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A SIMULATION APPROACH TO RISK-BASED DESIGN OF COMPLEX DYNAMIC SYSTEMS USED IN SPACE MISSIONS

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Presentation Outline

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Propulsion System Description

1. The system is needed for science missions at the outer solar system.
2. The system consists of five thruster assemblies and one propellant supply.
3. Each assembly has one propulsion power unit (PPU) and two ion engines (IE).
4. When an assembly is operating, the PPU provides power to just one ion engine.
5. The other engine remains on standby, unless failed.
6. In some phases the propulsion system only operates during part of the phase

Propulsion System Description (cont.)

7. Thruster needs 2 out of 4 assemblies during the first phase, and 3 out of 5 assemblies during the subsequent phases
8. The failed assembly is replaced by the lowest numbered standby assembly.
9. For example, in phase 1, in case of failure assembly 2 will be replaced by assembly number 3, and assembly number 4 becomes the available standby assembly
10. Mission fails if there are more than 2 failed assemblies

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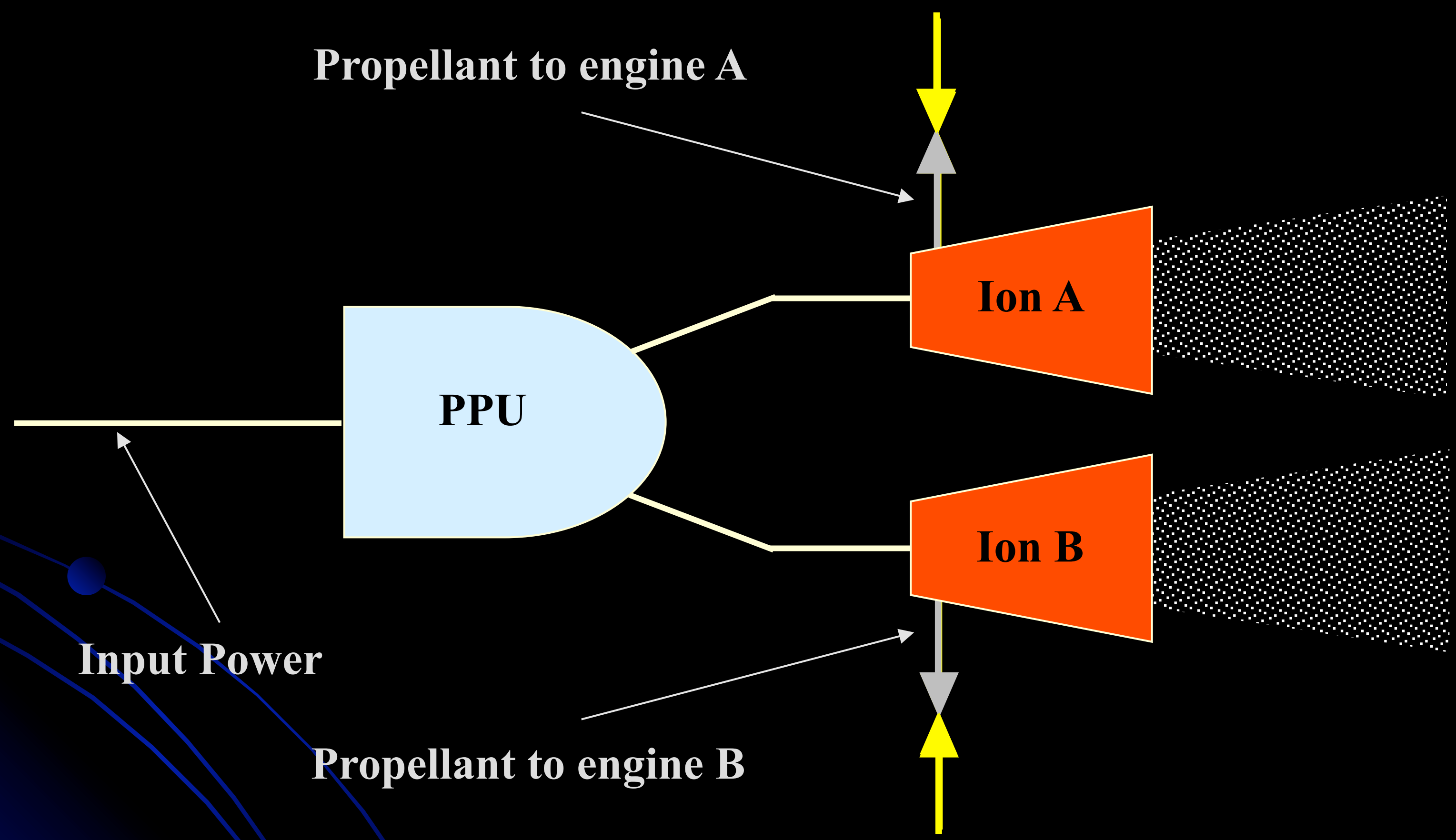
Thruster Assembly Design



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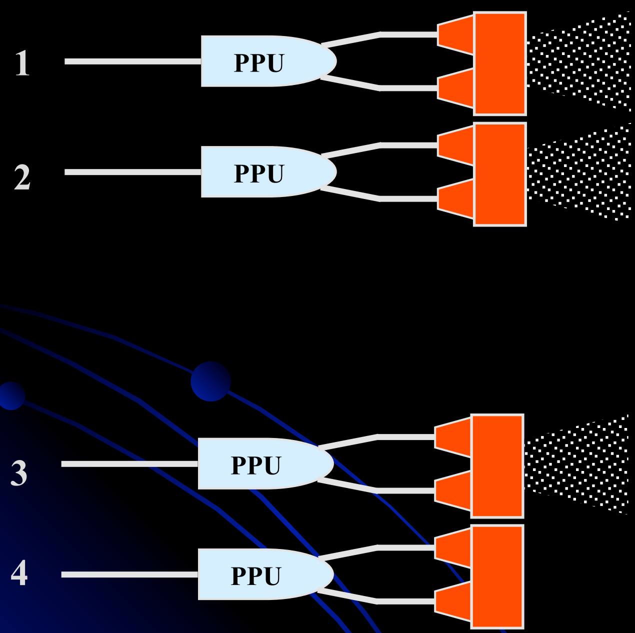
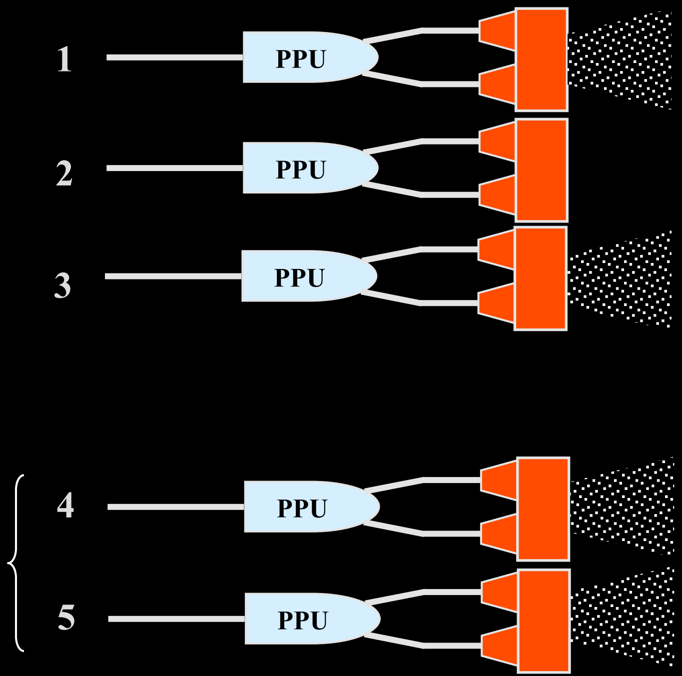
Propulsion System Design

Phase 1: 2 out of 4



Standby units

Phase 2 to 7: 3 out of 5



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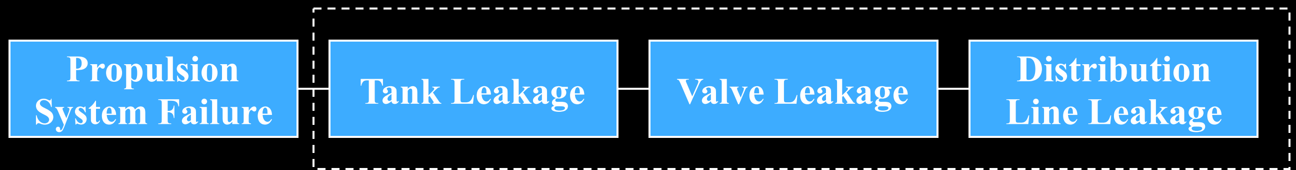
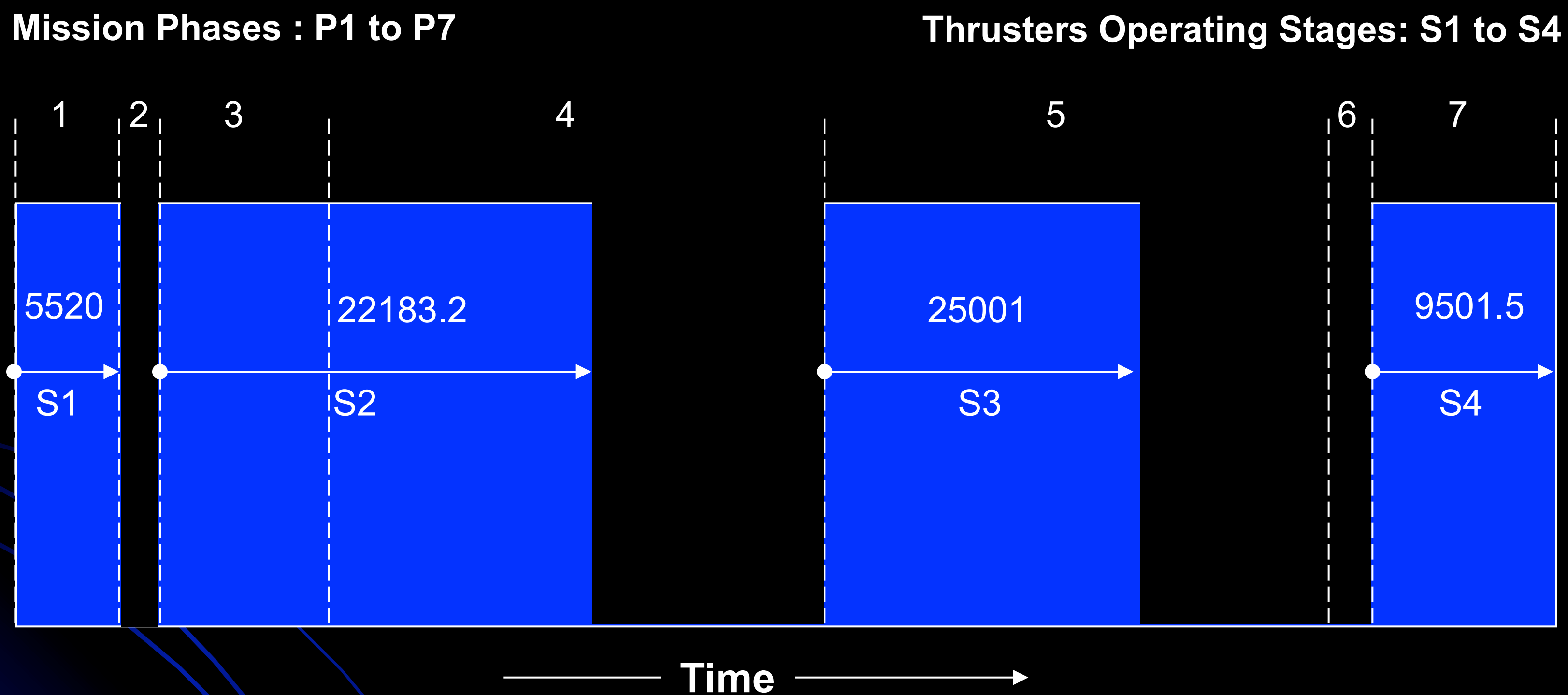
External Leakage

Mission Failure:



Mission Time Profile



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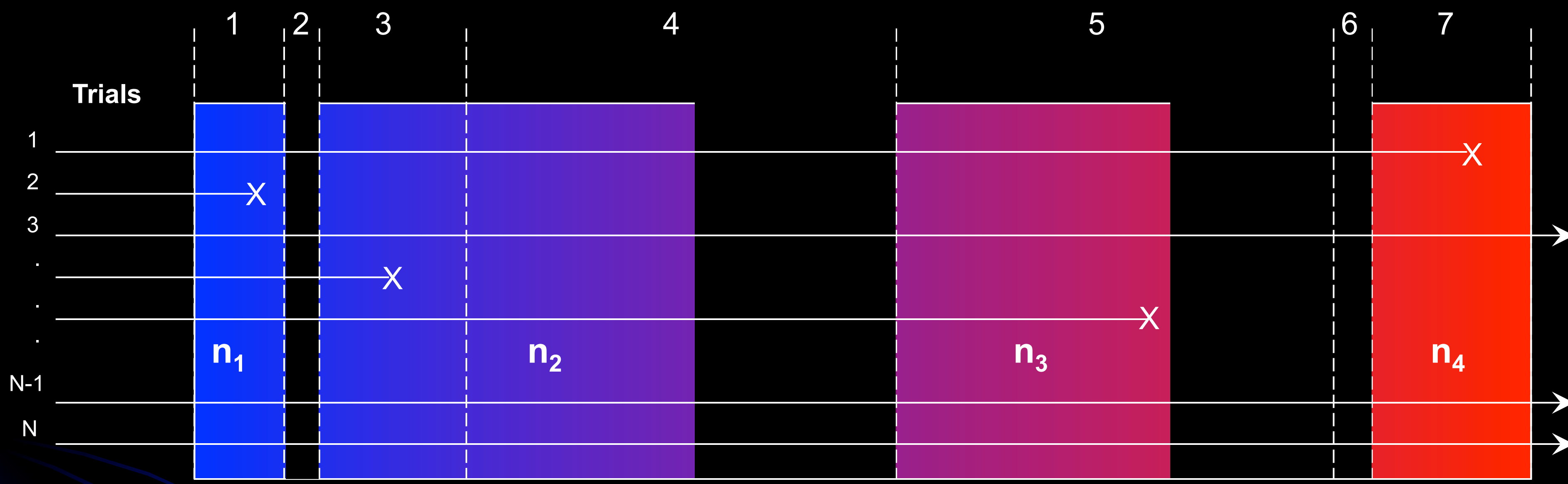
Simulation Overview



X : Failed Trials
→: Passed Trials
n_i: Number of Failures in Stage i
Ri: Reliability at Stage i

Time →

$$R_i = \frac{\text{Number of Survivals}}{\text{Total Number of Trials}} = \frac{N - \sum_{j=1}^{i} n_j}{N}$$

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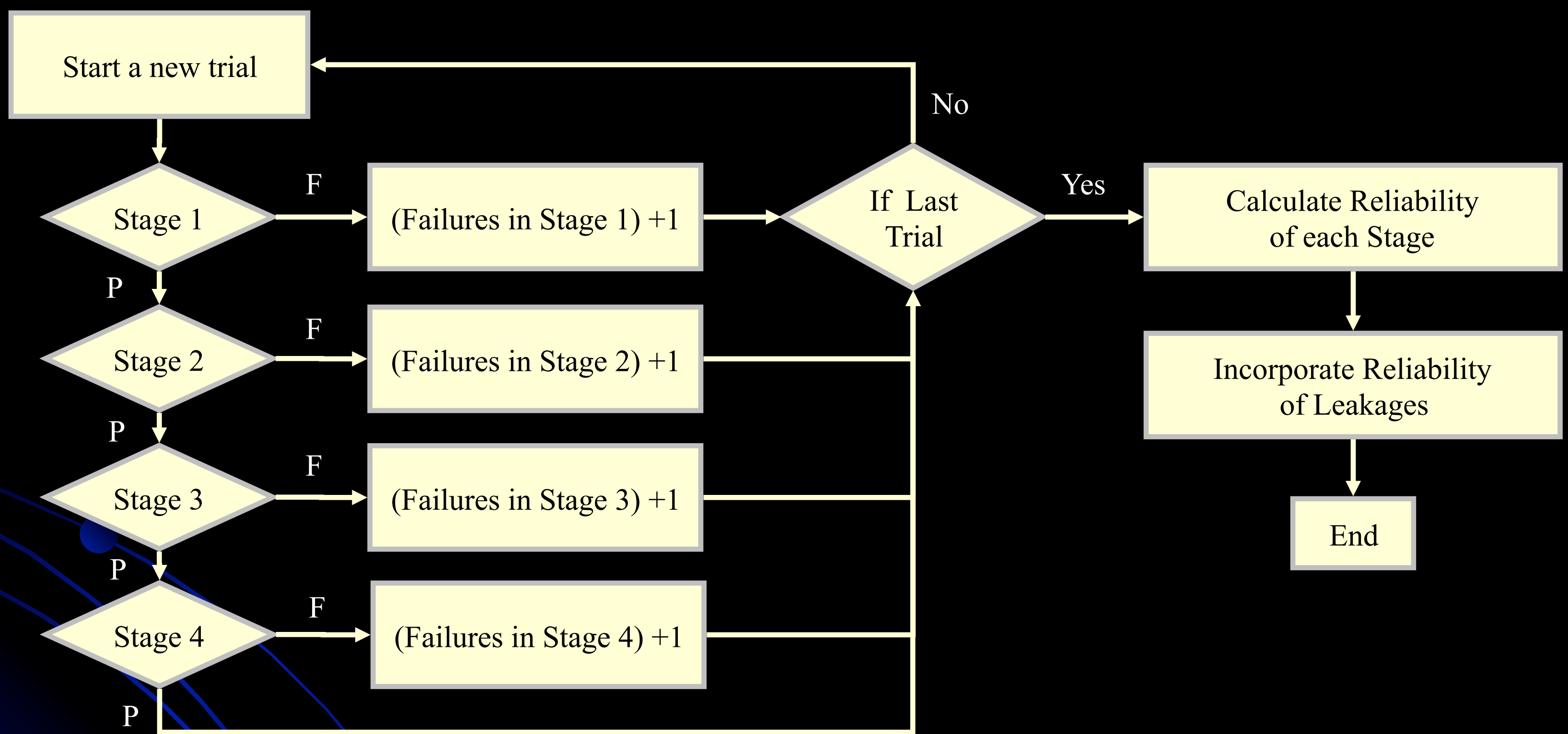
Simulation Flow Chart



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Agent-Oriented Approach

- Every part is replaced by an intelligent piece of software
  - Contain all properties of the part (attributes)
  - Mimic the behaviors of the part (methods)
  - Able to communicate with other agents
- Inquiry is directed to an agent
- The inquiry is processed autonomously
- The process depends on agent status and boundary conditions
- The agent responds appropriately
  - The autonomous reaction is in form of either activity or information
  - The agent may contact, activate or request a task from other agents

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Agent Definition

A piece of software capable of displaying

- Autonomy :
  - Capable of actions with no direct supervision
  - Have Some degree of control over its own actions ("self-activation")
- Reactivity :
  - Perceive their environment
  - Respond to the changes that occur in environment
- Pro-activity (goal orientation):
  - Act in a goal-directed manner
  - Take the initiative where appropriate
- Social activity (communication skills):
  - Interact when appropriate with other agents

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Simulation Model

- Dynamic vs. static
- Distributed vs. concentrated intelligence
- Simplicity vs. complexity
- Dependent vs. independent failures

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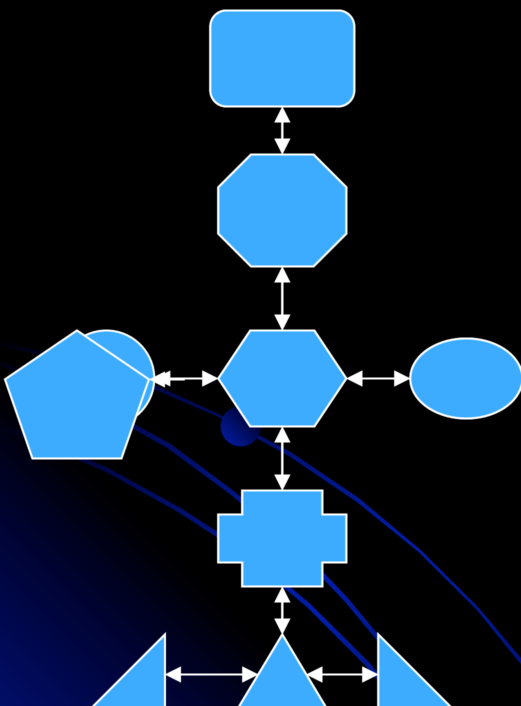
Dynamic Vs. Static



- Real time simulation instead of time snapshot model
  - Account for change in component properties
  - Account for changes in component behaviors
  - Account for changes in system configuration

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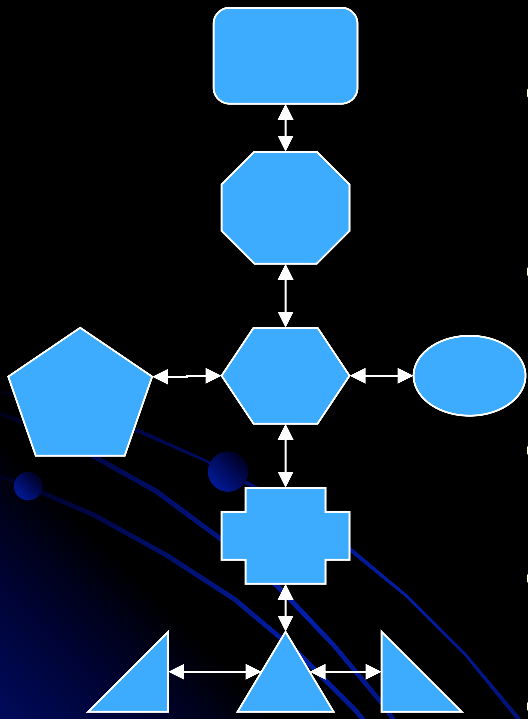
Why Distributing Intelligence?

System



- Components of system are physically distributed
- Components and subsystems are heterogeneous in functionalities
- Hierarchical representation of the system force a distributed view
- Complexity of system forces local viewpoint
- Simulation model should be adaptable to changes
- Failure modes are autonomous and have their own persistent thread of control

Modeling procedure is a journey from

<u>Distributed system</u>

to

<u>Distributed intelligence</u>

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Simplicity vs. Complexity

- The failure logic of the system is simple
- Complexity comes from plurality of scenarios
- Group of components act the same therefore:
  - Individuals can be instances of the same class
  - Individuals inherit the properties and methods from their parents
- Rules are the same for individuals of a group, yet each component is autonomous in action
- The failure logic can be modeled in a higher level without getting involved in detailed scenarios

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Dependent vs. independent

- Dependencies are traditionally added to the system model as extra independent events
- Direct simulation approach:
  - Make modeler able to assess the behavior of each object having the status of others (i.e. conditional probabilities)
  - Dependencies are modeled through communication of objects

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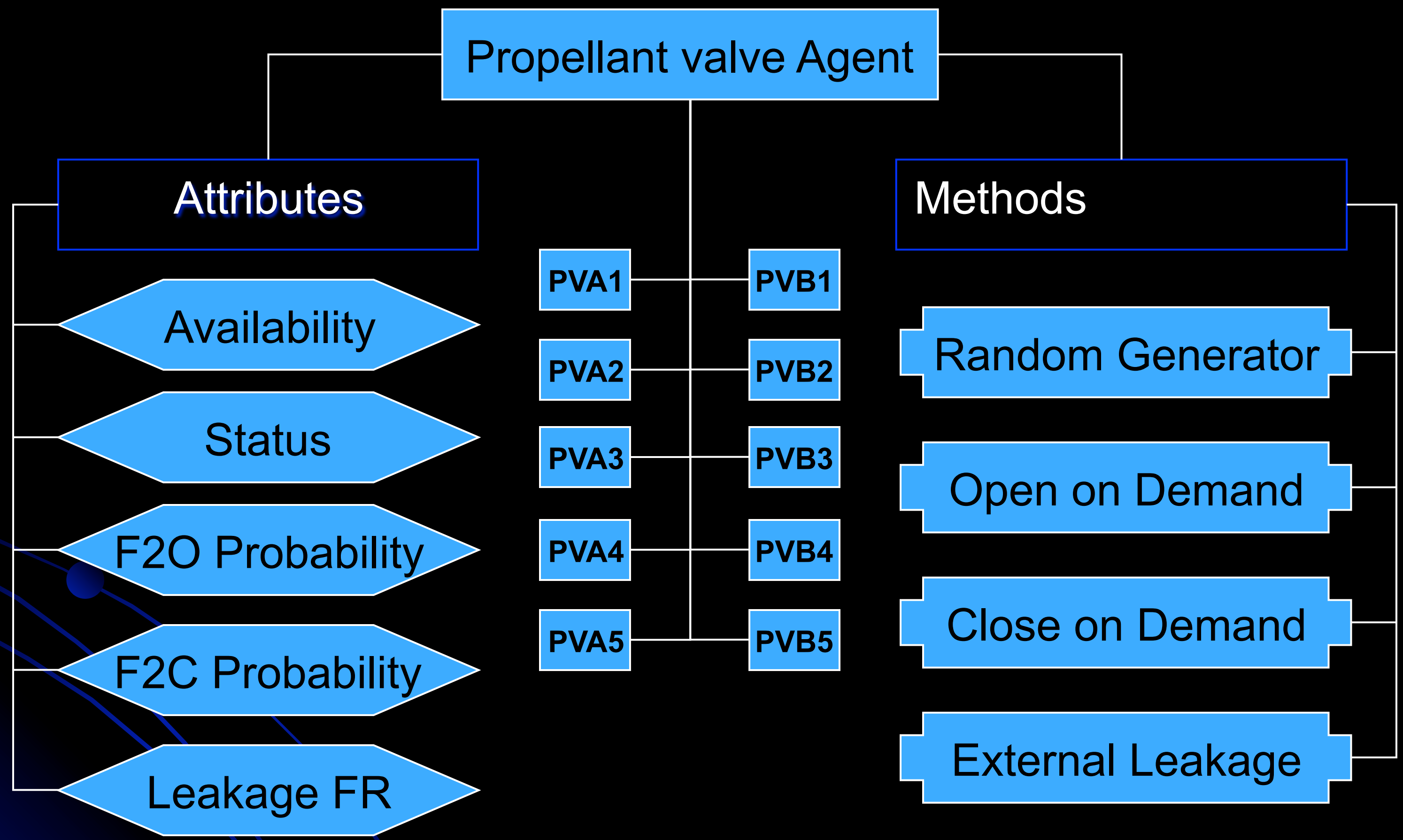
Example – Propellant Valve Agent



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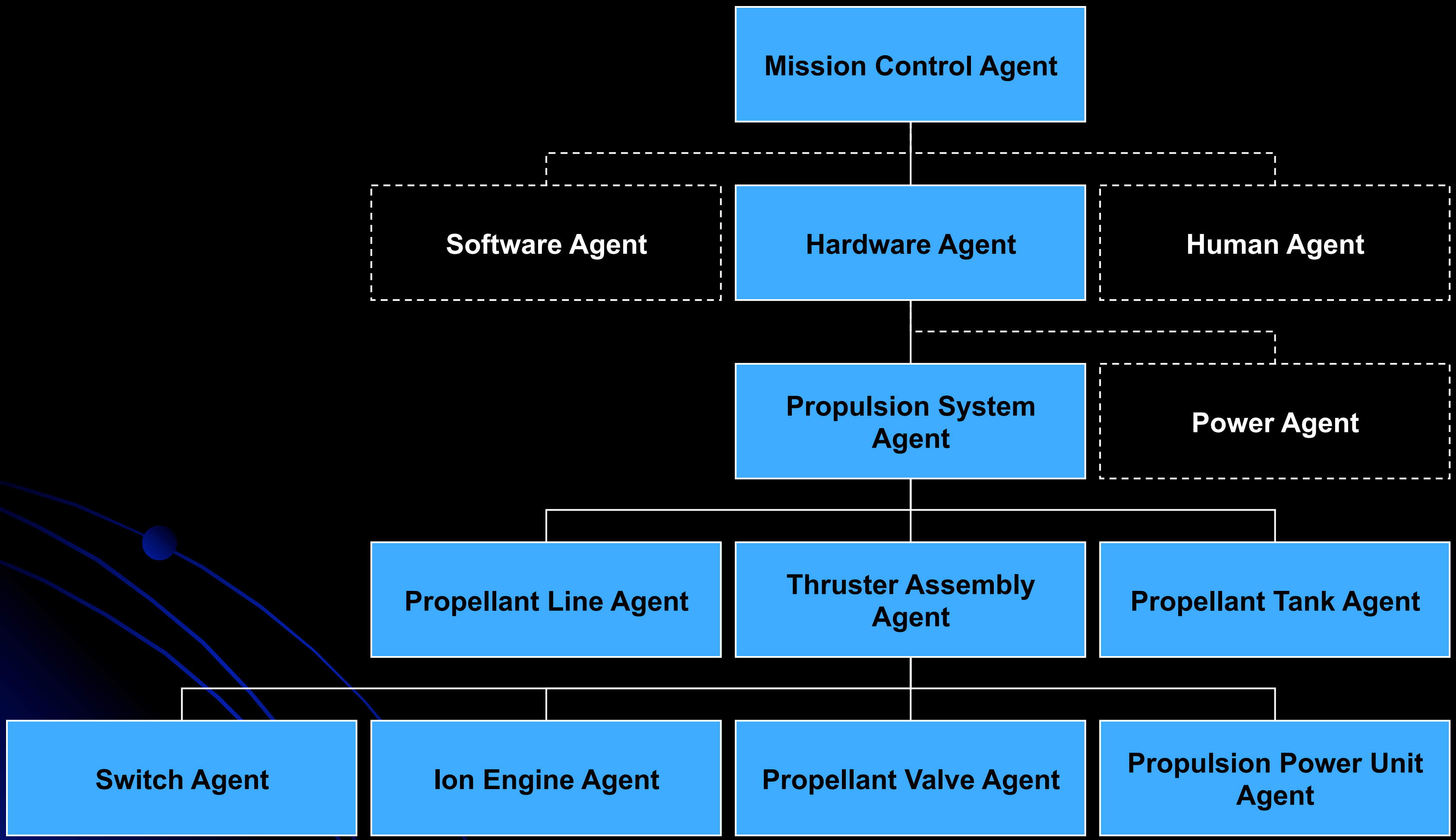
Hierarchy of Agents



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Feature 1: CCF Considerations

Group Size	Group Conditional Failure Probability (%)
2	8
3	4
4	2
5	1

- The CCF is applied using provided conditional probabilities
- The conditional probabilities are combined with simulation taking Monte Carlo sampling approach
  - Events are sampled in the order that are called by mission control agent
  - When a failure occurs, possible CCFs are identified and applied to the remaining components
  - An event once succeeds can not be a party of any CCF during the simulation
- Public attributes of agents (availability and status) are used to implement CCF

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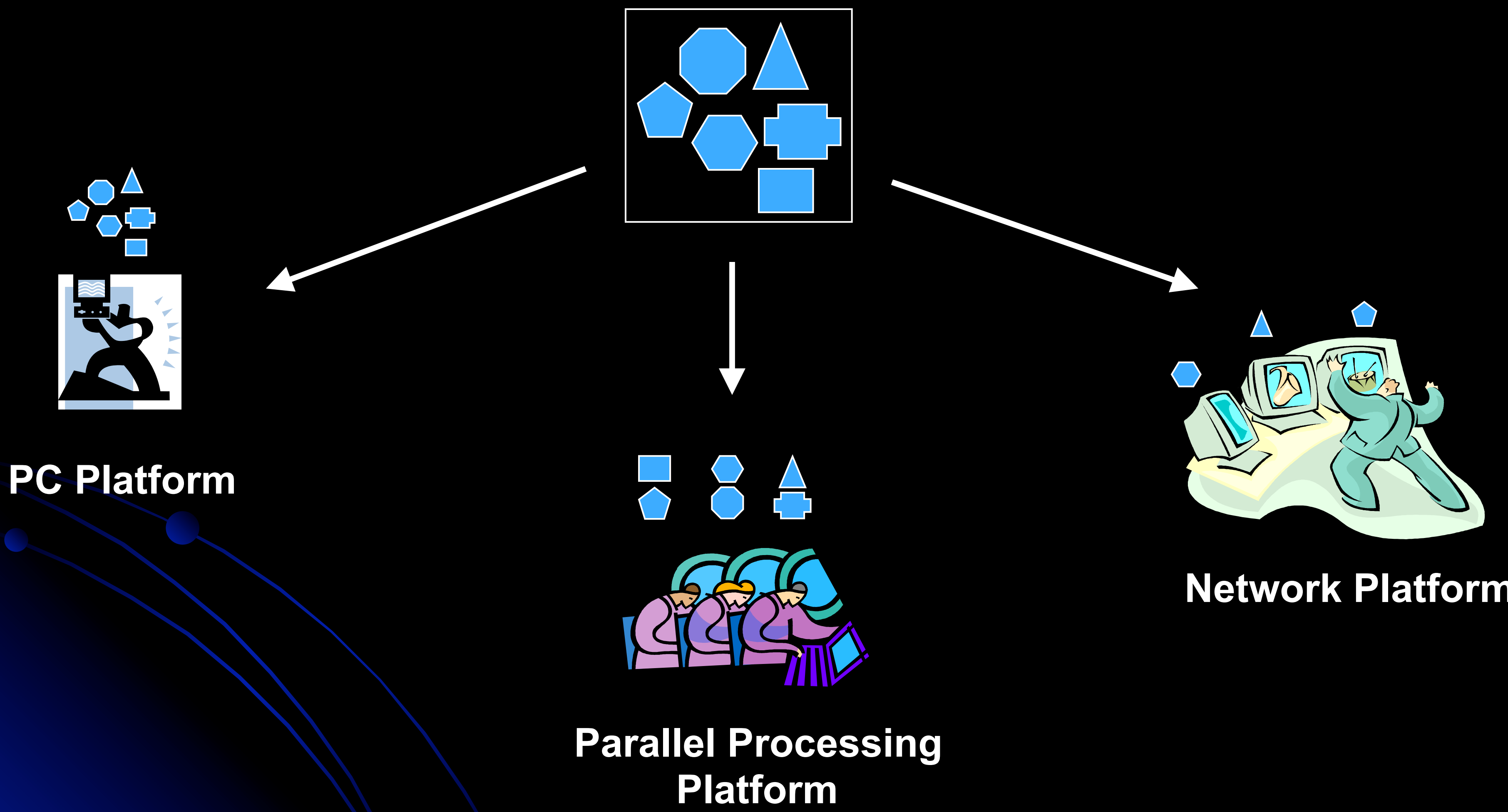
Feature 2: Computational Platform



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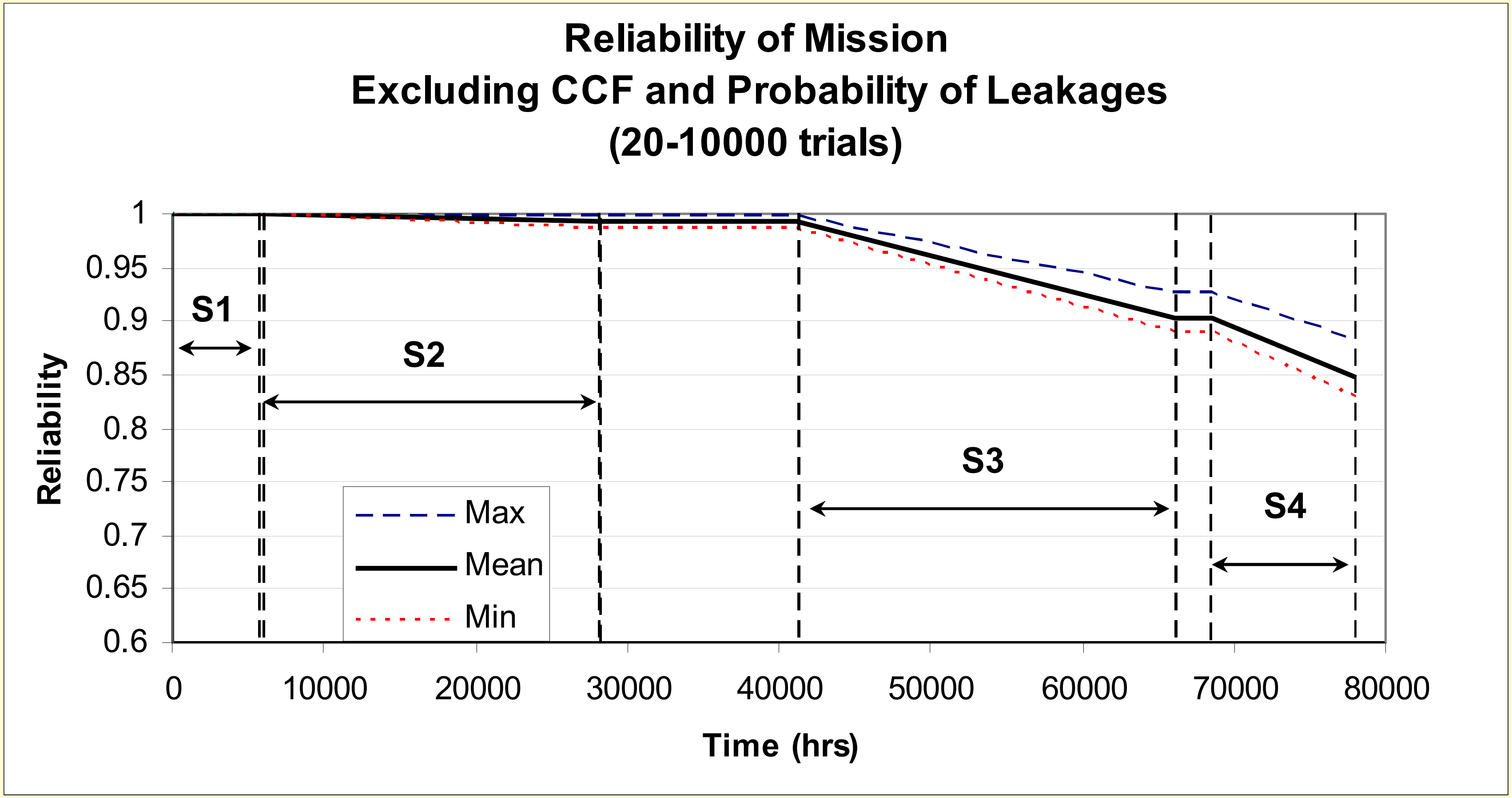
Mission Reliability
Excluding CCF & Leakages



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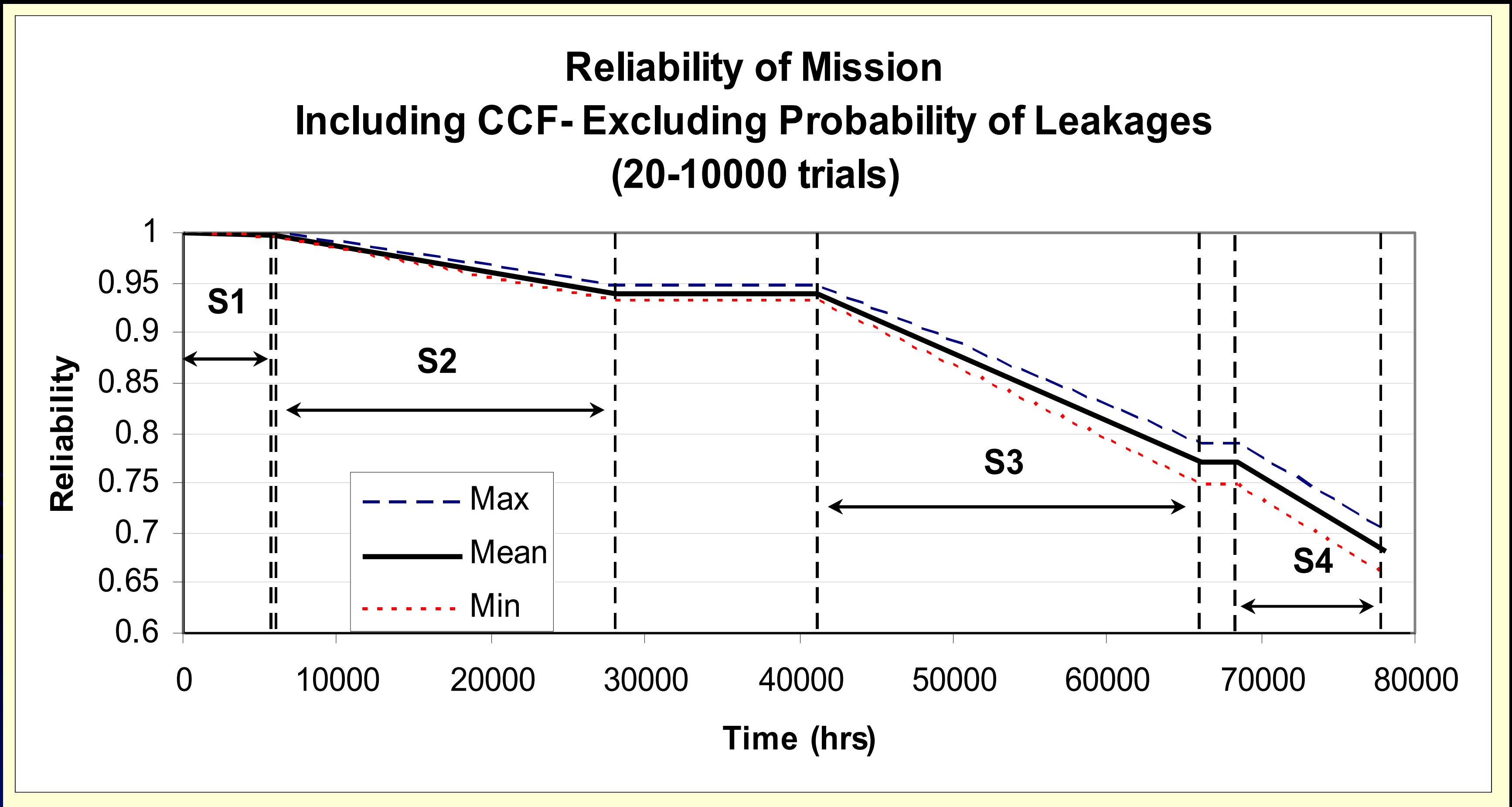
Mission Reliability
Including CCF



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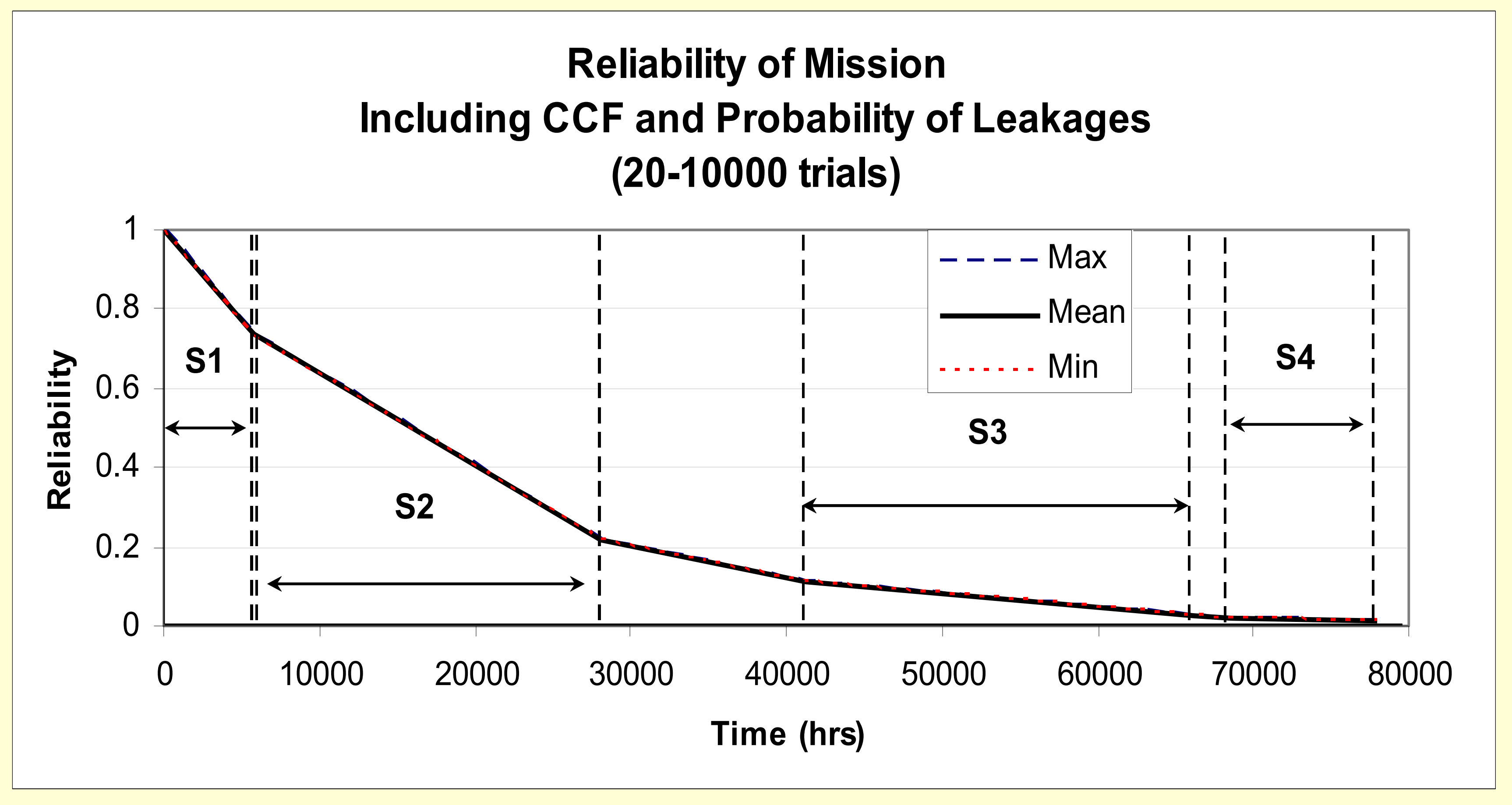
Mission Reliability
Including CCF & Leakages



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Concluding Remarks

Taking this approach

- Dynamic behavior of the system is incorporated
- Complexity is reduced
  - Have a local view point to the system parts
  - Components respond autonomously without any supervision
  - Groups of scenarios can be modeled at a convenient level of details
- Dependencies (CCF) are modeled using communication skills of agents
- Modeler can use other processing resources in a parallel processing framework
- Mobility feature of agents makes the entire network a single computing platform for remote collaboration of agents

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Thanks

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