Opportunities and Challenges of Integrating Systems Thinking into Systems Engineering
INCOSE Webinar
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Topics

- Position Statement
- Systems Thinking
- Systems Engineering
- Systems Taxonomy
- Systems Outcomes
- Barriers to Integration of Systems Thinking into Systems Engineering
- INCOSE Initiatives to Address Challenges
- Summary and Wrap-Up
- References
- Contact Information

Position Statement

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- Systems thinking and its application in different domains, e.g., education, around for 50+ years
  - Not embraced in systems engineering or widely accepted as a design paradigm for systems
- Systems engineering formalized over the last 70+ years based on a top-down, reductionist approach
- No improvement in systems outcomes for aerospace and defense systems over the same time period
- Application of systems integration processes and methods, based on experiences with deterministic and some stochastic systems, are not proven to be applicable to to most stochastic systems and to non-deterministic systems
- Successful integration of systems thinking into systems engineering requires changes to the context, architecting, and systems integration processes and methods suitable for stochastic systems and non-deterministic systems

The good news is that there are research opportunities!

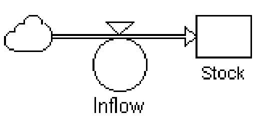
Systems Thinking

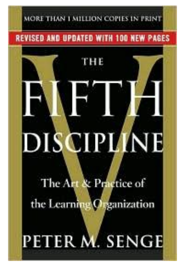
Progression of Systems Thinking

Systems One: An Introduction to Systems Thinking
Draper L. Kauffman, Jr.
Characteristics & Complexities of Systems 1980

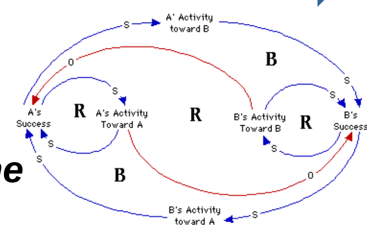
No Limits to Learning
The Club of Rome 1979

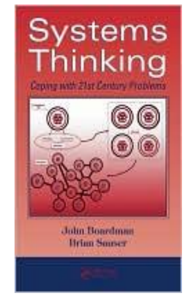
Industrial Dynamics
Jay Forrester
Stocks & Flows 1961

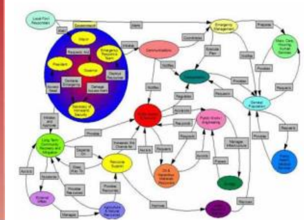




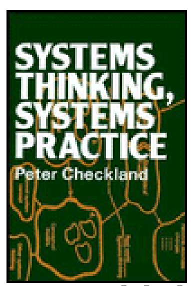
The Fifth Discipline
Peter Senge
System Archetypes
1990



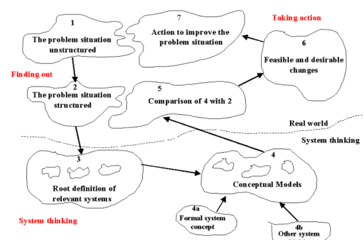


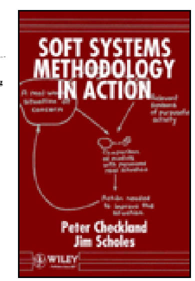


Systems Thinking
John Boardman
Brian Sauser 2008



Systems Thinking, Systems Practice
Peter Checkland
Formal Schematics
1981





Soft Systems Methodology In Action
Peter Checkland & Jim Scholes
Formal Schematics
1990

Advanced Systems Thinking, Engineering, and Management
Derek Hitchins 2003

Different Definitions of Systems Thinking

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1. Kauffman (1980) – A system is a group of interacting, interrelated, or interdependent elements that together form a complex whole. All the parts of the system are related to the same overall process, procedure, or structure, yet they are (most likely) all different from one another and often perform completely different functions.
2. Checkland (1981) – An *epistemology* which, when applied to human activity is based upon the four basic ideas: *emergence, hierarchy, communication*, and *control* as characteristics of *systems*. When applied to *natural* or *designed systems* the crucial characteristic is the *emergent properties* of the whole.
3. Senge (1990) – The 5th discipline that integrates the others (four disciplines of personal mastery, mental models, building shared vision and team learning), fusing them into a coherent body of theory and practice.

   Conceptual framework, body of knowledge, and tools developed over the past 50 years to understand and articulate patterns in systems.

   Systems thinking is a way of thinking about, as well as a language for describing and understanding, the forces and interrelationships that shape the behavior of systems.

   This discipline helps us see how to change systems more effectively, and to act more in tune with the larger processes of the natural and economic world
4. Boardman & Sauser (2008) – … can be thought of in two ways. First, … is to think about systems; in other words to use our mental capacities and the tools we have acquired for cognizing, analyzing and synthesizing to ruminate on the systems that confront us …. also describe concepts, advanced by engineers and systems analysts, to help organize one's thoughts and actions relative to the systems of interest, and specifically to their design.

Kauffman's Complex System Characteristics

- Self-Stabilizing
  - Loose versus Tight Specifications
- Goal-Seeking
- Program-Following
- Self-Reprogramming
- Anticipation
  - React to Warnings
- Environment Modifying
- Self-Replicating
- Self-Maintaining and Repairing
- Self-Reorganizing
- Self-Programming

Draper L. Kauffman, Jr., *Systems One: An Introduction to Systems Thinking*, The Innovative Learning Series, Future Systems, Inc., 1980.

Senge’s Laws of the Fifth Discipline

- Today’ s problems come from yesterday’ s solutions
- The harder you push, the harder the system pushes back
- Behavior grows better before it grows worse
- The easy way out usually leads back in
- The cure can be worse than the disease
- Faster is slower
- Cause and effect are not closely related in time and space
- Small changes can produce big results - but the areas of highest leverage are often the least obvious
- You can have your cake and eat it too - but not at once
- Dividing an elephant in half does not produce two small elephants
- There is no blame

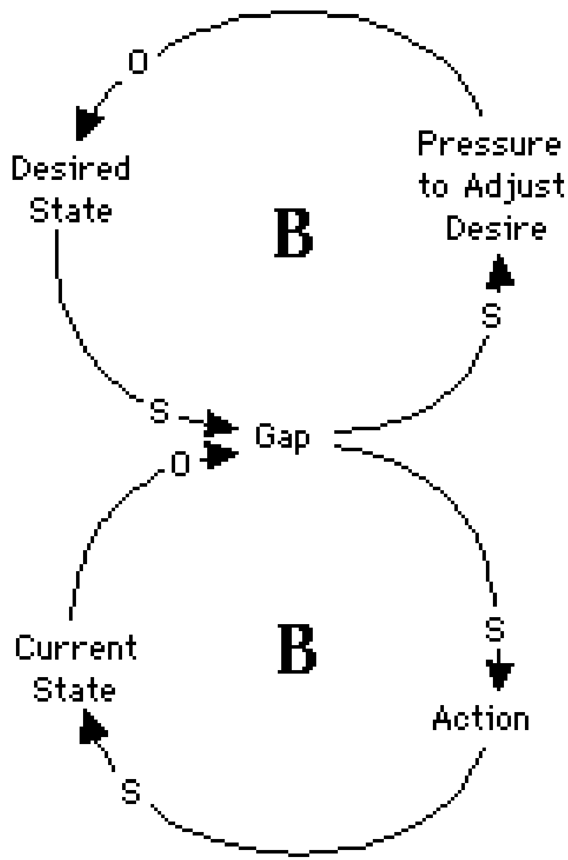
Peter M. Senge, *The Fifth Discipline*, Doubleday, 1991.

Senge's Systems Archetypes

- Balancing Process with Delay
  - Reaction Times
- Limits to Growth
- Shifting the Burden
  - Shifting the Burden to the Intervener
- Eroding Goals
- Escalation
- Success to the Successful
- Tragedy of the Commons
- Fixes that Fail
- Growth and Underinvestment

Peter M. Senge, *The Fifth Discipline*, Doubleday, 1991.

Example System Archetype: Eroding Goals



B is a balancing loop

R is a reinforcing loop

Description - Shifting the burden type of structure where short-term solution involves letting long-term, fundamental goal decline.

Early Warning Symptom - OK if performance standards slide, just until crisis is over.

Management Principle - Hold the vision.

Business Story - Companies lose market share due to late deliveries despite superior "quality" of their products

Peter M. Senge, *The Fifth Discipline*, Doubleday, 1991.

Progression of Systems Thinking in Engineering

- Although systems thinking has been around for 50+ years in the modern era, with apologies to the ancients, it has not been embraced in systems engineering or widely accepted as a design paradigm for systems

- Need to encourage systems engineering visionaries!

Systems Engineering

Evolution of Systems Engineering

Evolutionary Forces

•Increasing system complexity inducing actions to develop & apply methods by which efficient planning & design accomplished in complex situations where no one scientific/engineering discipline can account for all factors

•Context of expanding needs and environment including all external factors affecting/affected by the system … states of tension or unbalance

•Consequence of Shortage of Technically Trained People

Historical Development

•Examples of ***systems thinking*** from ancient times, e.g., pyramids

•Radio Corporation of America recognized need for ***systems approach*** for television in 1930s

•Operations research during and after World War II including ***systems analysis*** by RAND Corporation

•First attribution of term ***systems engineering*** by Bell Telephone Laboratories in early 1940s identifying functions performed by Bell System from its beginning

•First known systems engineering course taught by G.W. Gilman, Director of Systems Engineering at Bell Telephone Laboratories, at MIT in 1950 … systems engineering department case study to provide economical transmission system across Atlantic Ocean for live television broadcasting

Arthur D. Hall, Bell Telephone Laboratories, *A Methodology for Systems Engineering*, Van Nostrand Reinhold Company, 1962.

INCOSE Systems Engineering Handbook

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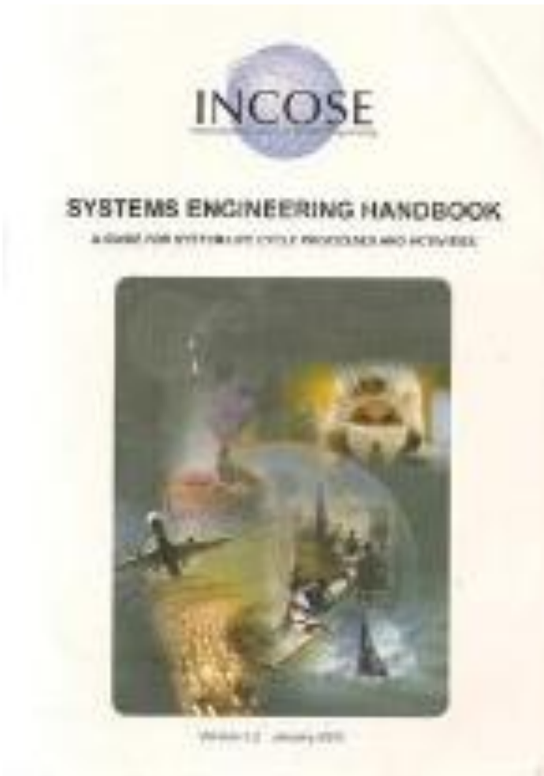


1 Systems Engineering Handbook Scope

1.2 Application

This handbook is consistent with ISO/IEC 15288:2008 – *Systems and software engineering – System life cycle processes* (hereafter referred to as ISO/IEC 15288:2008) to ensure its usefulness across a wide range of application domains – man-made systems and products, as well as business and services.

2.2 Definition of Systems Engineering

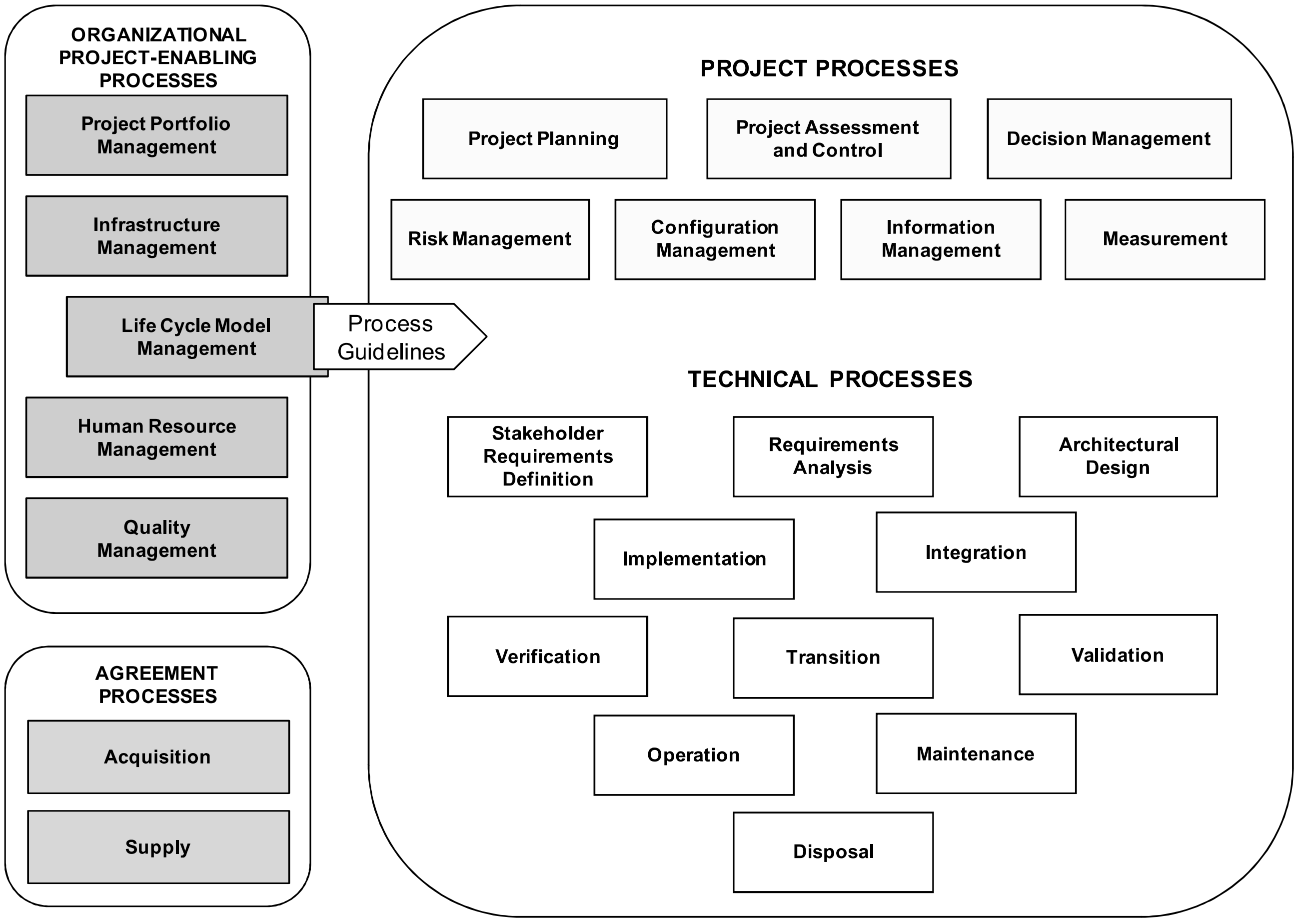
….

The SE perspective is based on systems thinking. Systems thinking occurs through discovery, learning, diagnosis, and dialog that lead to sensing, modeling, and talking about the real-world to better understand, define, and work with systems. Systems thinking is a unique perspective on reality—a perspective that sharpens our awareness of wholes and how the parts within those wholes interrelate. A systems thinker knows how systems fit into the larger context of day-to-day life, how they behave, and how to manage them. [page 7]

Systems thinking recognizes circular causation, where a variable is both the cause and the effect of another and recognizes the primacy of interrelationships and non-linear and organic thinking—a way of thinking where the primacy of the whole is acknowledged. [page 8]

Cecilia Haskins, editor, *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities*, Version 3.2.1, INCOSE-TP-2003-002-03.1.1, January 2011.

System Life Cycle Processes per ISO/IEC 15288-2008



Cecilia Haskins, editor, *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities*, Version 3.2.1, INCOSE-TP-2003-002-03.1.1, January 2011.

INCOSE Definitions

Systems

•An integrated set of elements, subsystems, or assemblies that accomplish a defined objective. These elements include products (hardware, software, firmware), processes, people, information, techniques, facilities, services, and other support elements.

Systems Engineering

•Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem:

- Operations
- Performance
- Test
- Manufacturing
- Cost & Schedule
- Training & Support
- Disposal

•Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

Consensus of INCOSE Fellows

Definition of a System

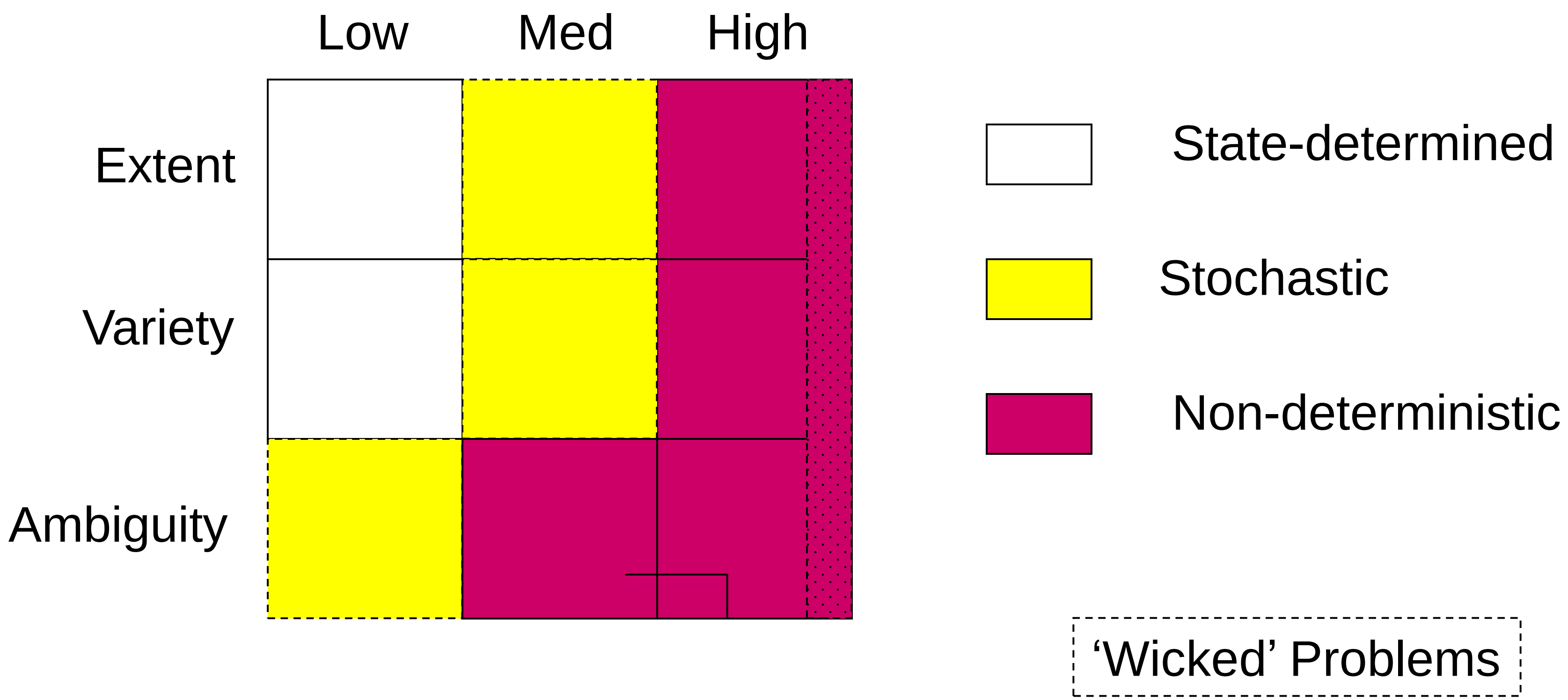
•A system is a construct or collection of different elements that together produce results not obtainable by the elements alone. The elements, or parts, can include people, hardware, software, facilities, policies, and documents; that is, all things required to produce systems-level results. The results include system level qualities, properties, characteristics, functions, behavior and performance. The value added by the system as a whole, beyond that contributed independently by the parts, is primarily created by the relationship among the parts; that is, how they are interconnected (Rechtin, 2000).

Systems Engineering

•Systems Engineering is an engineering discipline whose responsibility is creating and executing an interdisciplinary process to ensure that the customer and stakeholder's needs are satisfied in a high quality, trustworthy, cost efficient and schedule compliant manner throughout a system's entire life cycle. This process is usually comprised of the following seven tasks: **S**tate the problem, **I**nvestigate alternatives, **M**odel the system, **I**ntegrate, **L**aunch the system, **A**ssess performance, and **R**e-evaluate. These functions can be summarized with the acronym SIMILAR: **S**tate, **I**nvestigate, **M**odel, **I**ntegrate, **L**aunch, **A**ssess and **R**e-evaluate. This Systems Engineering Process is shown in Figure 1. It is important to note that the Systems Engineering Process is not sequential. The functions are performed in a parallel and iterative manner.

Systems Taxonomy

Systems Taxonomy

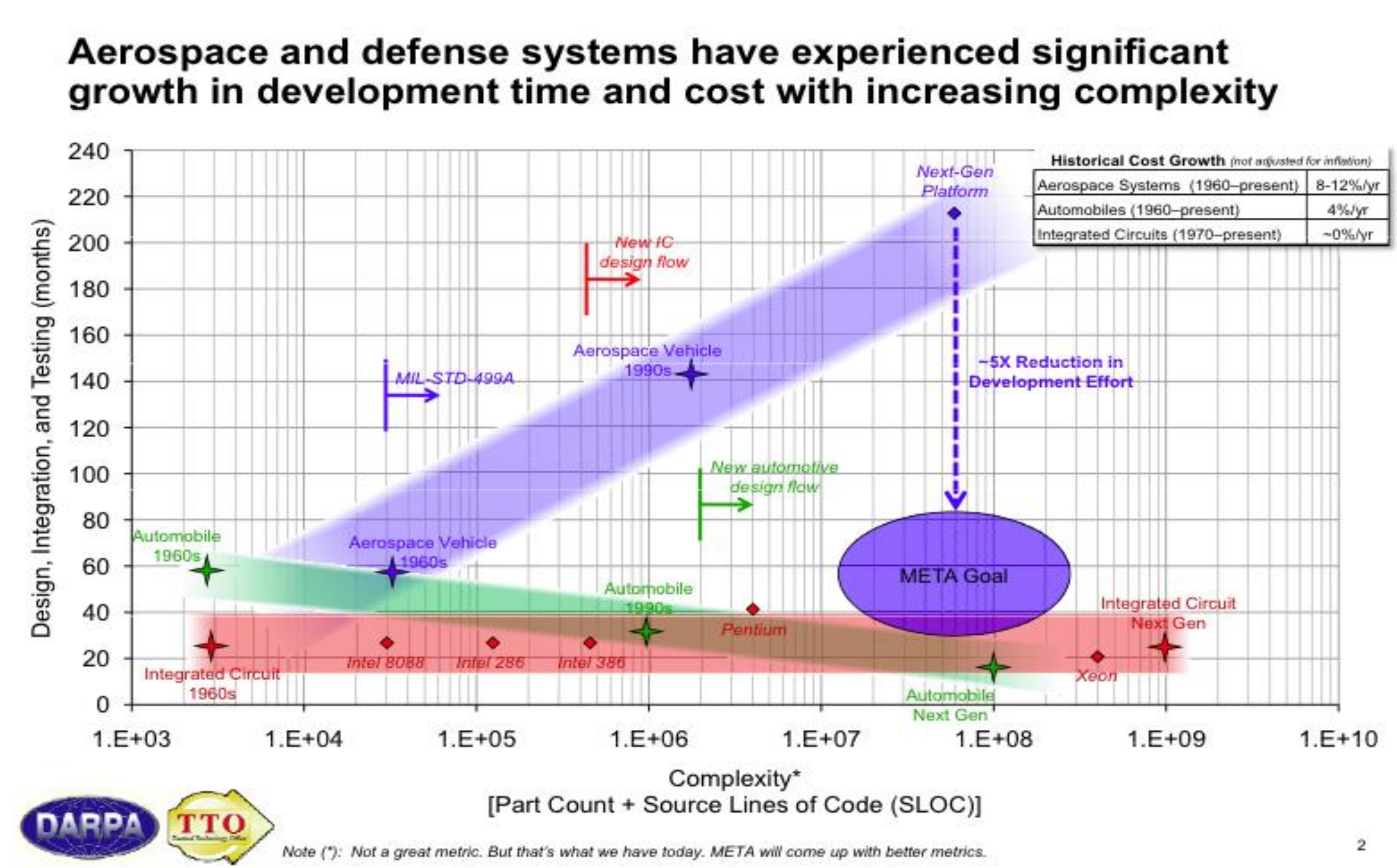


Extent: # of cognates
Variety: # of unique cognates, both semiotic and temporal
Ambiguity: fog, conflicting data, cognitive overload

Systems thinking applied to State-determined and some Stochastic systems … but not to Non-deterministic and most Stochastic systems!!!

Systems Outcomes

Systems Outcomes: Aerospace & Defense (1 of 3)

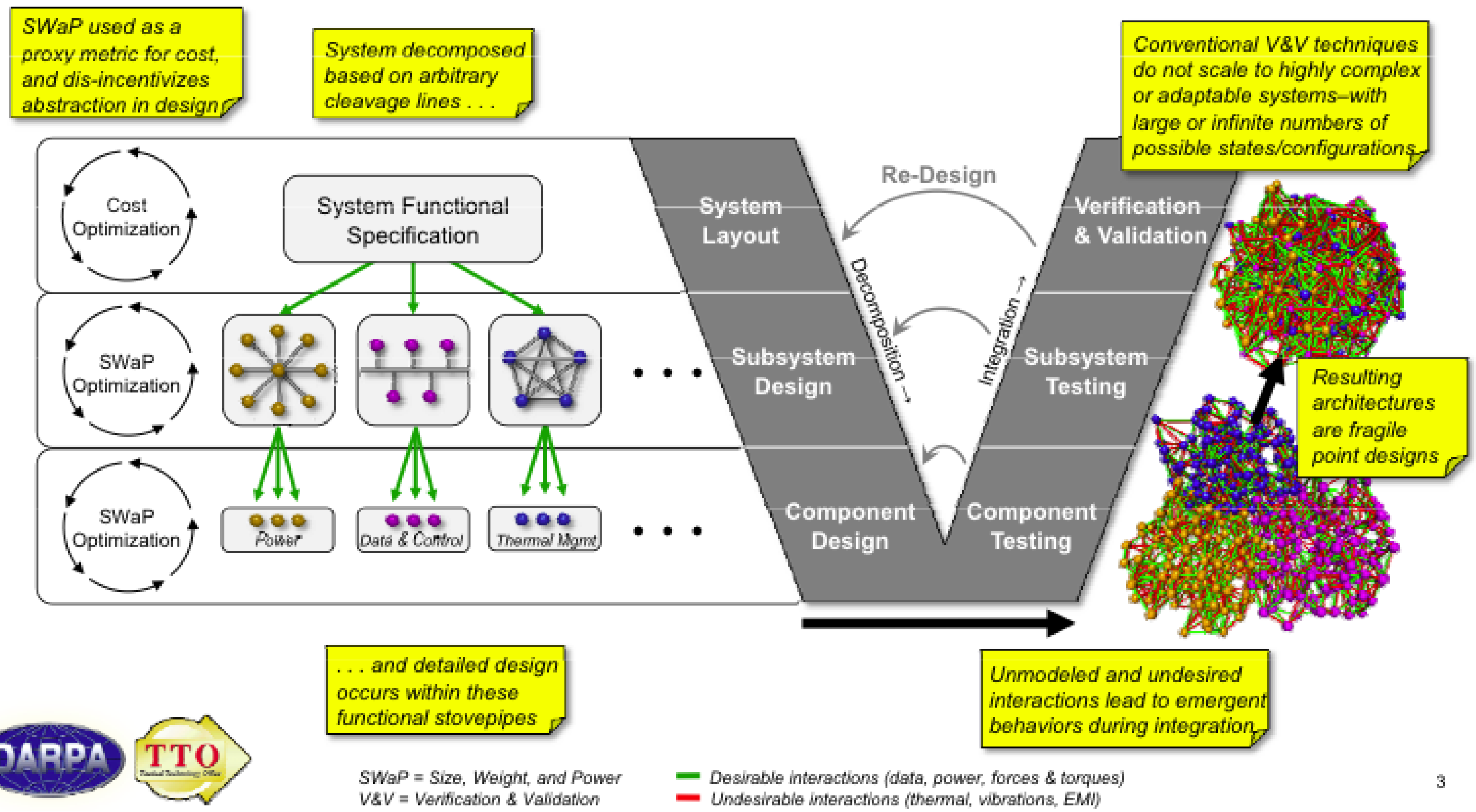


Source: US DARPA META Initiative

System Outcomes: Aerospace and Defense (2 of 3)

A major cause of these phenomena is the industry's failure to update a 1960s-vintage systems engineering, integration, and test process

MIL-STD-499A (1969) Systems Engineering Process – As Employed Today



Source: US DARPA META Initiative

Systems Outcomes: Aerospace and Defense (3 of 3)

Consider the hypothesis that aerospace and defense systems,

thought to be deterministic,

and managed as such,

are actually stochastic or non-deterministic,

in the context of their total life cycle phases,

including the interaction of enabling and external systems.

and the environments they encounter.

Barriers to Integration of Systems Thinking into Systems Engineering

Barriers to Integration of Systems Thinking into Systems Engineering

- Systems engineering based on early 20th Century assembly line industrial model
  - Top-down, reductionist model
- Reductionist model of systems engineering assumed to be a state-determined system but in the context of all the environmental, enabling and interfacing systems around it, is really a stochastic or non-deterministic system
- State of the art systems integration processes and methods based on application to state-determined (aka deterministic) systems and limited set of stochastic systems
  - Systems integration processes and methods not suitable to non-deterministic and most stochastic systems

INCOSE Initiatives to Address Challenges

INCOSE Initiatives to Address Challenges

- Model-Based Systems Engineering Initiative (MBSE)
- Systems Sciences Projects
- Support BKCASE Initiative to Capture and Evolve Body of Knowledge
- Expand INCOSE Reach into Additional Domains beyond Aerospace, Defense and Communications, e.g., Transportation and Energy
- Collaborations with Other Societies and Professional Organizations
- Nurture and Develop Systems Engineering Leadership

Summary and Wrap-Up

- Position Statement
  - Systems thinking not well integrated into systems engineering results in serious consequences for successful system outcomes
- Progression of Systems Thinking 50+ year history
  - Insignificant impact on engineering of systems and systems engineering
- Progression of Systems Engineering 70+ year history
  - Top-down reductionist approach to systems
- Systems Taxonomy
  - Deterministic aka state-determined systems, stochastic systems, and non-deterministic systems
- Systems Outcomes
  - Longer development times, higher costs, and system performance challenges for aerospace and defense systems applying state-determined systems engineering processes to what are likely stochastic or non-deterministic systems
- Barriers to Integration of Systems Thinking into Systems Engineering
  - Impedance mismatch between systems thinking and state-determined systems engineering processes
- INCOSE Initiatives to Address Challenges
  - Opportunities to affect change and make a difference!

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