
The Design of Early System Concepts using Systems Theory

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Bottom Line Up Front

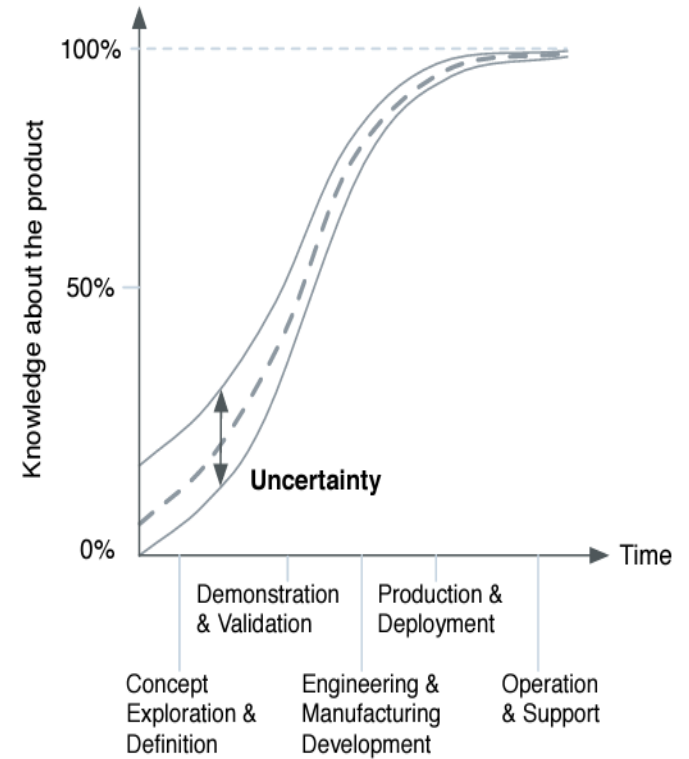
- **Early concepts presented today contain very little real information, and they fail to enable stakeholder mental models to coalesce around the actual concept in context**
- **Systems-Theoretic Concept Design is a 3-phased early concept generation framework that applies the principles of STAMP to generate technology-, requirements-, and architecture-agnostic early design concepts**
- **STCD presents early concepts in the language of Systems Theory using the Semantics of Systems-Theoretic Accident Model & Processes – while treating portfolio-level emergence as a control problem**
- **Remaining milestones:**
 - Thesis defense/publication in Nov 2024
 - Carry into real-world applications in January 2025

Research Goal: Enable programs to deliver capabilities, not platforms

Methodology Goal: Thoroughly develop & propose viable Early Design Concepts

Today's Agenda

- ➔ • **The Problem**
- **Systems-Theoretic Concept Design**
- **Research Outputs, Limitations, Future Work**
- **Conclusions**



[Mavris & Pinon, 2011]

Complex Systems are Hard

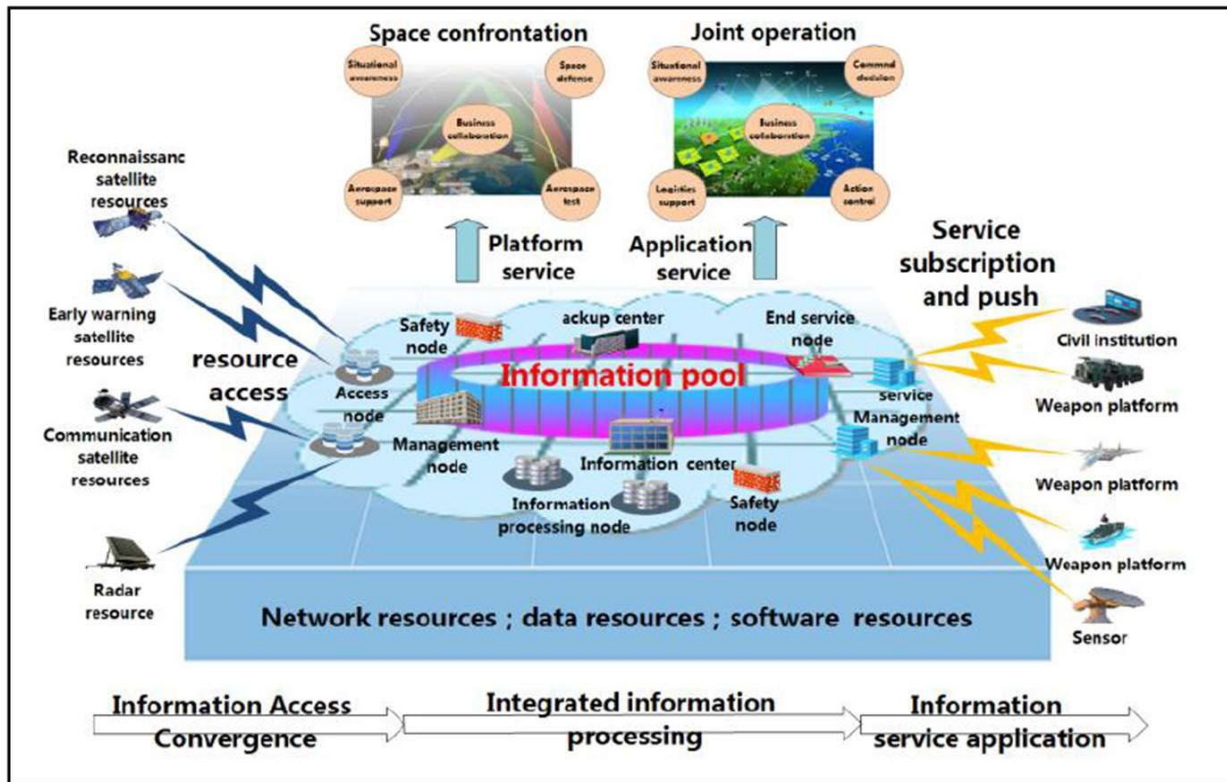
- **Context Matters:**
 - Designers love to focus on *How* a system will solve the problem at hand
 - *Architecture/Requirements Mismatch*: when the low-level, highly granular design specification doesn't align with high-level system goals or objectives
- **The Cart before the Horse:**
 - Engineers are trained and educated to apply expert precision in designing components, widgets, software, etc.
 - We're all guilty – decomposition guides us to solving the technical challenges we have been trained to solve

How can I create an early concept for a system that captures the appropriate context, addresses capability gaps, and does not marry a program to a particular architecture or technology?

Existing Models Convey Limited Information

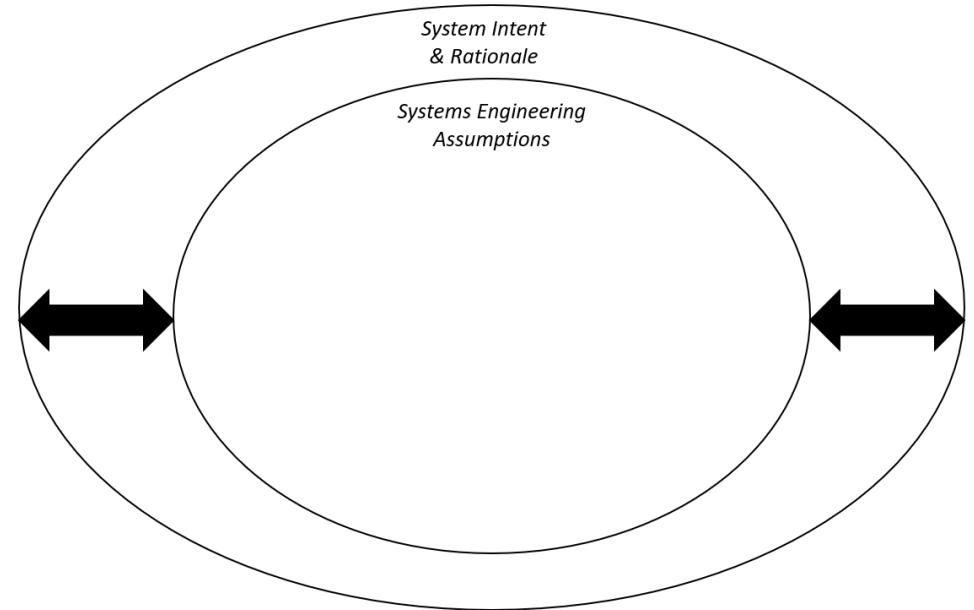
- The OV-1 has been in use for decades
- Provides limited context

- Forces stakeholders to anchor mental models to an architecture
- These models are often “just noise”



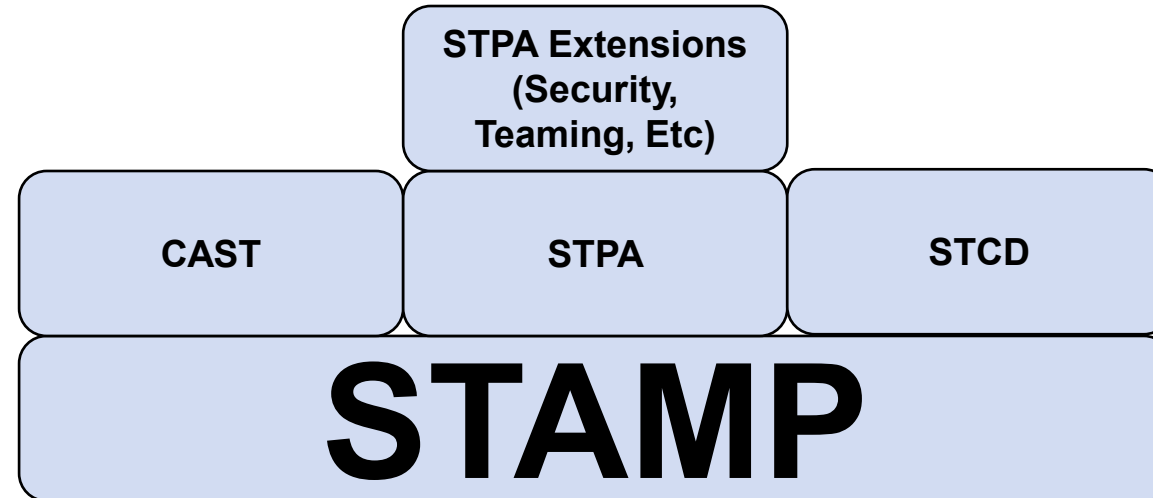
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Where does this work fit?

Building blocks for Systems-Theoretic Approaches for Engineered Systems:

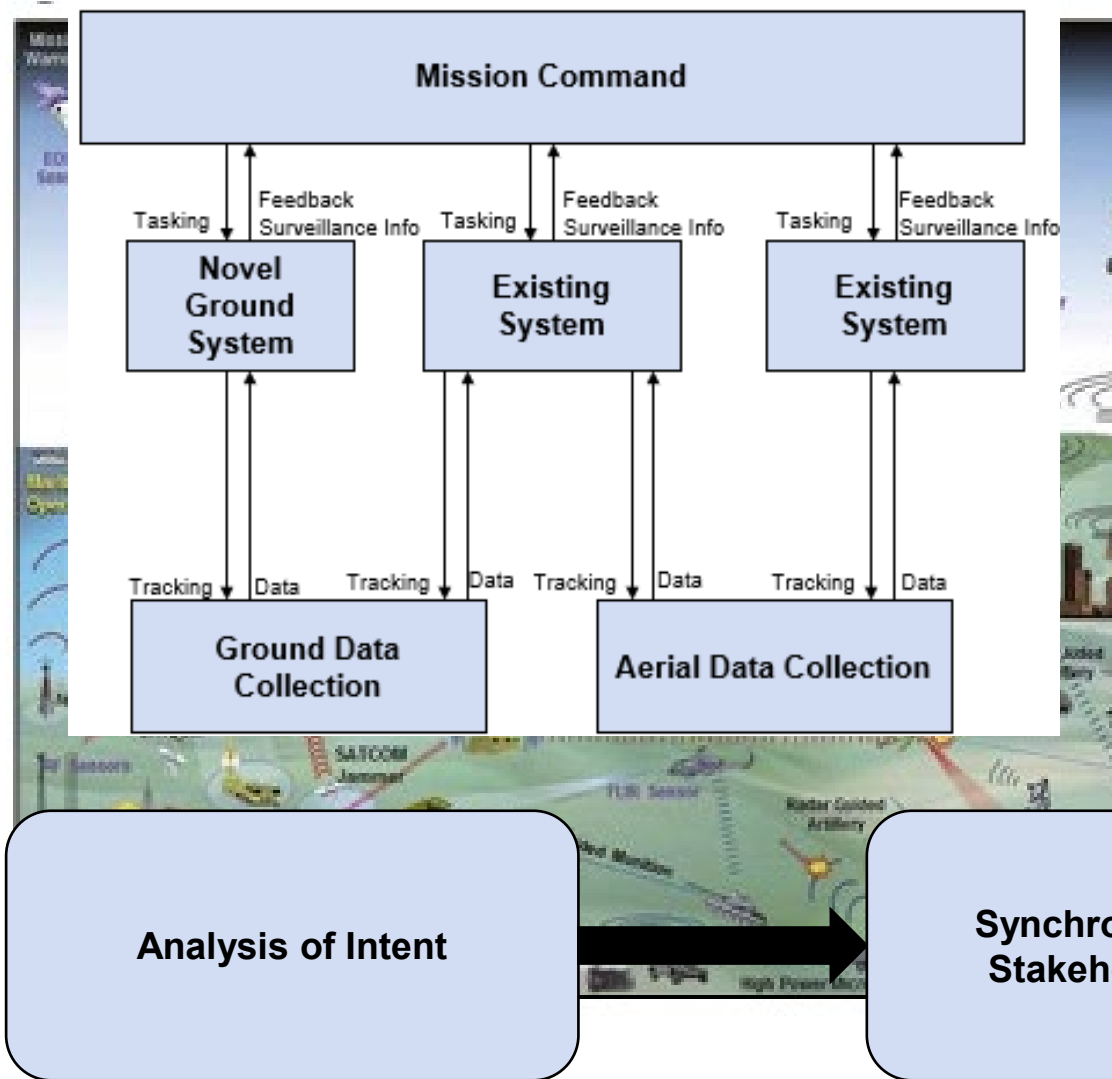


Introduction to Systems-Theoretic Concept Design

→ ~~Where we've been~~

→ What we're trying to do!

- Architecture Agnostic
- Not Technology Dependent
- Top-Down, synthetic, analytical approach
- Foundation for System Success



STCD Context

A portfolio-of-systems is designed, developed, and deployed to achieve a high-level policy.

*A portfolio-of-systems, comprised of its existing systems, operating environment, stakeholders, and other operators in the space, enacts a **BLACK BOX TRANSFORMATION**. This transformation achieves some **End State Attributes**, which may or may not align with the high-level policy.*

Any changes to the inputs to this transformation result in a new transformation. This context is critical to understanding the Portfolio-of-Systems context and STCD.



Mechanics of STCD

• Inputs

- Existing System Info
- Threat/Operating Environment Info
- Acquisitions Plans
- Stakeholder Identification
- Current portfolio info

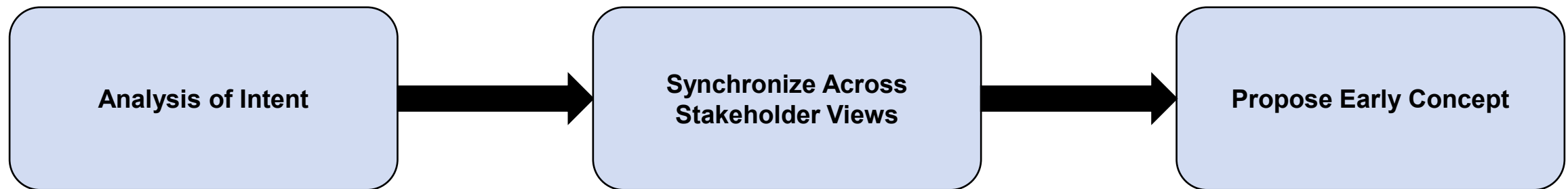
• Outputs

- Portfolio-of-Systems Control Structure
 - A Model of the New Concept
 - Control-based early design
- Intent Model for New System
 - In Context of Portfolio-of-Systems
 - Gaps to be filled by new system, new portfolio composition
- End State Exploration
 - Portfolio-level policy adjustments
 - System contributions to achieving policy
 - Current vs desired End State Info



Systems-Theoretic Concept Design

- **A New Approach to Propose Early Concepts**
 - A high-level, top-down framework
 - 3-Phases to move from mission analysis / Operational Design to a viable early concept
 - The trifecta: requirements-agnostic, technology-agnostic, & architecture-agnostic
- **Three Foundational Building Blocks for this Technique**
 - *Intent Model* for a new system: “Why”, “What”, assumptions & constraints
 - Systems-Theoretic roots to model both legacy systems & the portfolio as a whole
 - The principles of STAMP as a basis to build a design concept in context



Phase 1: Analysis of Intent

- Objectives: Understand Why a new System is needed for an existing portfolio
- Steps:
 - Translate capability gaps & the context of an existing portfolio-of-systems into an *Intent Model* for the new system
 - Capture, track & manage early system assumptions for use in future lifecycle activities

- Intent Model w/ 4 dimensions of *Intent*

Four general dimensions to System Intent

1. “Why”
 - High-level goals and objectives within a portfolio-of-systems
2. “What”
 - High-level functions, abstract function of the new system
3. Assumptions
 - Any fact, statement, or opinion that captures logic or rationale behind our early development decisions
4. Constraints
 - Limitations or restrictions, particularly on system scope; a bounding condition that would limit system behavior or development aims

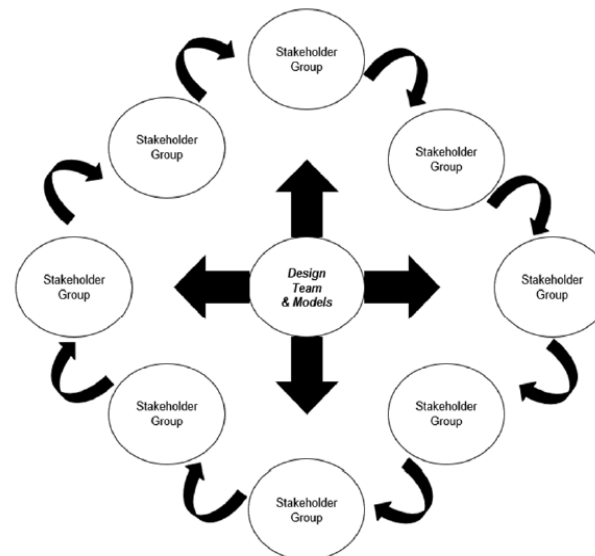
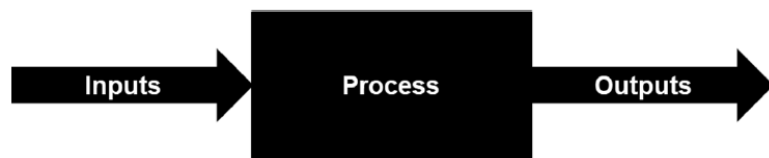
- Assumptions Taxonomy

Severity \ Classification	Critical	Vulnerable	Neither
Stakeholder Assumptions			
Technical Assumptions			
Operating Environment Assumptions			
Programmatic Assumptions			
Detailed Design Assumptions			

Phase 2: Synchronize Across Stakeholder Views

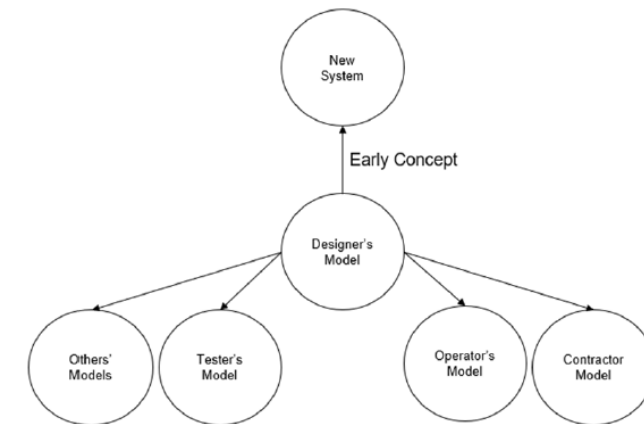
- **Objectives:** Help disparate stakeholder groups manage complexity
- **Steps:**
 - Present existing portfolio & new system as **Black Box Transformation Models**
 - Employ these models as epistemic objects across stakeholder groups to elicit feedback and lower semantic distance between stakeholders' mental models

Black Box Transformation Models



Mental Model Synchronization Loop

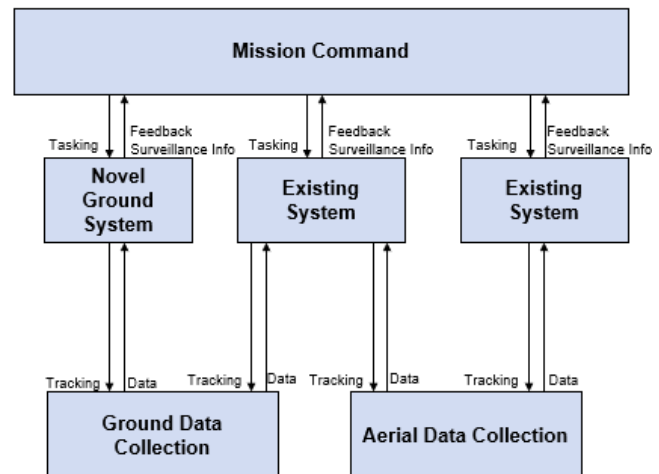
Semantic Distance for Stakeholders



Phase 3: Propose Early Concept

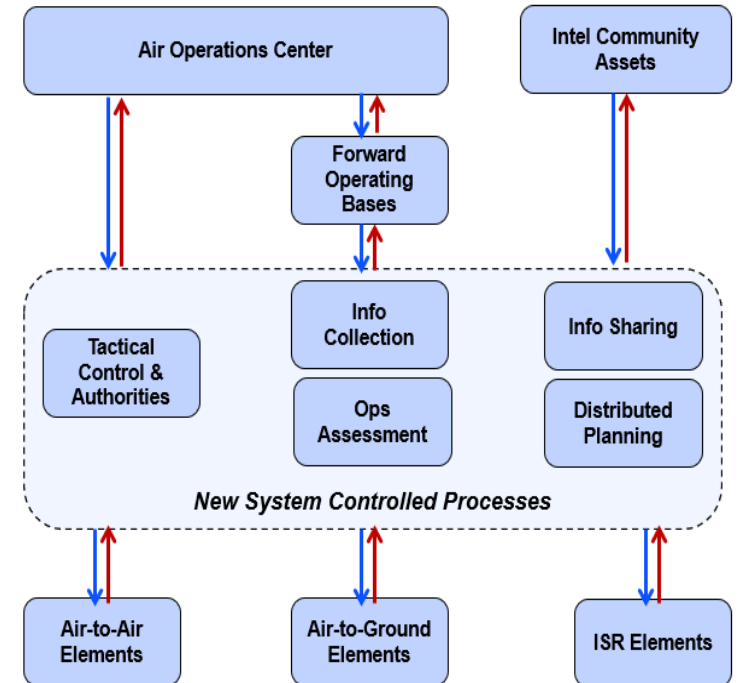
- **Objectives: Deliver an early concept that is viable while also maintaining tech-, reqt-, and architecture-agnostic**
- **Steps:**
 - **Digest & summarize stakeholder feedback from Phase 2**
 - **Translate *Intent Model* for the new system, existing portfolio, and P2 feedback into Portfolio-of-Systems model to present as first design artifact for the new system**

Portfolio-level Control Structure Model to display early concept



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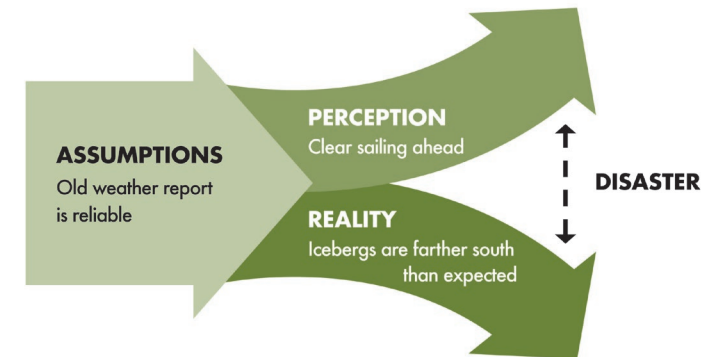


- **Paper presented at IEEE SysCon in Montreal, April 2024**
 - Paper topic: introduce portfolio-of-systems view & proposed extension of STAMP to use portfolio-level control structure as initial design artifact
- **Paper presented at INCOSE Symposium in Dublin, July 2024***
 - Paper topic: introduce systems-theoretic concept design and a novel intent model to aid in generation of early concept for new defense systems
- **Paper presented at Intl Conf for Transdisciplinary Engineering in London, July 2024**
 - Paper topic: synchronizing mental models across stakeholder views with Systems Theory
- **Paper presented at AIAA Aviation in Las Vegas, August 2024**
 - Paper topic: using 3-phased STCD approach for mission analysis for Defense Systems
- **Paper accepted at AIAA SciTech in Orlando, January 2025**
 - Paper topic: translating Portfolio-of-System design artifact & intent model into high-level requirements

Limitations?

- **Methodological Limitations:**

- Context here is for systems within a portfolio
- Assumptions Taxonomy hasn't been proven to be exhaustive, but the authors contend that it is at least useful
- Portfolio-of-Systems model is not *One Model to Rule them All* – but they are based on proven tools with Systems-Theoretic foundation
- While this has been applied to real-world inspired problems, results are still notional and squarely in the “hypothesis generating” camp
- This approach is limited to the design of control-oriented systems, mainly applied to aerospace & defense/national security systems



[The Circle of Assumptions, 2022]

The Future for STCD?

- Thesis Defense in November 2024
- AIAA SciTech paper for January 2025

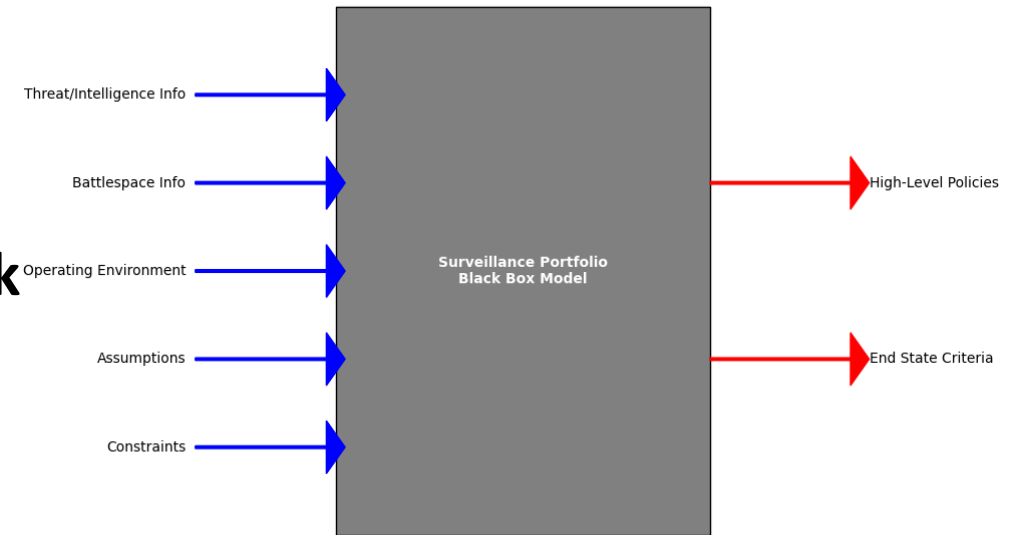


- Application in the real world!
 - Plan to carry forward this method & principles to solve real problems
 - Starting new job in January 2025, planning to apply to real systems engineering problems



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Questions?

