PURDUE UNIVERSITY

150 YEARS OF GIANT LEAPS

A Resilience-oriented Design Approach to Dynamic Performance of Extraterrestrial Habitat Systems

RETH

June, 2019

Resilient Extra-Terrestrial Habitats …

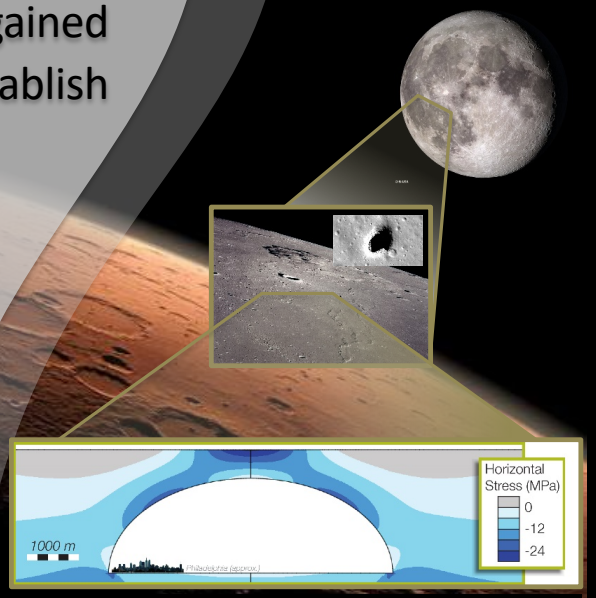
RETH

PURDUE UNIVERSITY

Challenge: The design of permanent extraterrestrial habitats represents an engineering and scientific grand challenge.

Vision: Leverage the lessons learned and tremendous experience gained by constructing settlements on Earth, to develop the methods for establish long-term resilient extraterrestrial habitats.

Safe & <u>Resilient</u> Habitat Systems: Our approach to design of the habitat systems will consider both degradation and vulnerability to various types of hazards, but focus on minimize disruptions affecting normal functions.



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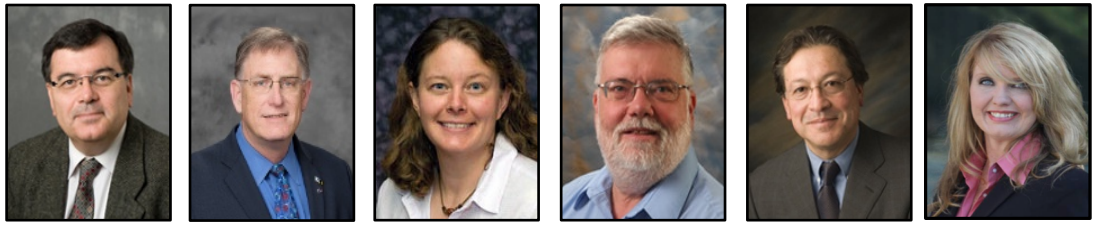
Purdue RETH Team

Faculty Members



Postdoctoral and Graduate Researchers

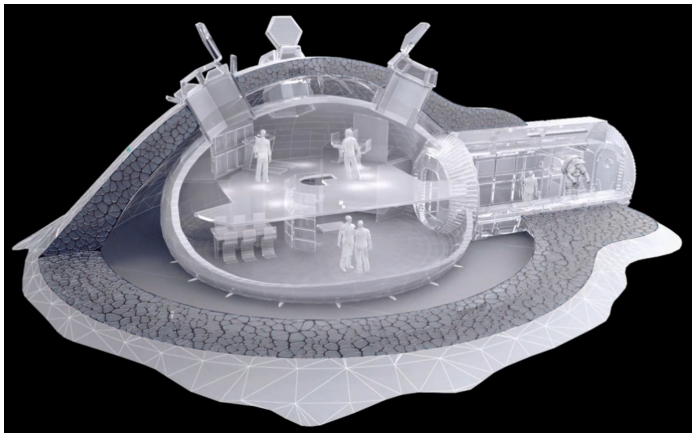
Undergraduate Researchers

Resilience is not simply robustness, reliability or redundancy …

- Risk analysis, risk management and health management are widely used to support system performance and reliability

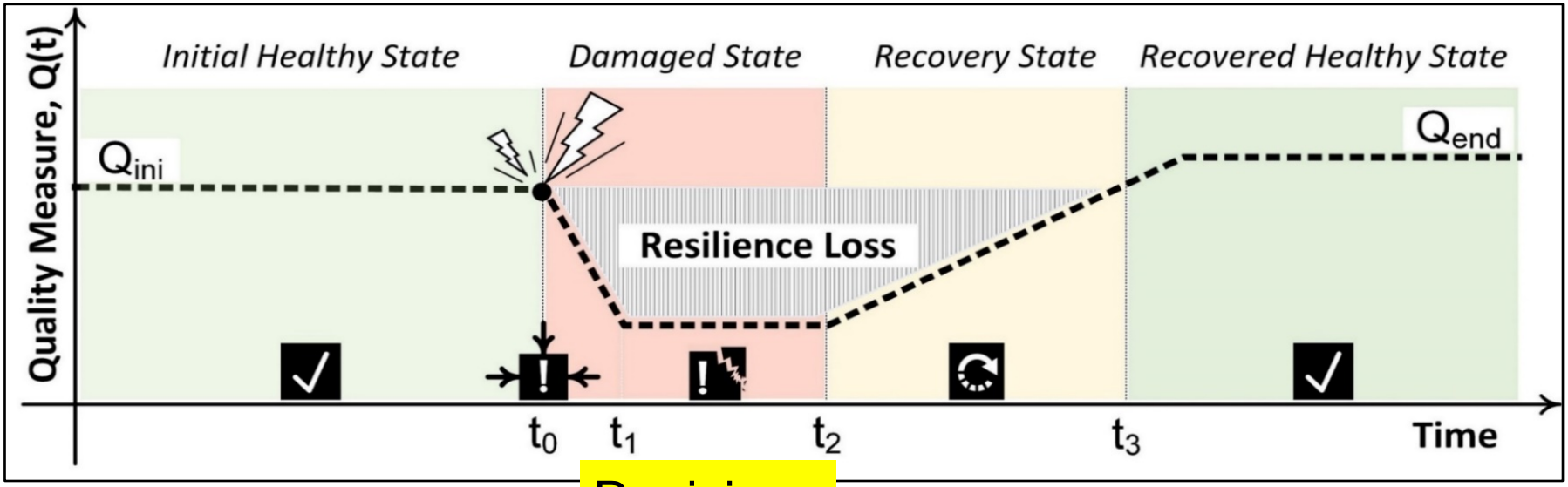
- Existing approaches are driven by entirely avoiding or minimizing the occurrence of known/anticipated faults.

- For long term space habitat system this is inadequate:
  - high reliability is inefficient and costly
  - disruptions are inevitable, yet difficult to predict
  - humans will not always be present



European Space Agency

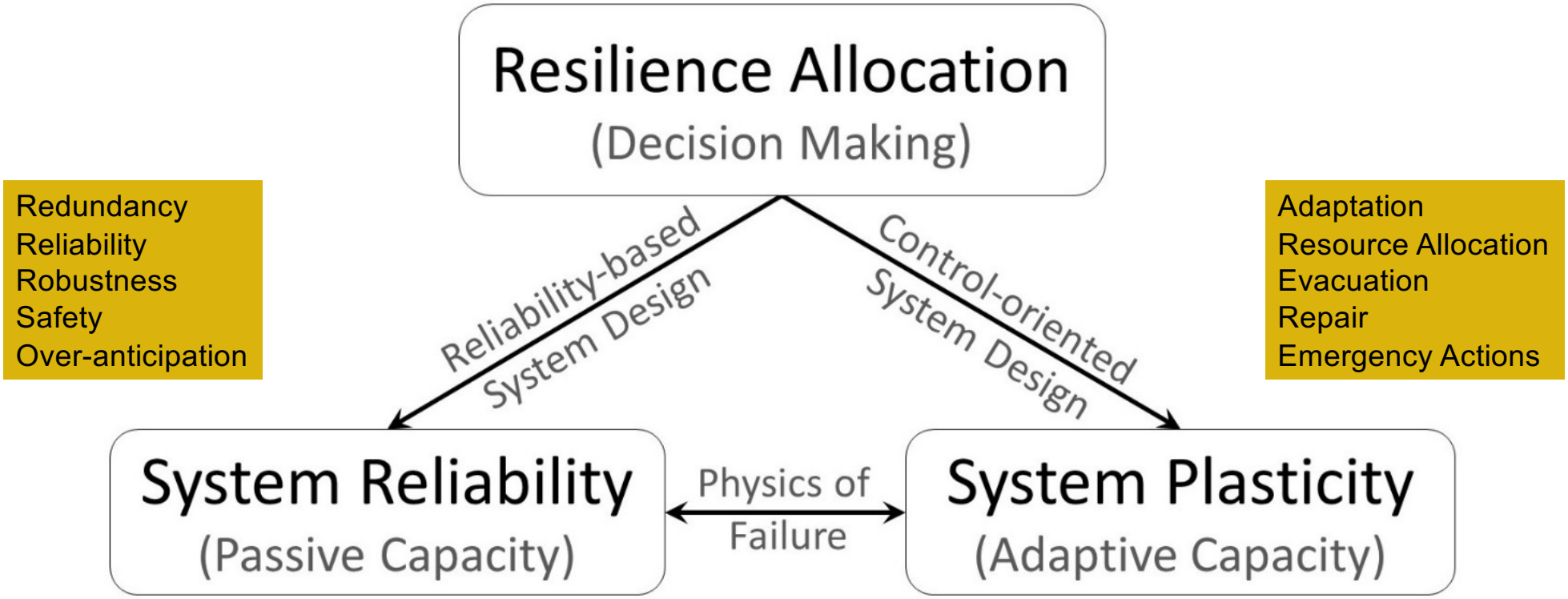
System Resilience …



Decisions

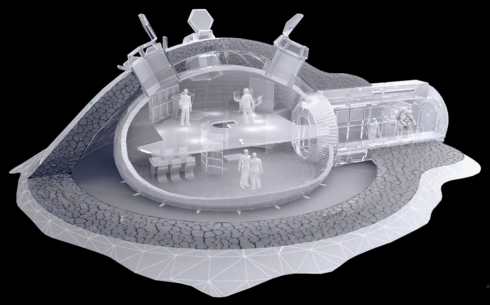
(1) What can go wrong?
(2) How does it go wrong?
(3) How likely is it?
(4) What are the consequences?
(5) What can be done about it?

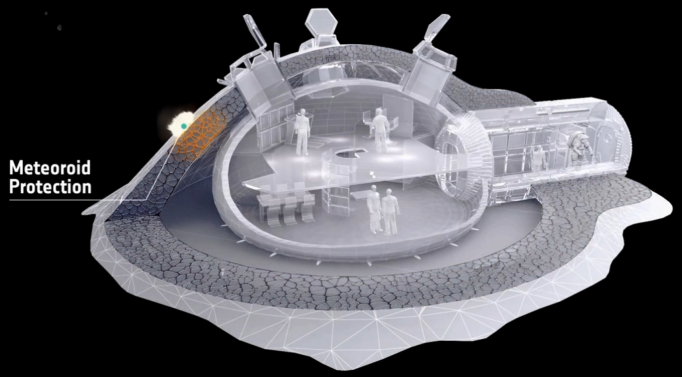
System Resilience … is both Passive and Adaptive

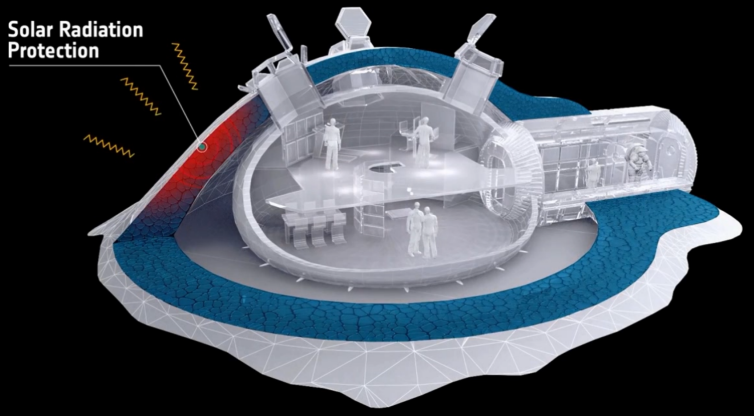


System Resilience

Resilience is understood as the ability of a system to **adapt**, **absorb** and **recover** quickly from a disruption, whether expected or unexpected, without fundamental changes in function or sacrifices in safety.







System Resilience … exploits monitoring and identification

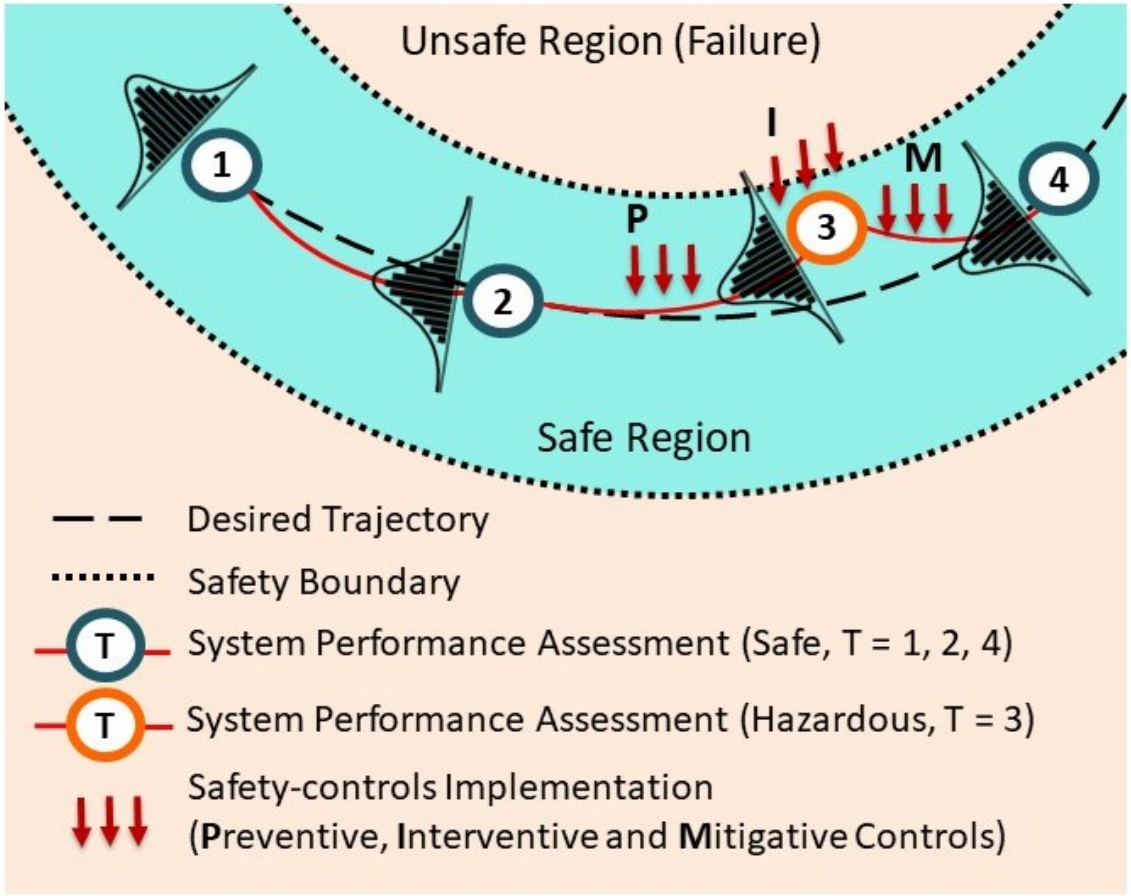
1 State estimation, assessment of performance or function.
2 Within boundary.

Safety-controls act (passive)

3 State estimation, identification of undesirable trajectory. Action must be taken. *Decision* made.

Safety-controls act (adaptive)

4 State estimation, assessment of performance or function. Within boundary.



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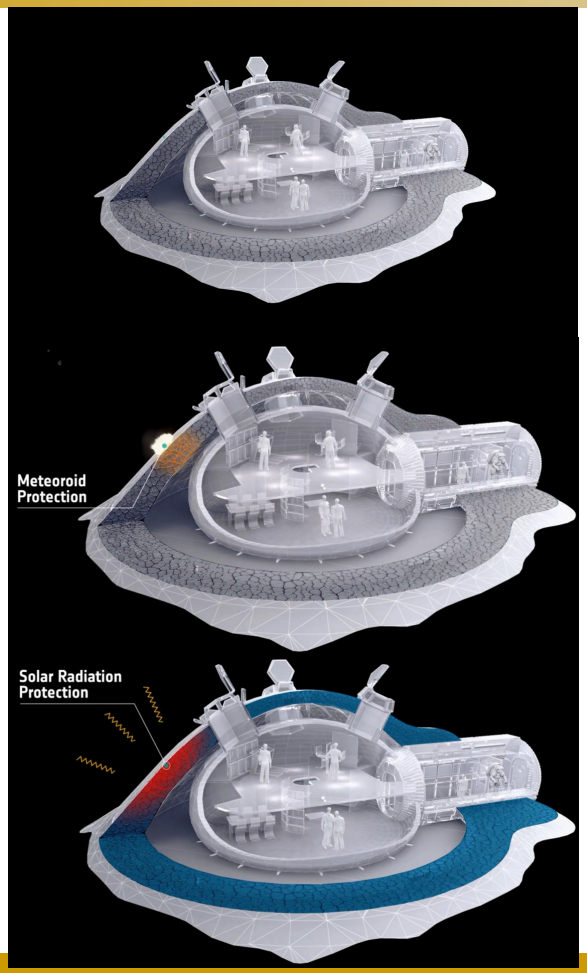
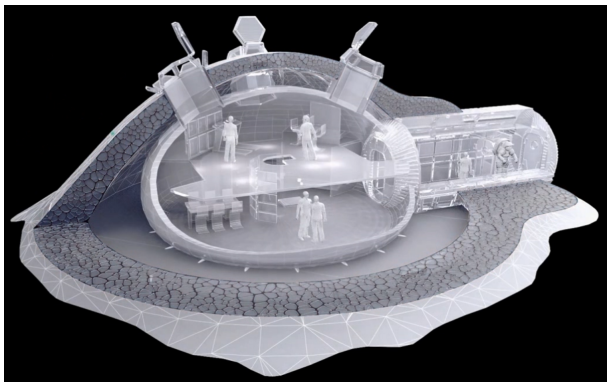


Control-Oriented Dynamic Computational Modeling Platform



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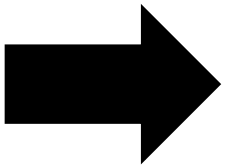
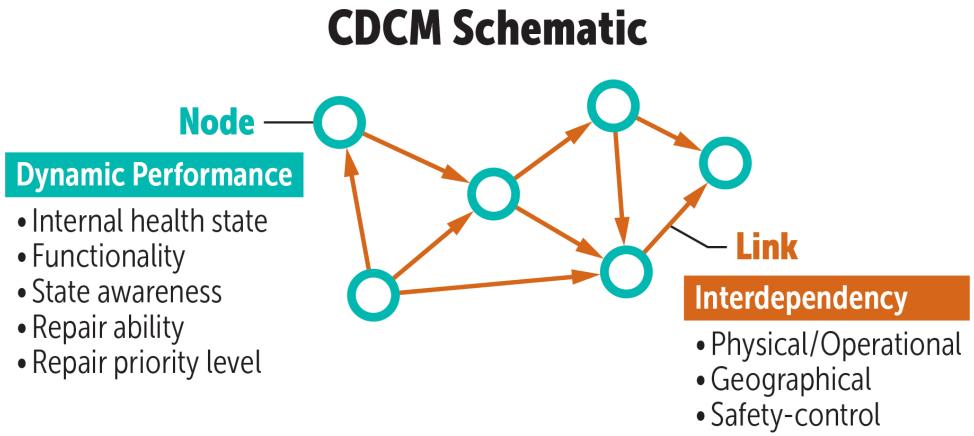
Safety-controls (passive)

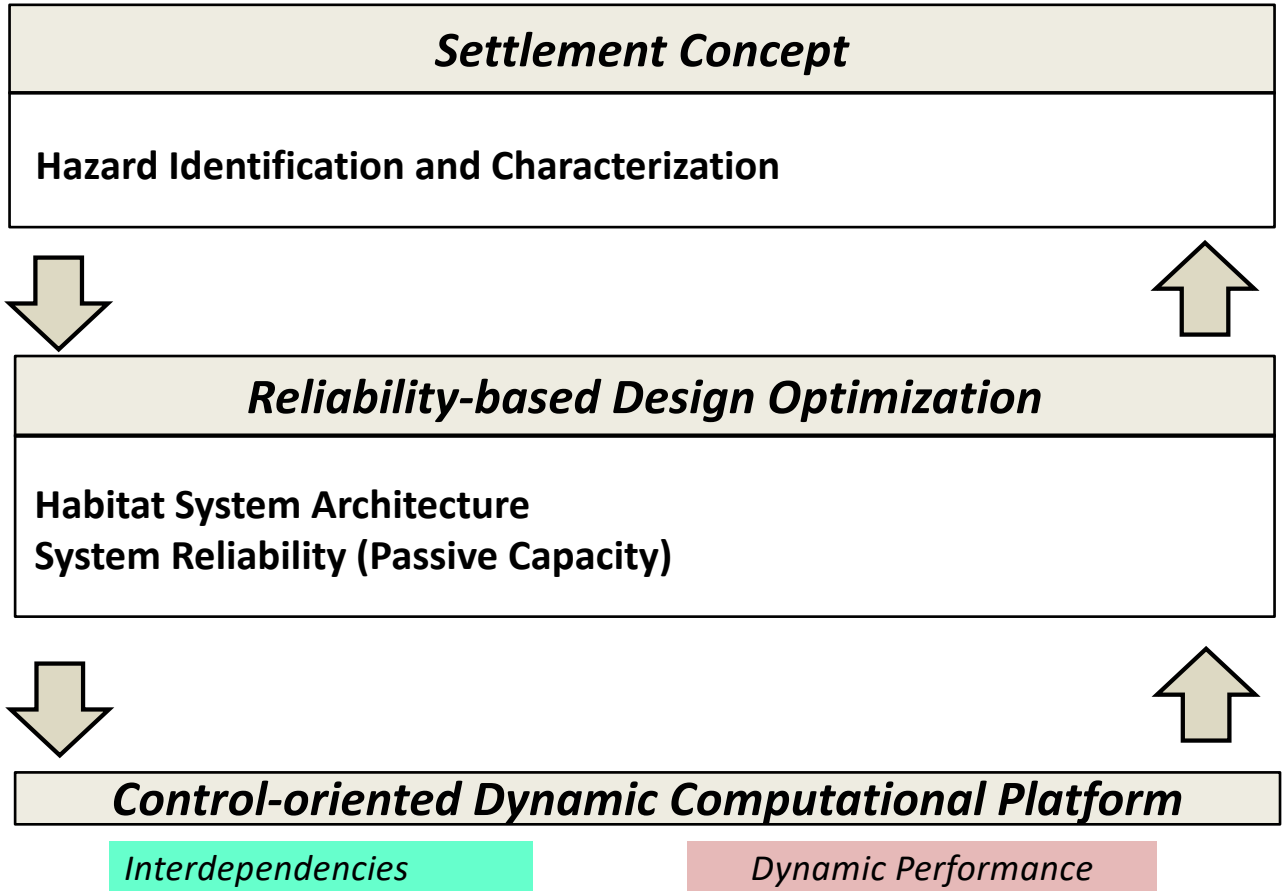
Safety-controls (adaptive)

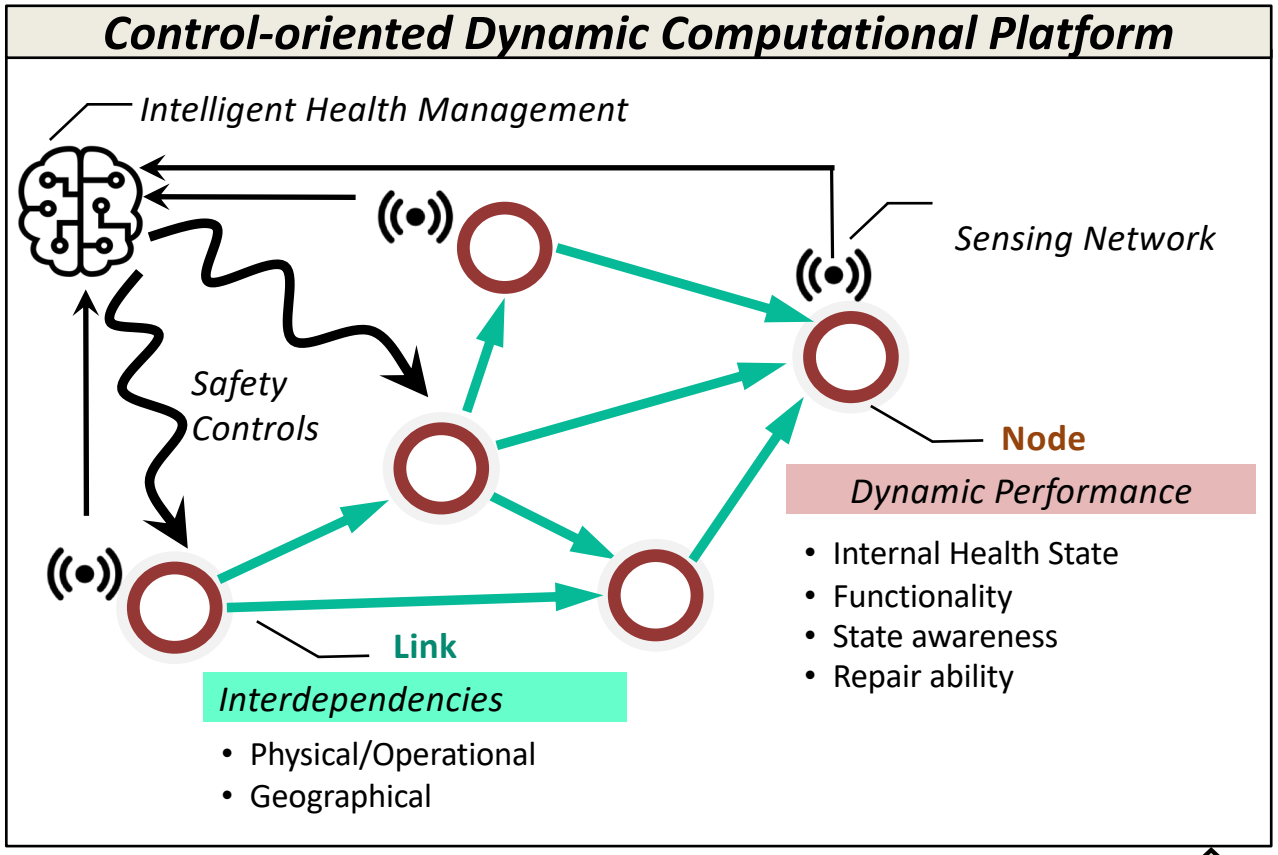
Computational Evaluation

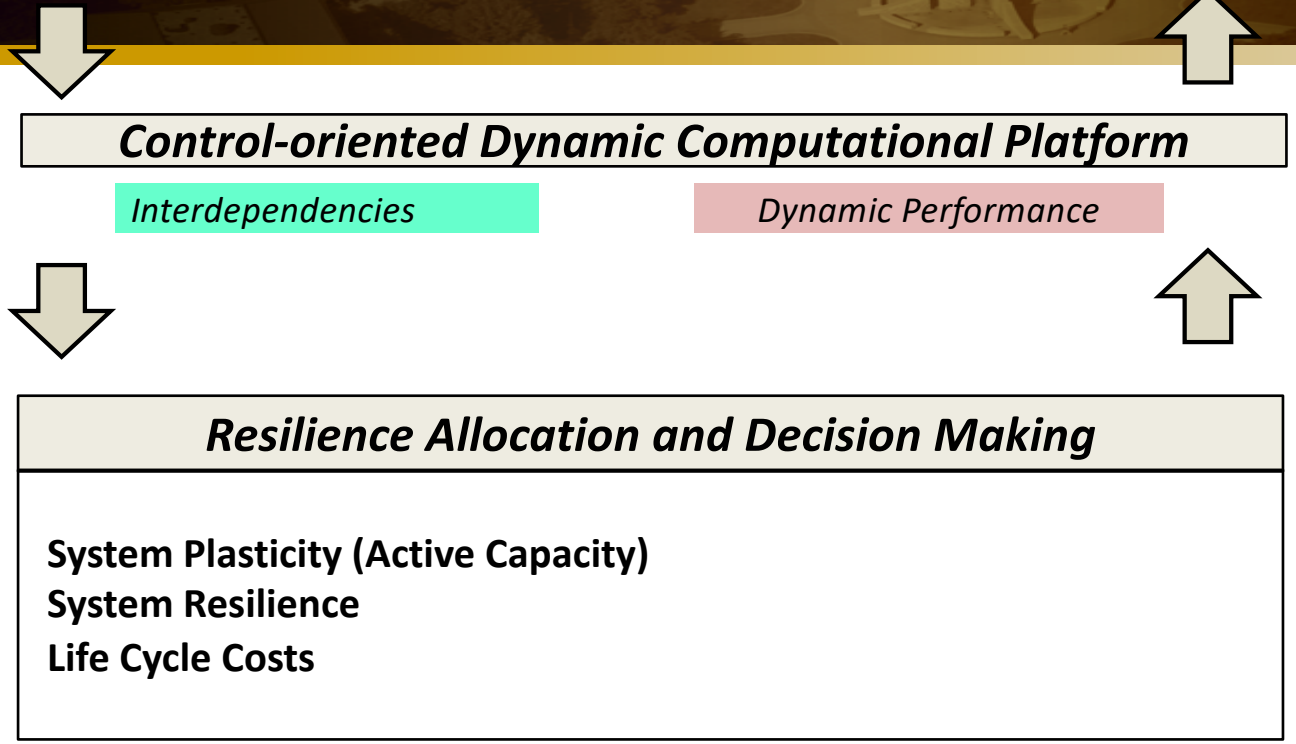




Using the Platform for Design Choices

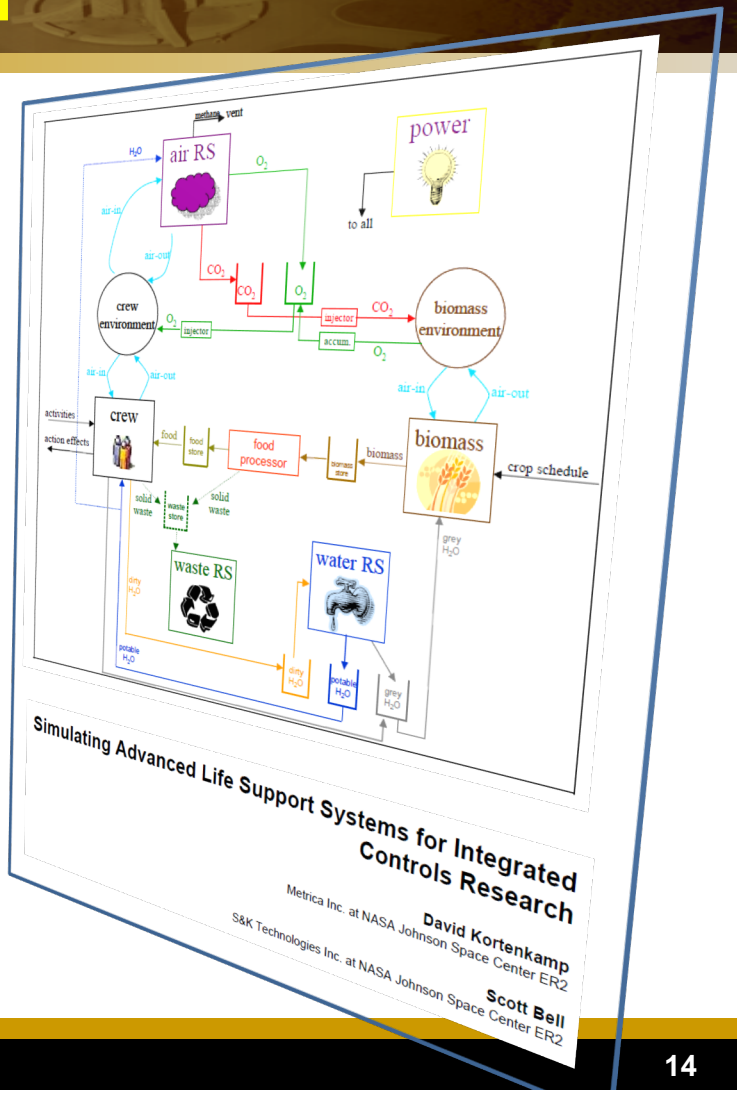



Control-oriented Dynamic Computational Platform
Intelligent Health Management
Sensing Network
Safety
Controls
Node
Dynamic Performance
• Internal Health State
• Functionality
• State awareness
• Repair ability
Link
Interdependencies
• Physical/Operational
• Geographical

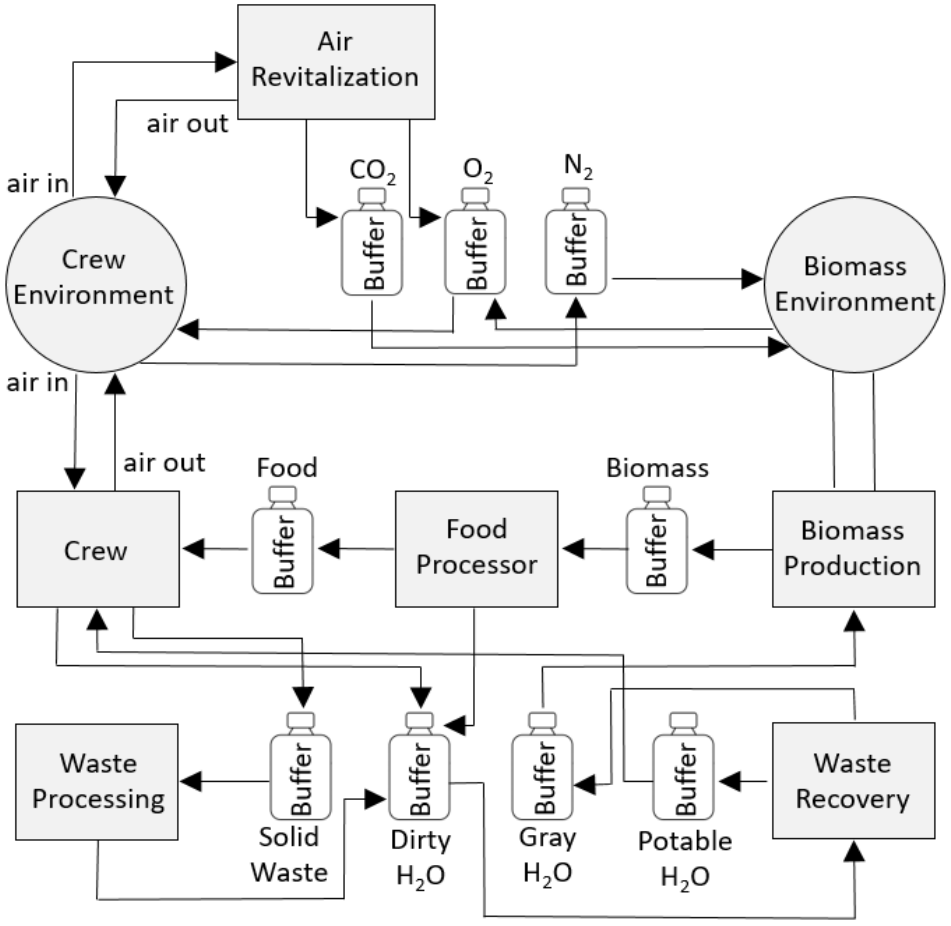

Control-oriented Dynamic Computational Platform
Interdependencies
Dynamic Performance
Resilience Allocation and Decision Making
System Plasticity (Active Capacity)
System Resilience
Life Cycle Costs

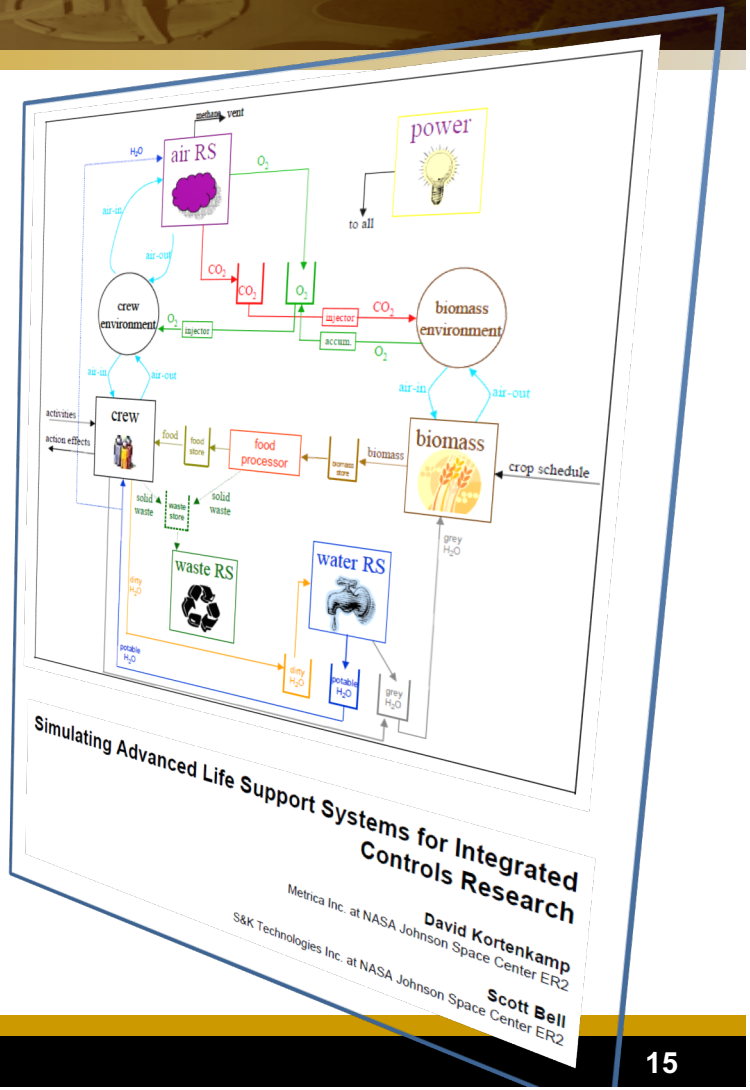
Case Study … Environmental Control and Life Support System

- The basic human metabolic spacecraft requirements of oxygen, water, and food have been **characterized well**.
- These requirements are largely been met for **short-duration missions** (from Project Mercury to the Space Shuttle) with **open-loop life support systems** using expendables.



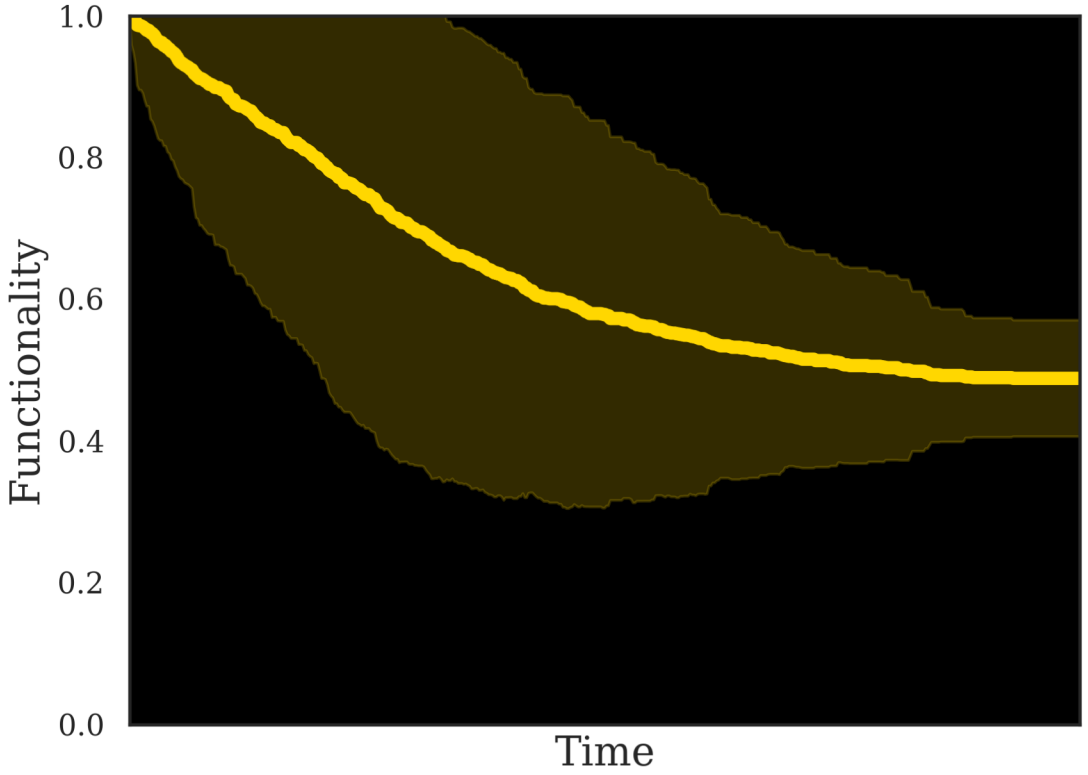
Case Study … Environmental Control and Life Support System





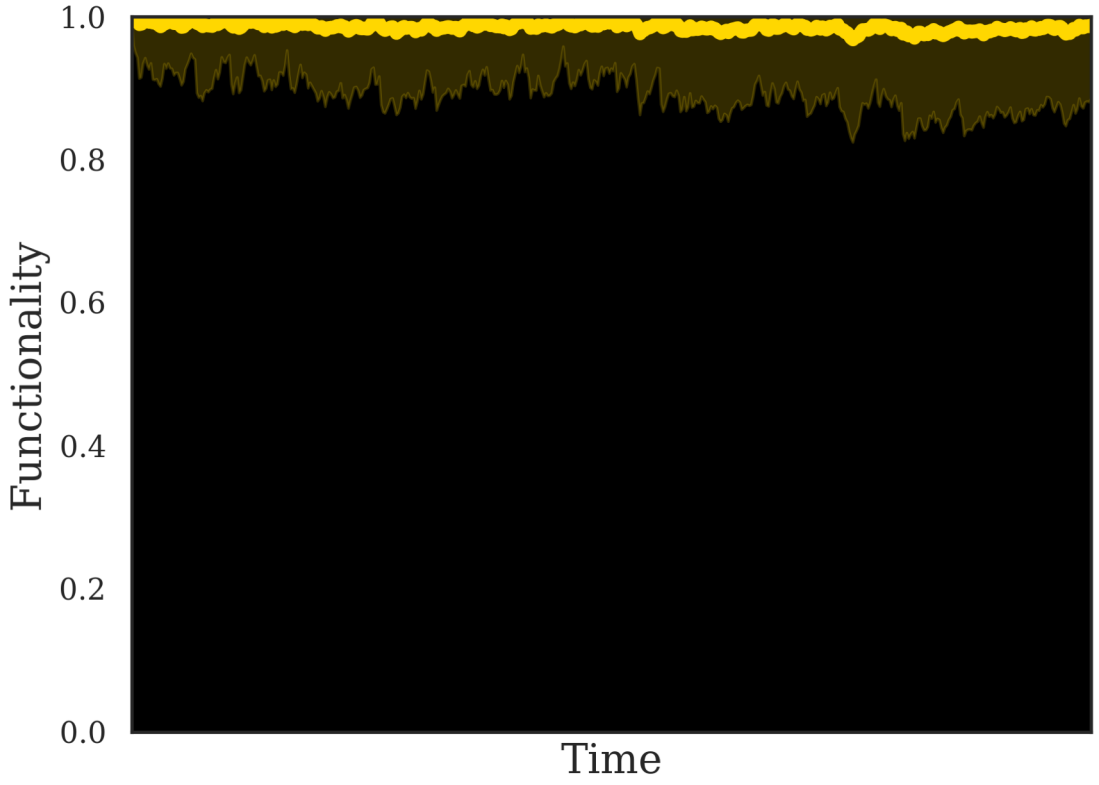
Case Study … Demonstration of the Computational Platform

Functionality of the system with **no resources** for recovery (no active capacity):



Case Study … Demonstration of the Computational Platform

Functionality of the system with **unlimited resources** for recovery (both active and passive capacity):



Case Study … Demonstration of the Computational Platform

Decision needed: How to choose resource allocation.

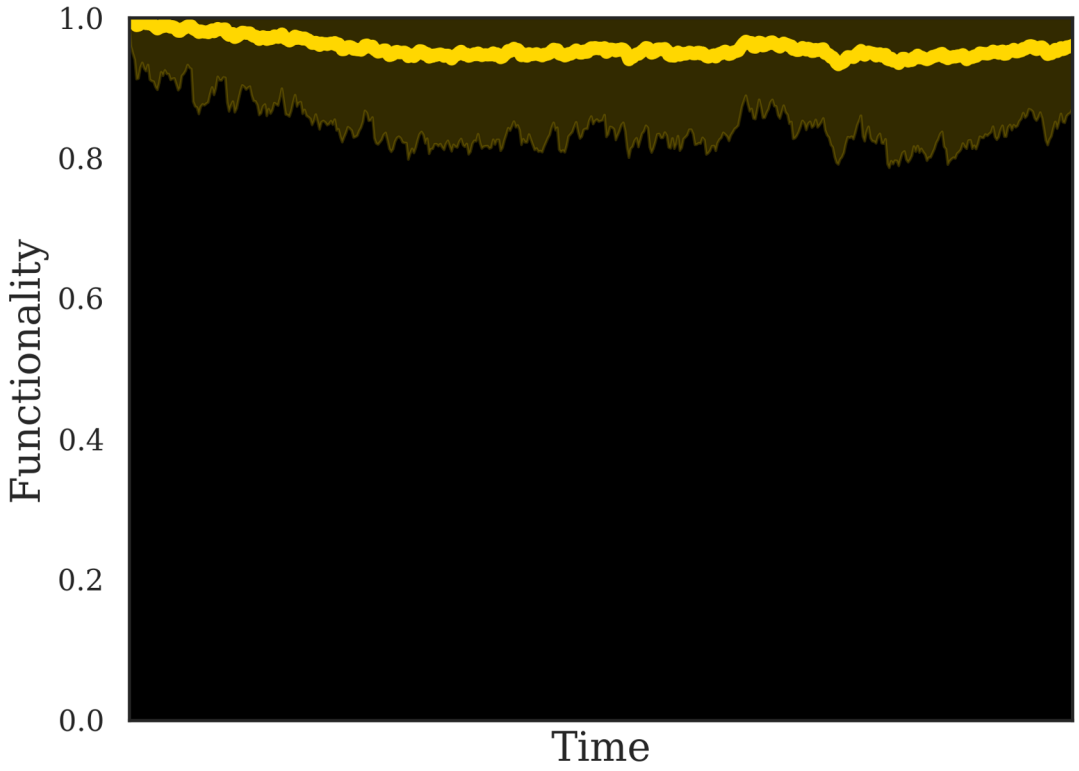
How much should we spend on improving the sensing system or allocating resources for recovery?

We need to analyze the cost-effectiveness (cost can be any negative consequence) of these scenarios.

So, first, we need to use our computational platform to understand the functionality of the system under each scenario.

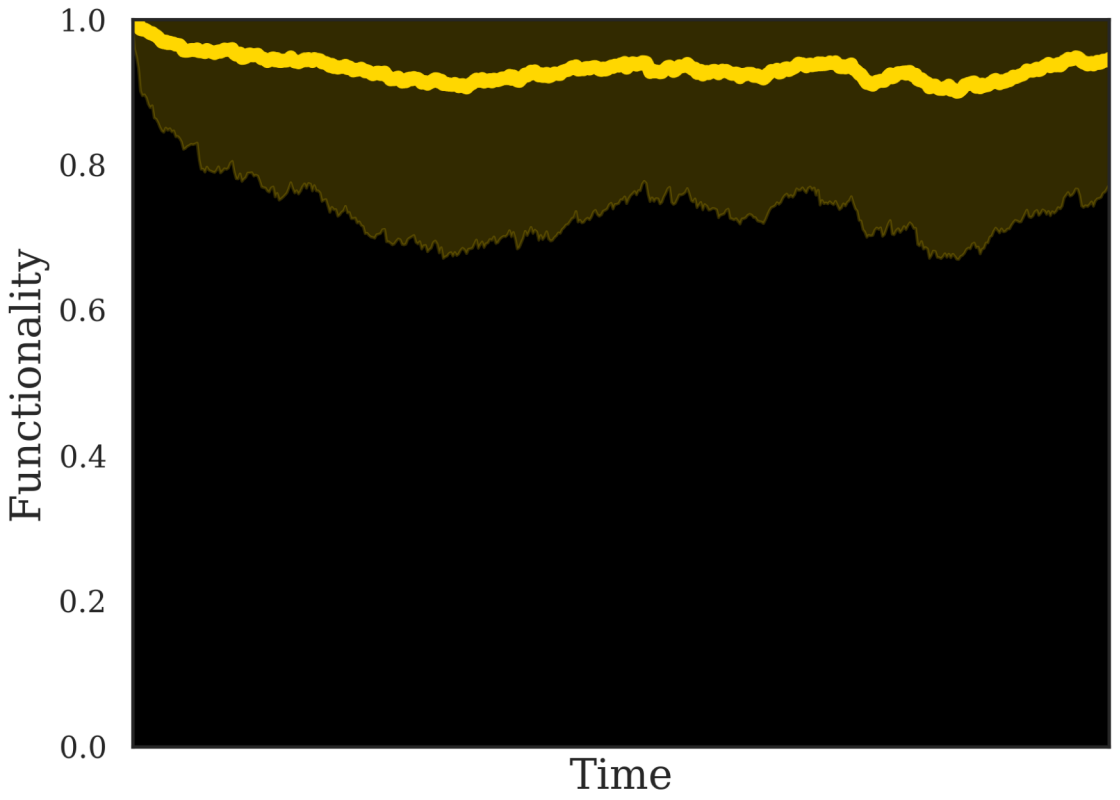
Case Study … Demonstration of the Computational Platform

Unlimited resources for recovery with **imperfect sensing** system:



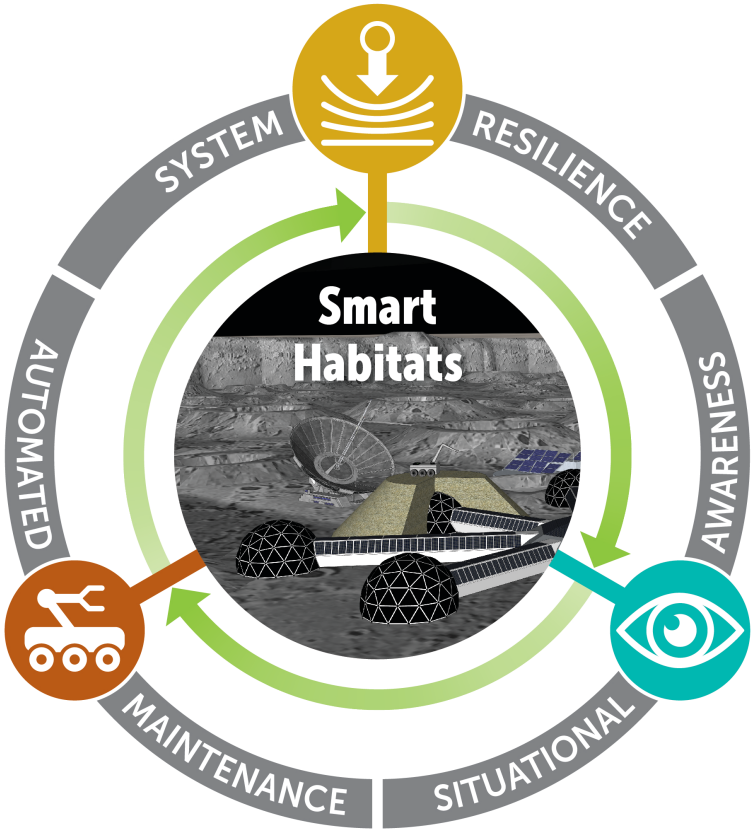
Case Study … Demonstration of the Computational Platform

Functionality with **limited resources** for recovery and a **perfect sensing** system:



Space Technology Research *Institute*: Resilient Extraterrestrial Habitat Institute

Smart Habs STRI
Thrust 1 System Resilience
Thrust 2 Situational Awareness
Thrust 3 Automated Maintenance



Resilience Extraterrestrial Habitat Insitute

Thrust 1 will develop the techniques needed to establish a control-theoretic paradigm for resilience, and the computational capabilities needed to capture complex behaviors and perform trade studies to weigh different choices regarding habitat architecture and onboard decisions.

Thrust 2 will develop and validate generic, robust, and scalable methods for detection and diagnosis of anticipated and unanticipated faults that incorporates an automated active learning framework with robots- and humans-in-the-loop.

Thrust 3 will develop and demonstrate the technologies needed to realize teams of independent autonomous robots, built using soft materials, that navigate through dynamic environments, select the appropriate modular sensors and end-effectors for specific needs, and collaboratively replace damaged structural elements using deployable modules.

Acknowledgements

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- Discovery Park at Purdue University