Past and Future of Systems Engineering in ASD Programs : Spain vs the World

INTA (Instituto Nacional de Técnica Aeroespacial)
Ministerio de Defensa

Torrejón de Ardoz (Madrid) , Spain, 8th October 2019

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- Introduction
- What is Systems Engineering (SE)
- Origins of SE
- SE Capability in Organizations
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On behalf of INCOSE

Promote SE research and organizational investment

Align SE initiatives, including SE research, SE standards, methods, tools, and curriculum

Identify SE capabilities to support future challenges and needs

Broaden the base of practitioners across industry domains

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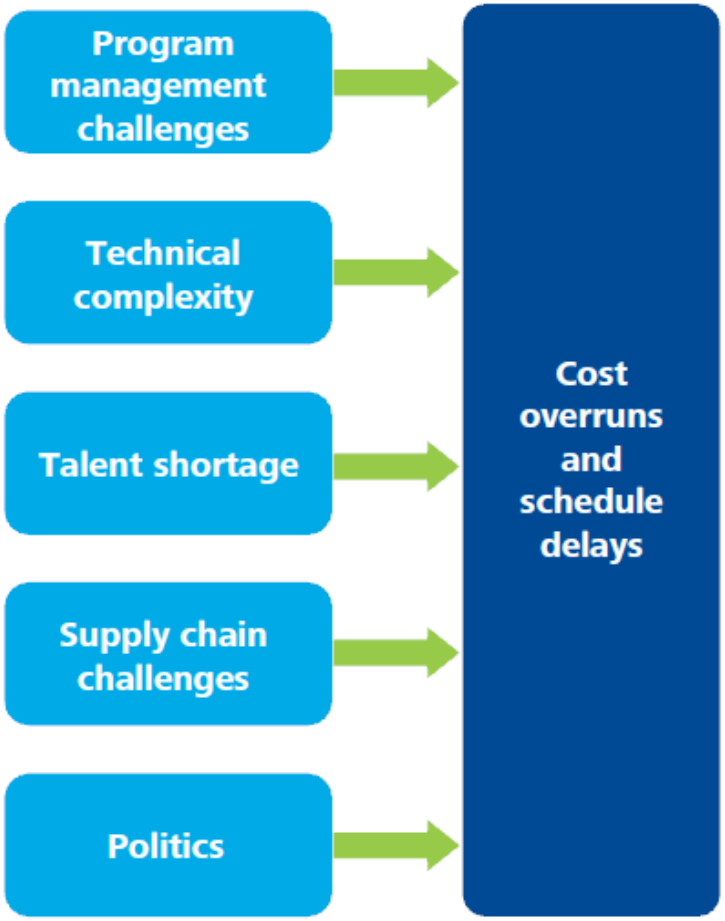
ASD Programs Challenges

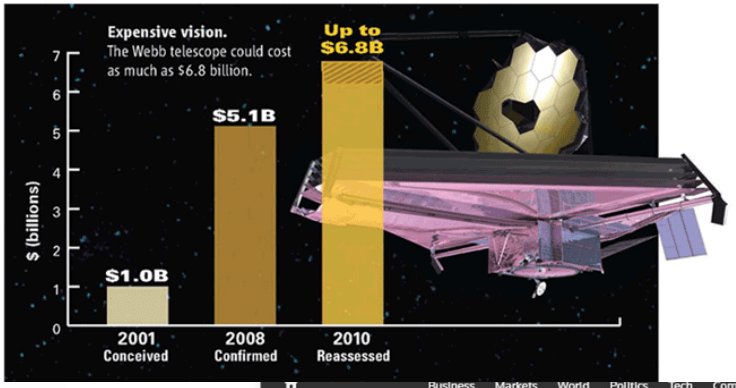


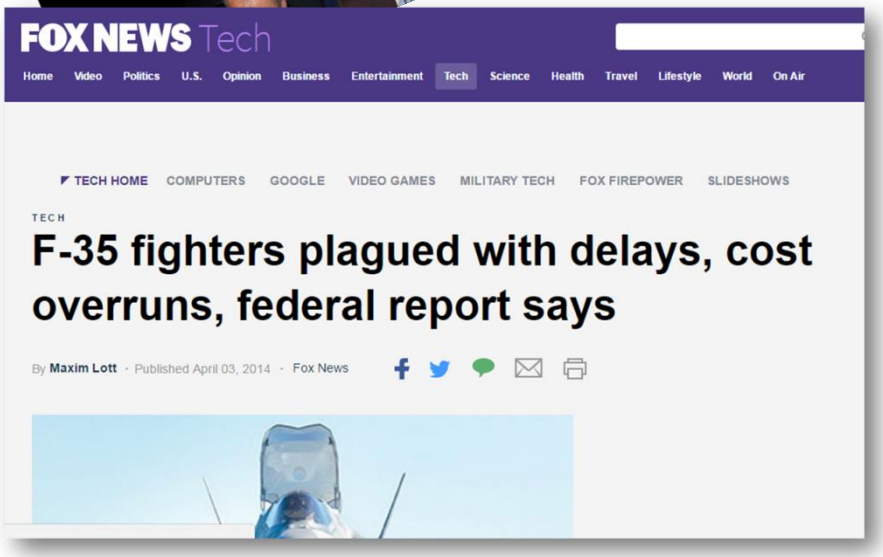
Root cause of failures on acquisition programs : US DoD

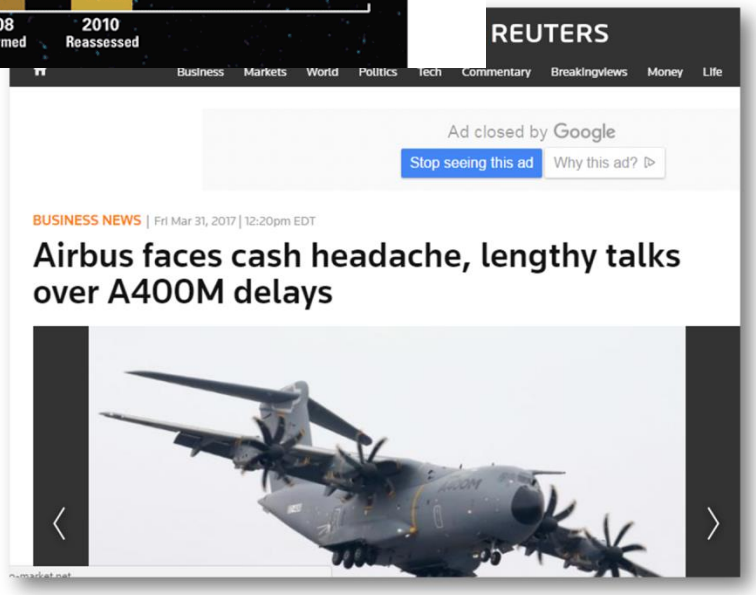
- Inadequate **understanding of requirements**
- Lack of **systems engineering discipline, authority, and resources**
- Lack of **technical planning** and oversight
- **Stovepipe developments** with late integration
- Lack of subject matter **expertise at the integration level**
- Availability of **systems integration facilities**
- Incomplete, obsolete, or inflexible **architectures**
- Low visibility of **software risk**
- **Technology maturity** overestimated

Karen B. Bausman
Air Force Center for Systems Engineering
Revitalization of Systems Engineering: Past, Present and Future
NDIA 25 October 2005

A Check on Reality







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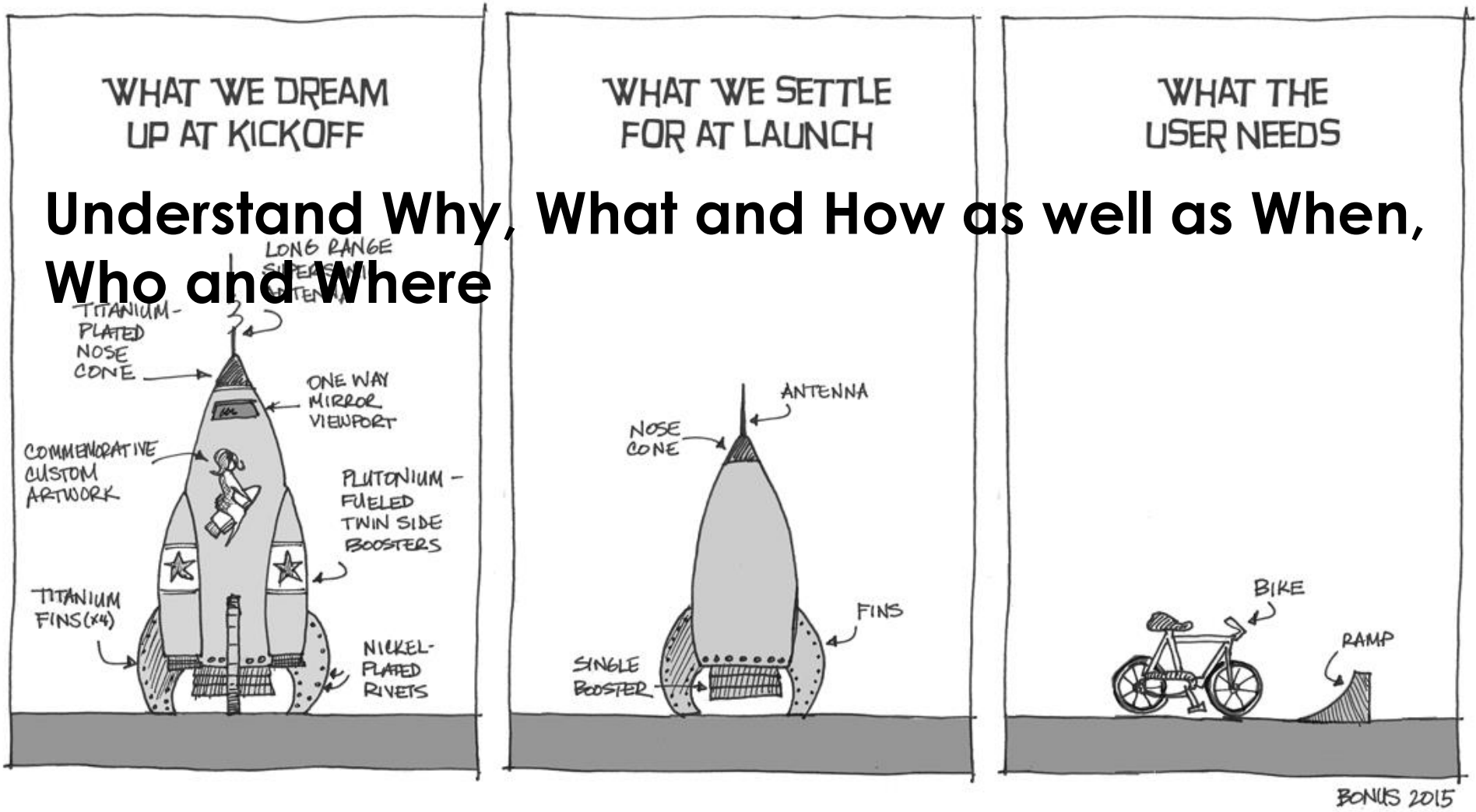
Definition of SE

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.

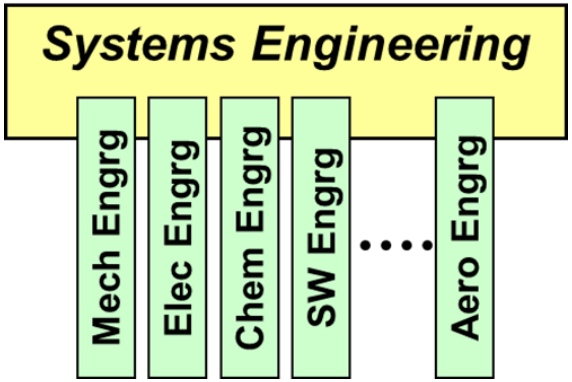
Problem vs Solution



Understand Why, What and How as well as When, Who and Where

Systems Engineering (SE)

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

Achieving balance between inherent conflicts in the Why, What, How, Which, When, Who and Where

Systems

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

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

The practice of Systems Engineering is…..

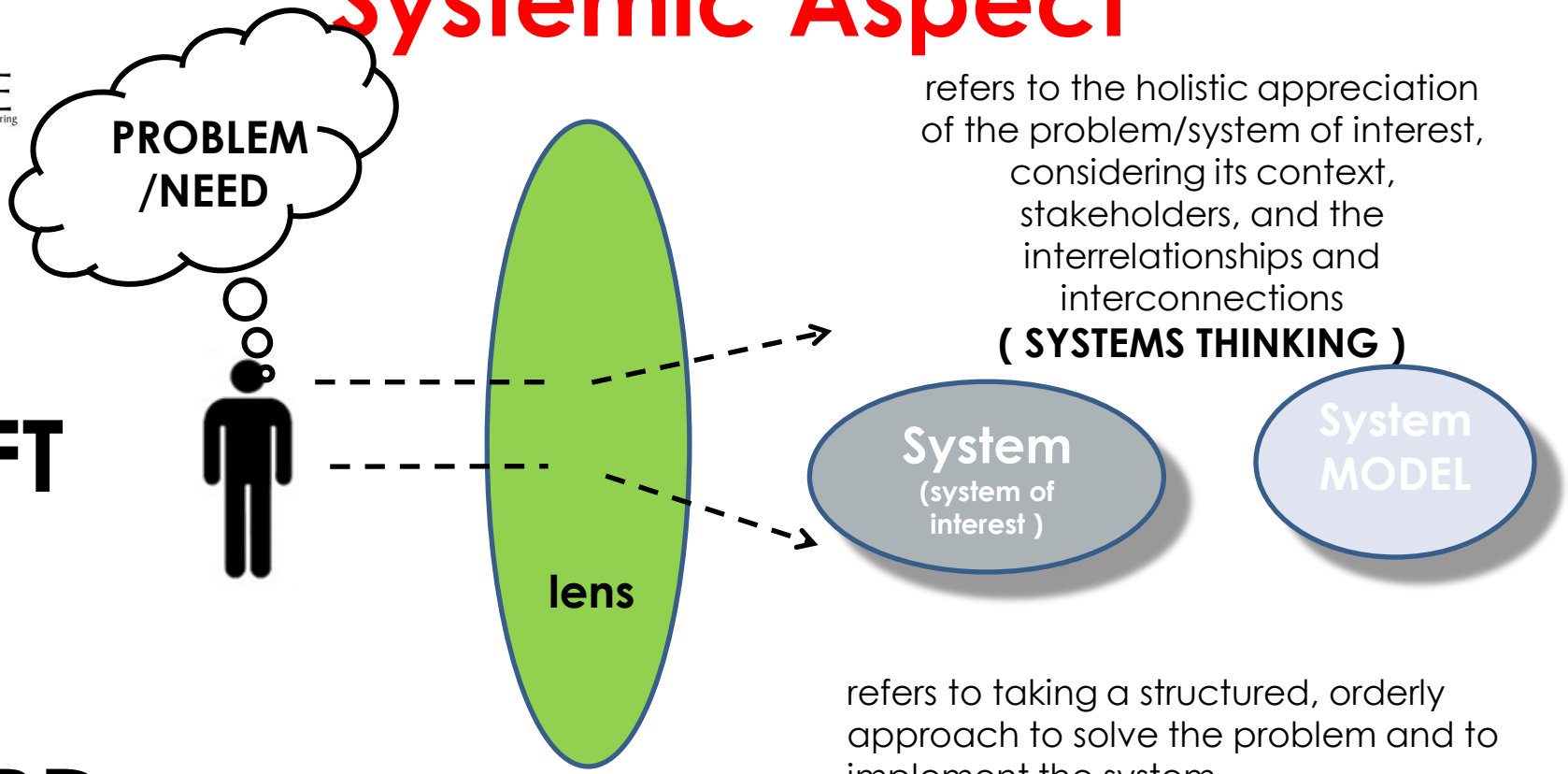
…..a **balance between** Systemic and Systematic aspects:

Systemic - thinking about the whole system, its context and stakeholders

Systematic - following a structured approach to the realization of the system

(INCOSE UK website)

Systemic Aspect



refers to the holistic appreciation of the problem/system of interest, considering its context, stakeholders, and the interrelationships and interconnections

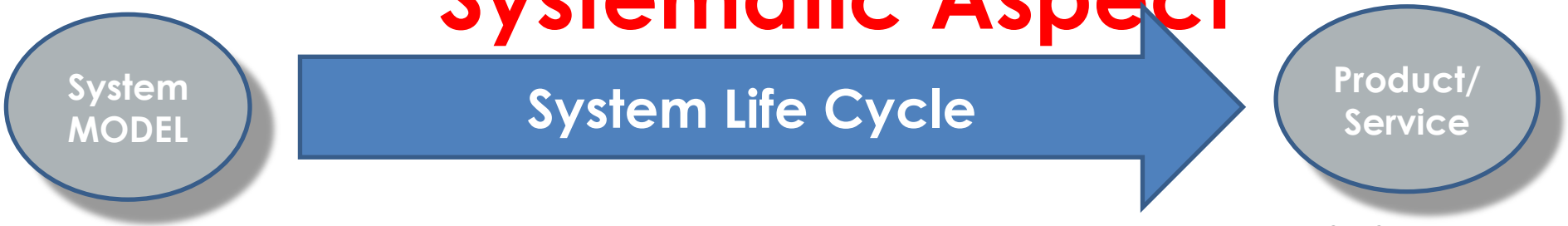
(SYSTEMS THINKING)

SOFT

HARD

refers to taking a structured, orderly approach to solve the problem and to implement the system

Systematic Aspect



SYSTEM SOLUTION

Systemic - thinking about the whole system, its context and stakeholders

(SYSTEMS THINKING VIDEO)

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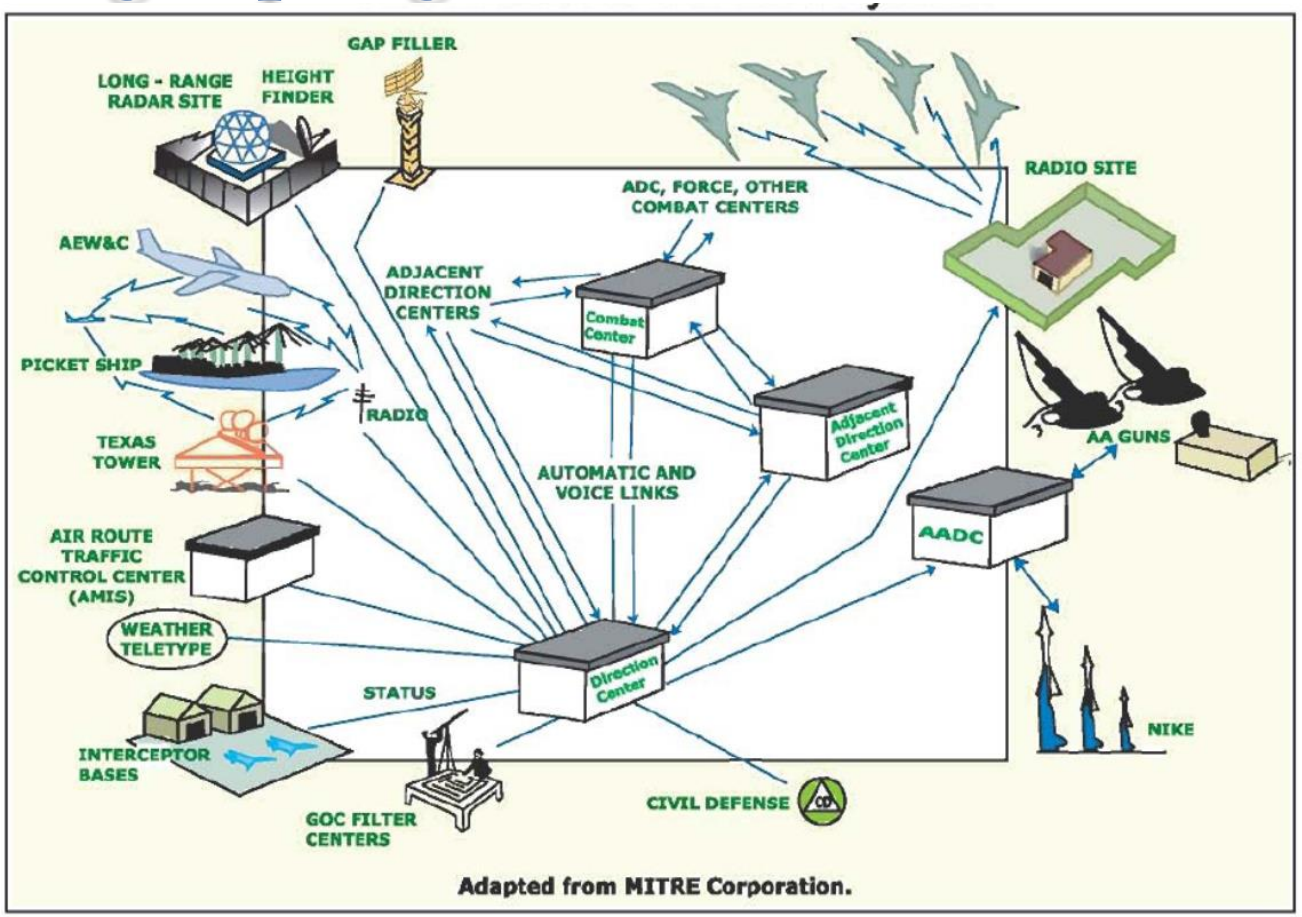
Origins of Systems Engineering

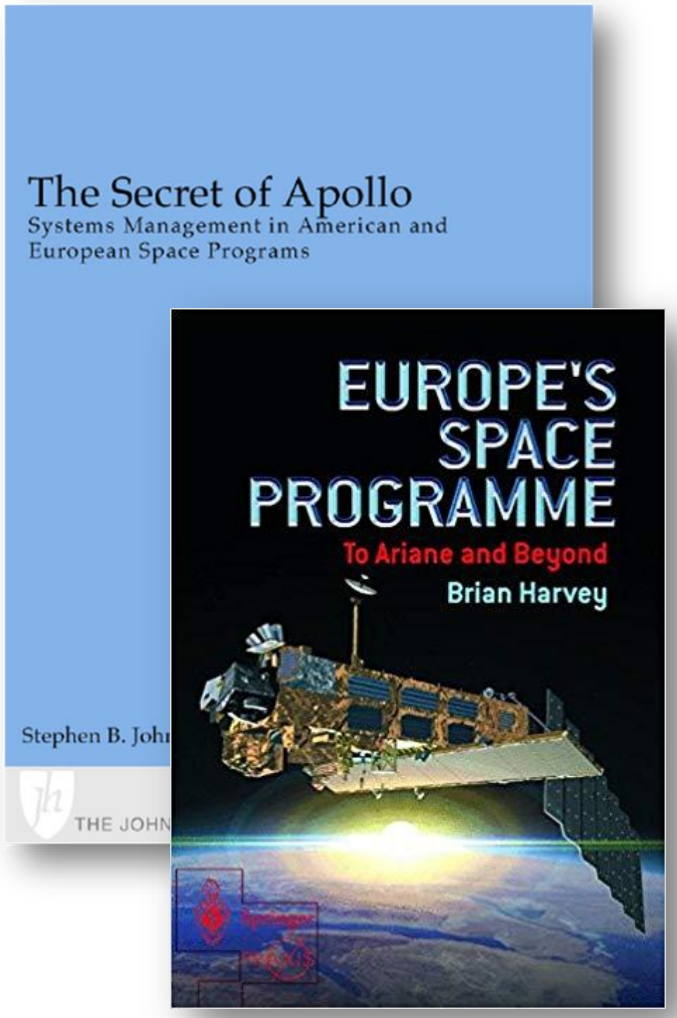
1937	British multidisciplinary team to analize the **air defence system**
1939-45	**Bell Labs** supports NIKE development (1st US operational anti-aircraft missile system) and Intercontinental Ballistic Missiles (ICBM) Program.
1951-80	**SAGE** (Semi-automatic Ground Enviroment) Air Defense System defined 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 important 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
2009-2012	Systems Engineering Body of Knowledge (**SEBoK**)
2019	**17000+** INCOSE members worldwide (70+ Chapters 35+ Countries)
2023	**INCOSE Systems Engineering Handbook version 5**

ICBM, NIKE and SAGE the largest single programs ever undertaken



At the time Systems Engineering was born

Space Programs : Why Systems Engineering



Two days in July 1969

3rd July : Europa I F-9 Launcher – 3rd Stage Failure

20th July : Apollo 11, Humankind on moon

1971

5th Nov - Europa 2 F-11 Launcher – Exploded at 150 secs

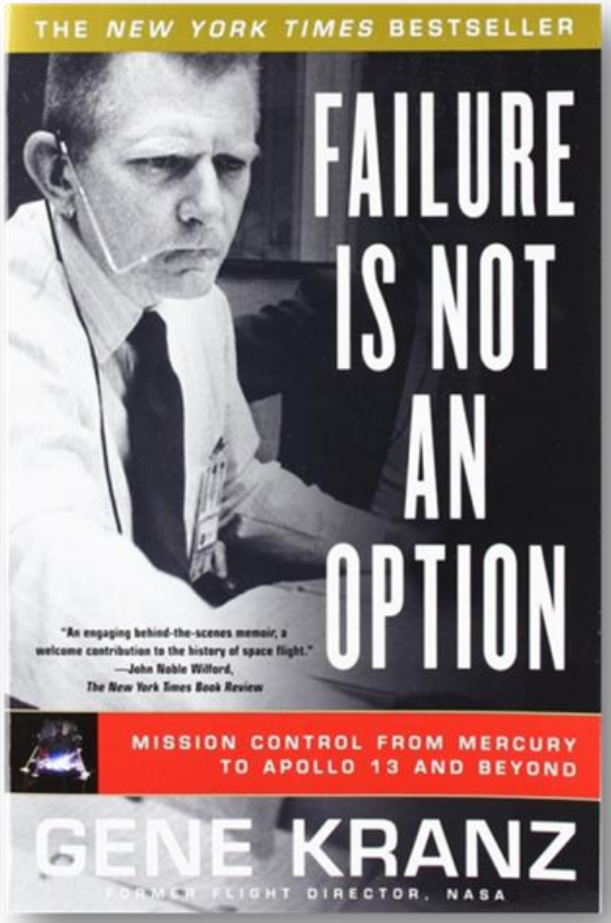
October 1973

Europa 2 F-12 Launcher CANCELED

What could be the difference ?

Stephen B. Johnson (The Secret of Apollo)
Brian Harvey (Europe's Space Programme: To Ariane and Beyond)

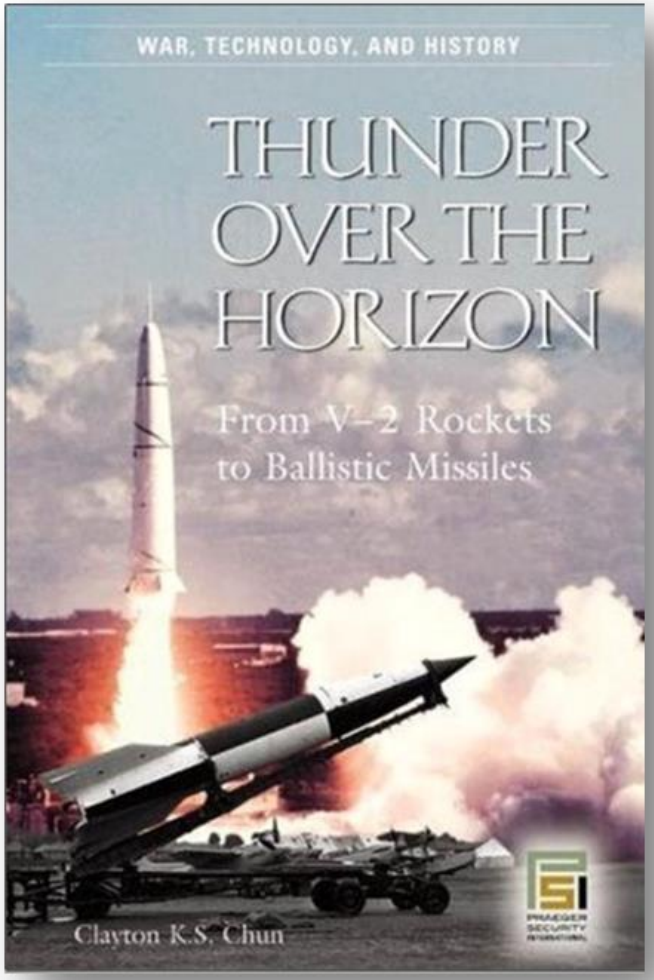
Space Programs : Why Systems Engineering



Difference

SYSTEMS ENGINEERING

Apollo Program : Reasons for Systems Engineering



Unprecedented Challenges

Short time scale due to **Cold War** technological race

Apollo Program : Reasons for Systems Engineering

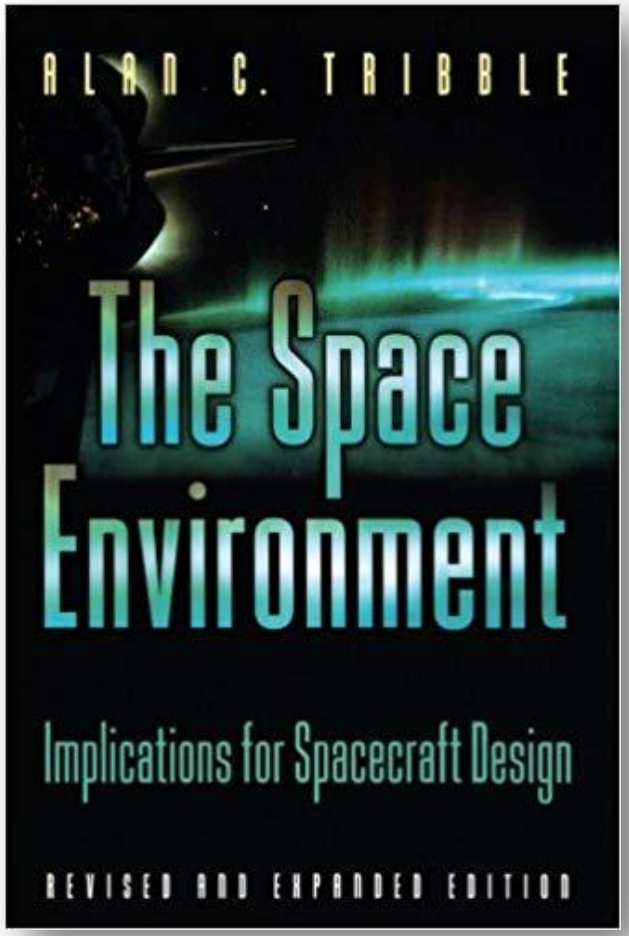
Multiple novel technologies

Technology enables new capabilities -> competitiveness and prestige

Threat

Immature technologies carry risk (cost, schedule, quality)

Apollo Program : Reasons for Systems Engineering



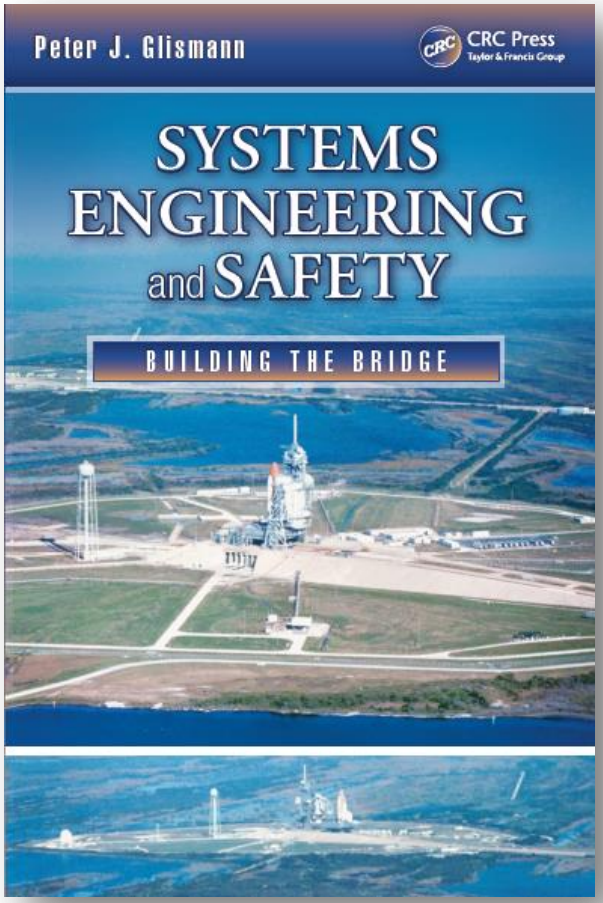
Threats

Launch Phase : Vibration, shock, acceleration, depressurization, contamination, impacts

Space : Ionising radiation, UV damage, hot/cold environment, charging, micro-vibrations, vacuum , micro-meteorites and space debris

Moon Landing : pressure, temperature, landing hazards

Apollo Program : Reasons for Systems Engineering

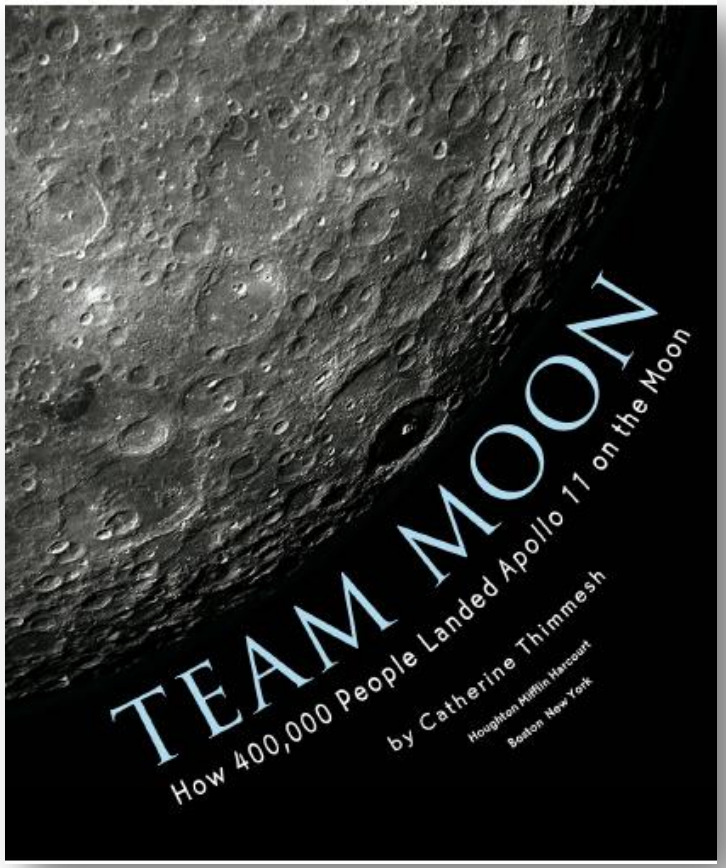


Multiple technologies -> adverse interactions

Threat

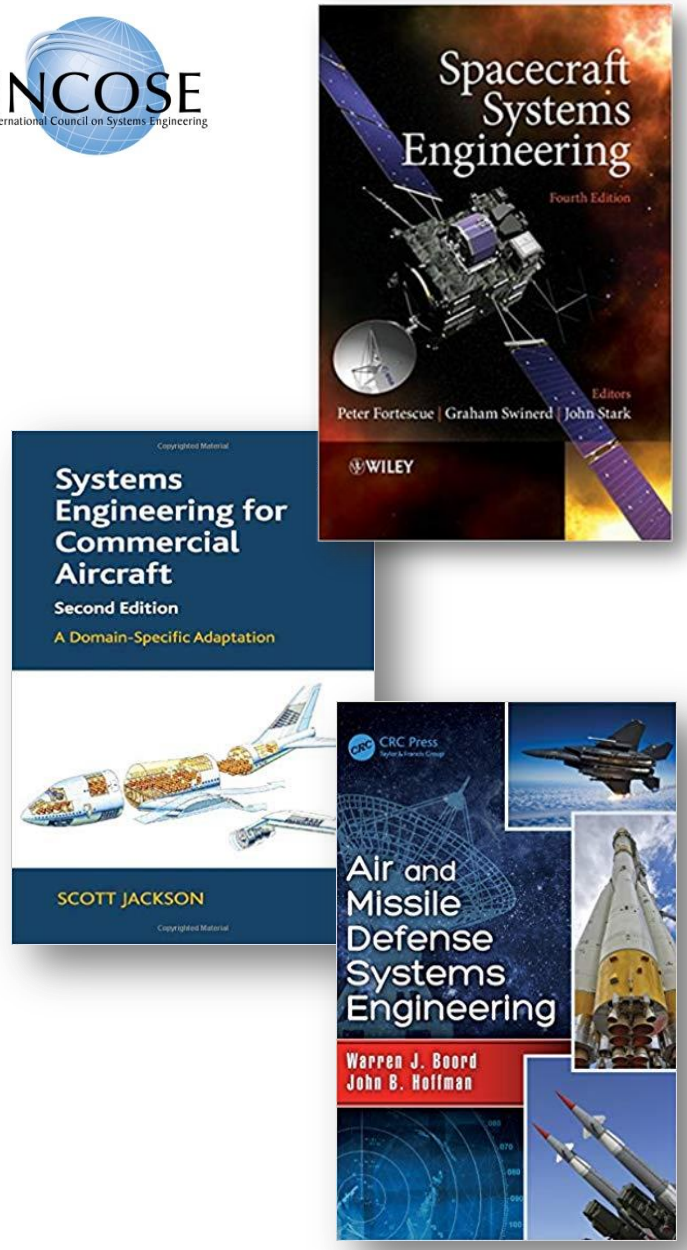
Safety -> Failure rate

Apollo Program : Reasons for Systems Engineering



At its peak, Apollo program employed **400,000 Americans** and required the support of over **20,000 industrial firms** and many universities.

Diverse Worlds



Today Systems Engineering is **an accepted practice** in the ASD sector (industry and government)

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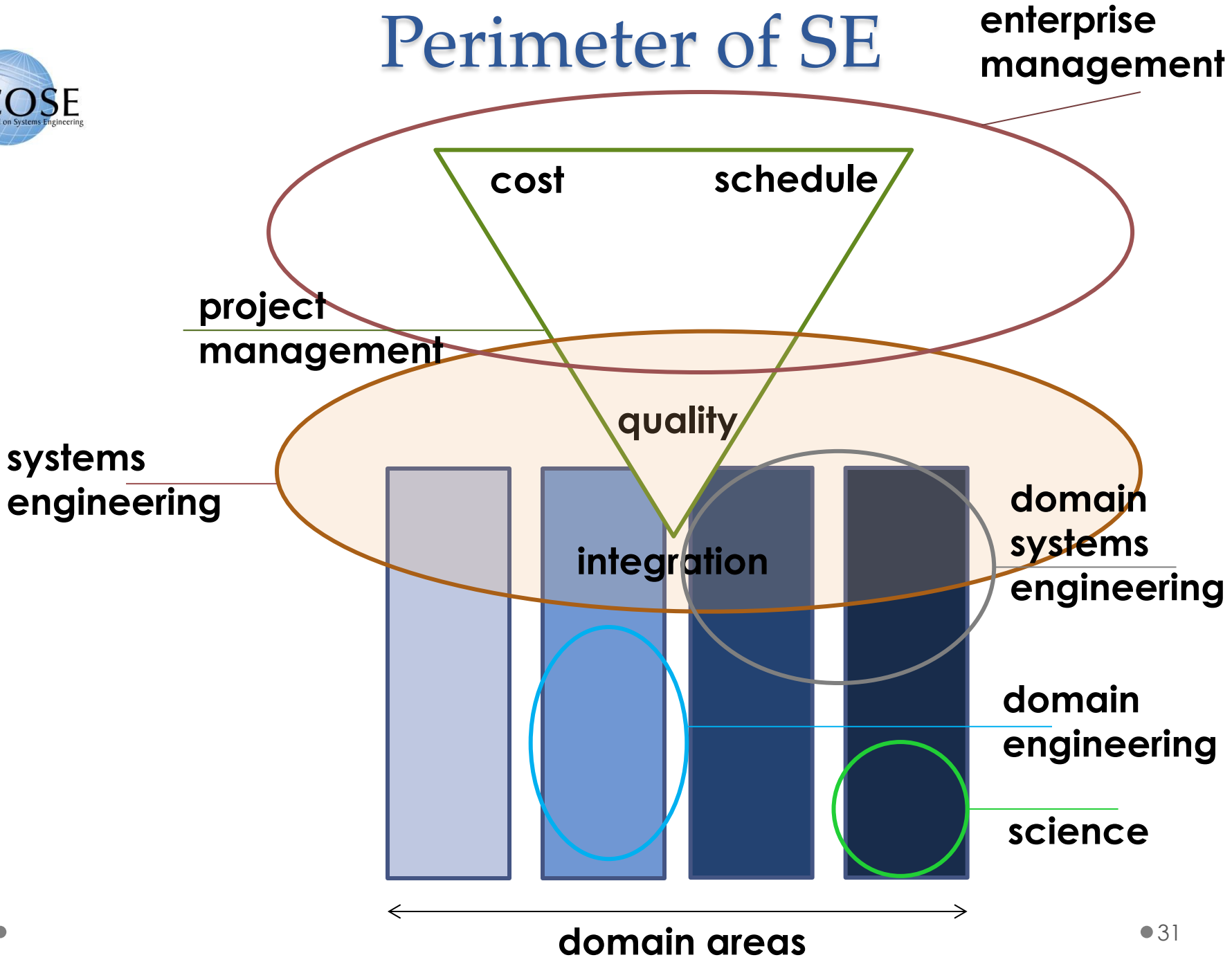
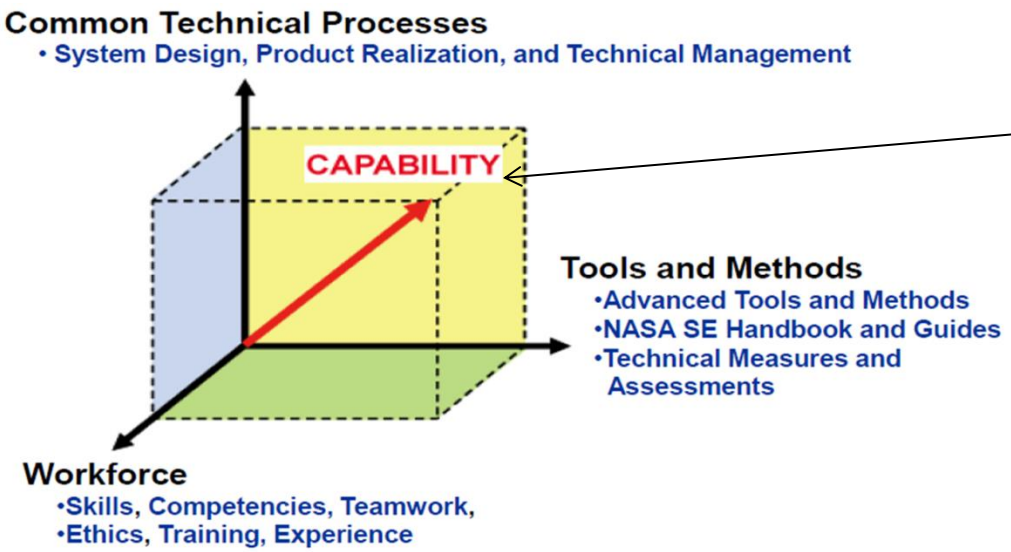
Perimeter of SE



SE Capability vs Competence



NASA (2007)

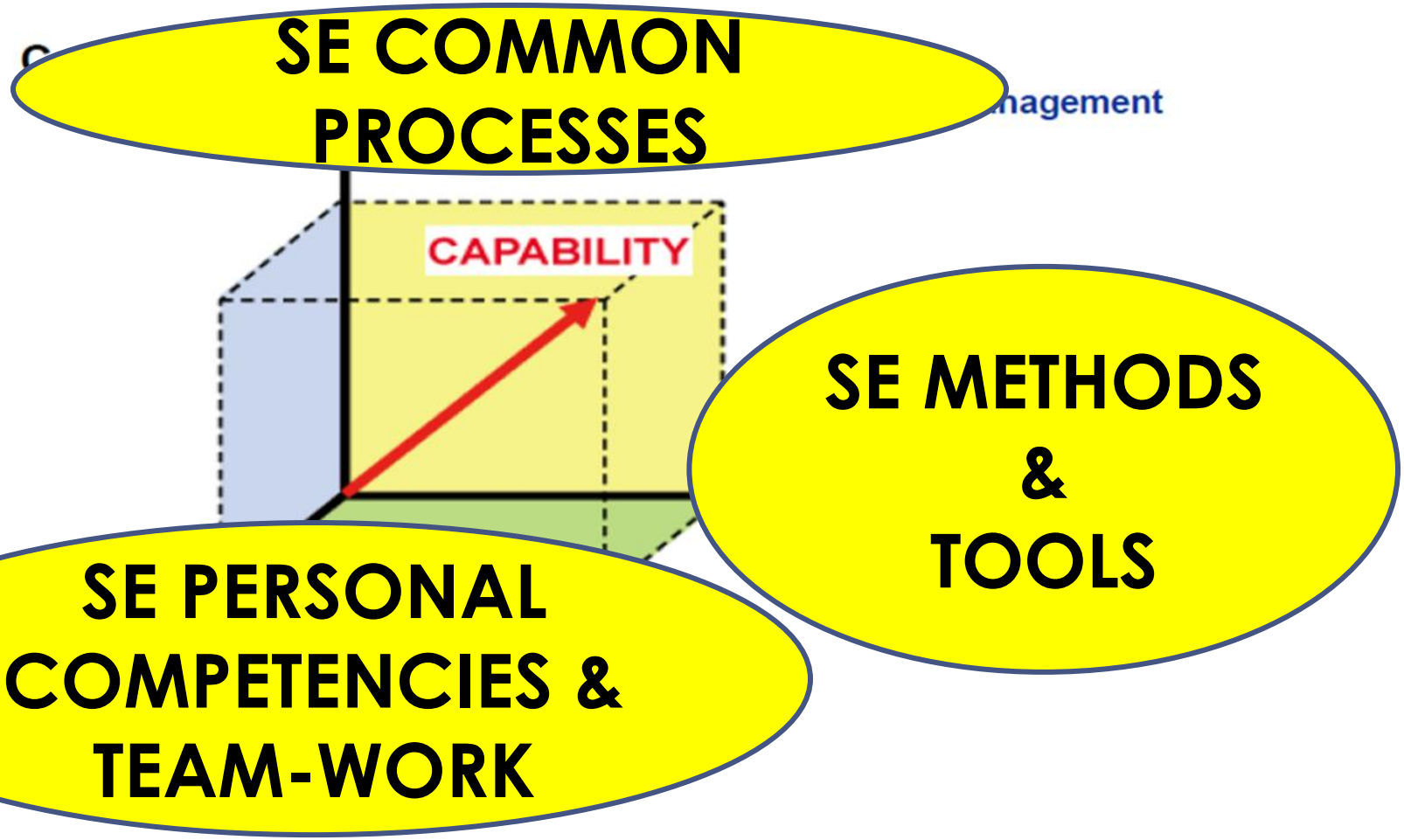
Capability describes the **ability of an organization** or organizational unit.

Holt and Perry (2011)

Competence describes the **ability of an individual** to do something.

Holt and Perry (2011)

SE Capability



NASA (2007)

SE Common Processes

ISO 15288

Agreement Processes	Organizational Project-Enabling Processes	Technical Management Processes	Technical Processes
Acquisition Process	Life Cycle Model Management Process	Project Planning Process	Business or Mission Analysis Process
Supply Process	Infrastructure Management Process	Process Assessment and Control Process	Stakeholder Needs & Requirements Definition Process
	Portfolio Management Process	Decision Management Process	System Requirements Definition Process
	Human resource Management Process	Risk Management Process	Architecture Definition Process
	Quality Management Process	Configuration Management Process	Design Definition Process
	Knowledge Management Process	Information Management Process	System Analysis Process
		Measurement Process	Implementation Process
		Quality Assurance Processy	Integration Process
			Verification Process
			Transition Process
			Validation Process
			Operation Process
			Maintenance Process
			Disposal Process

SE Methods & Tools

IBM Engineering Requirements Management – DOORS and DOORS Next

- Requirements Management

IBM Engineering Team Management (ETM)

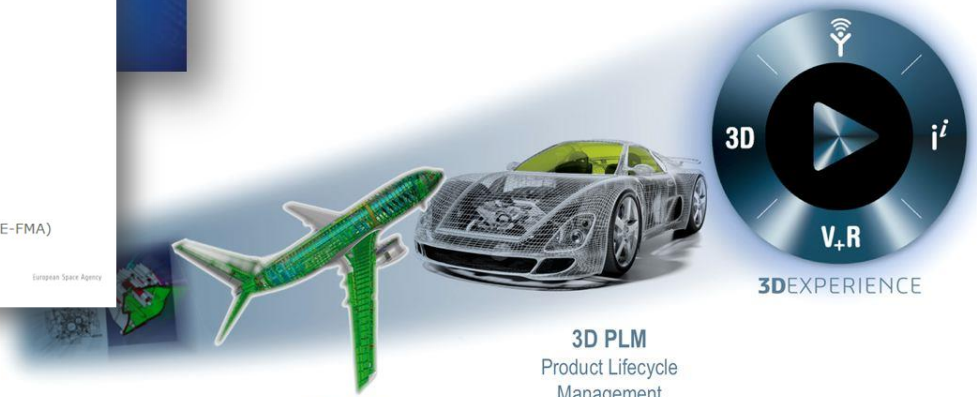
- Collaboration Planning
- Change Management
- Source Control
- Build Management

IBM Engineering Workflow Management (EWM)

- Quality Management

IBM Engineering Systems Design Rhapsody – Model Manager (RMM)

- Architecture
- Design

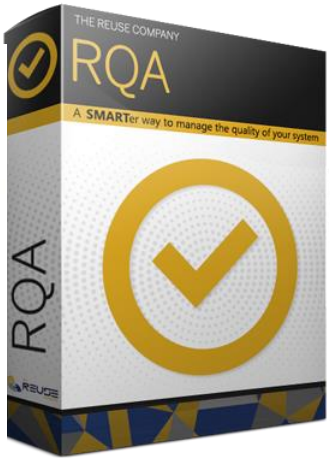


3D Design — V3

3D DMU Digital Mock-up — V4

3D PLM Product Lifecycle Management — V5

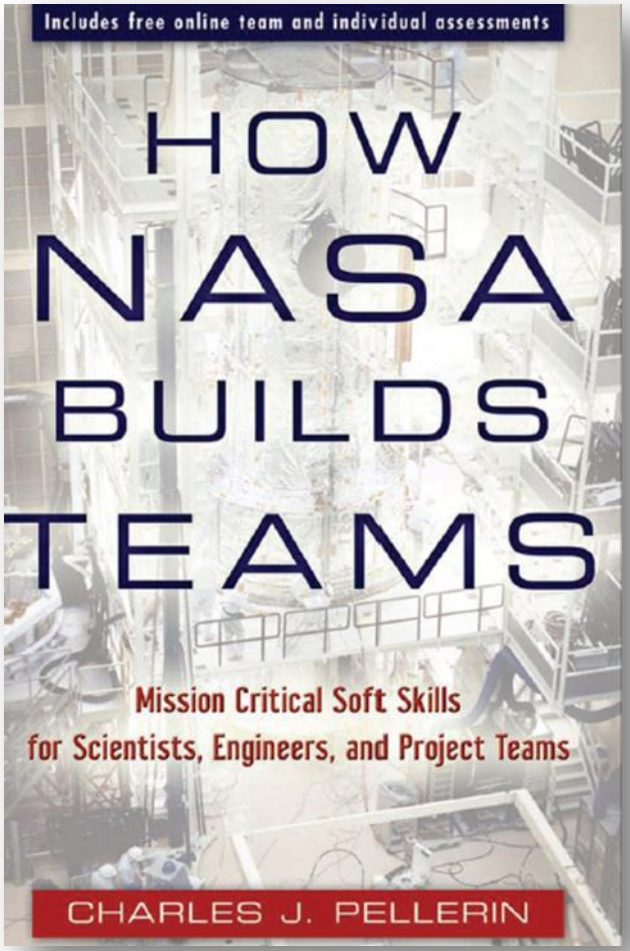
V6



Systematic - following a structured approach to the realization of the system

(SE TOOLS VIDEO)

Team Work



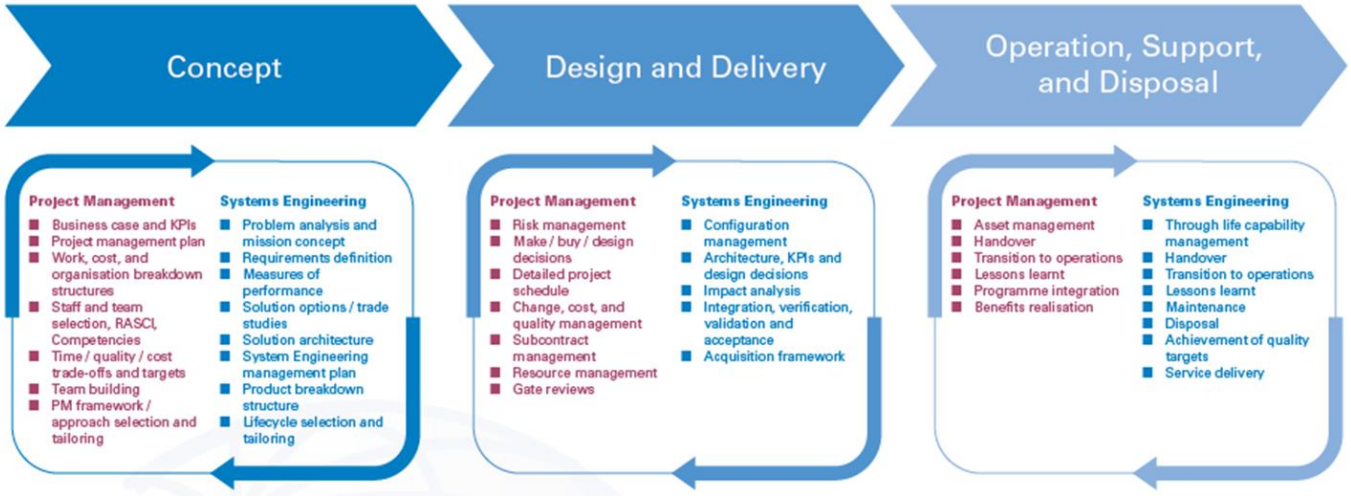
A good SE team will include many individual specialists who have learned how to work their areas into sensible interfaces with the contributions of the other specialists.

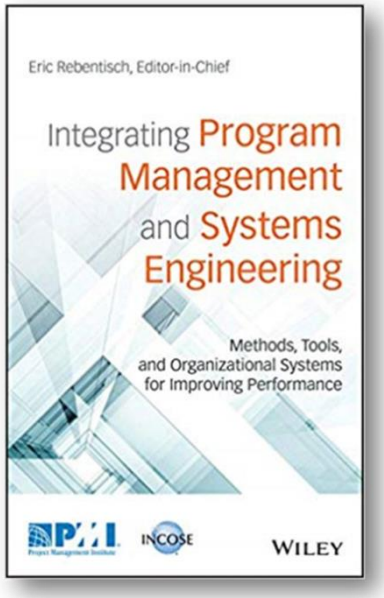
It is the team that must include **the total intelligence, background, experience, wisdom, and creative ability** to cover all aspects of the problem of applying science and technology, and particularly, who must integrate the overall intelligence

Simon Ramo

PM and SE
Complementary but Different

Life Cycle

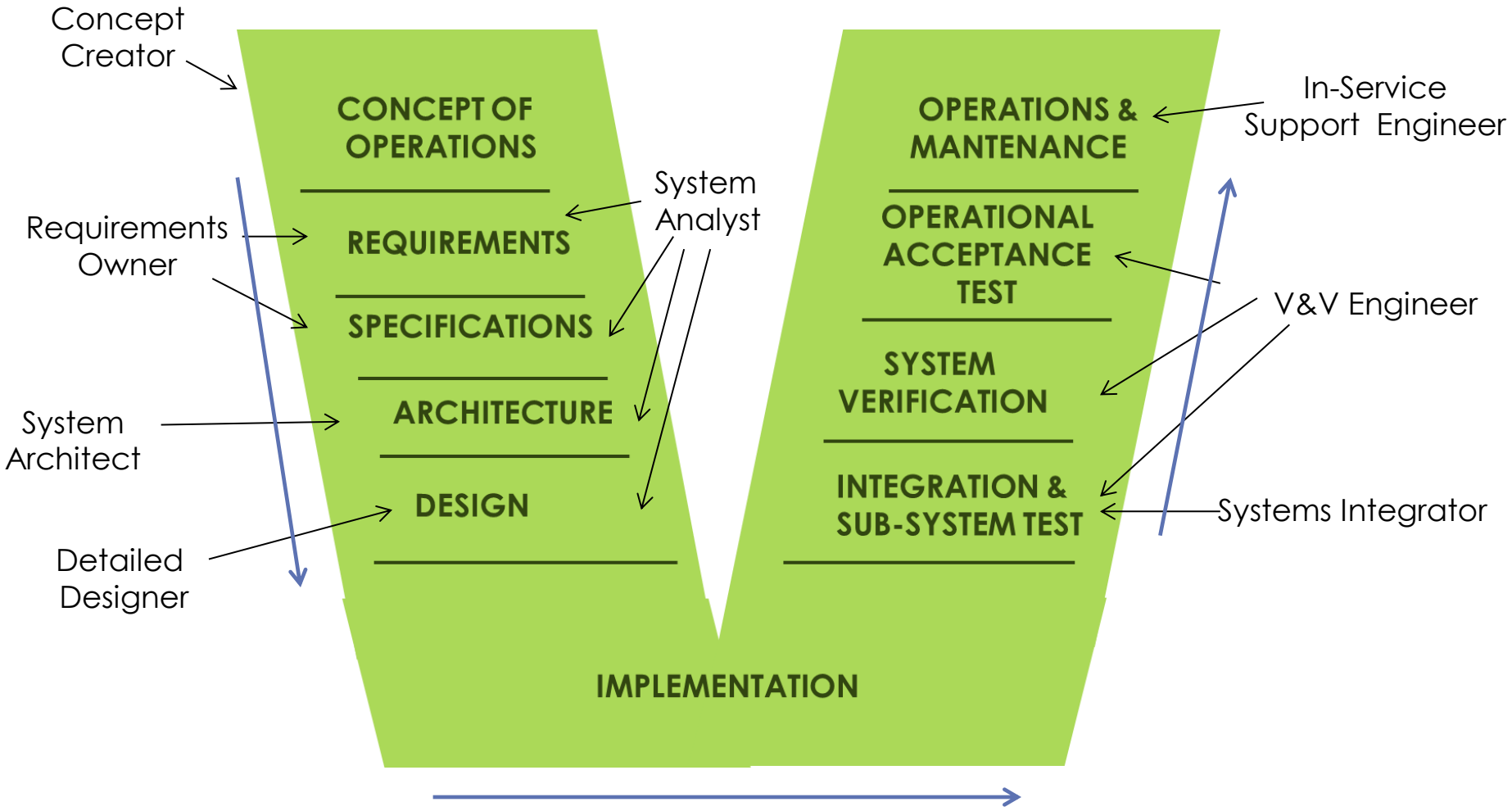




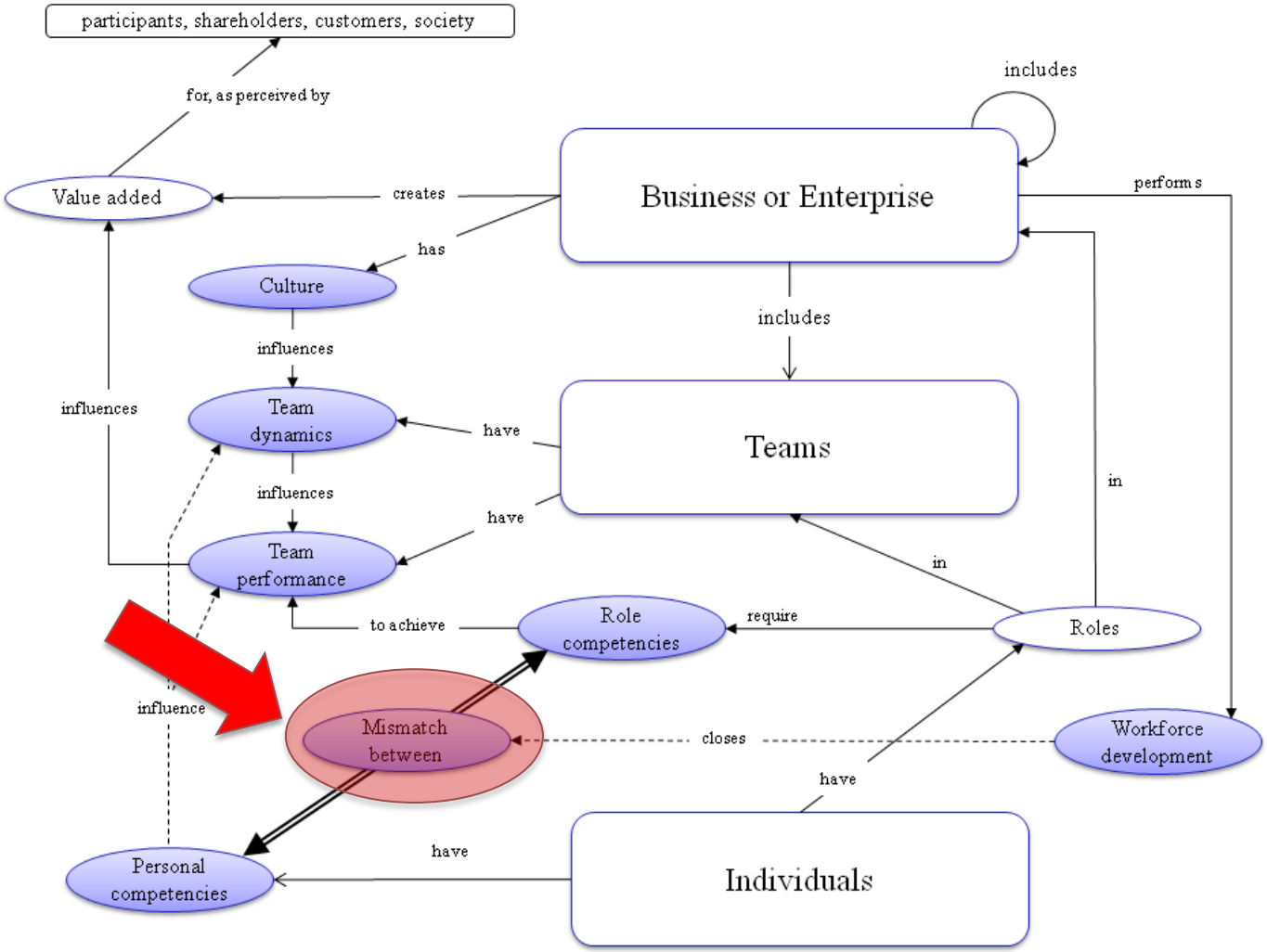
Z11 - Project Management and Systems Engineering – INCOSE UK Issue 1.1 Jan 2018

SE Roles onto the Vee

A role is the part that is played within a specific work process and within the company. Systems engineers will typically hold many positions, each with a different combination of roles.



Mismatch Personal Competencies vs Role Competencies

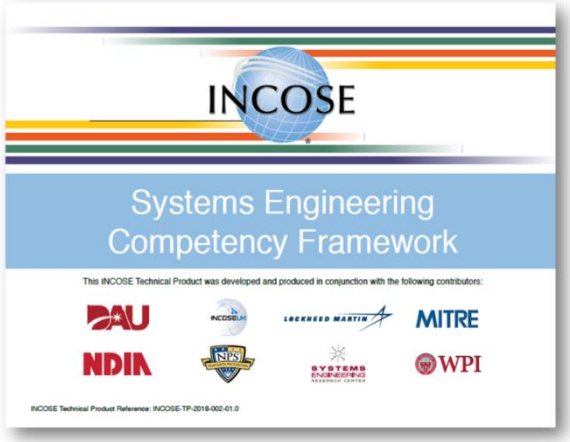


Competency Models/Frameworks are used

- **Recruiting**
- **Assessing** Candidates
- Improving **Education and Training** Programs
- Identifying Resources for **Professional Development**
- Aligning **Curriculum**
- Developing **Career Paths**
- **Others**

INCOSE Competency Framework (ISECF)

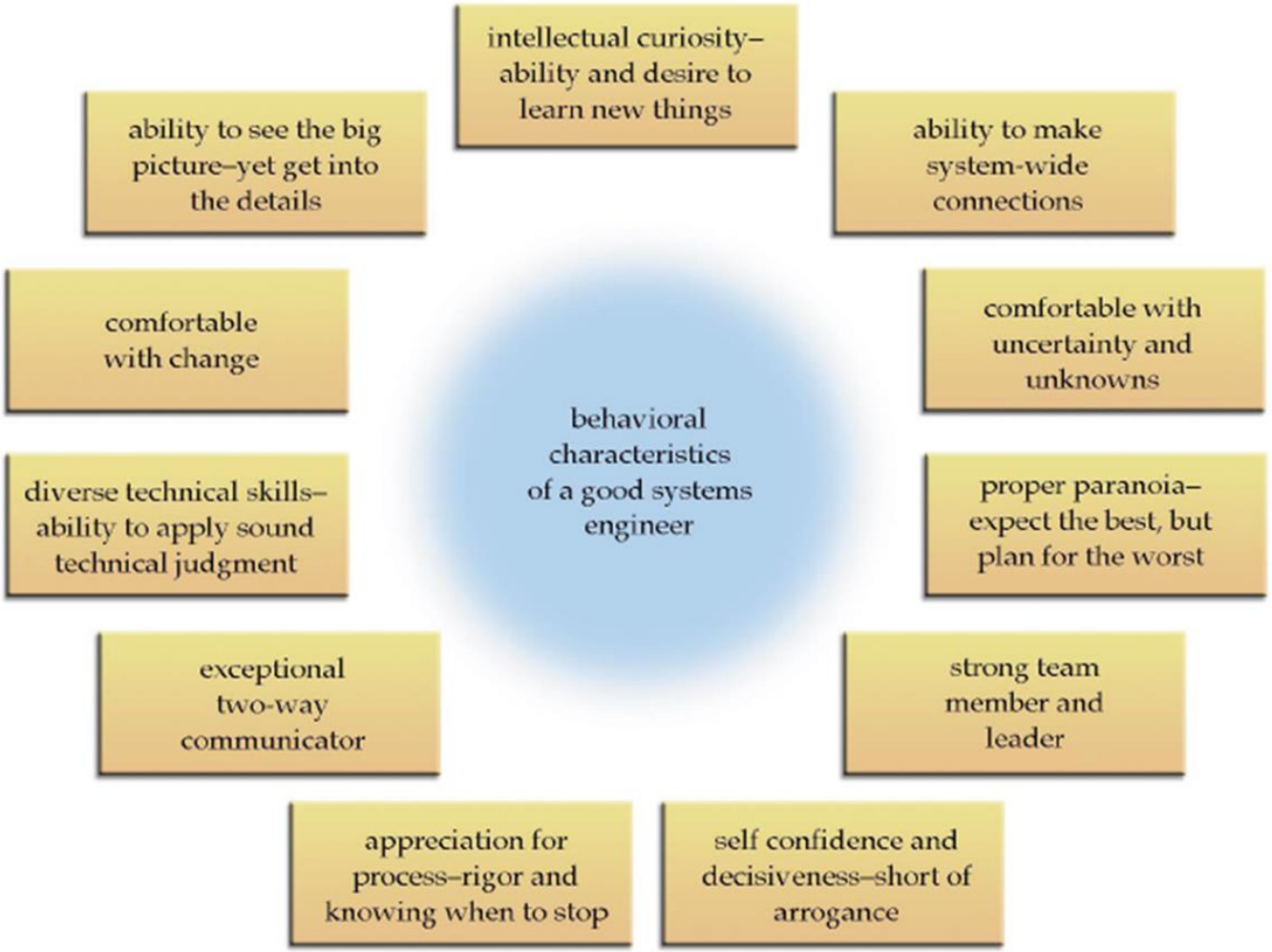
Competence Groups	Descriptions
Core Systems Engineering Principles	Covers core principles which underpin engineering as well as systems engineering.
Professional	Covers behavioral competencies which are all well-established within the Human Resources (HR) domain. Definitions of these competencies were taken from well-established, internationally-recognized sources to facilitate alignment with wider HR frameworks used in larger organizations.
Technical	Covers the competencies needed to perform a series of tasks associated with the Technical Processes identified in the INCOSE SE Handbook 4th Edition.
Systems Engineering Management	Covers the competencies needed to perform tasks associated with controlling and managing systems engineering work.
Integrating	Covers the systems engineering competencies required to understand and integrate the viewpoints and perspectives of others into the overall picture.



Core Systems Engineering Principles:	Professional:
• Systems Thinking • Lifecycles • Capability Engineering • General Engineering • Critical Thinking • Systems Modelling and Analysis	• Communications • Ethics and Professionalism • Technical Leadership • Negotiation • Team Dynamics • Facilitation • Emotional Intelligence • Coaching and Mentoring
Technical:	**Management:**
• Requirements Definition • System Architecting • Design for... • Integration • Interfaces • Verification • Validation • Transition • Operation and Support	• Planning • Monitoring and Control • Decision Management • Concurrent Engineering • Business & Enterprise Integration • Acquisition and Supply • Information Management • Configuration Management • Risk and Opportunity Management
Integrating:	
• Project Management • Finance • Logistics • Quality	

https://www.incose.org/products-and-publications/competency-framework

Personal Characteristics of a Good Systems Engineer



How to develop your Systems Engineering Competencies

- **Experiences** (most critical factor) : position, chronological time, number of organizations, roles, lifecycle phases, and systems (domain, type and level)
- **Mentoring arrangements**
- **Attending conferences**
- **Individual reading**
- **Certification**
- **Online courses**
- **Education & Training**

Systems engineering is not learned entirely in the classroom, it is also learned with hands-on experience working on real systems

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INCOSE

The **International Council on Systems Engineering (INCOSE)** is **a not-for-profit membership organization** founded to develop and disseminate the interdisciplinary principles and practices that enable the realization of successful systems.

INCOSE is designed to **connect SE professionals with educational, networking, and career-advancement opportunities in the interest of developing the global community of systems engineers and systems approaches to problems**. We are also focused on producing state-of-the-art work products that support and enhance this discipline's visibility in the world.

INCOSE vision & mission

Vision

A better world through **a systems approach**.

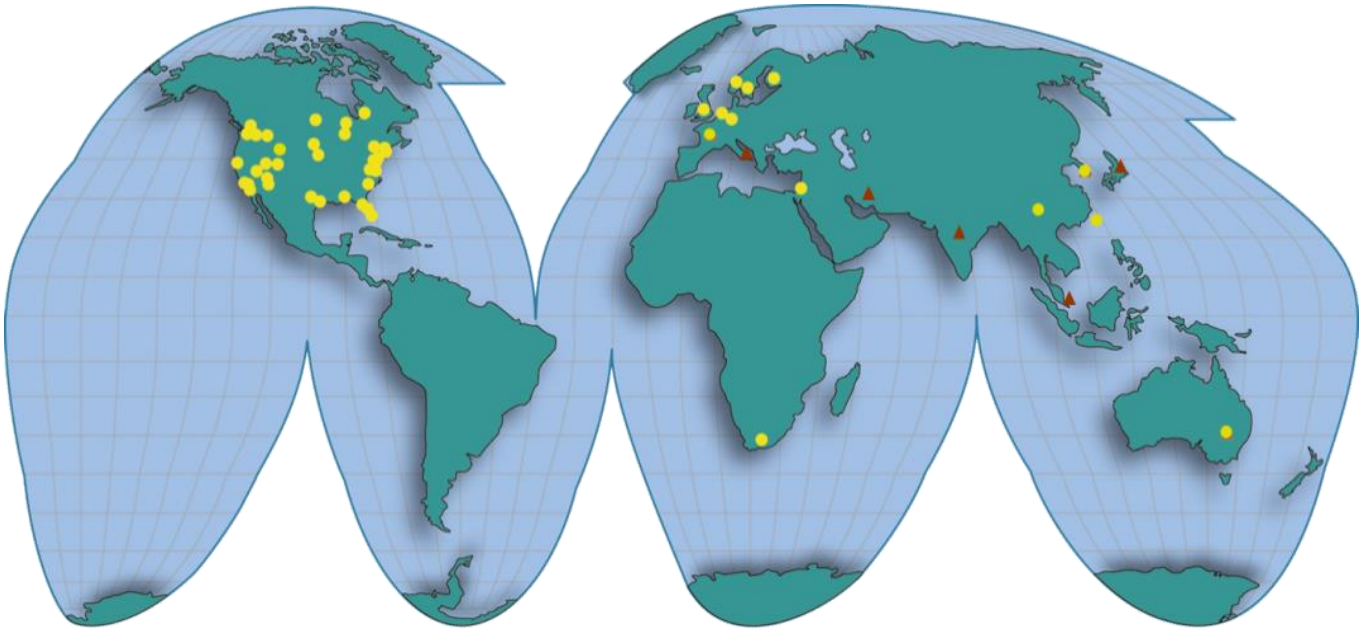
Mission

To address complex societal and technical challenges by **enabling**, **promoting**, **and advancing systems engineering and systems approaches**.

INCOSE Goals

- To provide a **focal point for dissemination** of systems engineering knowledge.
- To **promote international collaboration** in systems engineering practice, education, and research.
- To assure the **establishment** of competitive, scale-able **professional standards in the practice** of systems engineering.
- To **improve the professional status of all persons engaged in the practice** of systems engineering.
- To **encourage governmental and industrial support** for research and educational programs that will improve the systems engineering process and its practice.

About INCOSE- Impact



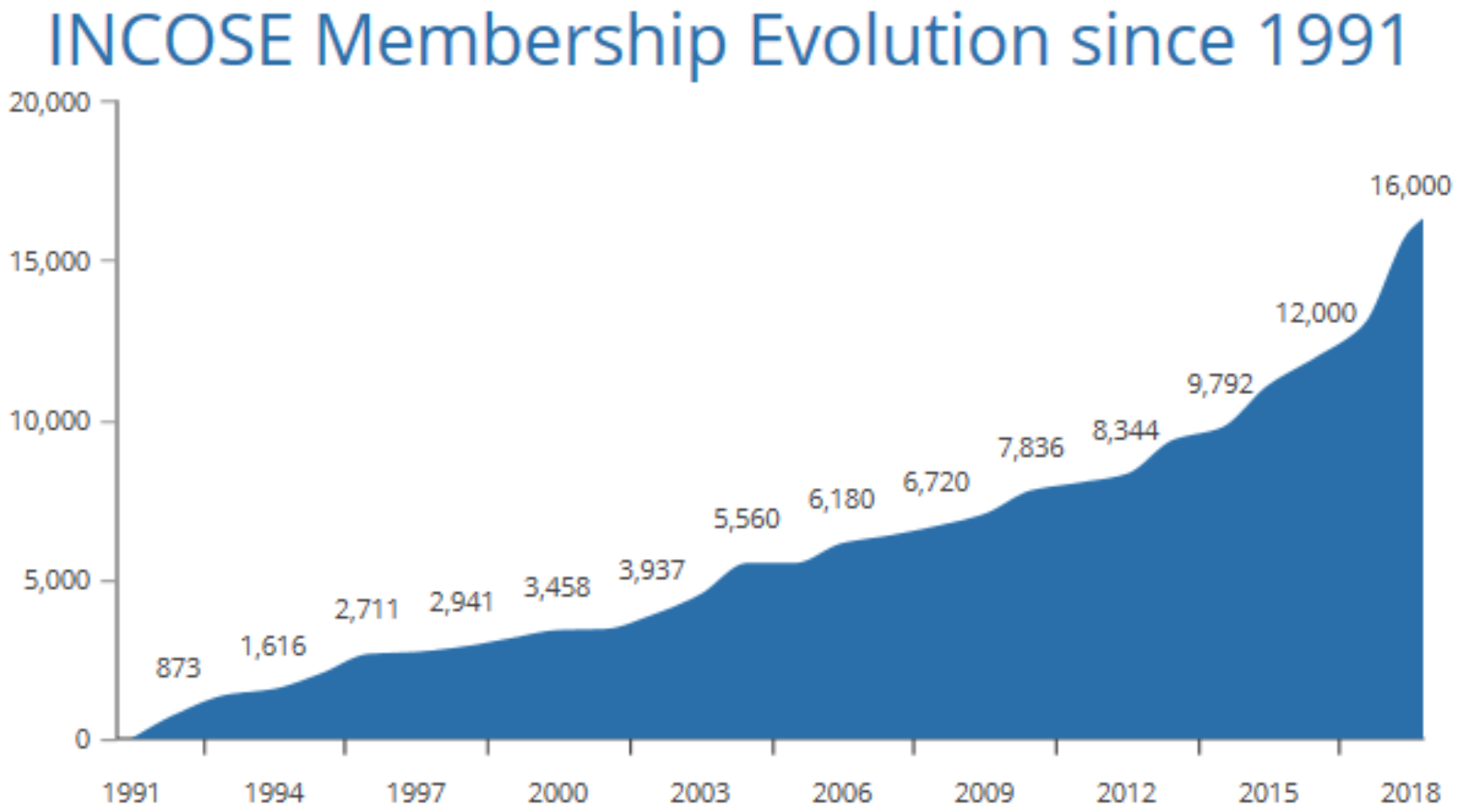
17000+
MEMBERS

70+
CHAPTERS

35+
COUNTRIES

100+
CORPORATE ADVISORY BOARD MEMBERS

About INCOSE- Impact



SEP (Systems Engineering Professional) Certification

INCOSE

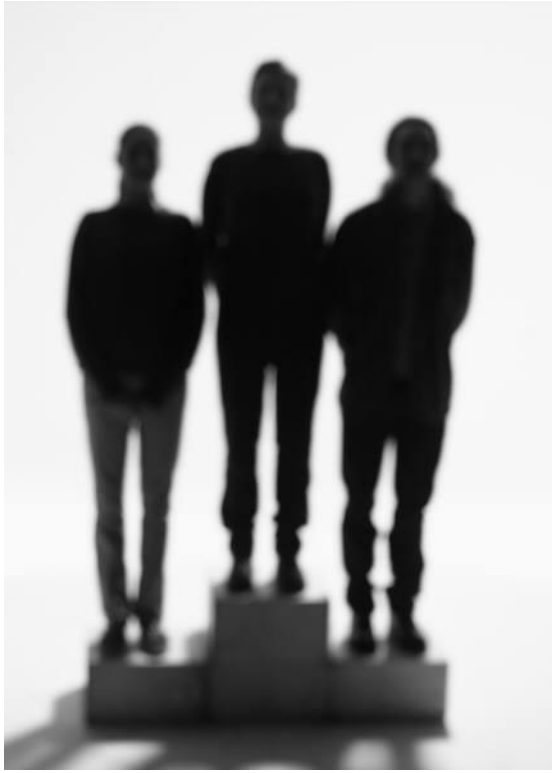
Multi-Level Base Credentials

The base ASEP, CSEP, and ESEP credentials cover the breadth of systems engineering at increasing levels of leadership, accomplishments, and experience.

Why is Certification Important?

For organizations…

- Formally recognizes the Systems Engineering capabilities of your professional staff
- Can provide a discriminator for your proposals
- Can be used as part of the hiring and promotion process
- Provides an independent external assessment
- Encourages employee participation in continuing education

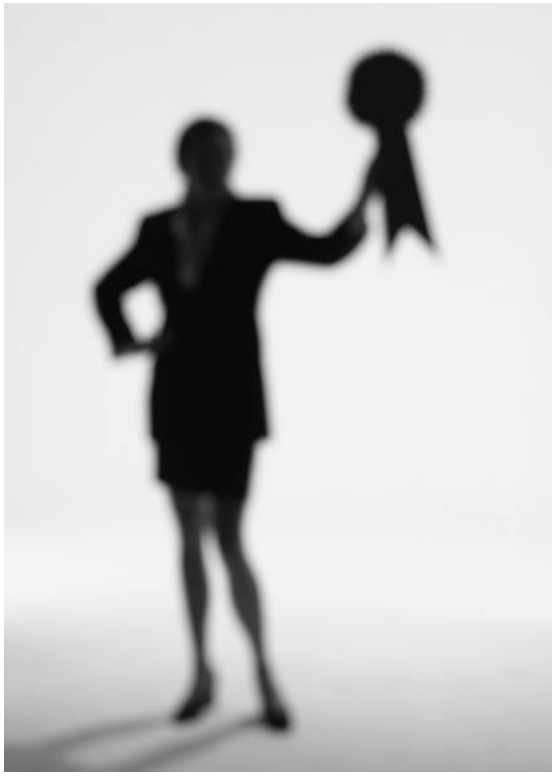


INCOSE SEP sets your organization apart!

Why is Certification Important?

For individuals…

- Formally recognizes your Systems Engineering capabilities
- Provides a discriminator for job applicants
- Provides a competitive advantage in your career
- Provides a portable Systems Engineering designation that is recognized across industry domains
- Participation in continuing education indicates your commitment to personal development



INCOSE SEP sets you apart!

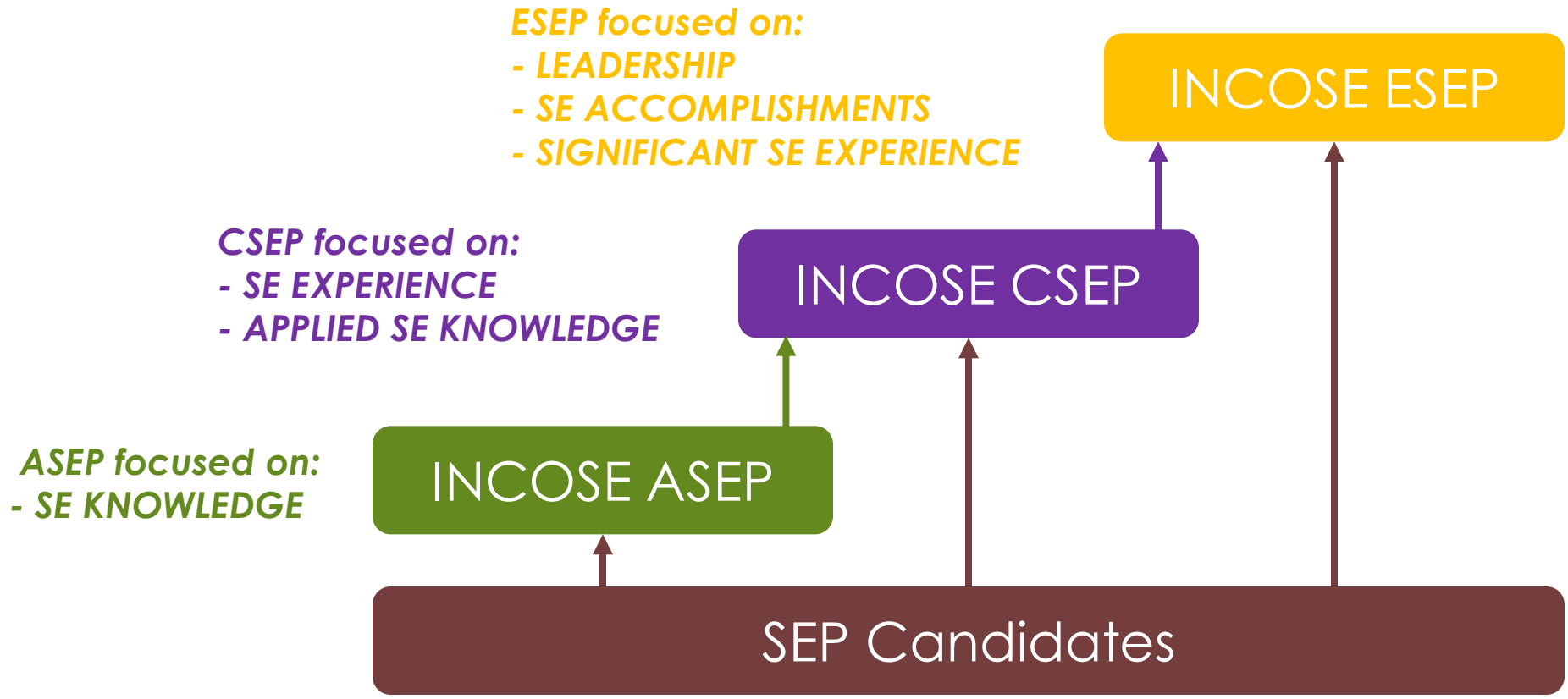
Why is Certification Important?

For your teams…

- Allows the team to level-set on Systems Engineering concepts and activities
- Helps establish a common Systems Engineering language for your team
- Helps break down…
  - geographic boundaries
  - organizational boundaries
  - cultural boundaries

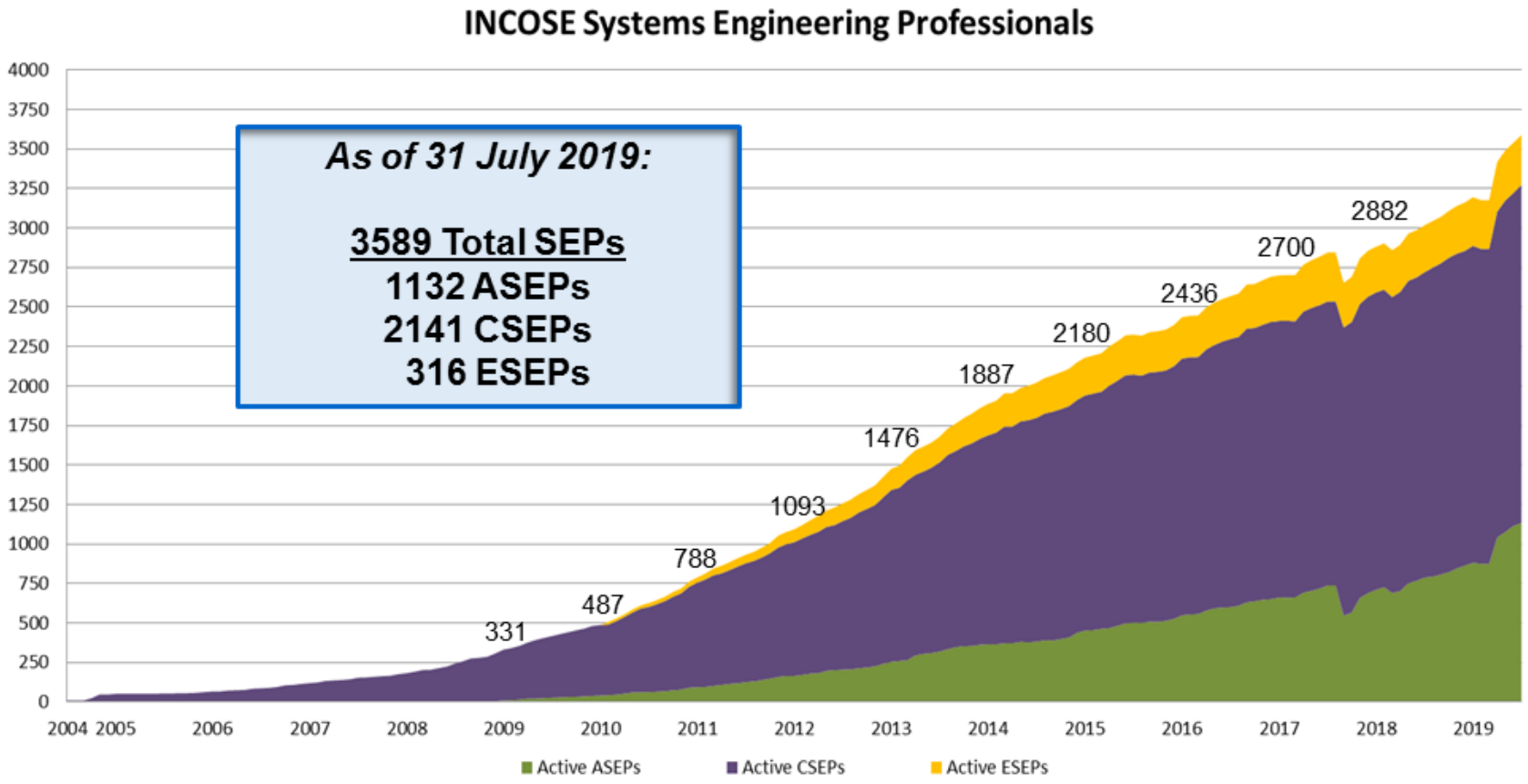
INCOSE SEP is particularly useful for multi-organization, geographically distributed teams.

The SEP Aligns with the Typical Levels of a Systems Engineering Career



You can enter at whatever SEP level is appropriate and can seamlessly transition between levels when ready.

About INCOSE - Certification



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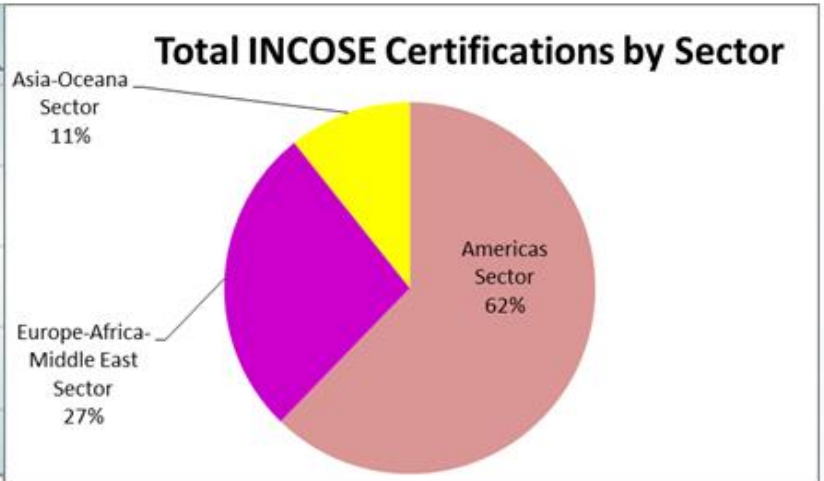
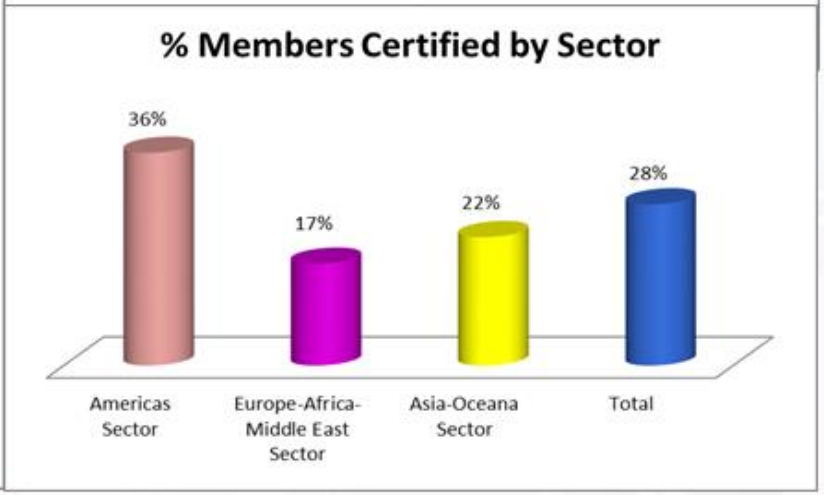


INCOSE Certifications by Sector

	Americas Sector	Europe-Africa-Middle East Sector	Asia-Oceana Sector
ESEP	270	31	6
CSEP	606	305	109
ASEP	1170	405	136



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- Conclusions

Creation of Spanish Chapter

13 June 2012

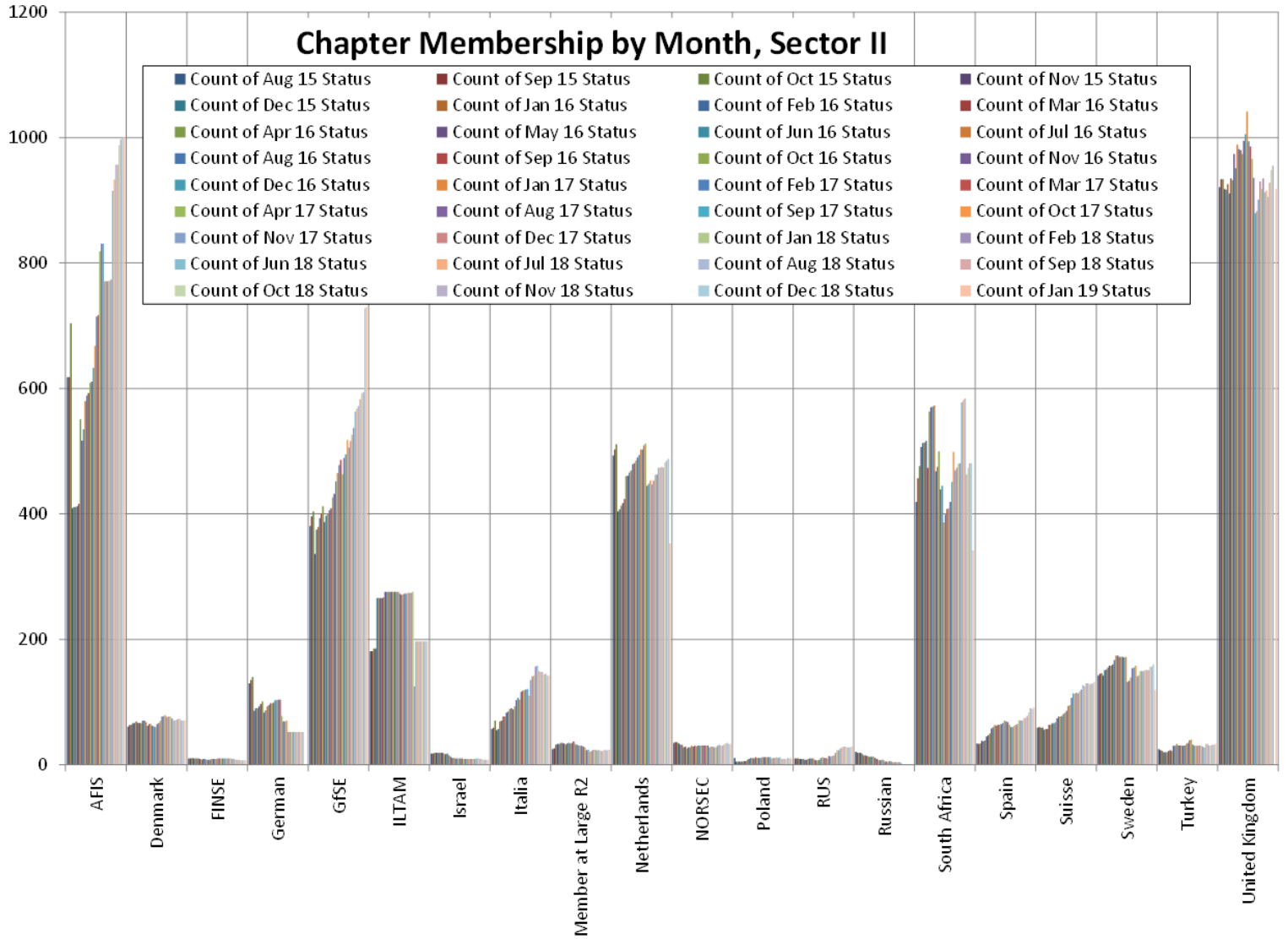
http://www.eoi.es/es/eventos/12360/constitucion-de-international-council-systems-engineering-incose-en-espana

Creation of "Asociación Española de Ingeniería de Sistemas (AEIS)"

AEIS (professional non profit organization) is a national legal entity hosted by **Spanish Royal Academy of Engineering** established in accordance with the law 30/1992 having the official representative role of INCOSE in Spain. In addition, within the international structure of INCOSE since **December 2014**, formally recognized as **Spanish Chapter of INCOSE**.

http://www.aeis-incose.org

Membership in EMEA



Figures in Spain

	Active	*Not Active*	*Total*
Members			
29/5/2019	**85**	**106**	**191**

Total SEP members 68

ASEP 5
CSEP 61
ESEP 2

Initial events in Spain

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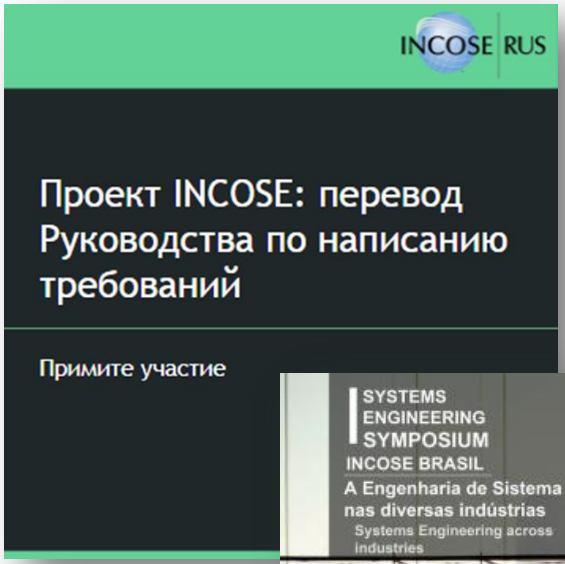
Unstoppable Growth

Unstoppable Growth

Unstoppable Growth



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Conclusions

- ASD complex products and complex management structures. **Systems Engineering** is a key factor in making this complexity manageable.
- Systems Engineers **practically apply systems thinking** to understand Why, What, How, Which, When, Who and Where
- Systems Engineers **provide the technical leadership** necessary to mature the products and/or services and they will continue to do so.
- Put INTA in the picture building up **careers in Systems Engineering**, INTA will be **a major player in ASD sector**.


http://www.aeis-incose.org
http://www.incose.org
THANK YOU
A WORLD IN
MOTION*
Systems Engineering Vision • 2025

References

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- NASA (2007), " NPR 7123.1A - NASA Interim Directive (NID) - NASA Systems Engineering Processes and Requirements", NASA Procedural Requirements - March 26, 2007