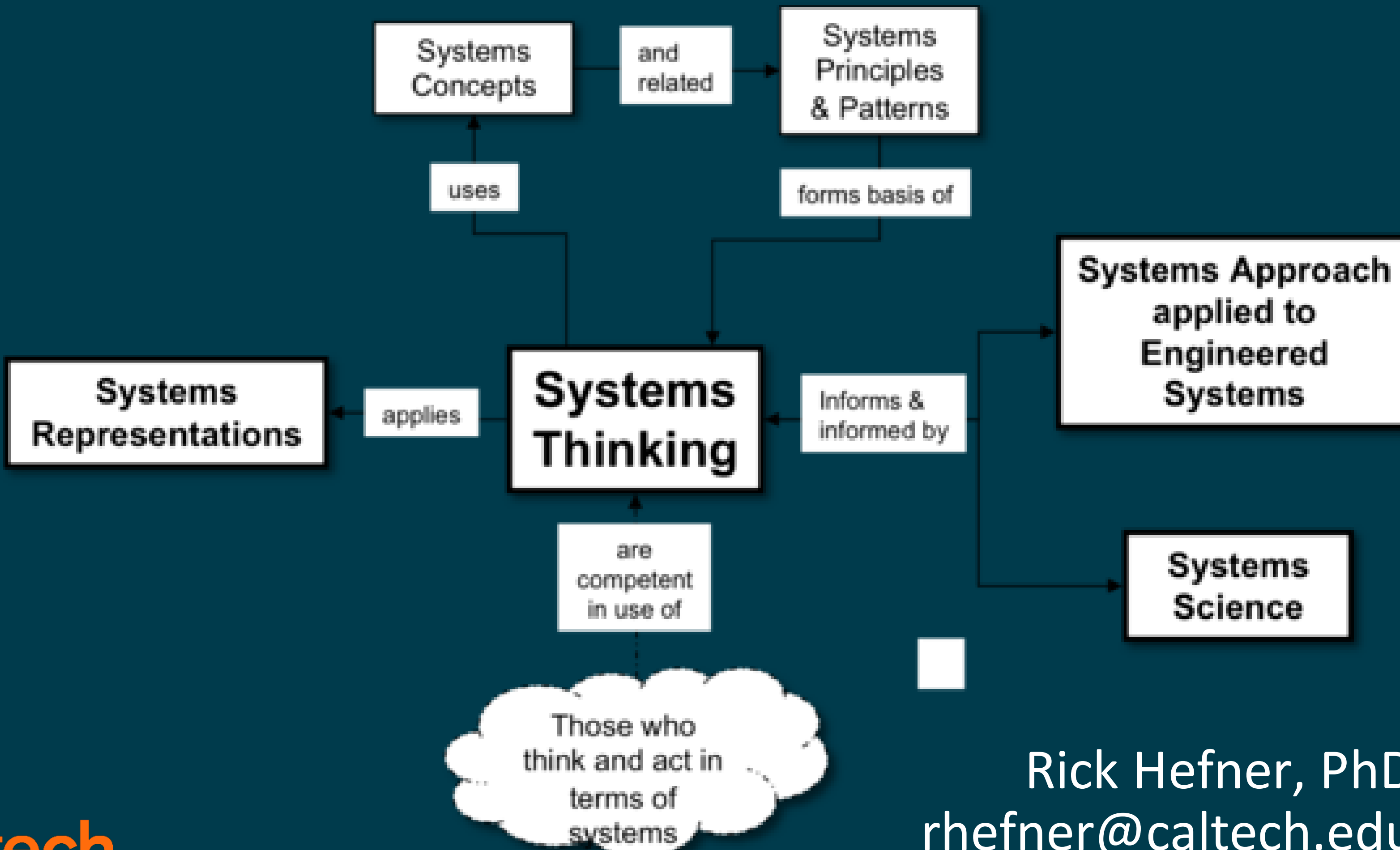
Systems Thinking:
A Foundation for Product Development

Presentation to INCOSE Heartland Chapter



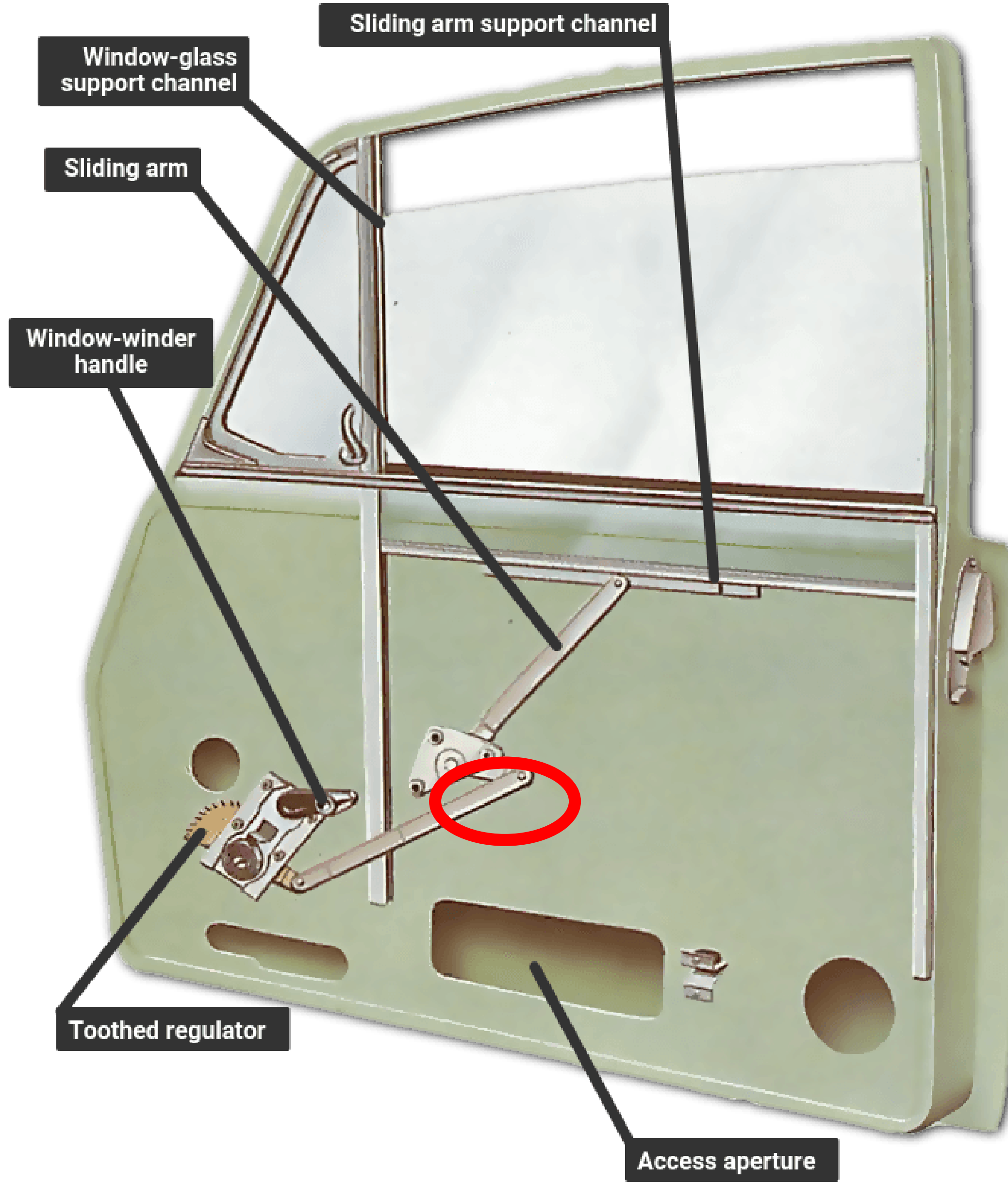
Rick Hefner, PhD
rhefner@caltech.edu

Caltech

You are the subsystem design engineer responsible for an automotive power window mechanism

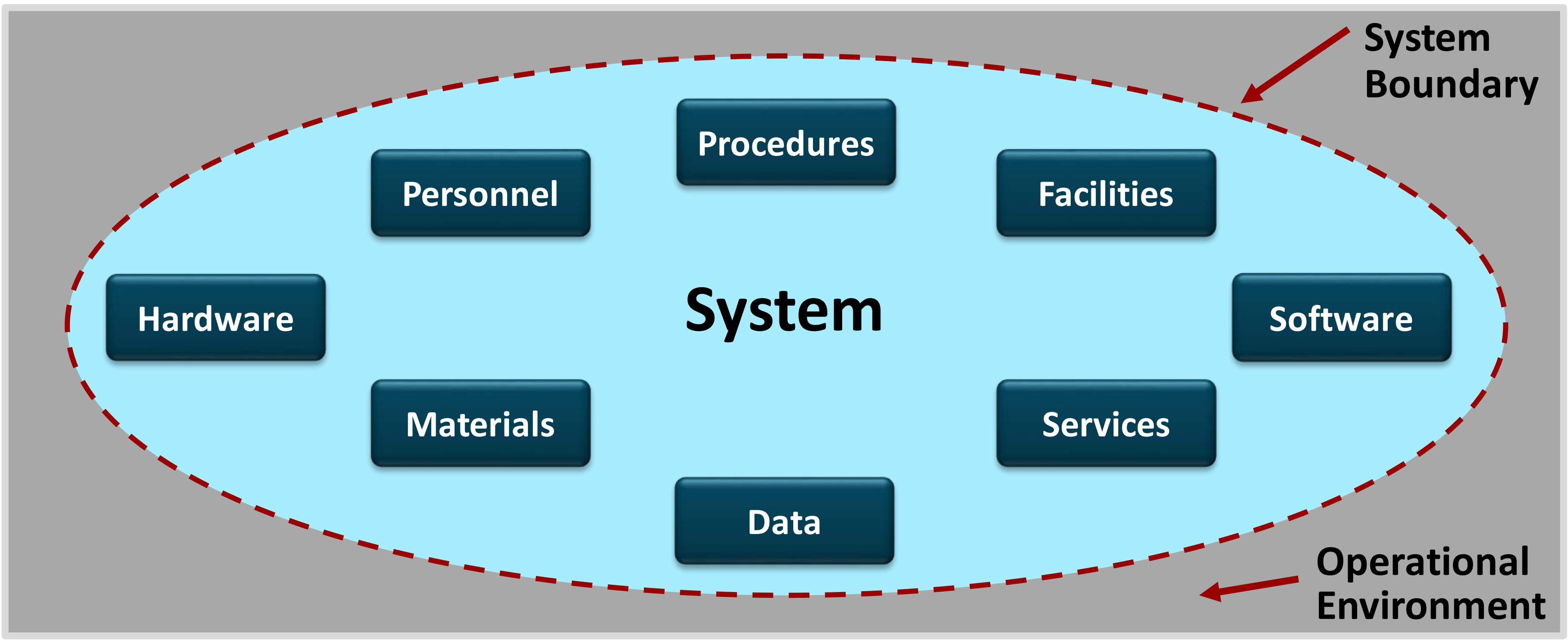
Your boss says “we need to improve the design by reducing cost and weight”

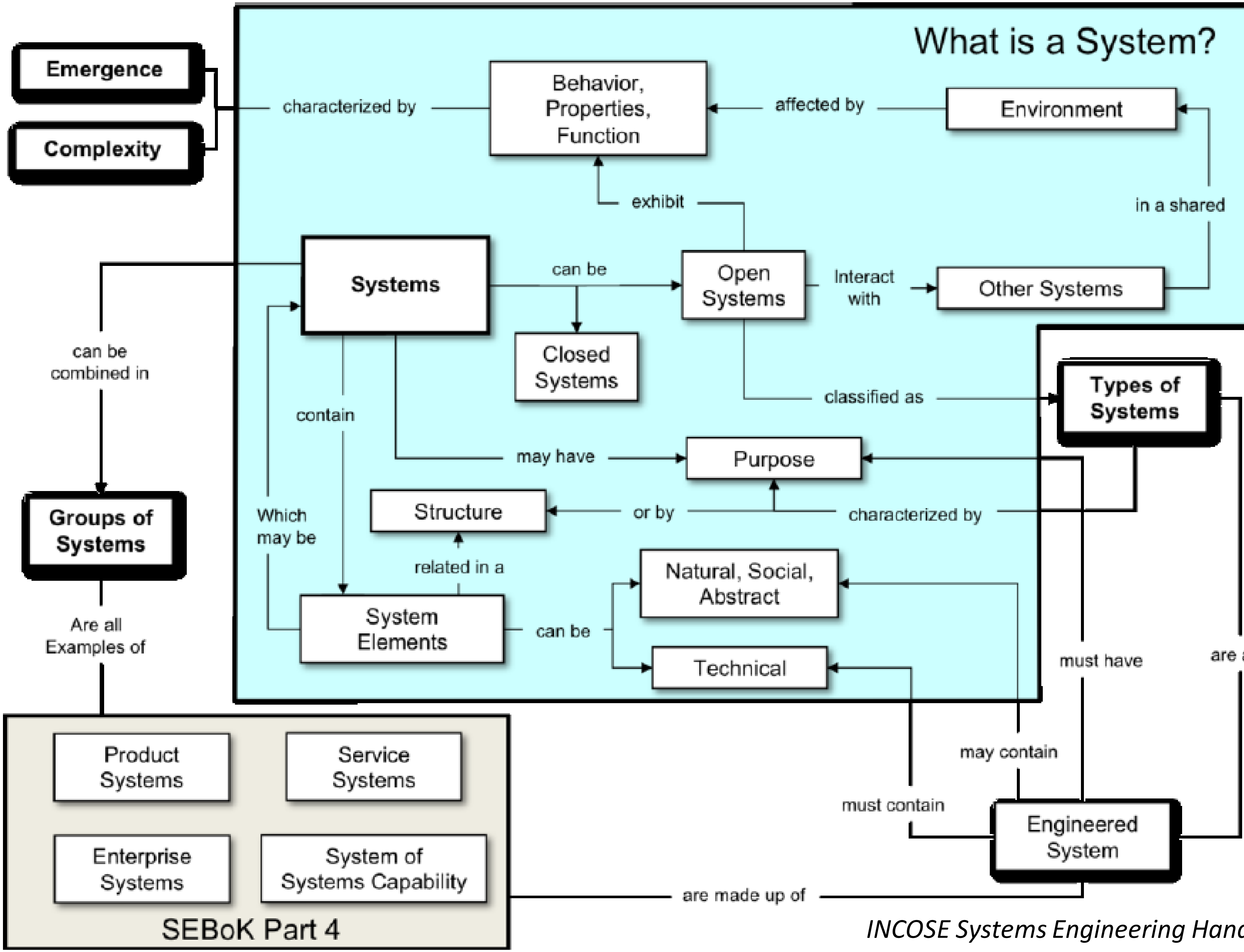
What do you do?



What is a System?

An integrated set of elements, subsystems, or assemblies that accomplish a defined purpose; these elements include products hardware, software and firmware), processes, people, information, techniques, facilities, services and other support elements [INCOSE Systems Engineering Handbook]



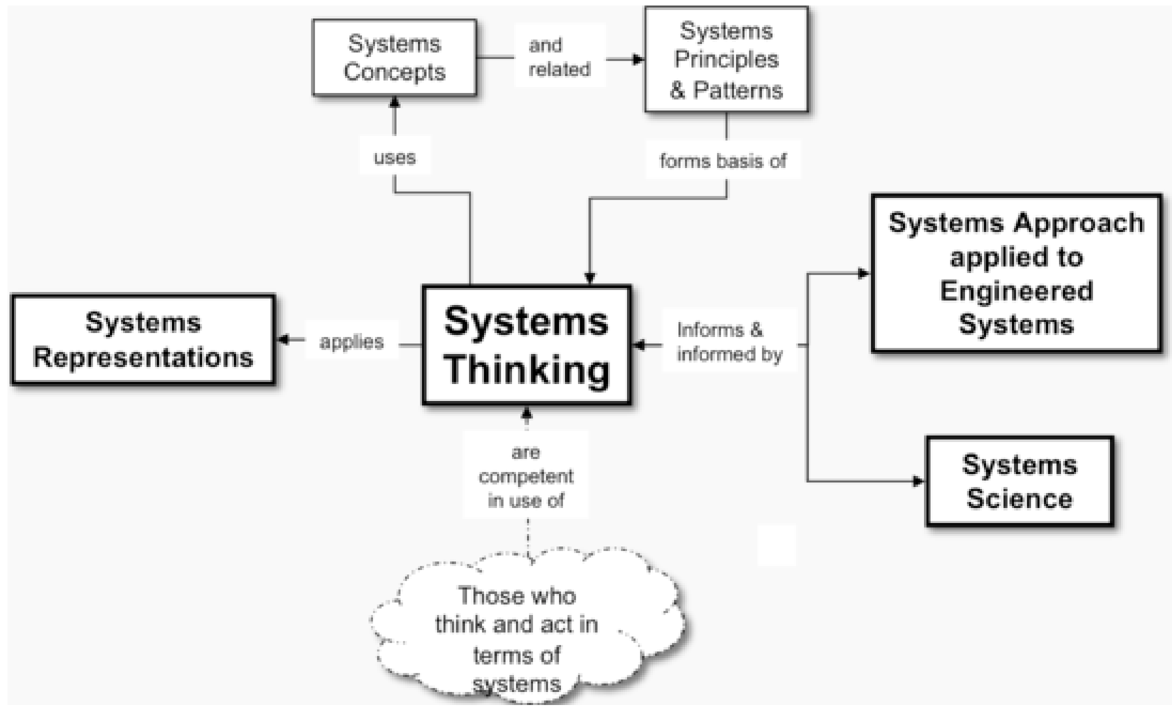


INCOSE Systems Engineering Handbook

Systems Thinking

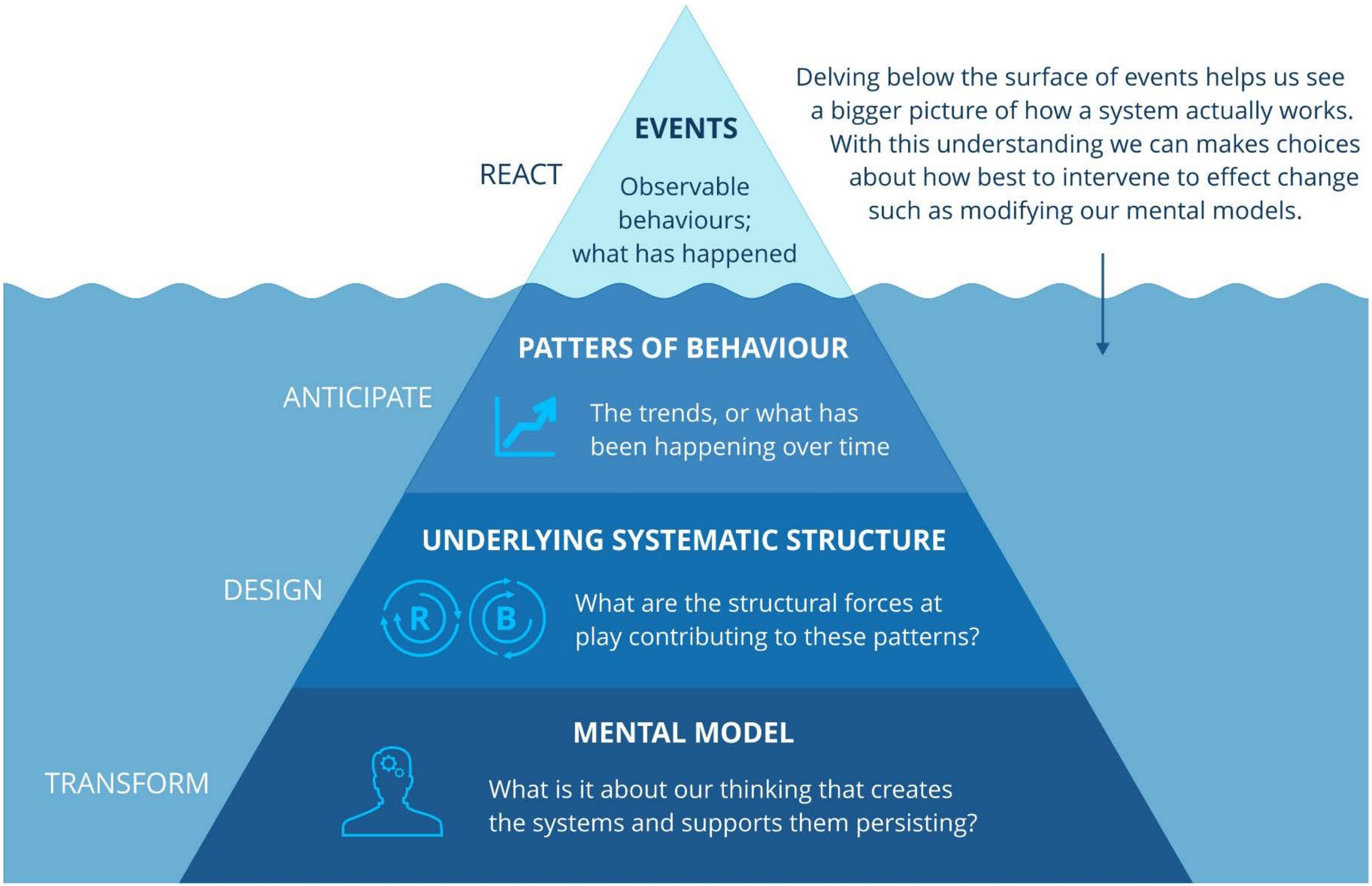
Systems thinking is concerned with understanding or intervening in problem situations, based on the principles and concepts of the *systems paradigm* [INCOSE SE Body of Knowledge – sebokwiki.org]

Systems thinking considers the similarities between systems from different domains in terms of a set of common systems concepts, principles and patterns

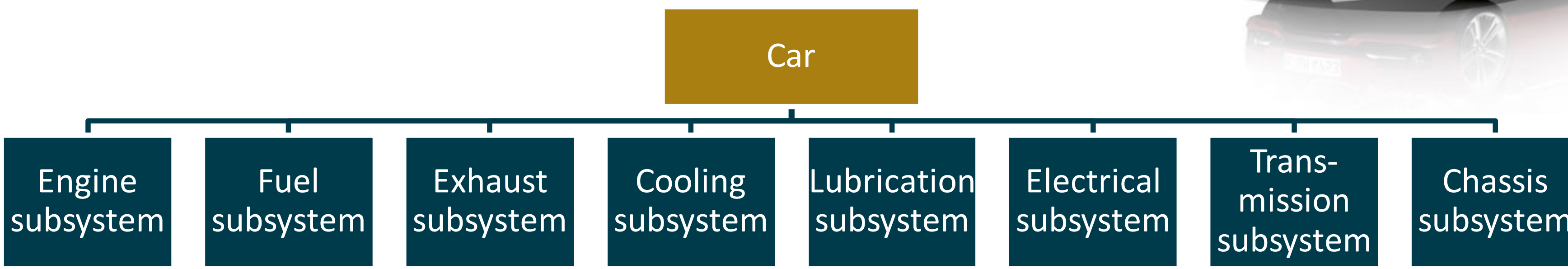


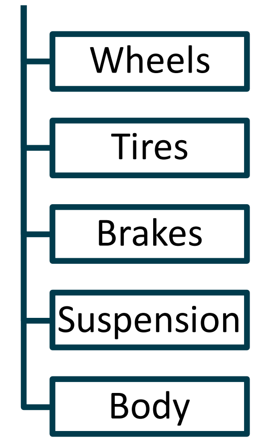
INCOSE Systems Engineering Handbook

Systems Thinking Iceberg



Systems Thinking in Product Development





- For the team designing the suspension: What are the impacts of our design decisions on the overall properties of the car? (handling, gas mileage, ride quality, weight, …)
- Could we model the car properties to better drive design decisions (or at least evaluate their impacts)?

Systems Principles (1 of 2)

INCOSE SE Body of Knowledge – sebokwiki.org

Abstraction	A focus on essential characteristics is important in problem solving because it allows problem solvers to ignore the nonessential, thus simplifying the problem.
Boundary	A boundary or membrane separates the system from the external world. It serves to concentrate interactions inside the system while allowing exchange with external systems.
Change	Change is necessary for growth and adaptation, and should be accepted and planned for as part of the natural order of things rather than something to be ignored, avoided, or prohibited.
Dualism	Recognize dualities and consider how they are, or can be, harmonized in the context of a larger whole.
Encapsulation	Hide internal parts and their interactions from the external environment.
Equifinality	In open systems, the same final state may be reached from different initial conditions and in different ways (Bertalanffy 1968). This principle can be exploited, especially in systems of purposeful agents.
Holism	A system should be considered as a single entity, a whole, not just as a set of parts.
Interaction	The properties, capabilities, and behavior of a system are derived from its parts, from interactions between those parts, and from interactions with other systems.
Layer Hierarchy	The evolution of complex systems is facilitated by their hierarchical structure (including stable intermediate forms) and the understanding of complex systems is facilitated by their hierarchical description.
Leverage	Achieve maximum leverage (Hybertson 2009). Because of the power versus generality tradeoff, leverage can be achieved by a complete solution (power) for a narrow class of problems, or by a partial solution for a broad class of problems (generality).
Modularity	Unrelated parts of the system should be separated, and related parts of the system should be grouped together.

Systems Principles (2 of 2)

INCOSE SE Body of Knowledge – sebokwiki.org

Network	The network is a fundamental topology for systems that forms the basis of togetherness, connection, and dynamic interaction of parts that yield the behavior of complex systems.
Parsimony	One should choose the simplest explanation of a phenomenon, the one that requires the fewest assumptions. This applies not only to choosing a design, but also to operations and requirements.
Regularity	Systems science should find and capture regularities in systems, because those regularities promote systems understanding and facilitate systems practice.
Relations	A system is characterized by its relations: the interconnections between the elements. Feedback is a type of relation. The set of relations defines the network of the system.
Separation of Concerns	A larger problem is more effectively solved when decomposed into a set of smaller problems or concerns.
Similarity/ Difference	Both the similarities and differences in systems should be recognized and accepted for what they are. Avoid forcing one size fits all, and avoid treating everything as entirely unique.
Stability/ Change	Things change at different rates, and entities or concepts at the stable end of the spectrum can and should be used to provide a guiding context for rapidly changing entities at the volatile end of the spectrum (Hybertson 2009). The study of complex adaptive systems can give guidance to system behavior and design in changing environments.
Synthesis	Systems can be created by choosing (conceiving, designing, selecting) the right parts, bringing them together to interact in the right way, and in orchestrating those interactions to create requisite properties of the whole, such that it performs with optimum effectiveness in its operational environment, so solving the problem that prompted its creation”
View	Multiple views, each based on a system aspect or concern, are essential to understand a complex system or problem situation. One critical view is how concern relates to properties of the whole.

Conceptagon Framework

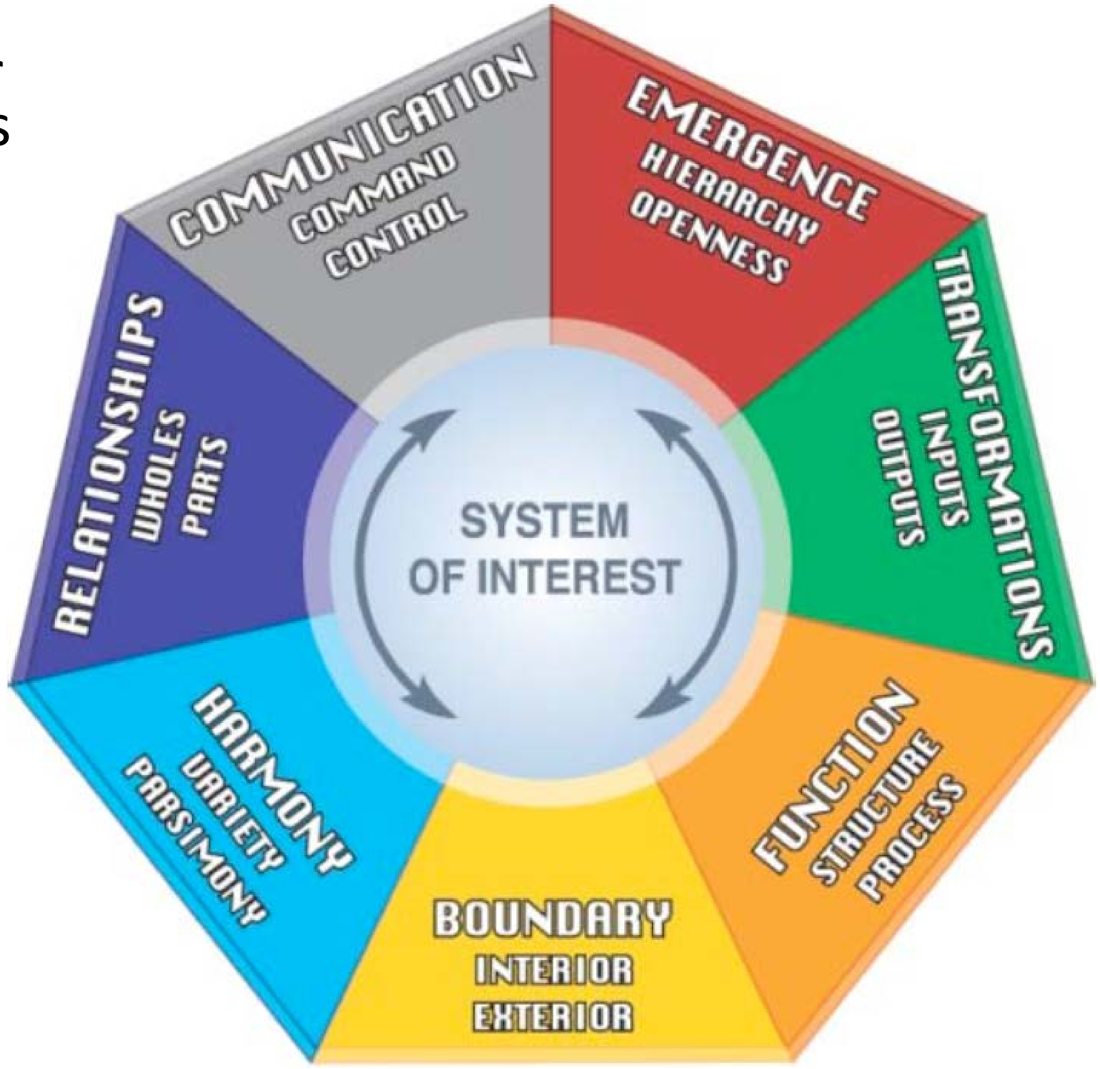
A systems thinking tool for analyzing complex systems

Forms a framework for thinking about the dimensions of a systems

Each area is a new lens or perspective for describing one dimension of a system

‘The conceptagon: a framework for systems thinking and systems practice," in IEEE International Conference on Systems, Man and Cybernetics (SMC 2009) San Antonio, TX, 2009, pp. 3299 – 3304

‘Federal Aviation Administration NextGen: Applying Systems Thinking in Practice’, Proc. of the 2011 6th International Conference on System of Systems Engineering, Albuquerque, New Mexico, USA - June 27-30, 2011



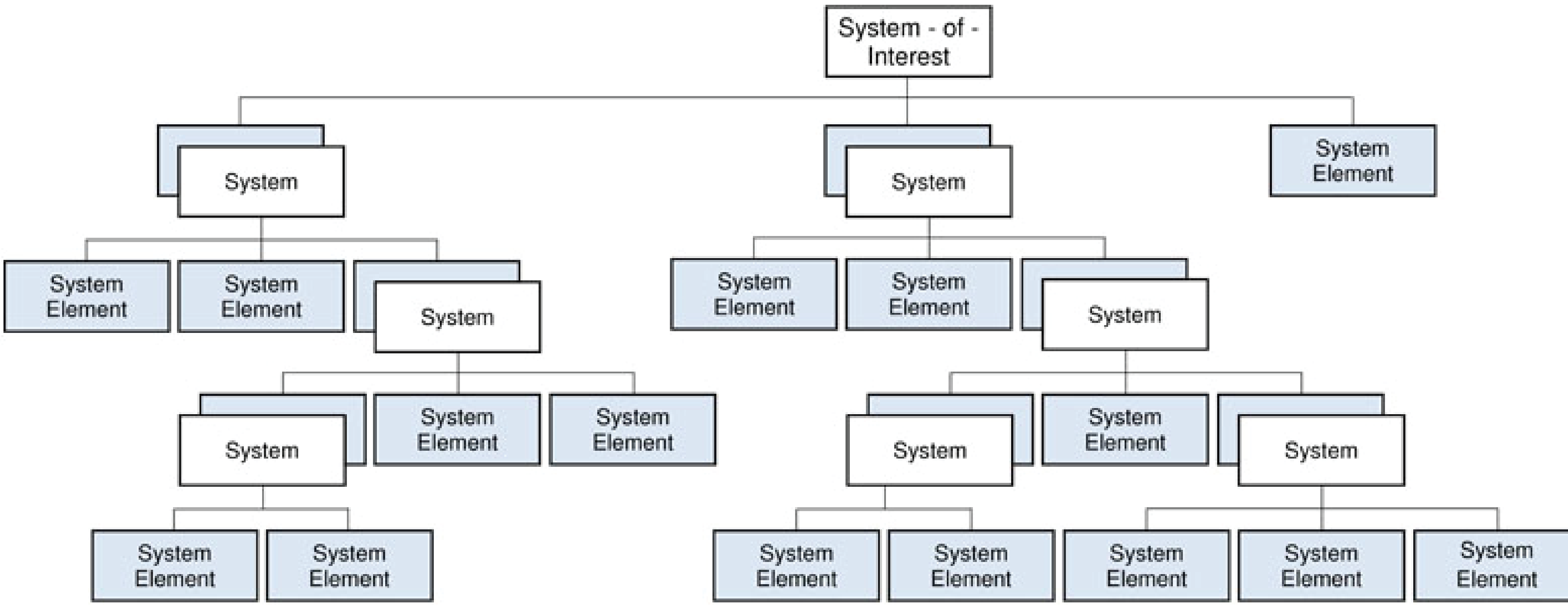
Systems Thinking

A holistic approach to analysis that focuses on the way that a system's **constituent parts interrelate** and how systems **work over time** and **within the context of larger systems**

Key concepts:

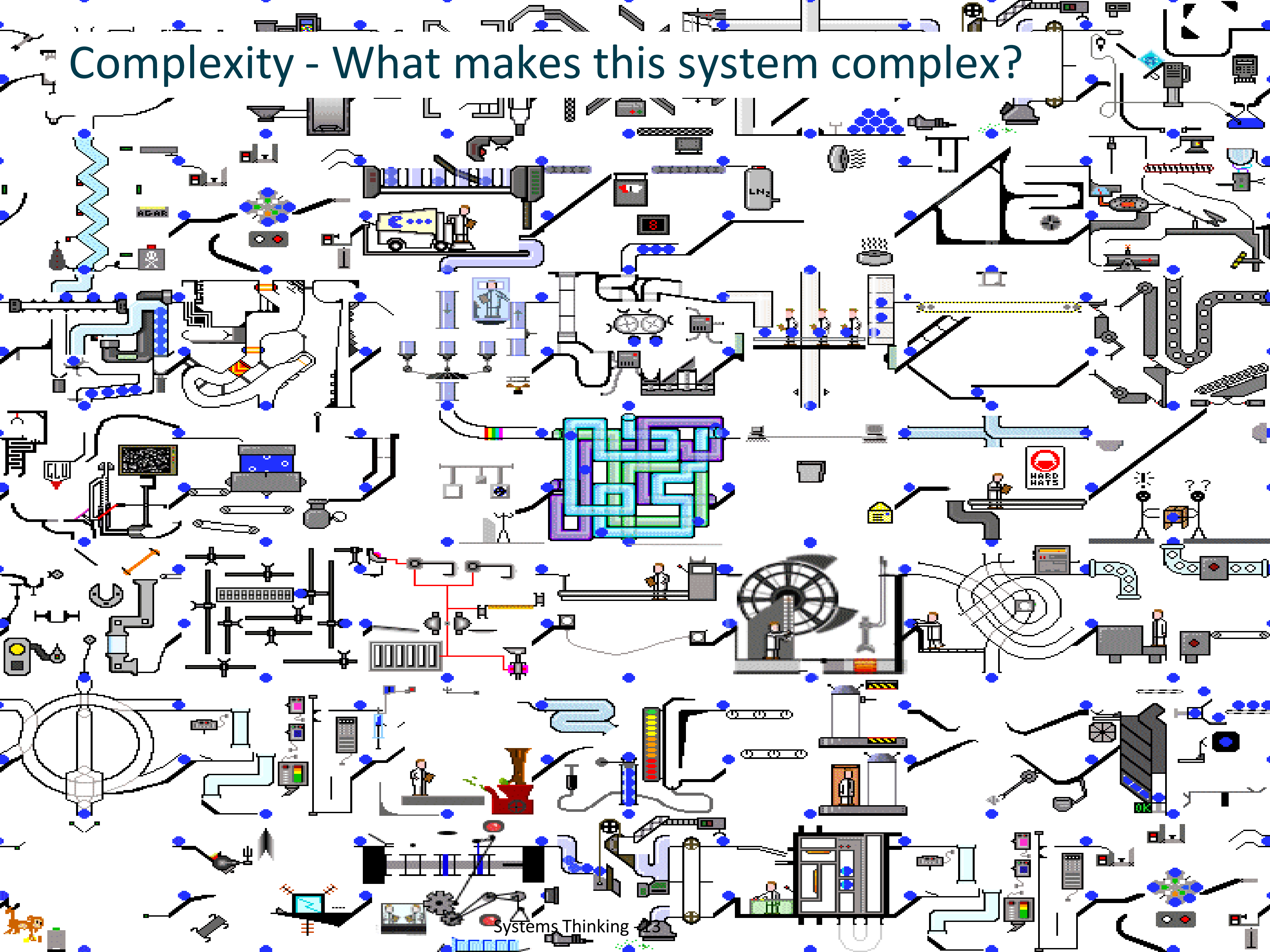
- **Hierarchy** – Systems are composed of smaller subsystems
- **Complexity** – Creates unknown (and sometimes undesirable) emergent behavior
- **Emergent behavior** – Properties of the system result from the both the components and their interactions

Hierarchy - System-of-Interest, System Element



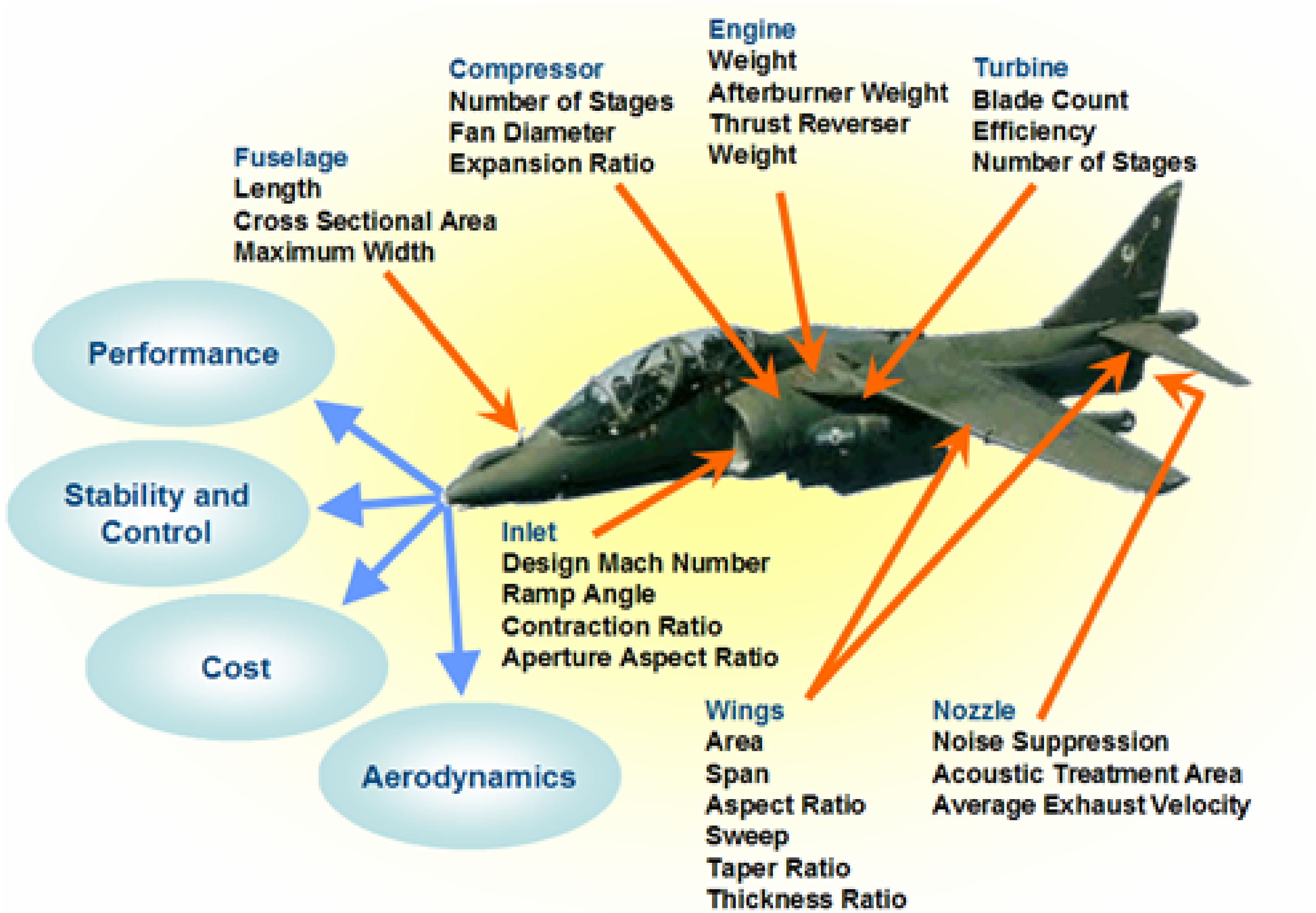
ISO/IEC/IEEE 15288

Complexity - What makes this system complex?



Emergent Behavior

Properties of the system result from both the components and their interactions



Discussion – System Example

- What is the hierarchy of systems?
- What makes the system-of-interest complex?
- What emergent behaviors (positive and negative) might we try to influence in the system design process?

Systems Engineering

- An **interdisciplinary** approach encompassing the entire technical development effort to **evolve and verify** an integrated and **life-cycle balanced** set of system, people, product and process solutions that satisfy customer needs

Systems engineering encompasses:

- **Technical efforts** related to the development, manufacturing, verification, deployment, operations, support, disposal of and user training for, system products and processes
- Definition and management of the **system configuration**
- Translation of the system definition into **work breakdown structures**
- Development of information for management **decision making**

EIA 632, Systems Engineering

System Engineering Process

INCOSE Handbook and ISO/IEC/IEEE 15288

AGREEMENT PROCESSES

- Acquisition
- Supply

TECHNICAL MANAGEMENT PROCESSES

- Project Planning
- Project Assessment and Control
- Decision Management
- Risk Management
- Configuration Management
- Information Management
- Measurement
- Quality Assurance

ORGANIZATION PROJECT-ENABLING PROCESSES

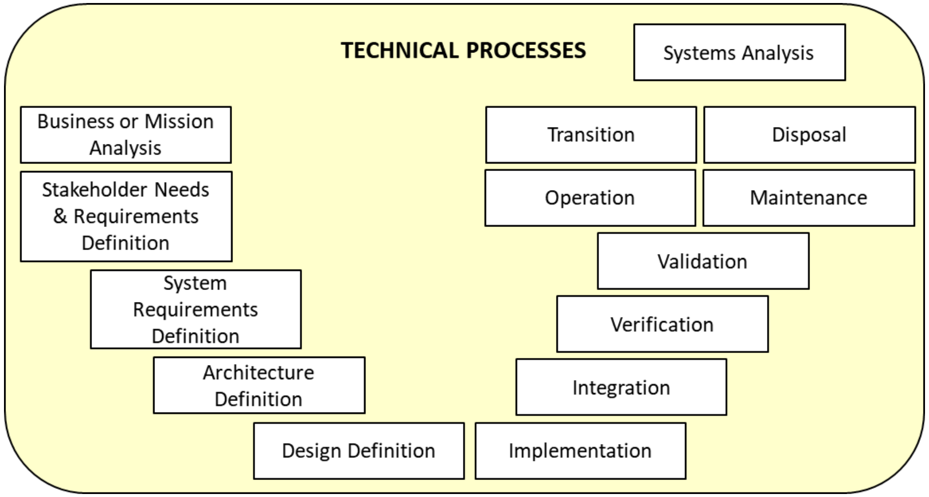
- Life Cycle Model Management
- Infrastructure Management
- Human Resource Management
- Quality Management
- Knowledge Management

TECHNICAL PROCESSES

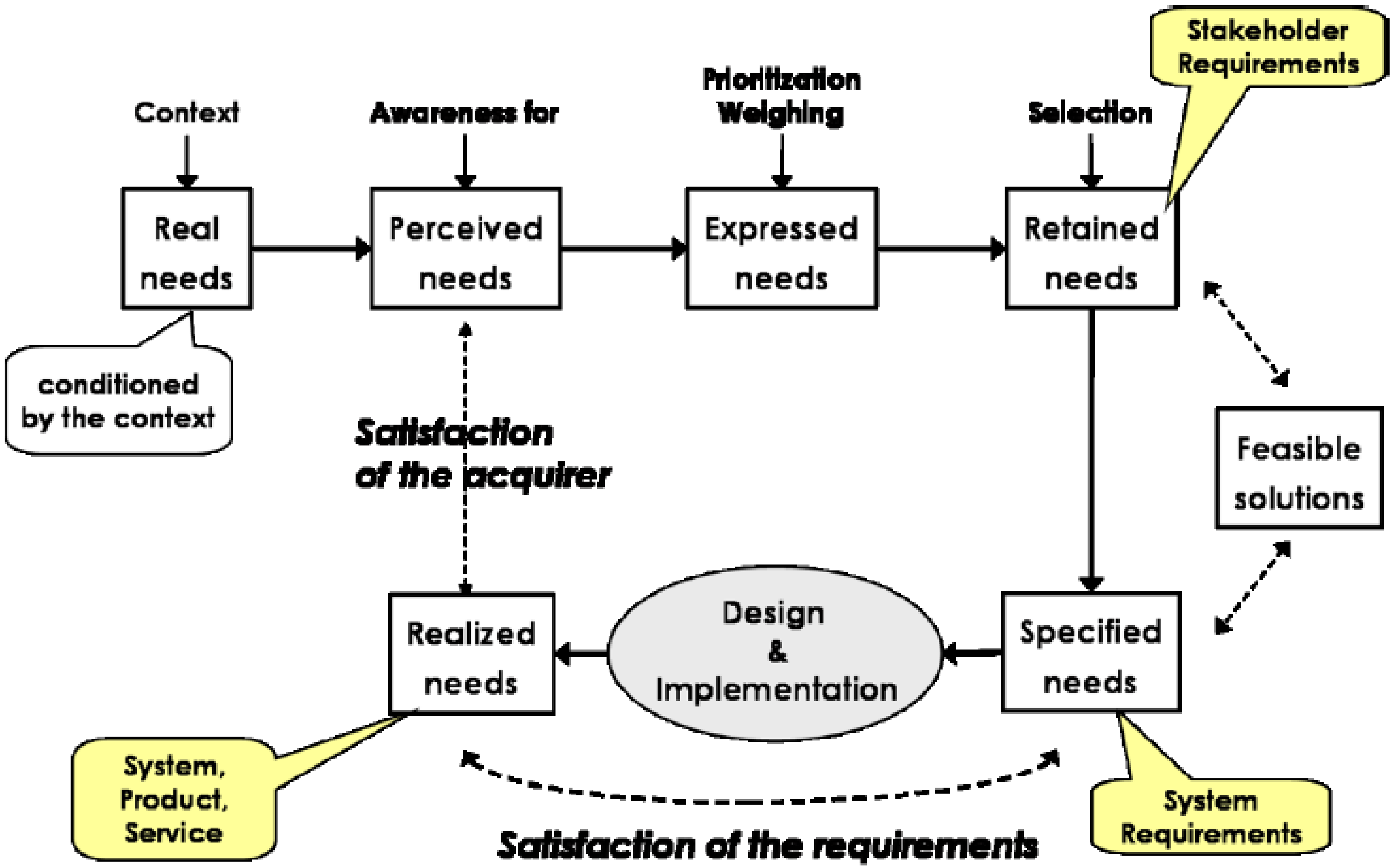
- Systems Analysis
- Business or Mission Analysis
- Stakeholder Needs & Requirements Definition
- System Requirements Definition
- Architecture Definition
- Design Definition
- Implementation
- Integration
- Verification
- Validation
- Operation
- Maintenance
- Transition
- Disposal

How Does Systems Thinking Change Traditional Product Development?

- Systems thinkers consider the impact of their element in a broader context (typically two layers up in the hierarchy)
  - Interfaces and interactions
  - Emergent properties
  - Impacts and effects
- Systems thinkers recognize the impacts of early lifecycle decisions on later lifecycle activities
  - More time is spent understanding the problem context without rushing into design (e.g., context diagrams, stakeholder analysis)
  - More iteration among activities



Cycle of Stakeholder Needs



Cited in SEBoK. Permission granted by Singery'Com

Model-Based Systems Engineering (MBSE)

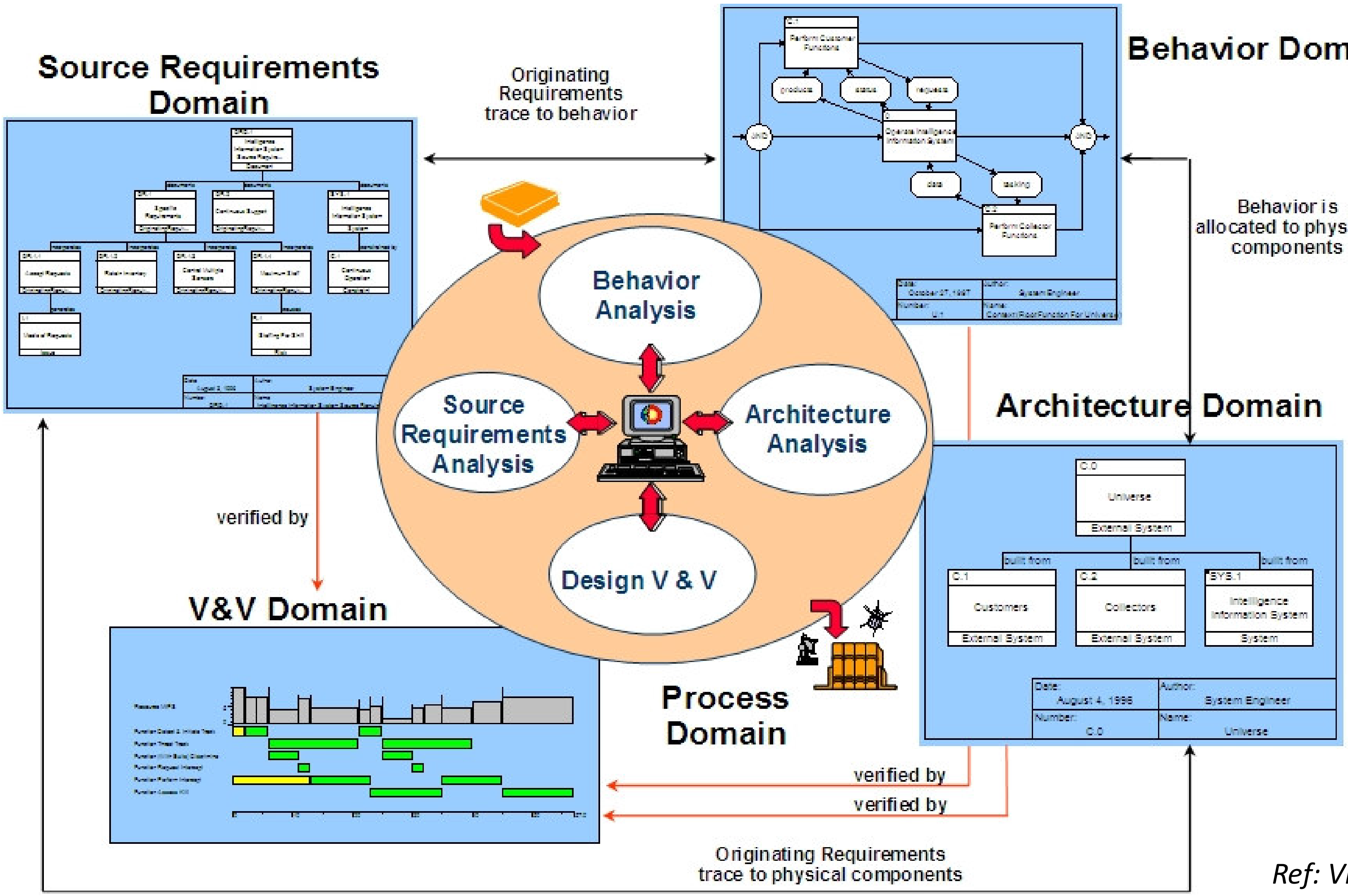
Model-Based Systems Engineering (MBSE) is the formalized application of modeling *to support system requirements, design, analysis, verification and validation activities* beginning in the conceptual design phase and continuing throughout development and later life cycle phases.

- INCOSE SE Vision 2020 (INCOSE-TP-2004-004-02), Sept 2007

Helps to:

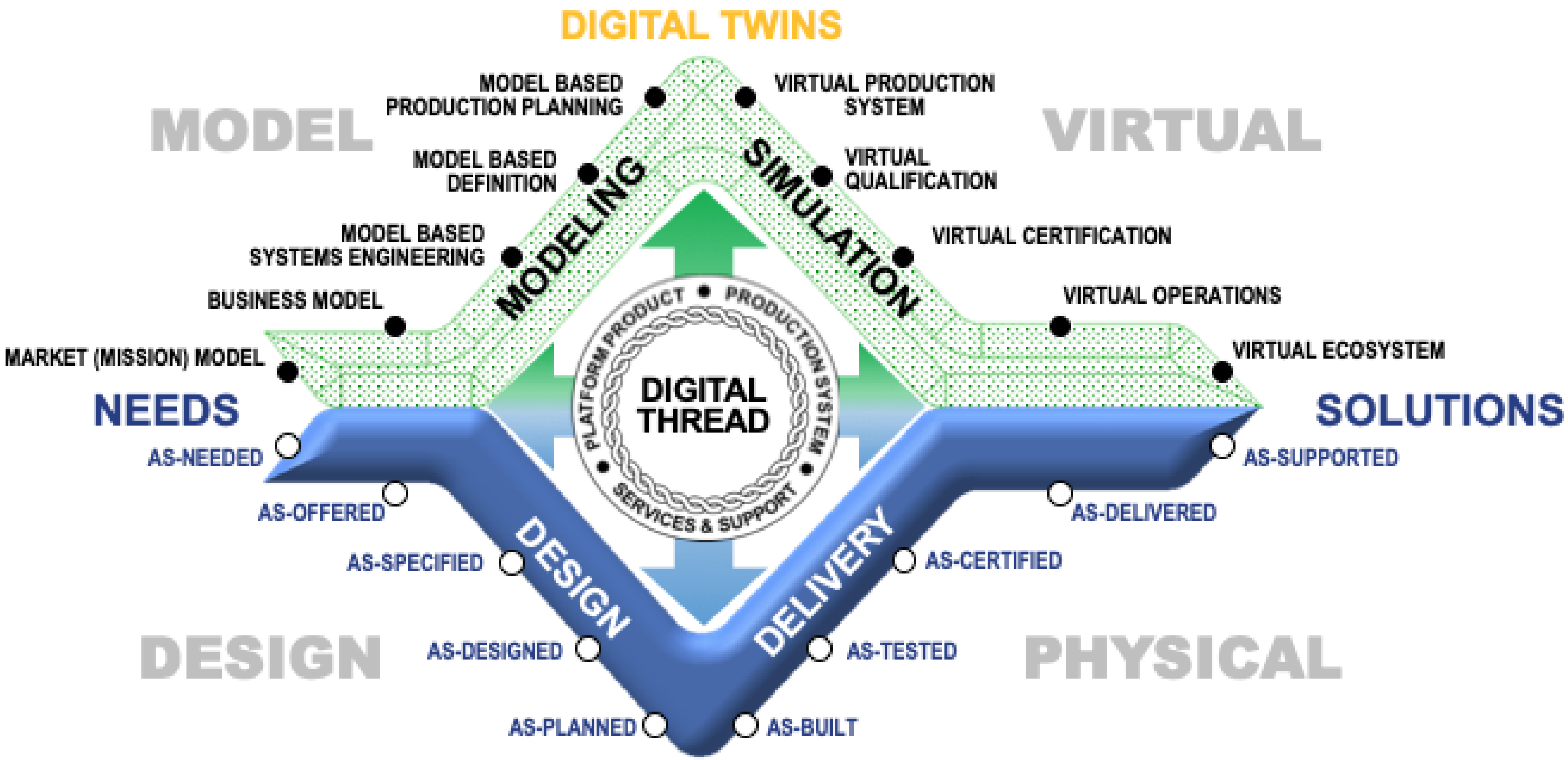
- Document system functions and requirements
- Assess the mission performance
- Estimate costs
- Evaluate tradeoffs
- Provide insights to improve performance, reduce risk, and manage costs

MBSE Domains



Ref: Vitech

A Shift In Thinking



Model-Based Systems Engineering Trends

- MBSE is increasingly integrating technical, programmatic, and business concerns
  - Model-based approaches will require broader and deeper collaboration among roles across the lifecycle
- Tool suites and virtualization capabilities are maturing
  - Mastering the concepts and tools requires training and practice
- Model-based approaches will enable understanding of complex system behavior much earlier in the product life cycle
  - Customers will expect a more collaborative approach to requirement definition and architecture selection

For Further Study

- Caltech 5-day Systems Engineering Fundamentals Certificate Program
  http://ctme.caltech.edu/programs-for-individuals/advanced-engineering-open/systems-engineering-fundamentals-open
- What is Systems Thinking?, INCOSE SEBOK
  http://sebokwiki.org/wiki/What_is_Systems_Thinking?
- Basic principles of systems thinking as applied to management and leadership, The Institute of Systemic Leadership
  http://www.systemicleadershipinstitute.org/systemic-leadership/theories/basic-principles-of-systems-thinking-as-applied-to-management-and-leadership-2/
- What are the General Principles Applicable to Systems?, D. Hitchins
  https://connect.incose.org/Library/INSIGHTArchive/INSIGHT%20Library/vol-13-issue-1.pdf#search=%22What%20are%20the%20General%20Principles%20Applicable%20to%20Systems%22
- How Systems Thinking Contributes to Systems Engineering, INCOSE UK
  https://incoseonline.org.uk/Documents/zGuides/Z7_Systems_Thinking_WEB.pdf