Introduction to Systems Engineering

Awareness Seminar
SESGE-AEIS/INCOSE

Escuela Politécnica Superior
Universidad Carlos III de Madrid

Leganés (Madrid) , Spain, 29th May 2019

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INCOSE Vision

About the instructor

Contents

- What is a system?
- What is systems thinking?
- What is systems engineering (SE)?
- Why is it important ?
- Background and history
- What are the Technical SE Process and the Vee-Model approach?
- What is the System Life Cycle?
- Requirements, Architecture, Verification, Validation and Testing
- Applied standards (ISO15288: 2015), techniques and SE management.
- Trends

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The Systems Praxis Framework, a joint project of the International Council on Systems Engineering and the International Society for the Systems Sciences

INTEGRATIVE SYSTEMS SCIENCE

Identifying, exploring, and understanding patterns of complexity through contributions from

Scientific Disciplines e.g., Physics, Neuroscience

Humanistic Disciplines e.g., Psychology, Culture, Rhetoric

Pragmatic Disciplines e.g., Accounting, Design, Law

Formal Disciplines e.g., Math, Logic, Computation

Foundations

Meta-theories of Methodology, Ontology, Epistemology, Axiology, Praxiology (theory of effective action), Teleology, Semiotics and Semiosis, Categories, etc.

Theories

General Systems Theory, Systems Pathology, Complexity, Anticipatory Systems, Cybernetics, Autopoiesis, Living Systems, Science of Generic Design, Organization Theory, etc.

Representations

Models, Dynamics, Networks, Cellular Automata, Life Cycles, Queues, Graphs, Rich Pictures, Narratives, Games and Dramas, Agent-based Simulations, etc.

practice informs theory

SYSTEMS THINKING

Appreciative and reflective practice using 'systems-paradigm' concepts, principles, patterns, etc.

theory informs practice

SYSTEMS APPROACHES TO PRACTICE

Addressing complex problems/opportunities using methods, tools, frameworks, practice patterns, etc.

direct input from disciplines

measured and specified data, metrics, etc.

input from experience and legacy practices

solicited local values, knowledge, etc.

Pragmatic, Pluralist, or Critical multi-methodology uses heuristics, prototyping, model unfolding, boundary critiques, etc., to understand assumptions, contexts, and constraints, including complexity from stakeholder values and valuations; chooses appropriate mix of 'hard', 'soft', and custom methods; sees systems as networks, societies of agents, organisms, ecosystems, rhizomes, discourses, machines, etc.

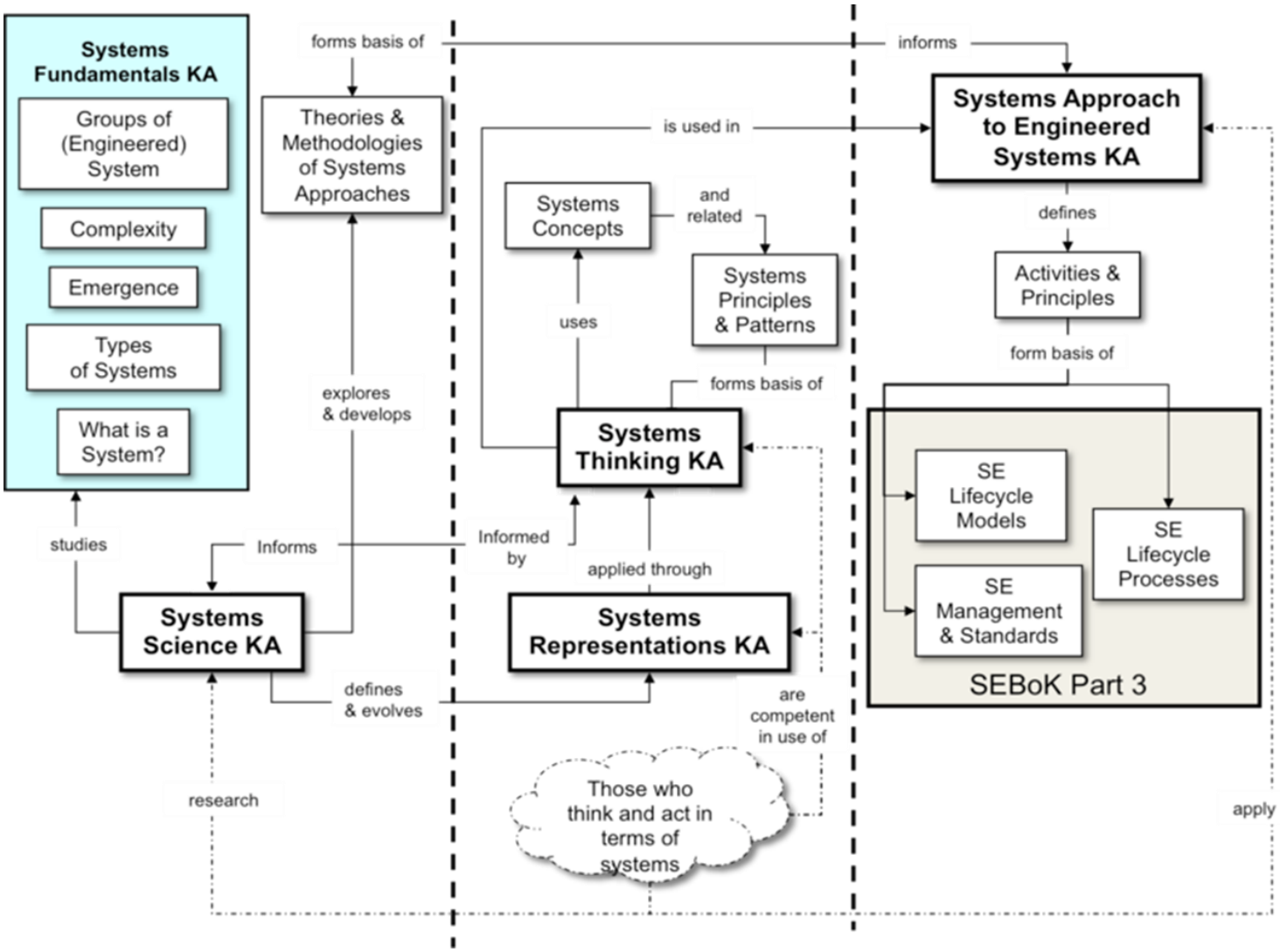
'Hard' methods are suited to solving well-defined problems with reliable data, clear optimization goals, and at most objective complexity; use machine metaphor and realist/functionalist foundations.

'Soft' methods are suited to structuring problems involving incomplete data, unclear goals, perspective and role complexity, etc.; use learning system metaphor and constructivist/interpretivist foundations.

Outcomes *Actions*

http://www.systemspraxis.org

Systems Knowledge Area (KA)

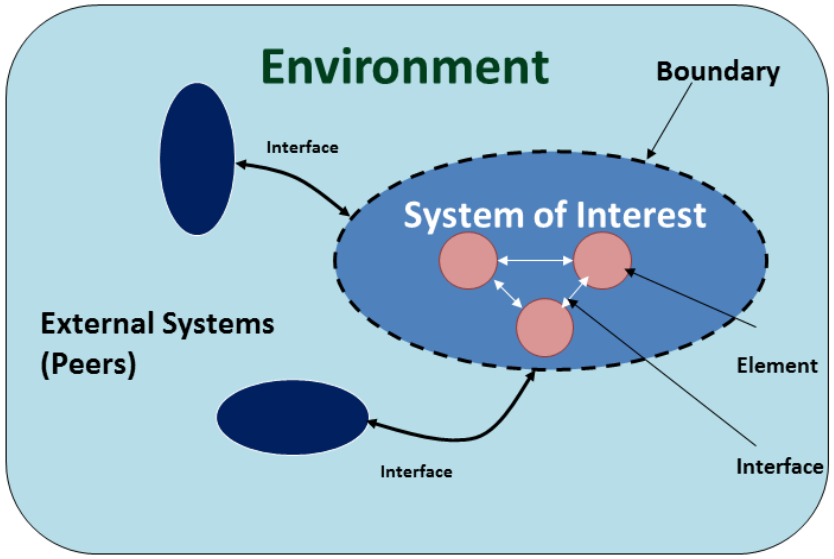


Seeing Systems

Seeing the world in a particular way, because **how you see things** affects the way you approach situations or undertake specific tasks.

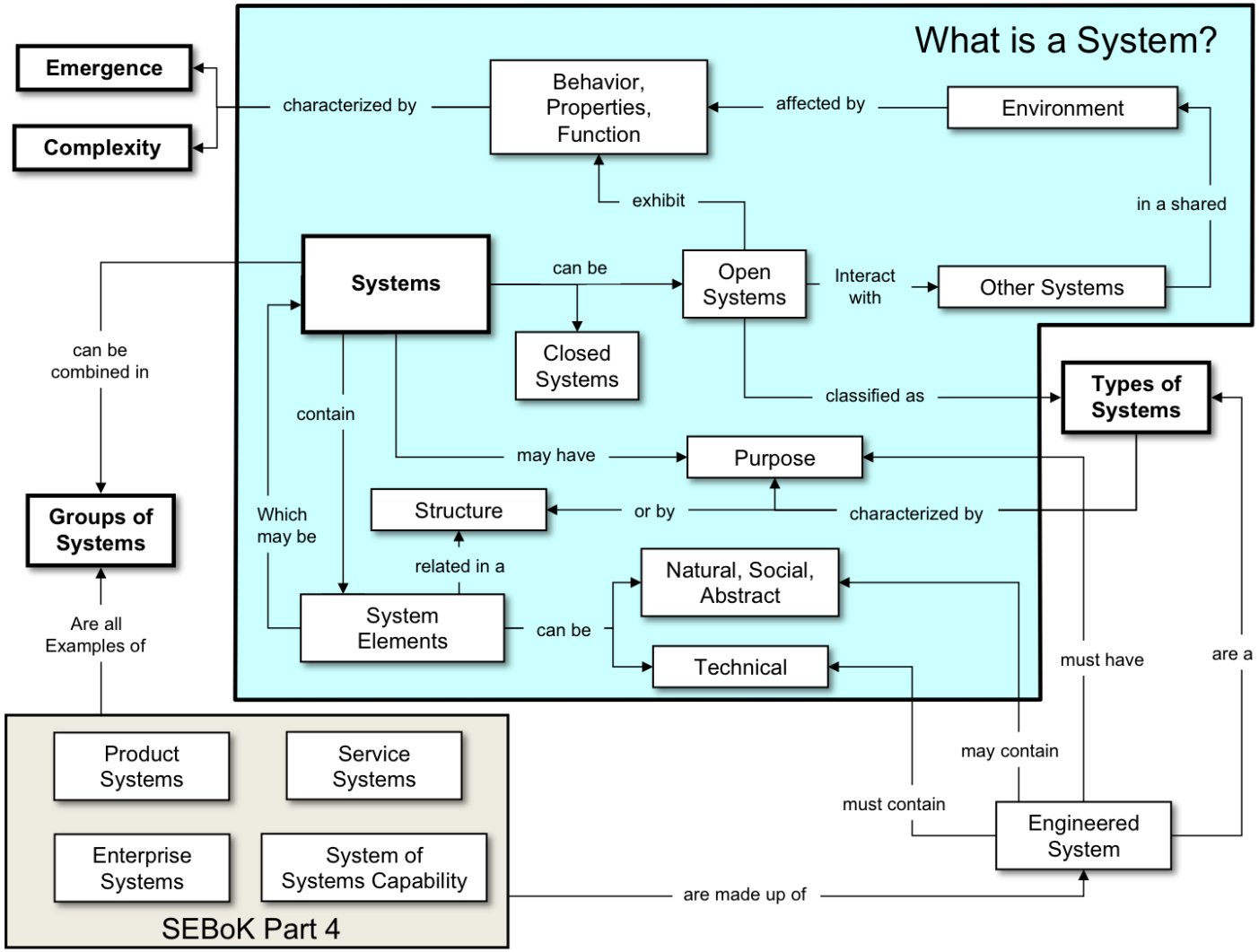
A definition of System

A system is a group of interacting, interrelated, or interdependent elements forming a complex whole.



System of Interest is **the system** of concern to those who have interest in it.

What is a System



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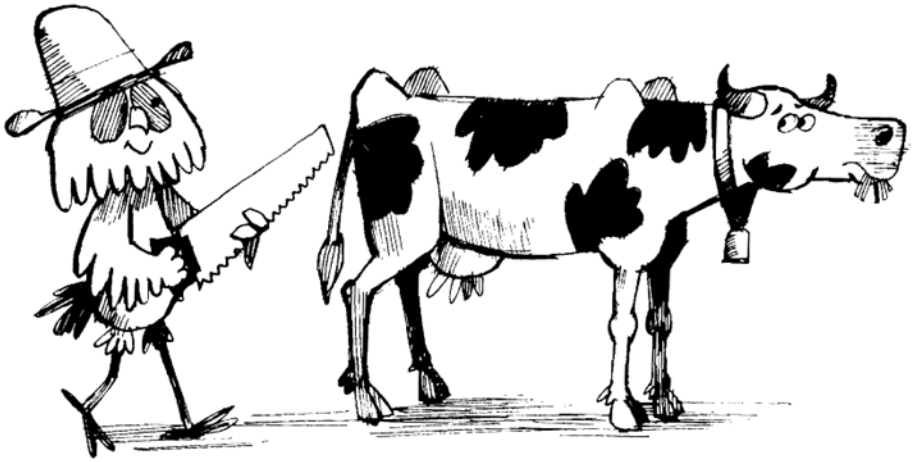
Powerful approach to problem analysis

Systems thinking provides a very powerful approach to problem analysis that gives analysts the ability to **view problems within the context of an overall system**, and thereby better identify and prevent unintended negative consequences of **proposed solutions** (changes).

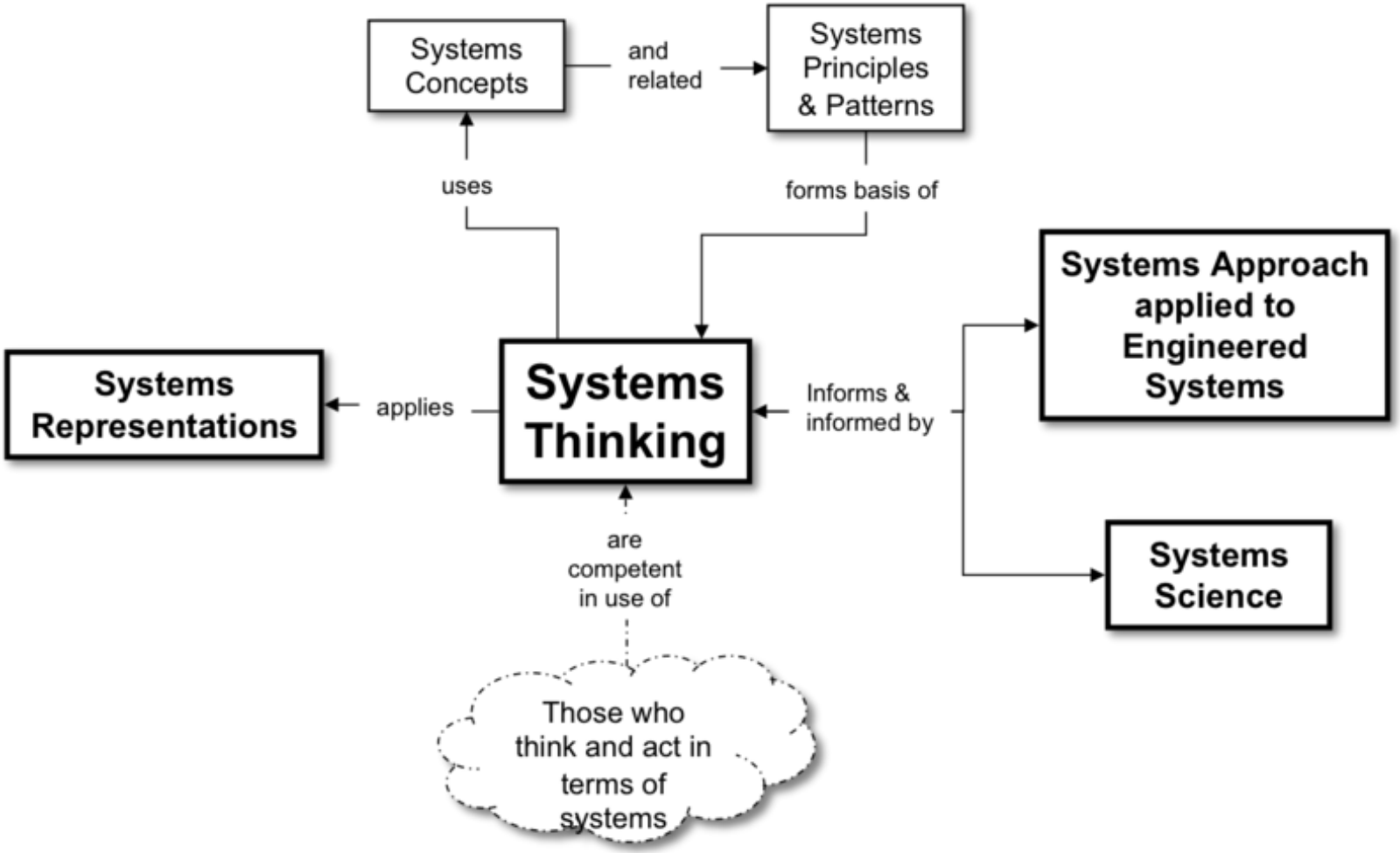
Systems Thinking

Systems thinking is the process of understanding how things, regarded as systems and components of systems, influence one another within a whole. Focused on the entire system and how the parts interrelate.



"Dividing a cow in half does not give two smaller cows"

Systems Thinking

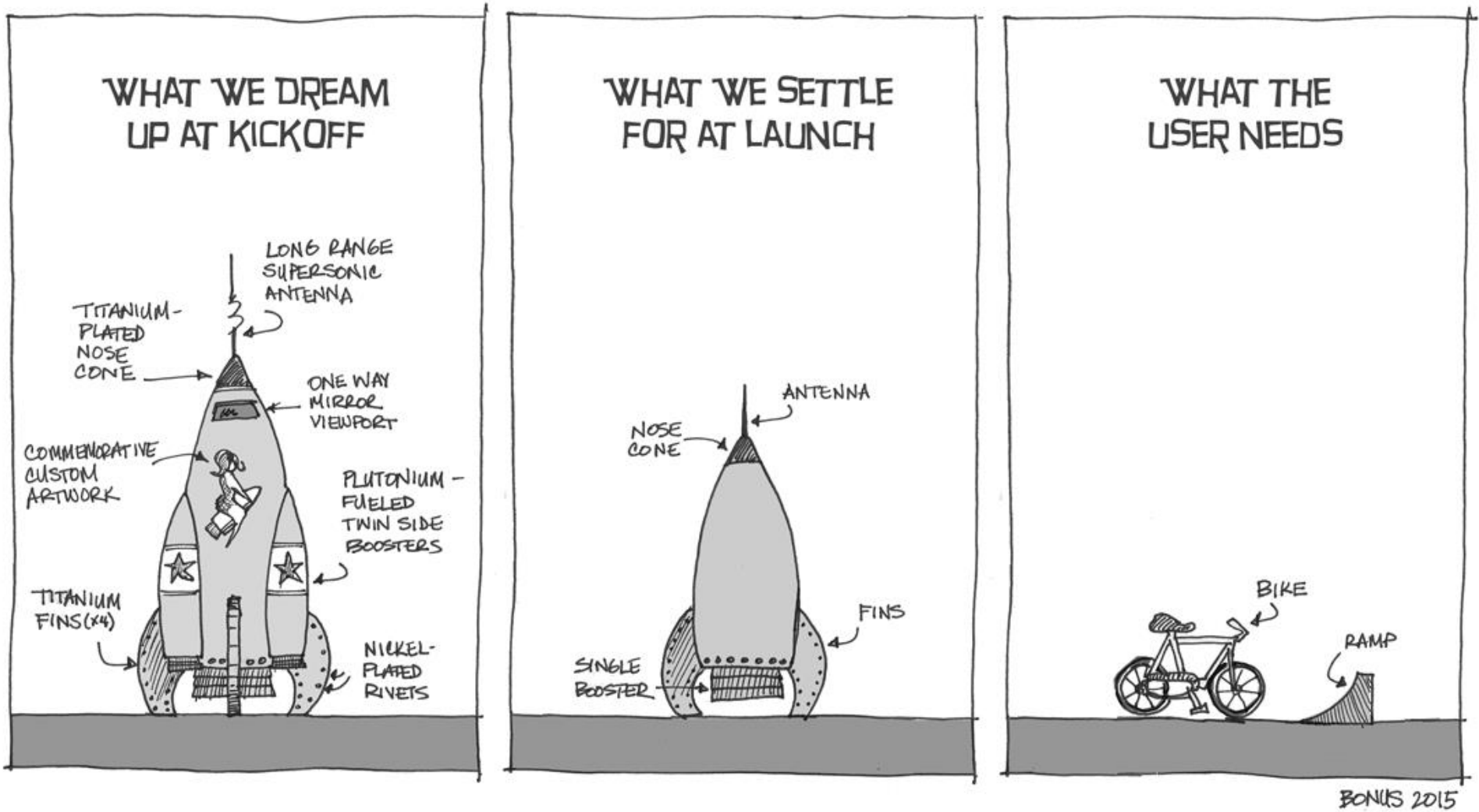


A broader view of the world

Systems Engineers practically **apply systems thinking** to understand **Who**, **When**, **Where**, **What**, **How** and **Why**

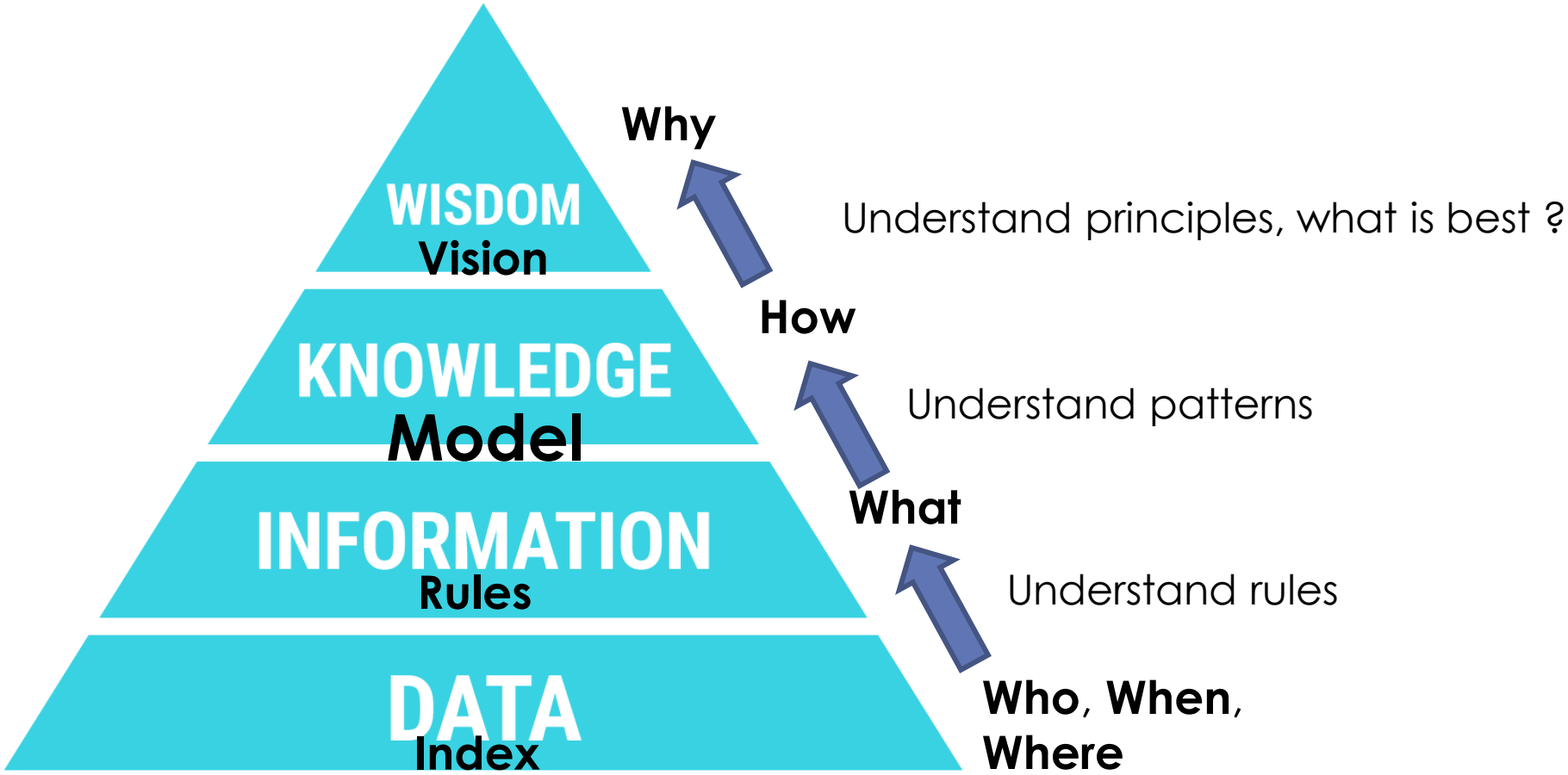
Appreciate **the interconnectedness** of all things

Problem vs Solution

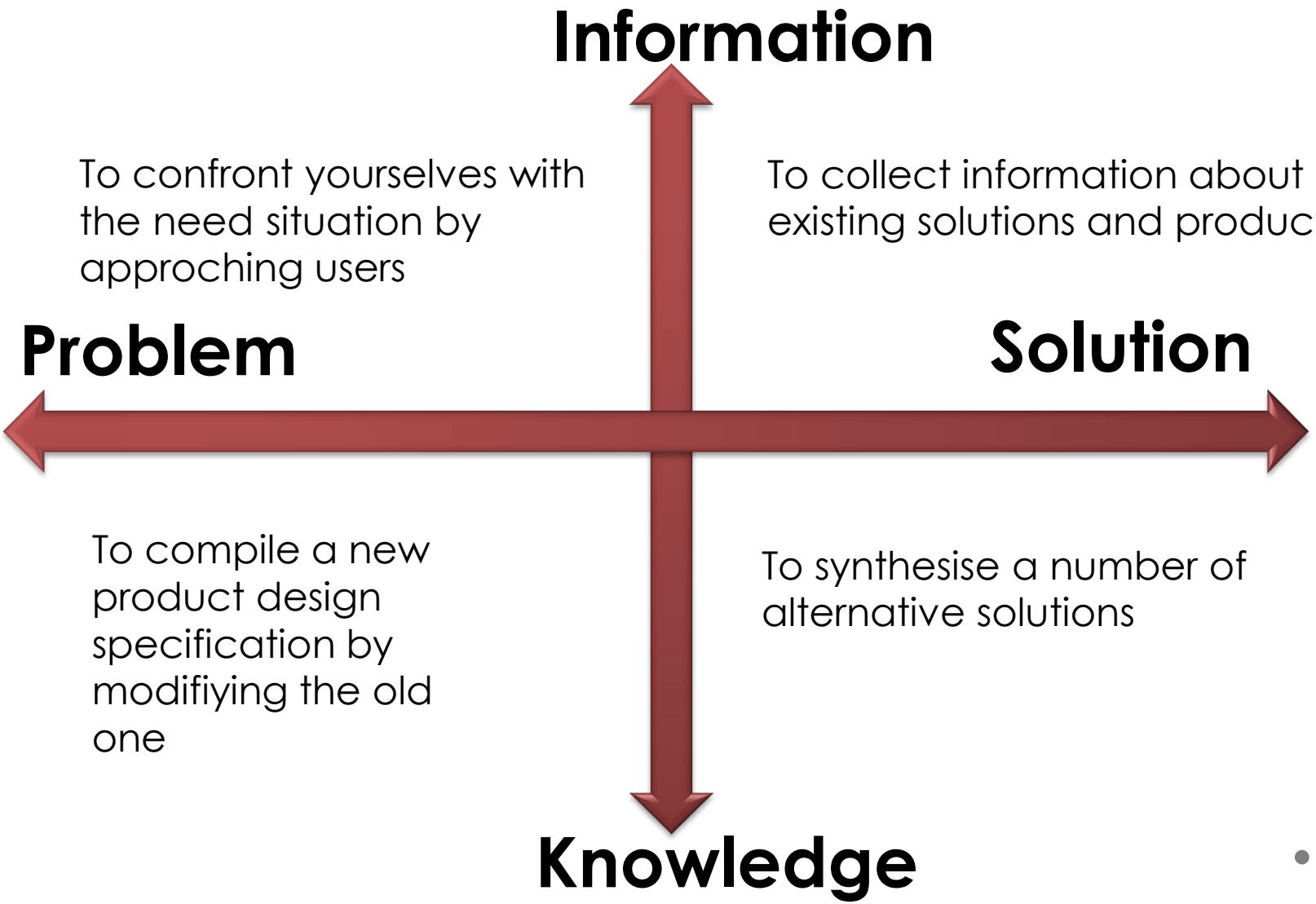


Who, **When**, **Where**, **What**, **How** and **Why**

Focused on the entire system and how the parts interrelate



Four dimensions for attacking a problem



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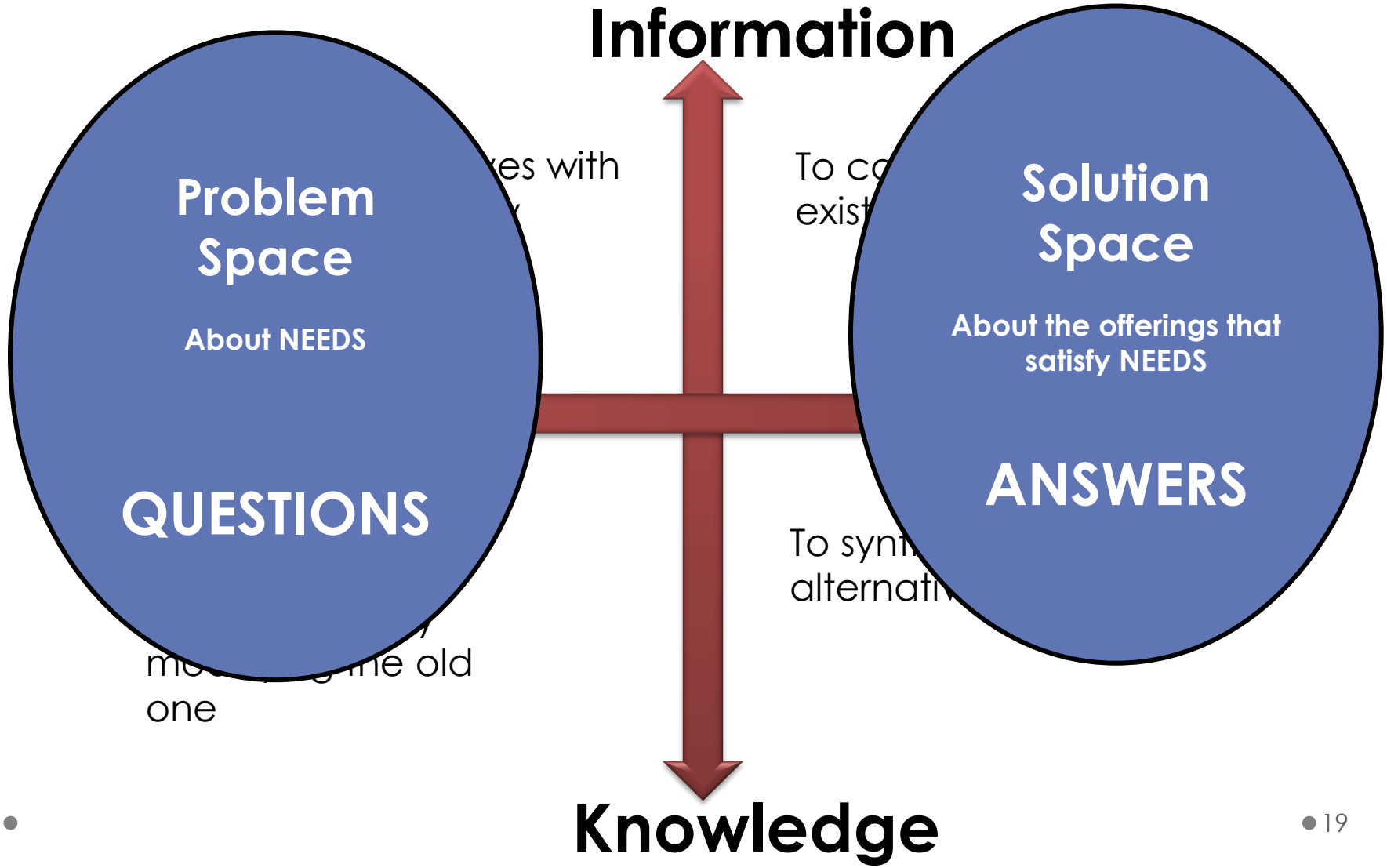

Full creativity of the team

It is **very difficult** for people describing requirements **to avoid jumping to solutions instead of describing needs**.

This constrains the team in realizing the optimal solution and **fails to employ the full creativity of the team**.

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Common Misconception

Systems Engineering (SE) is a narrow branch of engineering associated with computers, software, and information technology (IT).

Clarification

- **SE is a very broad** , overarching, and generally applicable engineering discipline. Many types of systems are developed using SE. These include biomedical systems, space vehicle systems, weapon systems, transportation systems, and so on.
- **SE involves the coordination of work** performed by engineers from all other engineering disciplines (electrical, mechanical, computer, software, etc.) as required to complete the engineering work on the project/program.

J. Stein,“ Systems, Systems Engineering, and INCOSE: A Five Minute 50,000 Foot Overview”, INCOSE IW , Torrance, CA January 24-25,2015

Demand is soaring for Systems Engineers

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Money/Payscale.com's list of great careers

Full List | High Pay | Job Growth | Quality of Life | Sectors

1. Systems Engineer

1 of 50 | Next

Top 50 rank: 1
Sector: Information Technology

What they do: They're the "big think" managers on large, complex projects, from major transportation networks to military defense programs. They figure out the technical specifications required and coordinate the efforts of lower-level engineers working on specific aspects of the project.

Why it's great: Demand is soaring for systems engineers, as what was once a niche job in the aerospace and defense industries becomes commonplace among a diverse and expanding universe of employers, from medical device makers to corporations like Xerox and BMW.

Anne O'Neil, a chief systems engineer at the N.Y.C. Transit Authority, is one of five female senior managers in a department of 1,500.

Pay can easily hit six figures for top performers, and there's ample opportunity for advancement. But many systems engineers say they most enjoy the creative aspects of the job and seeing projects come to life. "The transit system I work on really makes a tangible difference to people," says Anne O'Neil, chief systems engineer for the New York City Transit Authority.

Drawbacks: Long hours are common; project deadlines can be fierce.

Pre-reqs: An undergrad engineering degree; some jobs might also require certification as a certified systems engineering professional (CSEP).

Systems Engineer job openings

jobs by simplyhired

Systems Engineer
Fort George G Meade, MD - National Security Agency (NSA)

Senior Systems Engineer*
Atlanta, GA - Unisys

Systems Engineer
Foster City, CA - Visa

Systems Engineer
Santa Ana, CA - First American

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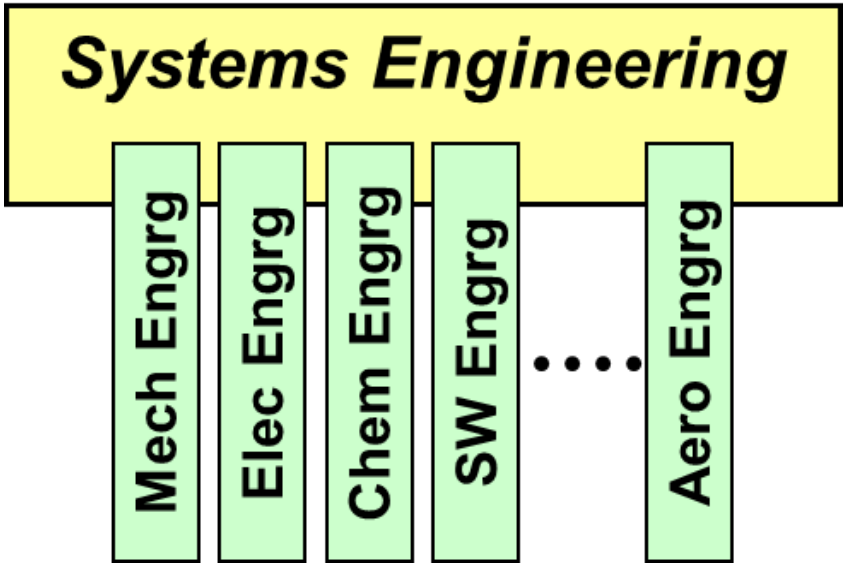
Definition of SE

Systems Engineering is an **interdisciplinary approach** and means to enable the realization of **successful systems**. It focusses on defining **customer needs** and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while **considering the complete problem**: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal.

Systems Engineering (SE) considers both **the business and technical needs** of all customers with the goal of providing a quality product that meets the user needs."

(INCOSE SE Handbook)

Meta-Discipline



Meta-Discipline that integrates technical effort across the Development Project

- Functional Disciplines
- Technology Domains
- Specialty Concerns

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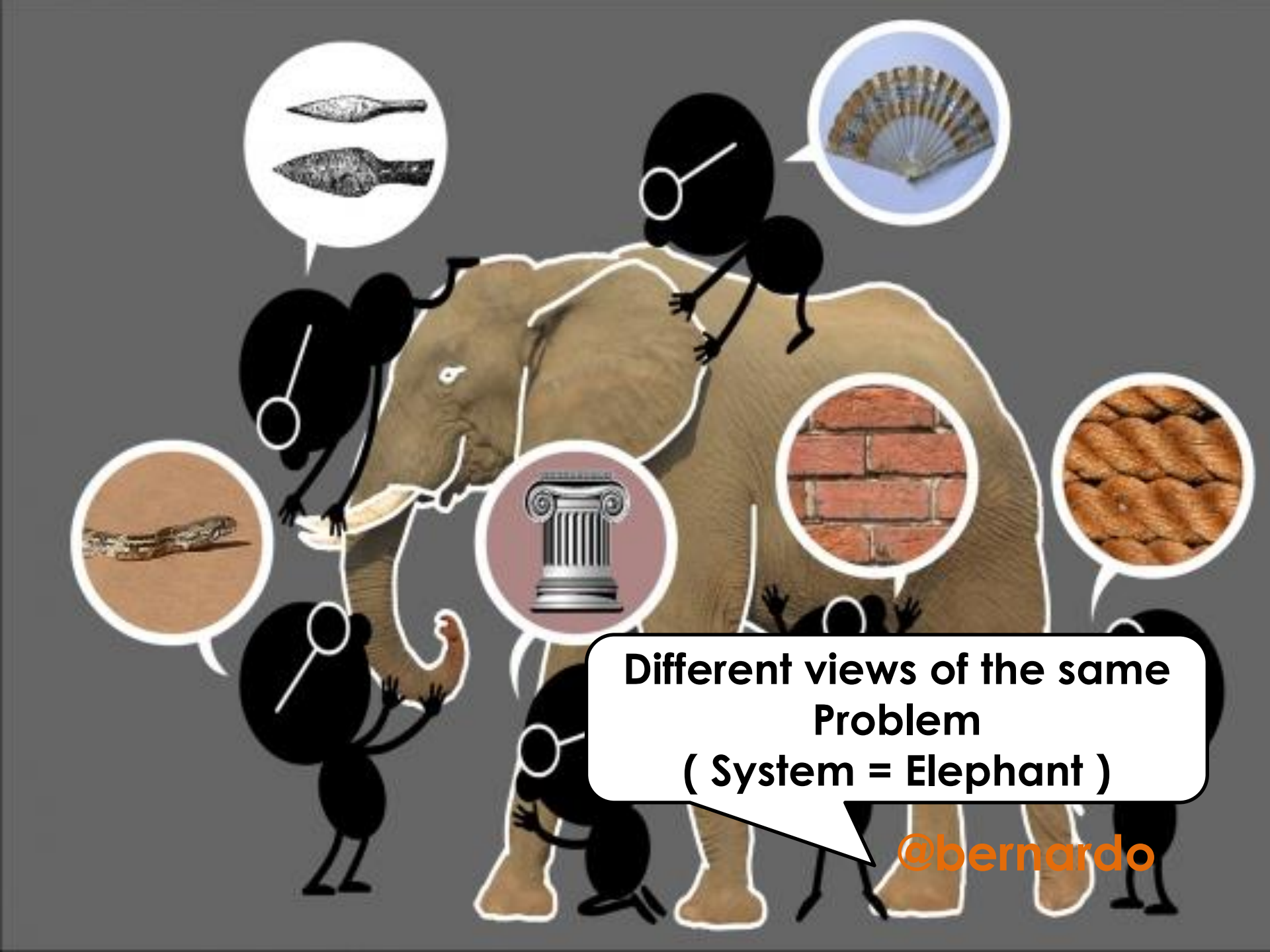
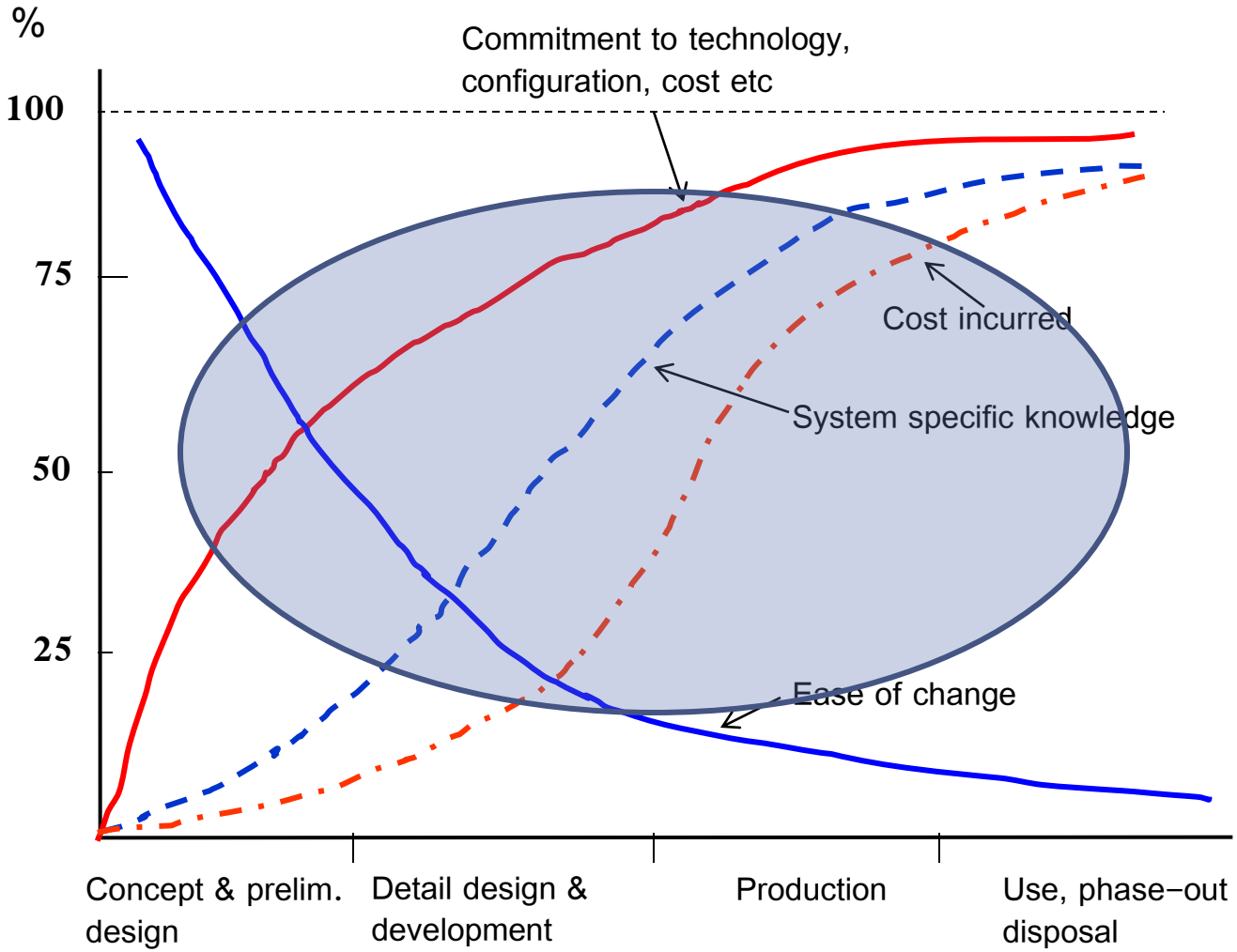
Systems Engineering needed due to product complexity is increasing

- High Complexity
- Multidisciplinary
- Cost
- Time


Different views of the same Problem
(System = Elephant)
@bernardo

Why Systems Engineering ?



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Origins of SE

1937	British multidisciplinary team to analize the air defence system
1939-45	Bell Labs supports NIKE development (1st US operational anti-aircraft missile system)
1951-80	SAGE (Semi-automatic Ground Enviroment) Air Defense System defined and managed by MIT/Jay Forrester
1956	Invention of systems analysis by RAND corp.
1960-70	Apollo Program First SE standards (e.g. MIL-STD 499, NASA procedures)
1962	Publication of Arthur D. Hall – A Methodology for Systems Engineering
1989	EIA recognizes SE as importan part of system development
1990	NCOSE is founded
1990-2000	Release of SE standards IEEE 1220, EIA 632
1994	NCOSE renamed to INCOSE
2002	Release of ISO/IEC 15288
2008	App. 6500 INCOSE members worldwide
2019	17000+ INCOSE members worldwide (70+ Chapters 35+ Countries)

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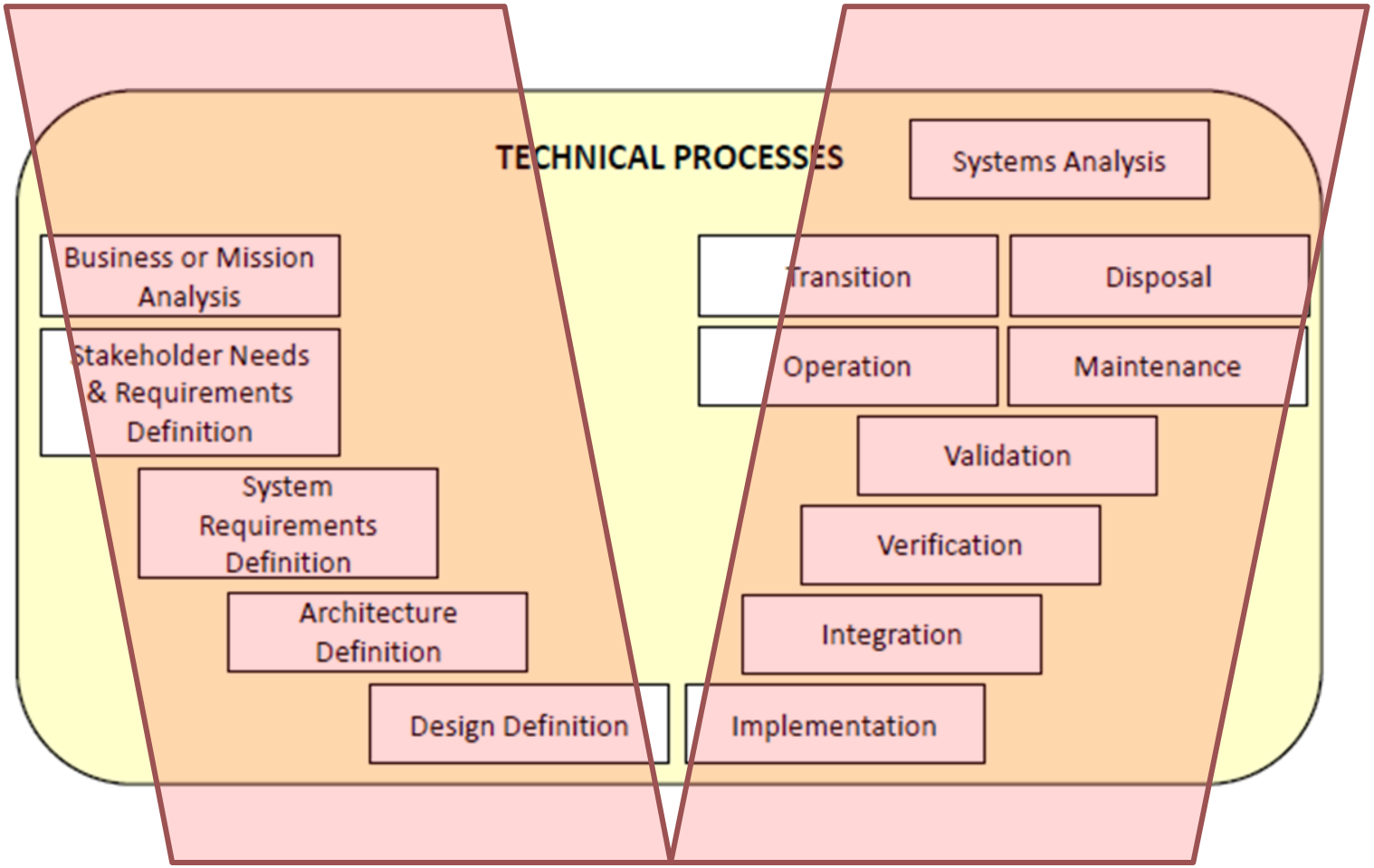
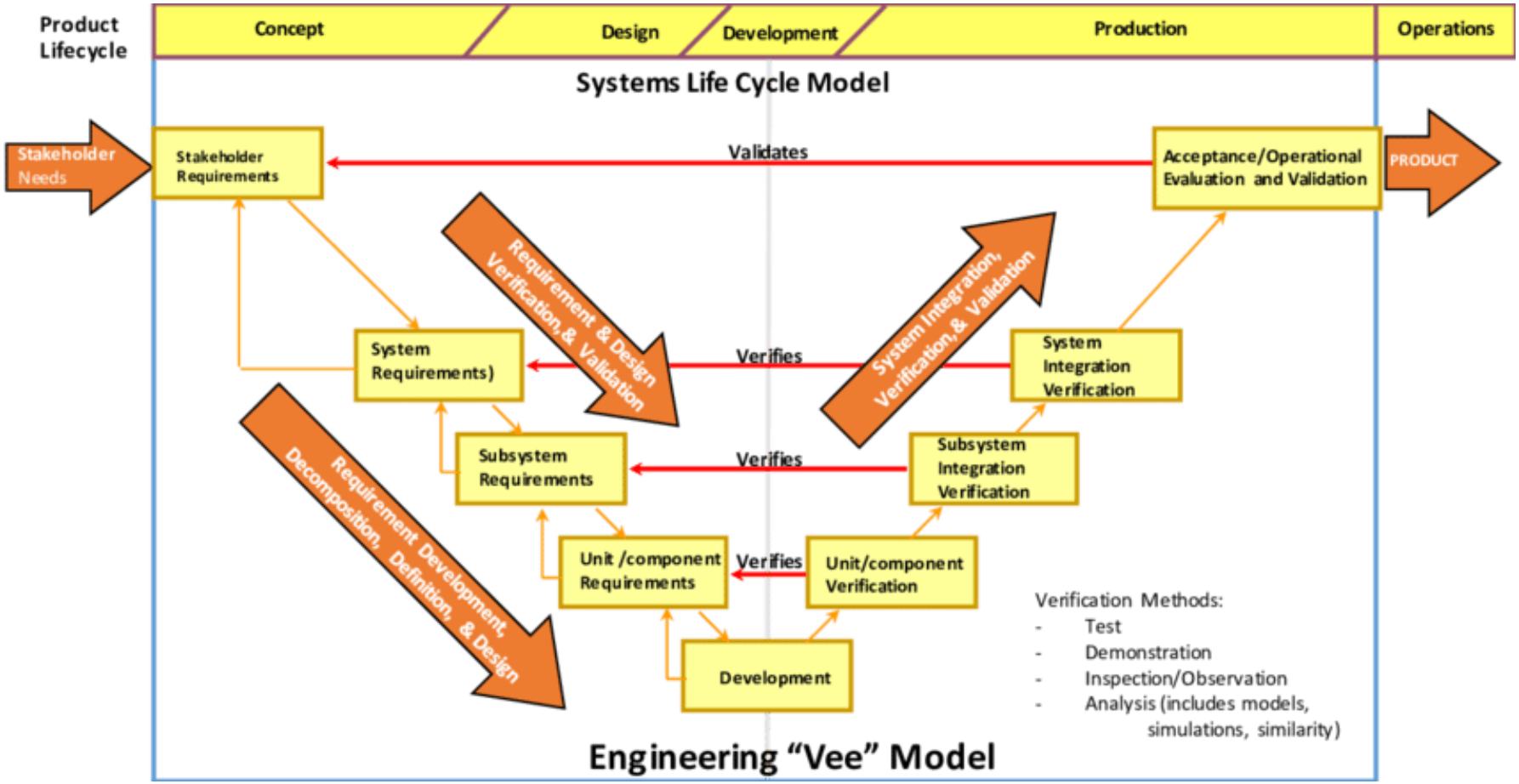
Technical SE Processes

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



Vee Model Approach



Ryan, Michael J. ; Wheatcraft, Louis S. (2017), "On the Use of the Terms Verification and Validation", INCOSE International Symposium

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Life Cycle

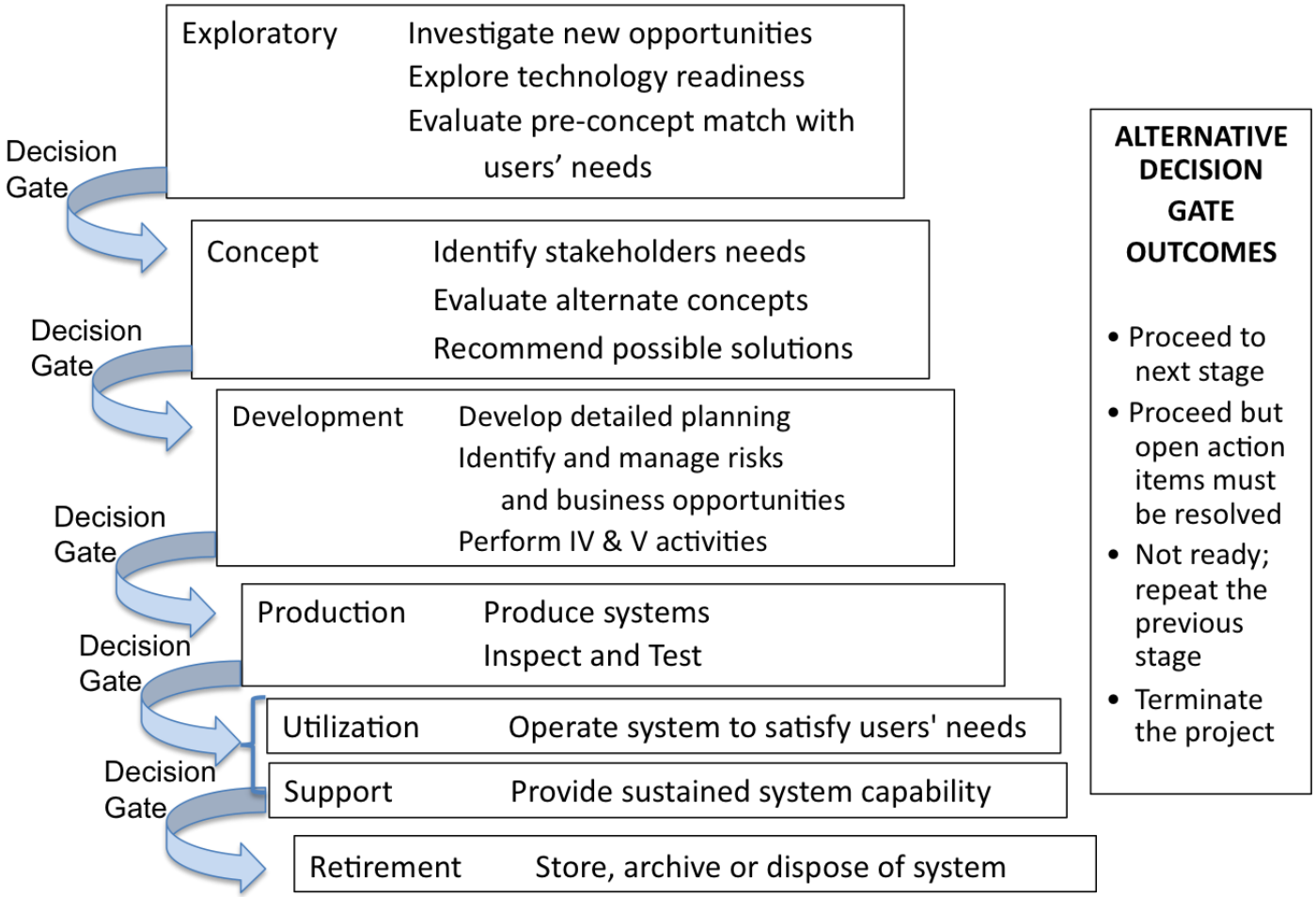
Life Cycle is the evolution of a system, product, service, project or other human-made entity from conception through retirement.

(ISO/IEC/IEEE 15288 : 2015)

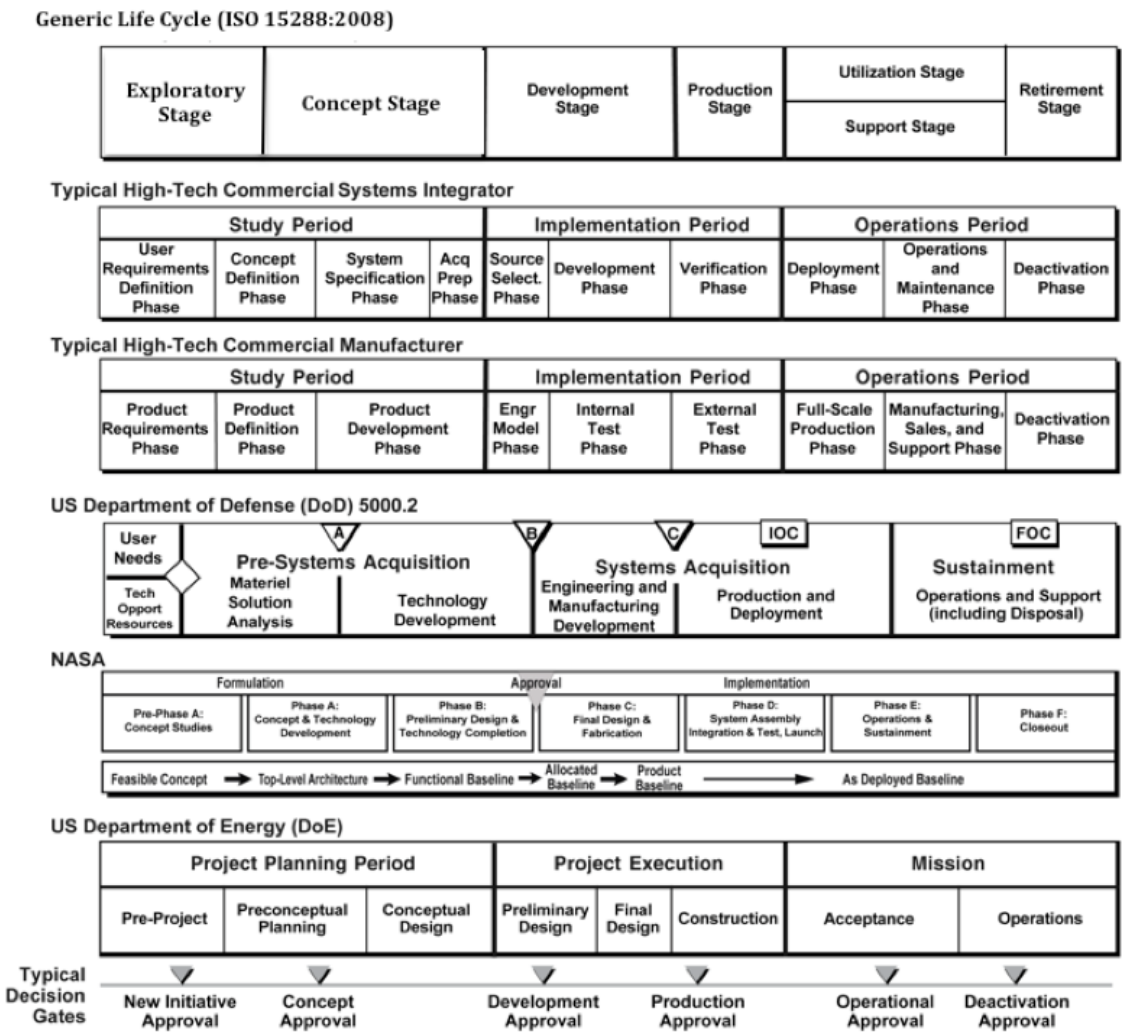
A **life cycle for a system** generally consists of a series of stages regulated by a set of management decisions which confirm that the system is mature enough to leave one stage and enter another.

(SEBoK Version 1.9.1 2018)

Life Cycle Stages & Decision Gates



Comparisons of Life Cycle models



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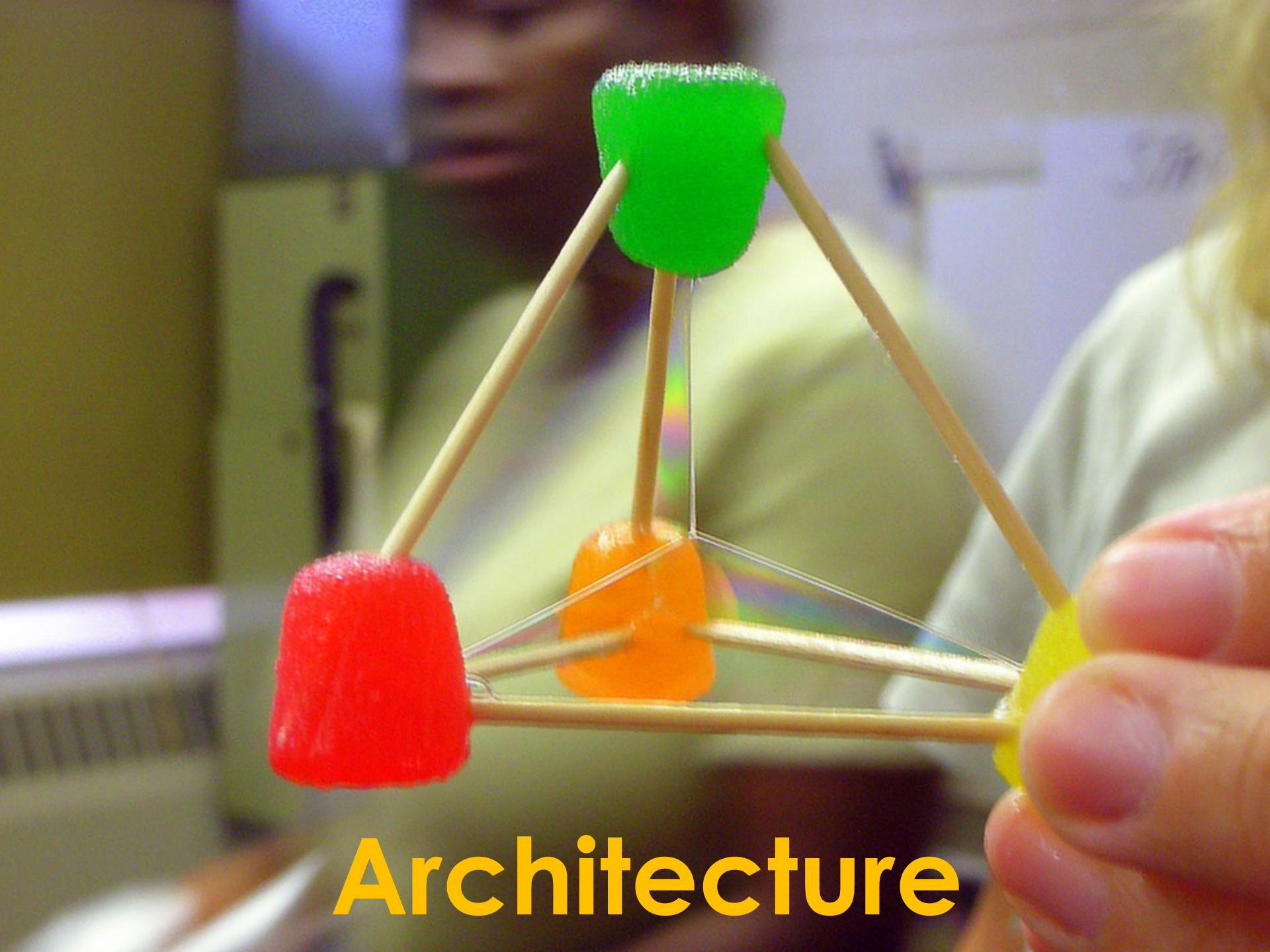
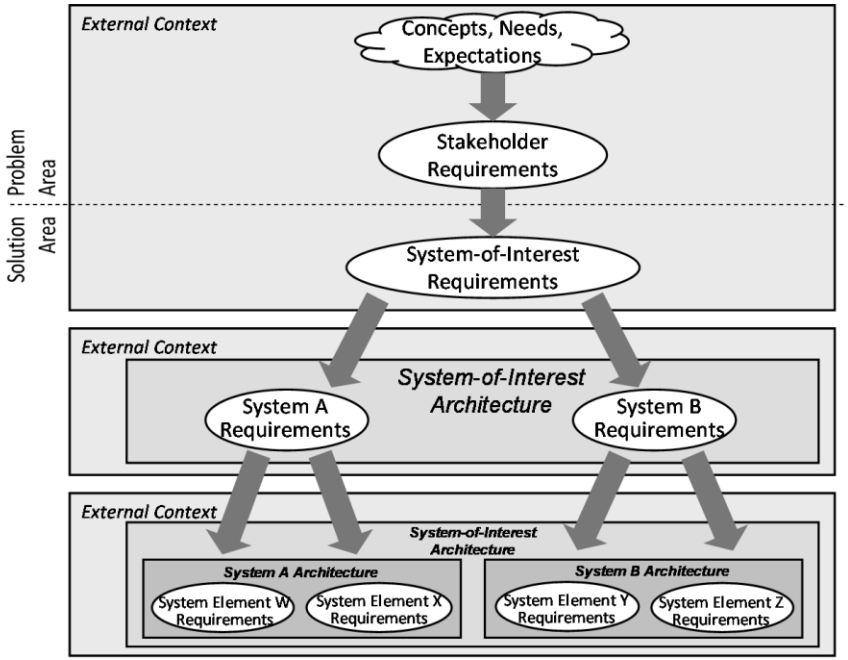


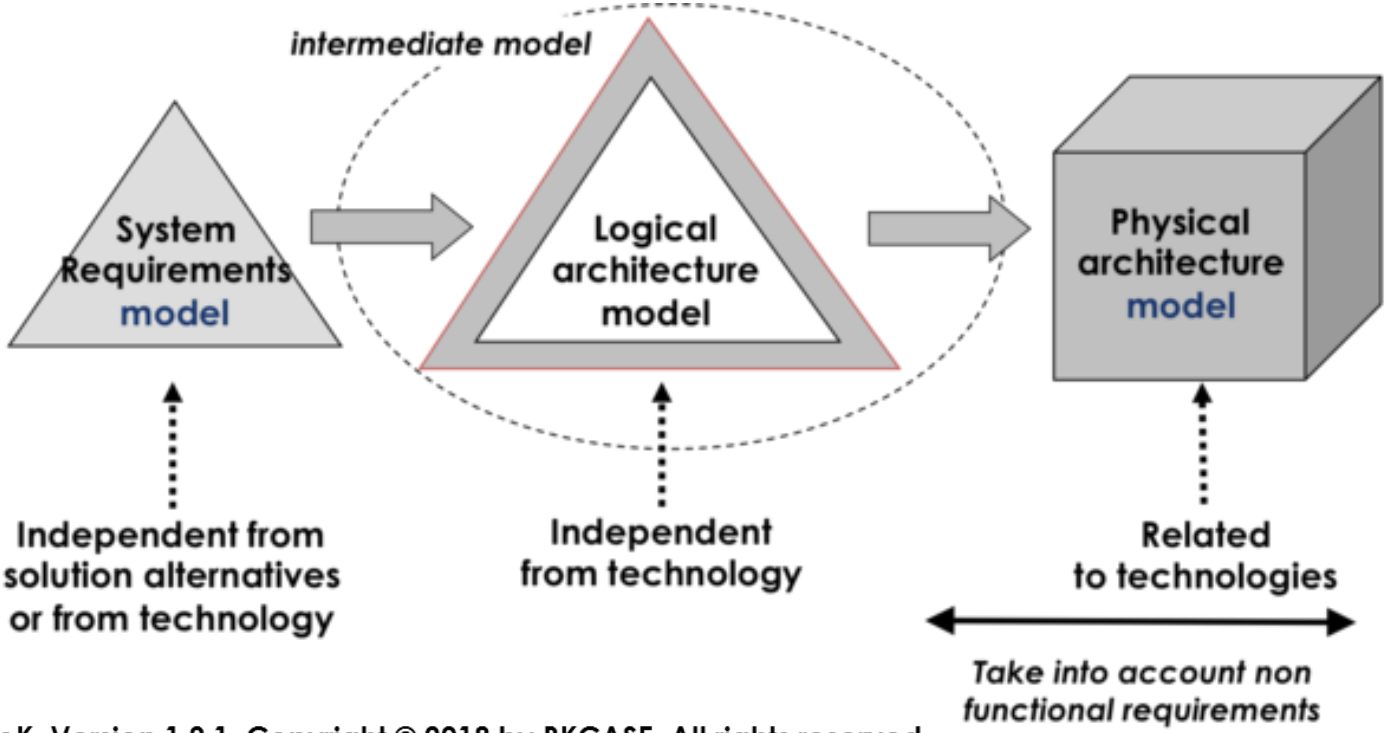
Architecture

Architecture



System Architecture is abstract, conceptualization-oriented, global, and focused to achieve the mission and life cycle concepts of the system.

Architecture Model



Logical and physical models (or views) are often used for representing fundamental aspects of the system architecture

Requirement

A requirement is "**a statement that identifies a system**, product or process characteristic or constraint, which is unambiguous, clear, unique, consistent, stand-alone (not grouped), **and verifiable**, and is deemed necessary for stakeholder acceptability."

(INCOSE Systems Engineering Handbook)

System Requirements

System requirements are **all of the requirements at the system level that describe the functions which the system as a whole** should fulfill to satisfy the stakeholder needs and requirements, and is expressed in an appropriate combination of textual statements, views, **and non-functional requirements; the latter expressing the levels of safety, security, reliability, etc., that will be necessary.**

System requirements play major roles in systems engineering, as they:

- Form the basis of **system architecture** and **design activities.**
- Form the basis of **system integration** and **verification activities**.
- Act as **reference for validation** and stakeholder acceptance.
- Provide **a means of communication between the various technical staff** that interact throughout the project

V & V

Verification ensures you built the system right

Validation ensures you built the right system

V&V in Requirements, Design, System

(INCOSE SE Handbook)

V & V Requirements

Requirement Verification: ensuring the requirement meets **the rules and characteristics defined for writing a good requirement**. The focus is on the wording and structure of the requirement.

Requirement Validation: confirmation that the requirements and requirement set is an agreed-to transformation that **clearly communicates the stakeholder needs and expectations** in a language understood by the developers.

Ryan, Michael J. ; Wheatcraft, Louis S. (2017), "On the Use of the Terms Verification and Validation", INCOSE International Symposium

V & V System

System Verification: a process done after design and build or coding, **ensuring the designed and built or coded system meets its requirements**. The focus is on the built or coded system and how well it meets the agreed to requirement set that drove the design and fabrication.

Methods used for system verification include: **test, demonstration, inspection, or analysis**.

"Did we build the thing right?"

Ryan, Michael J. ; Wheatcraft, Louis S. (2017), "On the Use of the Terms Verification and Validation", INCOSE International Symposium

V & V System

System Validation: a process that occurs after system verification that confirms the designed, built, and verified system meets its intended purpose in its operational environment.

The focus is on the completed system and how well it meets stakeholder expectations (needs) that were defined during the scope definition phase that should have occurred at the beginning of the project.

"Did we build the right thing?"

Ryan, Michael J. ; Wheatcraft, Louis S. (2017), "On the Use of the Terms Verification and Validation", INCOSE International Symposium

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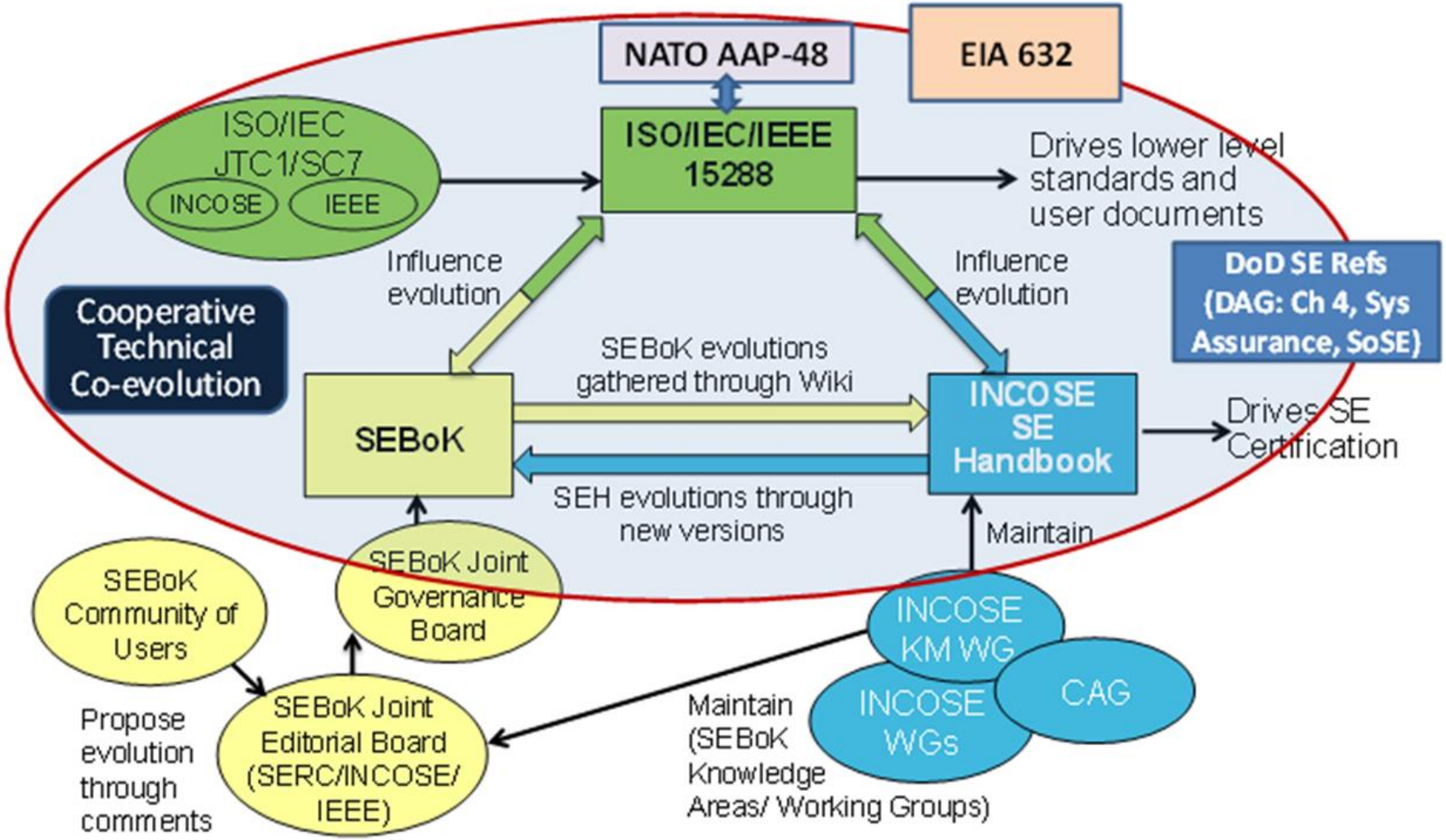
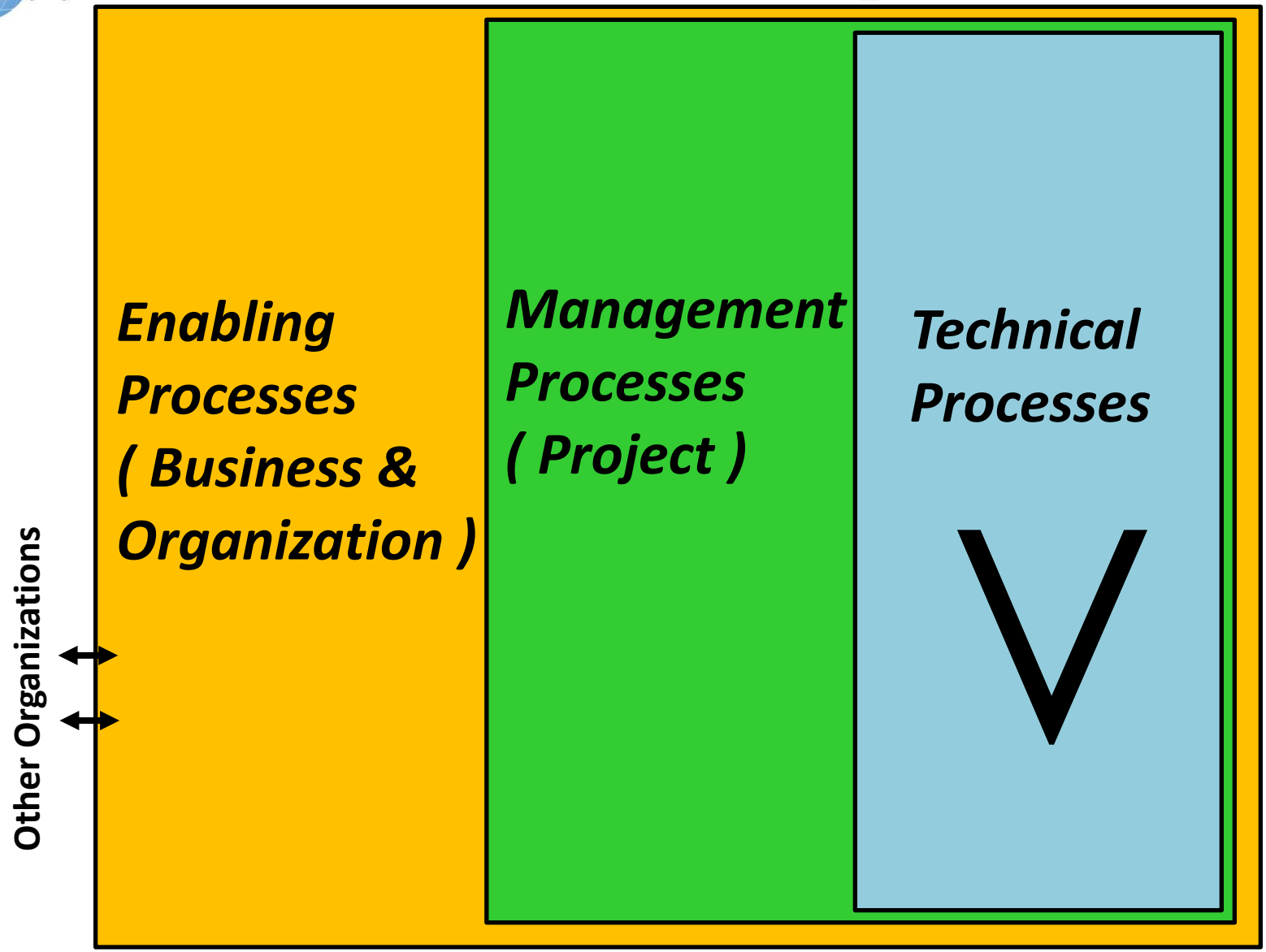
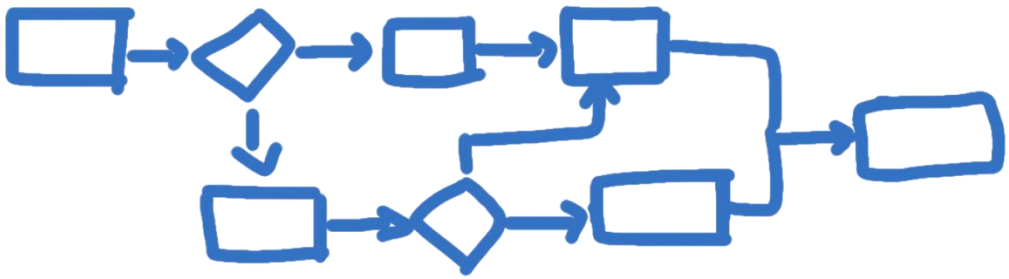
Harmonization



Manage the project and the relationships



ISO 15288 Processes



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
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- Implementation
- Integration
- Verification
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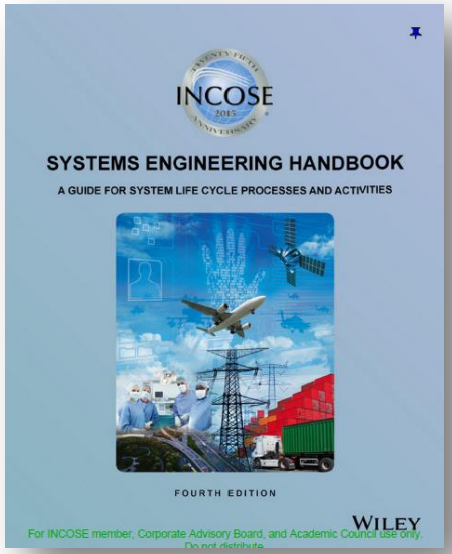
- Operation
- Maintenance
- Transition
- Disposal

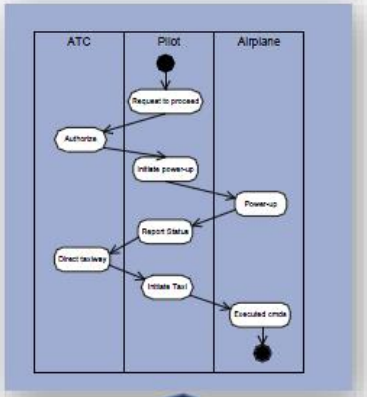


Moving from Document-Centric to Model-Centric

Traditional

- Specifications
- Interface requirements
- System design
- Analysis & Trade-off
- Test plans

Future



Today
standalone models related through documents
Still Document-Centric

Future
shared system model with multiple views, and connected to discipline models

What is Model-Based Systems Engineering (MBSE) ?

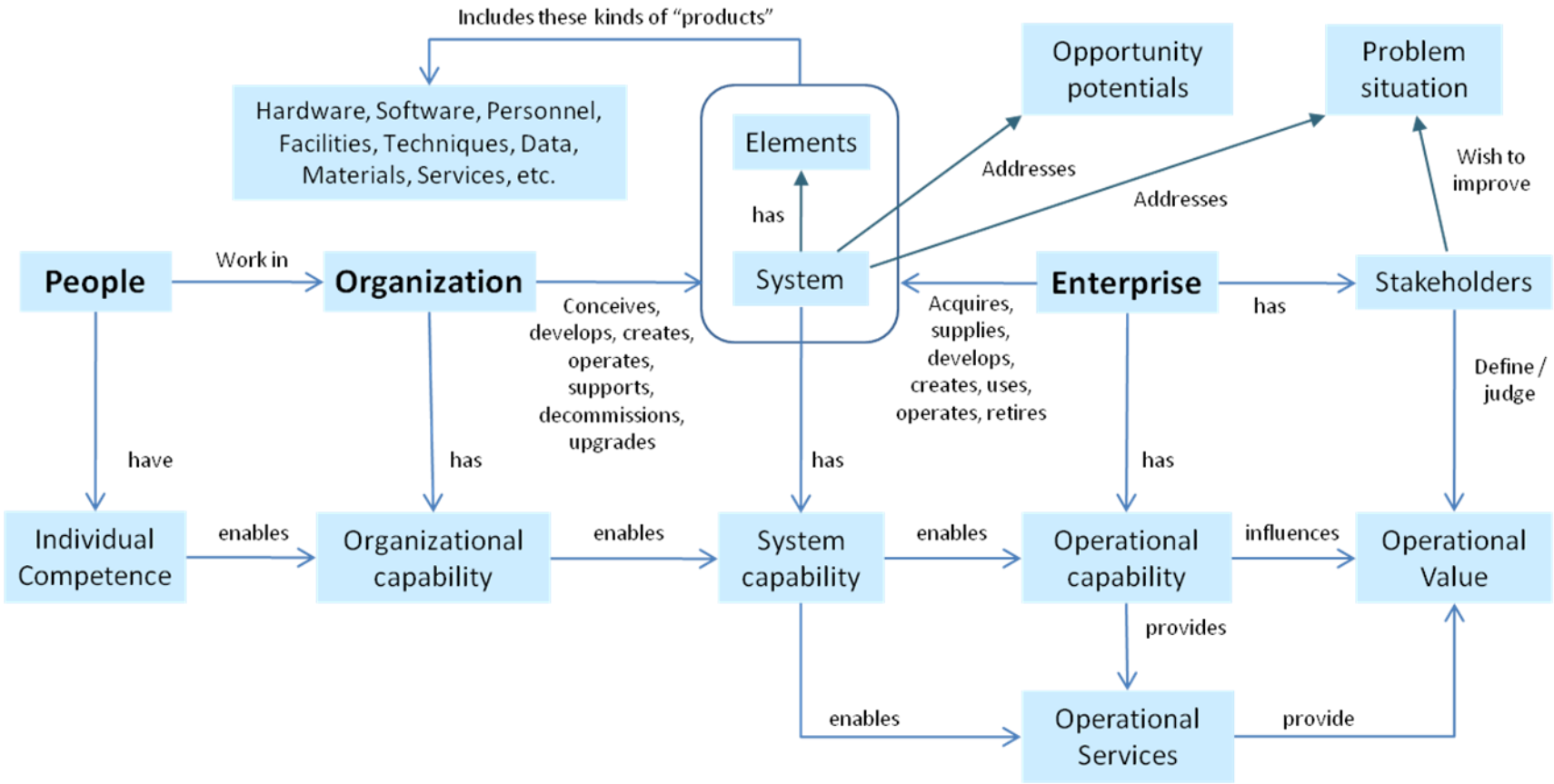
MBSE is the **formalized application of system modelling techniques** to support the product development.

It includes analysis of the system context, the development of system requirements, design of the system architecture and continuous system validation applied to all systems engineering activities.

Improved:

- Product quality
- Management of product complexity
- Communication of designs and stakeholders
- Knowledge capture and re-use

Individual Competence Leads to Organizational, System & Operational Capability



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Challenging Complex Projects

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TECH

F-35 fighters plagued with delays, cost overruns, federal report says

By Maxim Lott · Published April 03, 2014 · Fox News

EDITION: UNITED STATES

REUTERS

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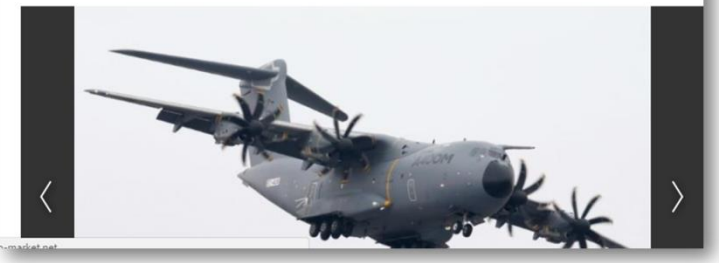

Berlin airport opening delayed to 2018

The Brandenburg Willy Brandt Airport was originally set to open in 2011.

By JOSHUA POSANER | 12/28/16, 10:07 AM CET | Updated 12/28/16, 11:22 AM CET

The opening of Berlin's troubled new airport is to be postponed to spring 2018, marking the project's latest delay, according to Germany's Die Zeit.

The Berlin Brandenburg Willy Brandt Airport was originally set to open in 2011 but cost overruns and construction errors caused repeated delays.

Latest estimates have been for a late 2017 opening, but an airport spokesperson said an announcement would be made in January on the exact date.

Germany's biggest carrier Lufthansa had described a winter 2017 start-up date for the terminal as "unsuitable," instead suggesting that 2018 is more realistic.

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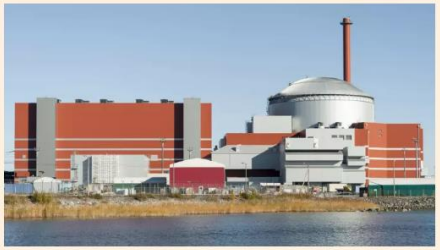
Western Europe's first atomic power station in 15 years is test of Areva technology



Save

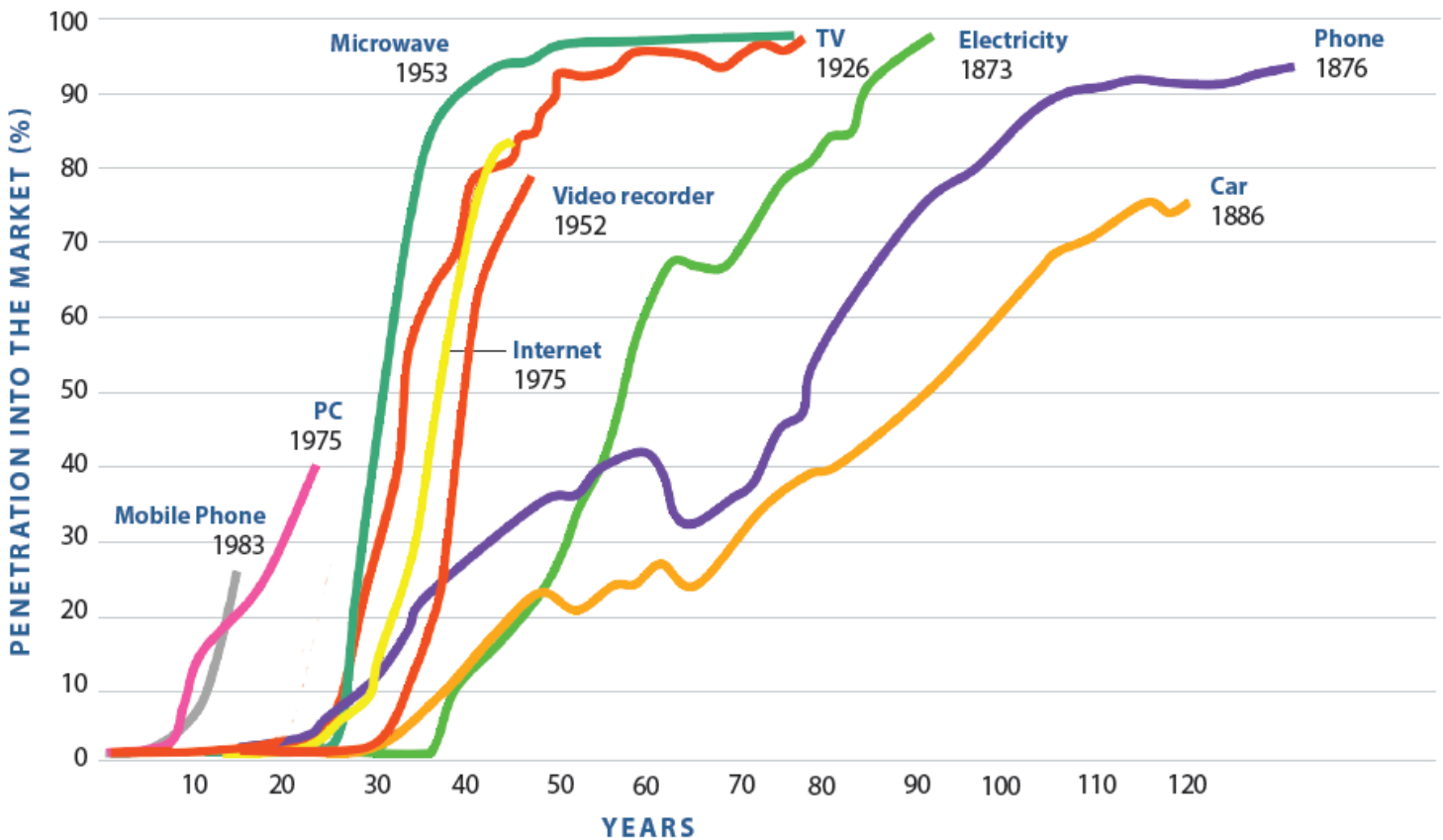
MAY 18, 2017 by: Andrew Ward, Energy Editor

On the shores of the Baltic Sea, beneath the big azure sky of a Nordic spring, Finland's Olkiluoto-3 nuclear plant looks almost complete.

Increasing Rate of Technology Adoption

NEW TECHNOLOGIES CHANGE OUR DAILY LIFE AT AN EVER INCREASING RATE

Source: Forbes magazine



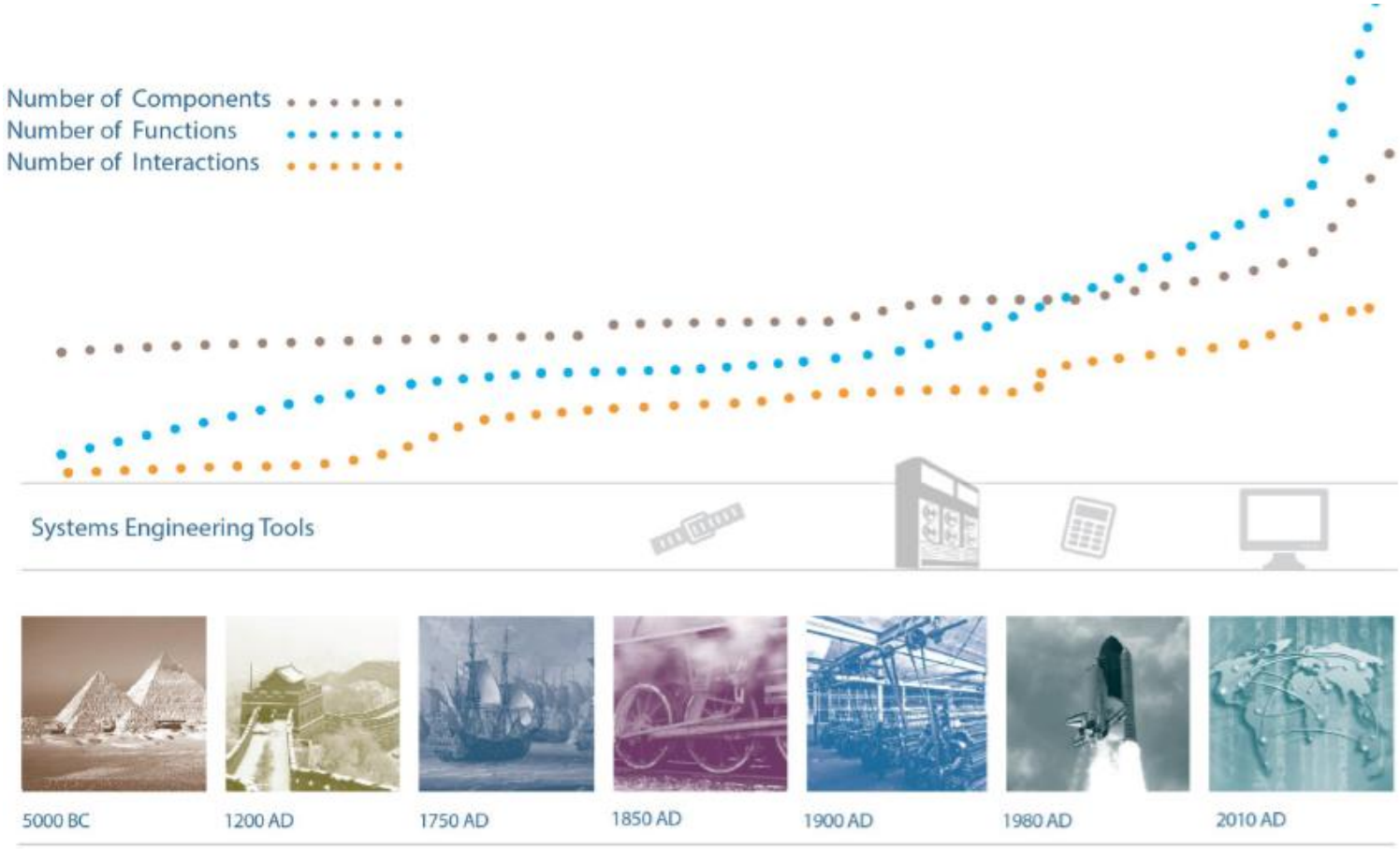
Complex Global Trends

Human Needs translate to…

Societal Needs that are satisfied by…

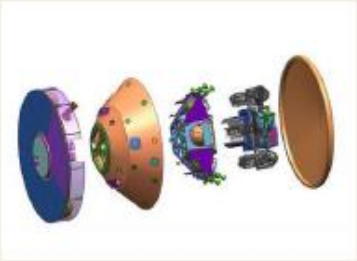
System Solutions

Increasing Complexity of System Solutions



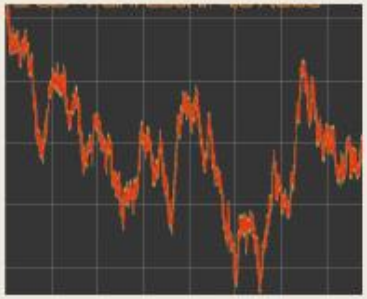
Need to adapt SE approaches

TAILORED TO THE DOMAIN



SCALED TO PROJECT SIZE

SCALED TO SYSTEM COMPLEXITY



Need for **agility**

Creating Systems that work

1. Debate, define, revise and pursue **the purpose / need**
2. Think **holistically**
3. Follow a **systematic** procedure
4. Be **creative**
5. Take account of the **people**
6. Manage the **project** and the relationships

UK Royal Academy of Engineering (2007) "Creating systems that work: Principles of engineering systems for the 21st century"

Creating Systems that work

1. Debate, define, revise and pursue **the purpose / need** **Life cycle phases and long-term view**
2. Think **holistically** **systems thinking**
3. Follow a **systematic** procedure **SE processes**
4. Be **creative** **divergent thinking**
5. Take account of the **people** **multidisciplinary integration**
6. Manage the **project** and the relationships **management**

UK Royal Academy of Engineering (2007) "Creating systems that work: Principles of engineering systems for the 21st century"

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