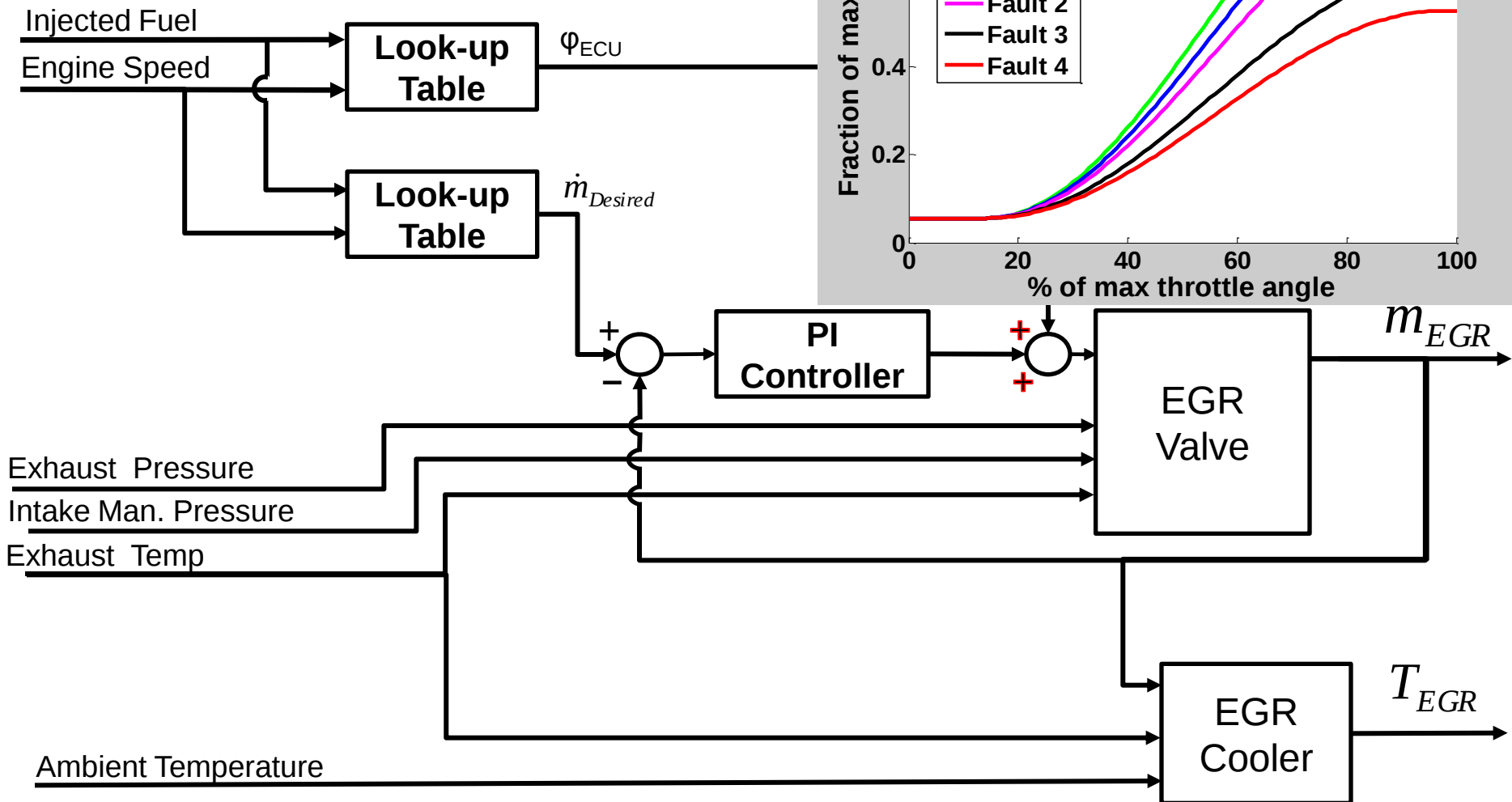




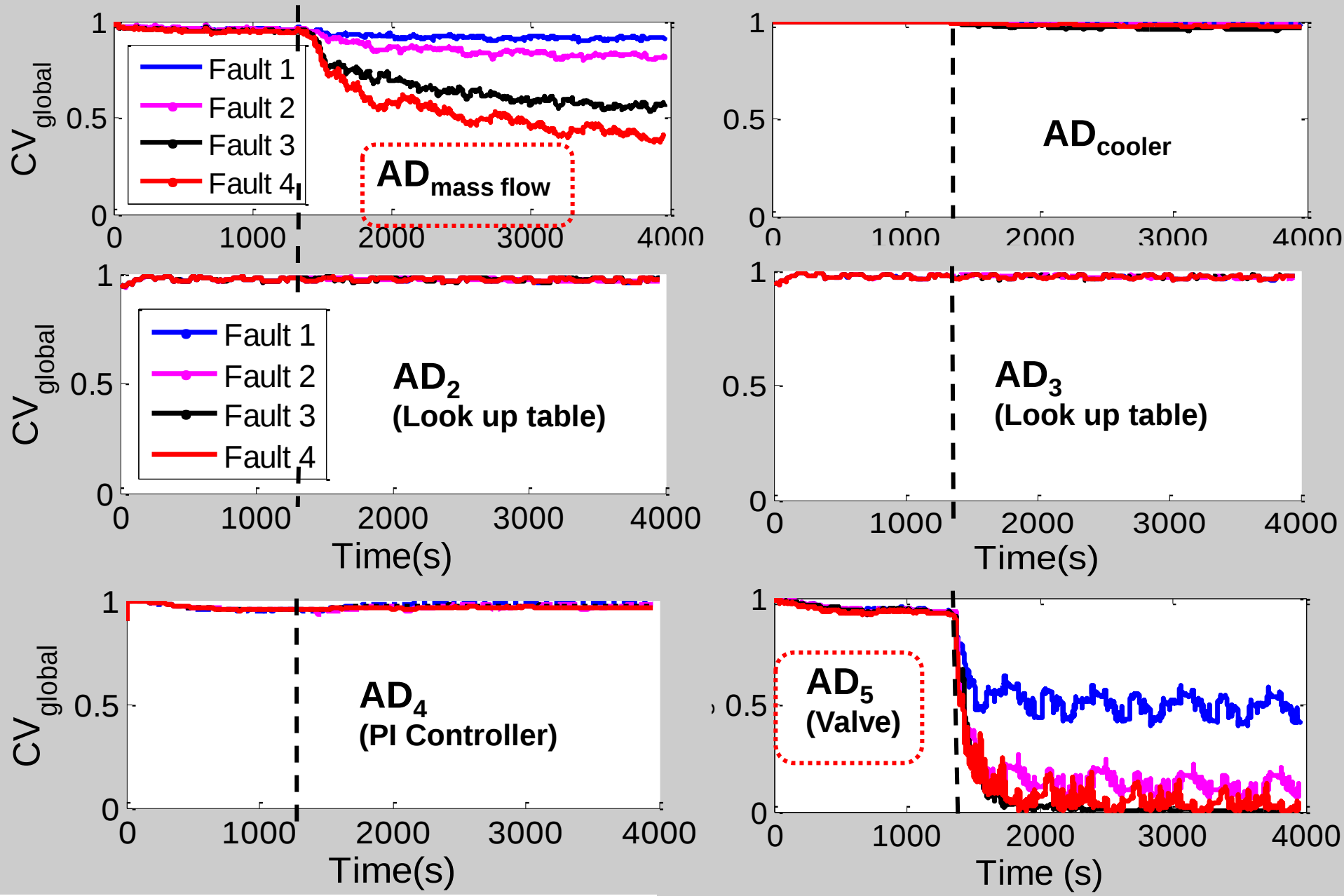
Precedent Free Fault Isolation in the Exhaust Gas Recirculation (EGR) System of a Diesel Engine



Anomalies in the EGR Valve (Clogging of the Valve)



Detection and Isolation of an Anomaly in the EGR Valve



Variability of Operations and Condition Degradation



Time

Preventative
Maintenance

Operation 1

Operation 2

Operation 1

Operation 3

Observations



Observation
Model₁

Observation
Model₂

Observation
Model₁

Observation
Model₃



Un-
observable
Condition



Dynamic
Model₁

Dynamic
Model₂

Dynamic
Model₁

Dynamic
Model₃



Degradation Model using a Mixture of HMMs



Time

Preventative
Maintenance

Operation 1

Operation 2

Operation 1

Operation 3

Observations



HMM₁

HMM₂

HMM₁

HMM₃

Un-
observable
Condition



HMM₁

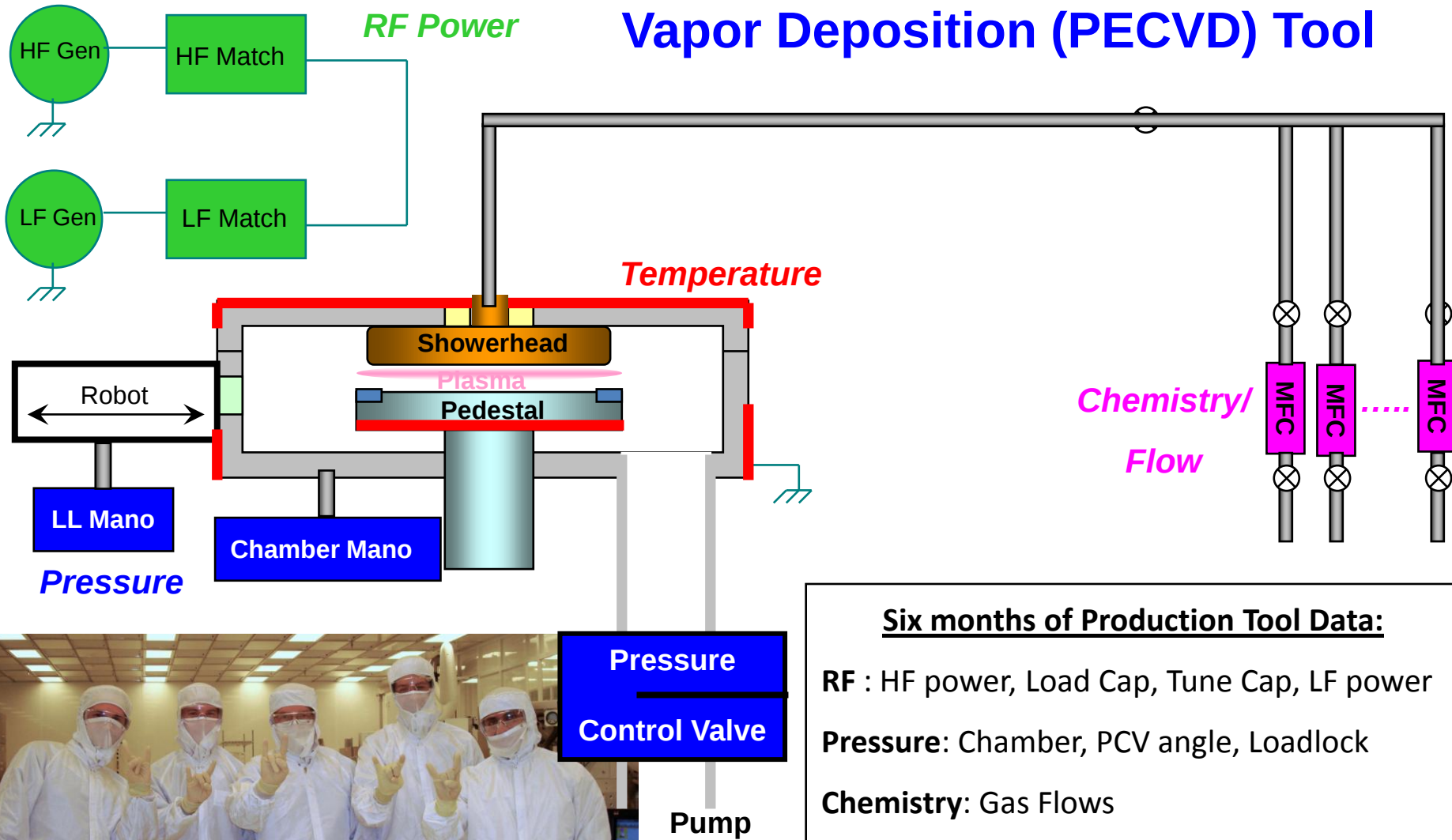
HMM₂

HMM₁

HMM₃



Plasma-Enhanced Chemical Vapor Deposition (PECVD) Tool



Six months of Production Tool Data:

RF : HF power, Load Cap, Tune Cap, LF power

Pressure: Chamber, PCV angle, Loadlock

Chemistry: Gas Flows

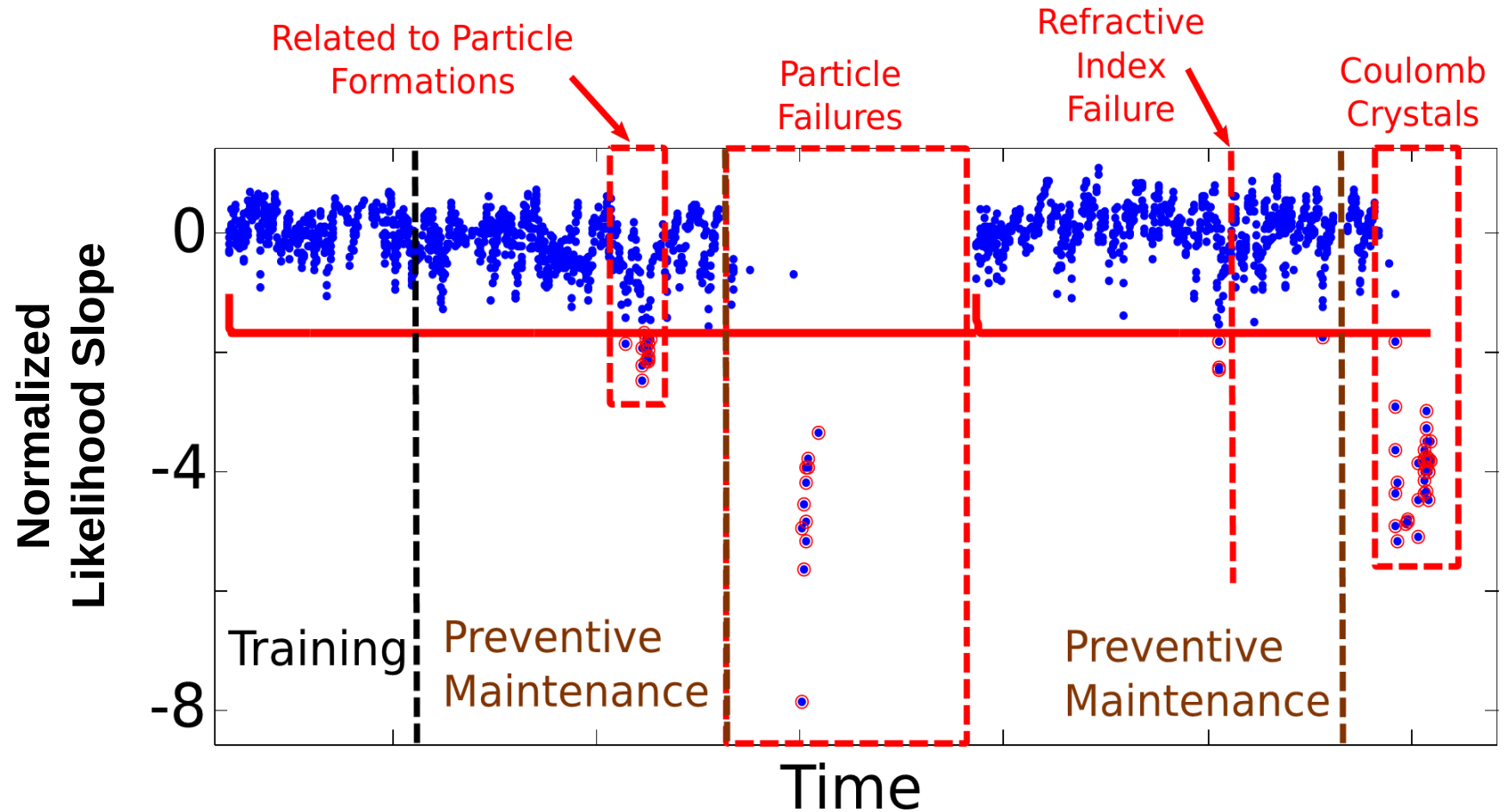
Temperature: Chamber, Pedestal

Production schedules/maintenance events

On-Board metrology – thickness, uniformity



PECVD Process Monitoring in a Fab



Each dot is a *Front Opening Unified Pod* (FOUP) of wafers

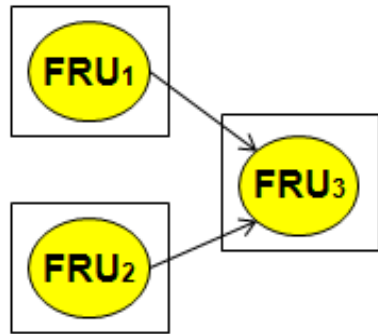


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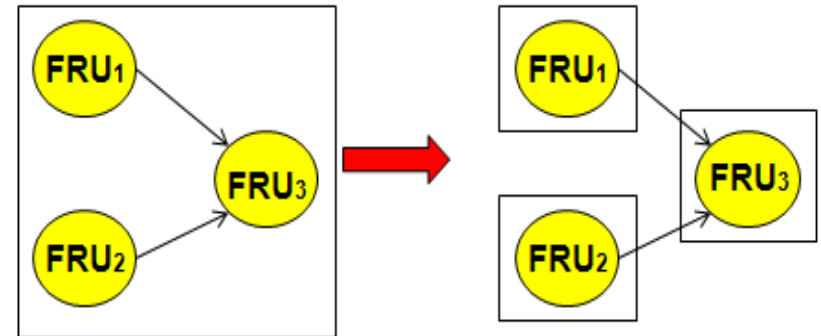
Explorations of Diagnostic Coverage and Computational Costs



Policy 1

d_0 – Detection rate for grouped anomaly detector

d_1 – Detection rate for individual FRU anomaly detectors



Policy 2

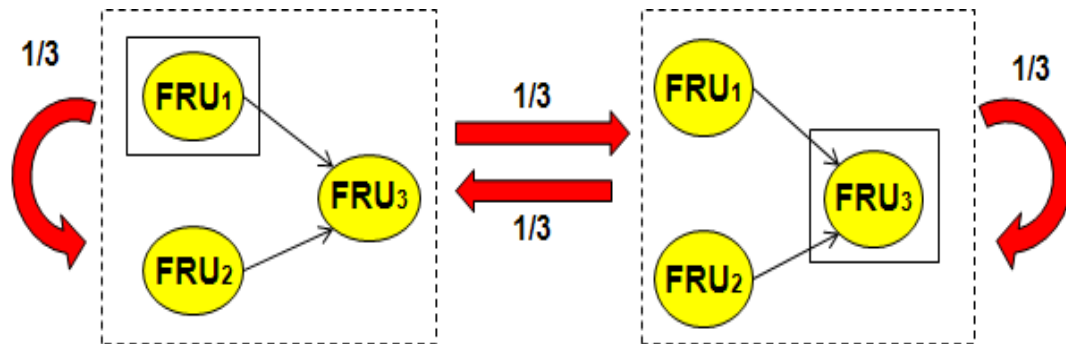
C_c – Computational cost per unit time

C_i – Cost of failing to localize the fault per unit time

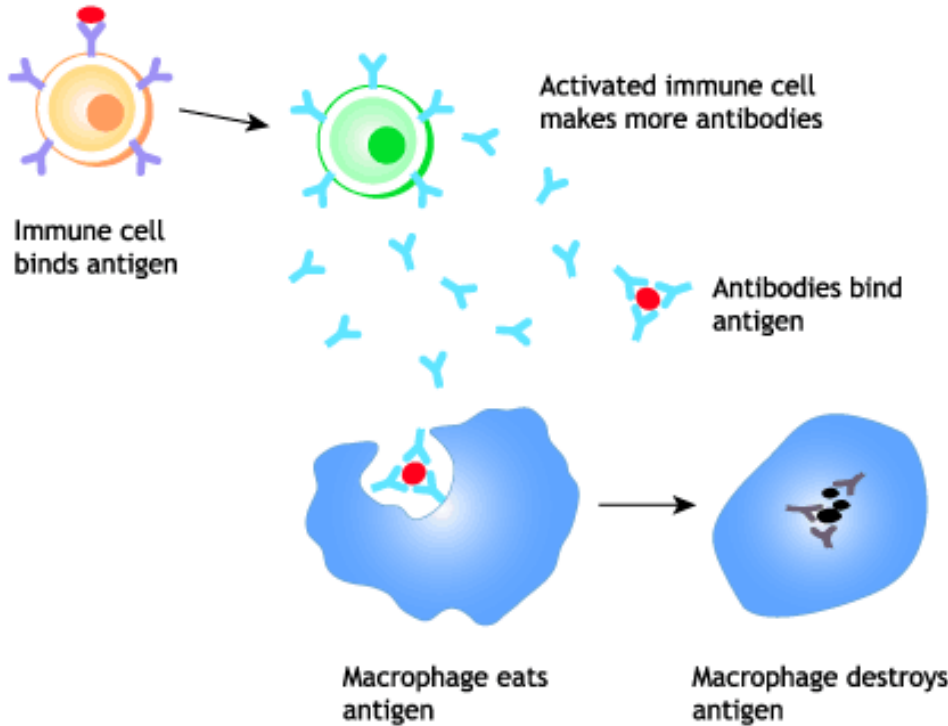
$$Cost_1 = \frac{C_i}{d_1} + 3C_c;$$

$$Cost_2 = C_i \left(\frac{1}{d_0} + \frac{1}{d_1} \right) + 2C_c;$$

$$Cost_3 = C_i \left(6 + \frac{1}{d_1} \right) + C_c$$



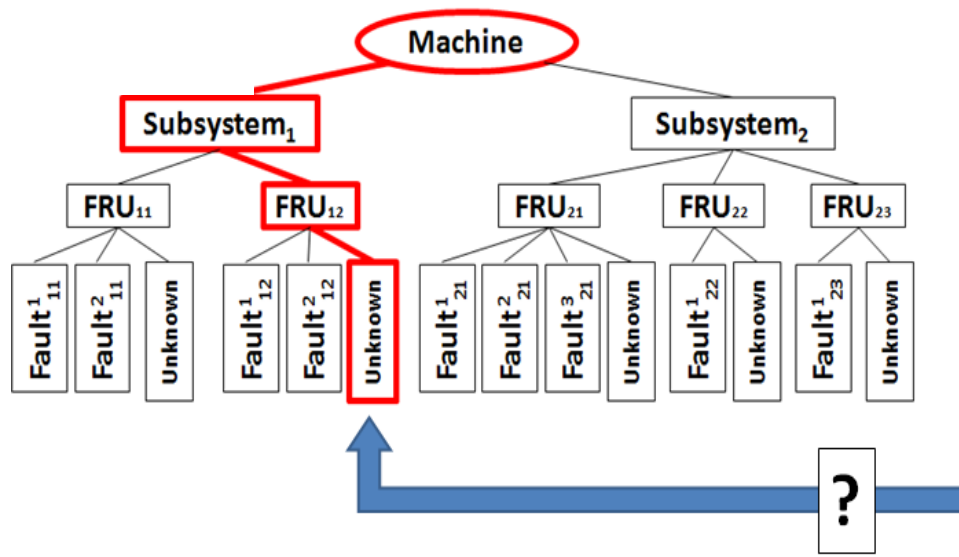
Policy 3



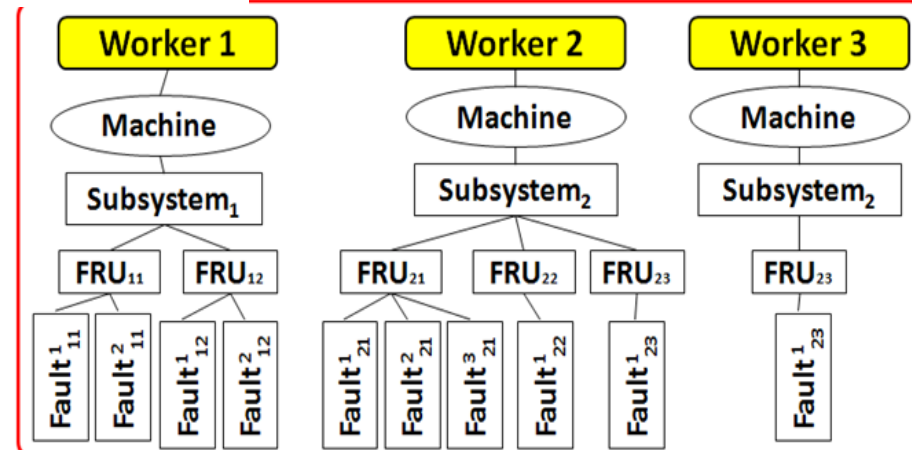
Decision-Making with Unknown Faults

- Distributed system
- Based on detecting non-self
- Leukocytes kill anything labeled with antibodies
 - Anomaly detectors act as b-cells and antibodies
 - Leukocytes act as controllers or humans

- Leukocytes destroy anything labeled with antibodies.
- Our “leukocytes” are very diverse (different skills), they learn and forget over time



Representation of a Maintenance Crew



Thank you!

