Trends in Systems Engineering

Thur Aug 12, 2021
7:00 – 8:30 PM CDT

A FREE Virtual Event
Registration Required

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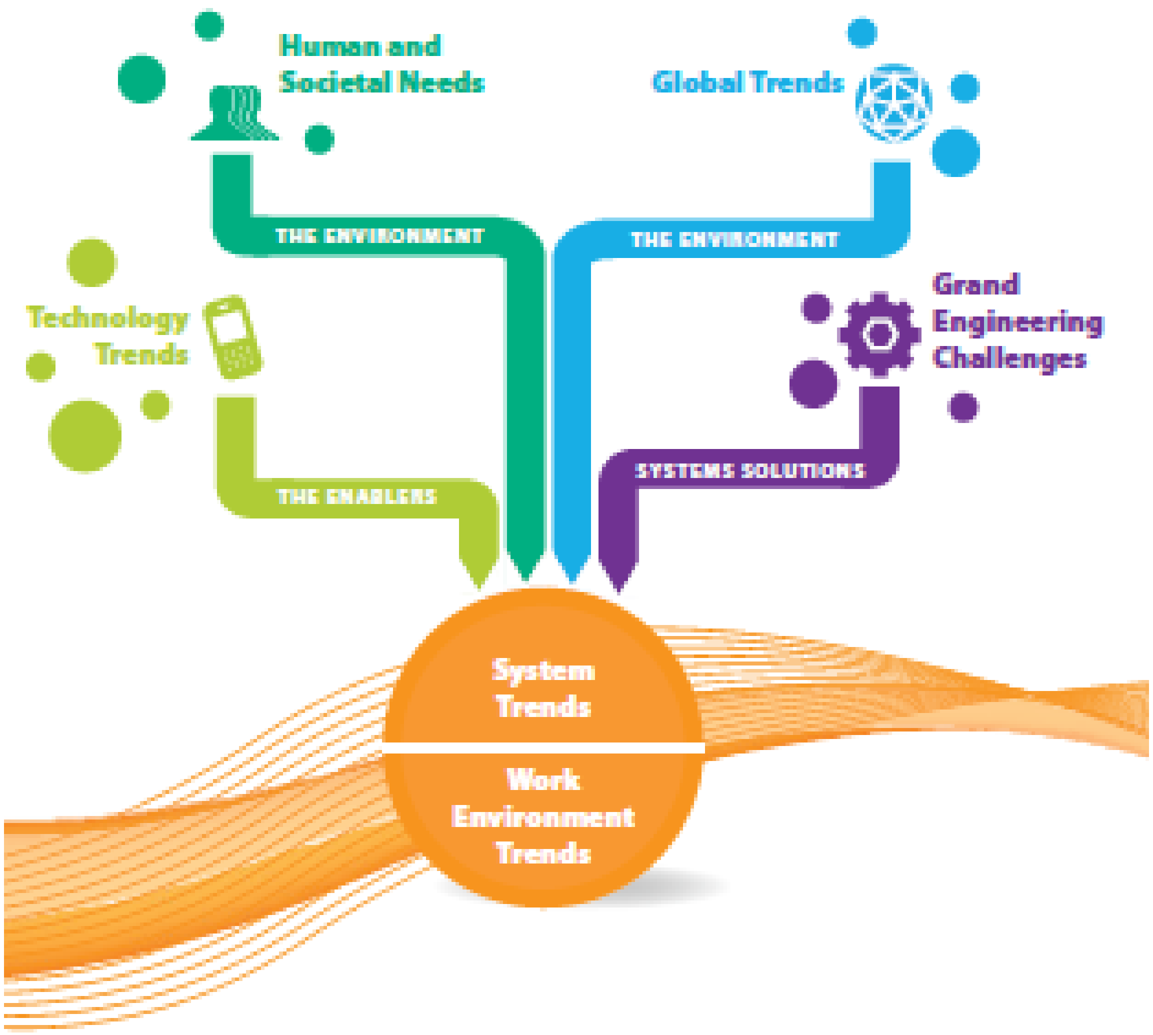
Caltech INCOSE

The Global Context for Systems Engineering



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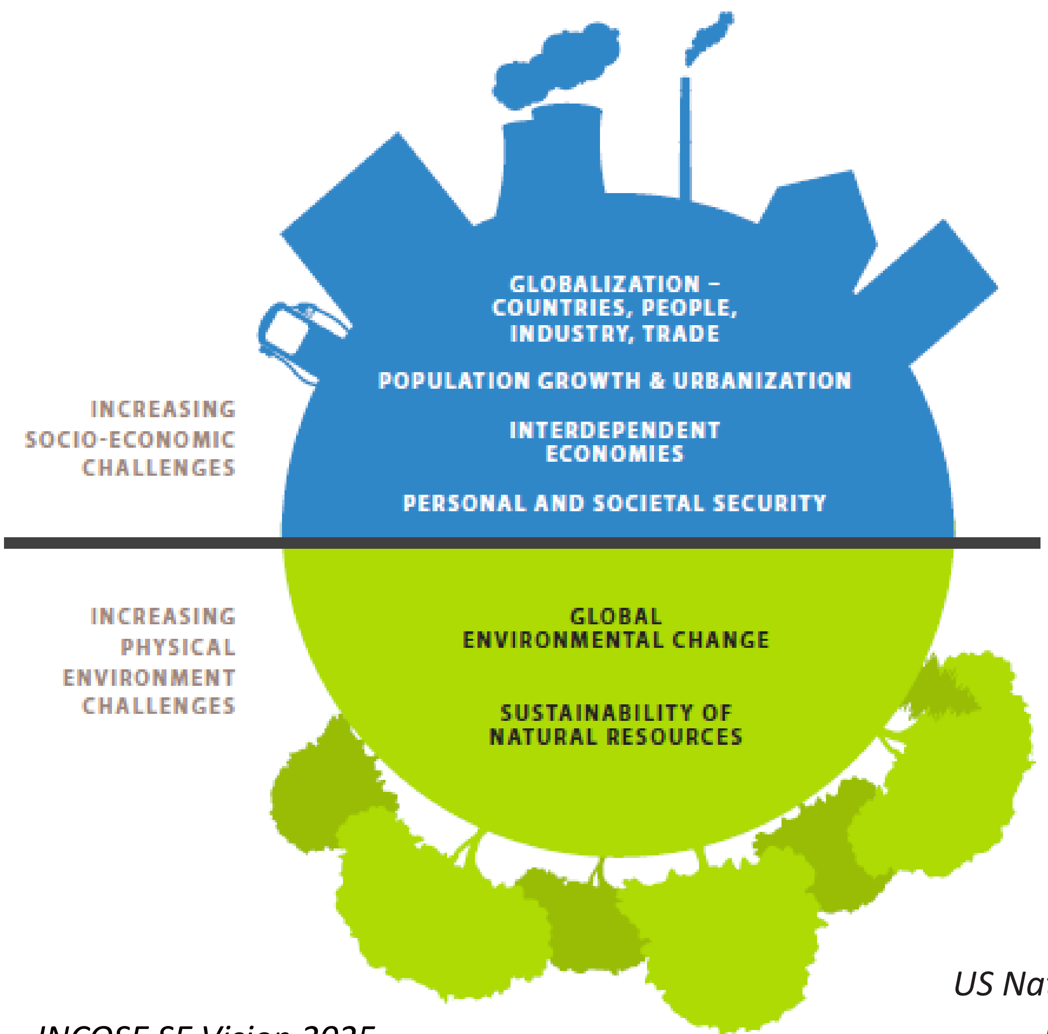
Societal Needs Drive Future Systems



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US National Academy of Engineering (NAE)

Technology Trends Drive Future Systems

COMPUTATIONAL POWER

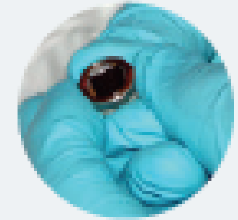
...continues to increase while computers are getting smaller and more efficient. Extensive reasoning and data management capabilities are now embedded in everyday systems, devices and appliances, yet data centers exhibit very high power densities requiring more sustainable power and thermal management systems.

MINIATURIZATION

...of system components provides increased capabilities in smaller and more efficient packages but can contribute to hidden levels of system complexity.

BIO-TECHNOLOGY

...contributes to health and human welfare, but can have unintended consequences.



SENSOR TECHNOLOGIES

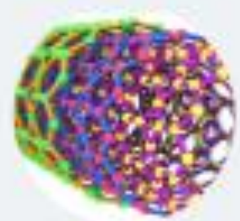
...provide information to a multitude of systems about location, human inputs, environmental context and more. For example, GPS now provides complete and accurate information about a system's geographic position - information that was previously unobtainable. Advances in medical systems, Geographic Information Systems and many industrial systems are based upon ever better and more efficient sensor technologies.

COMMUNICATION TECHNOLOGIES

...bring our world closer together and enable systems that are aware of and can respond to much greater environmental stimuli and information needs.

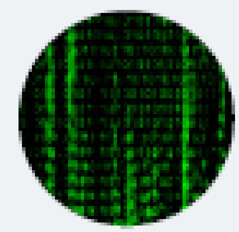
HUMAN-COMPUTER INTERACTION

...technologies enable the exploration of virtual environments allowing engineers to interact more deeply and comprehensively with systems before they are built. They also advance human control by integrating multiple information streams into manageable pieces.



MATERIAL SCIENCE

...new capabilities lead to systems with improved properties, such as weight and volume, electrical conductance, strength, sustainability or environmental compatibility.



SOFTWARE SYSTEMS

...embody algorithms that manage system state but also reason about the system's external environment and accomplishment of objectives. As systems become more "intelligent" and dominate human-safety critical applications, software certification and system reliability and integrity become more important and challenging.

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Changing Focus of Systems Engineering

A fresh look at Systems Engineering – what is it, how should it work

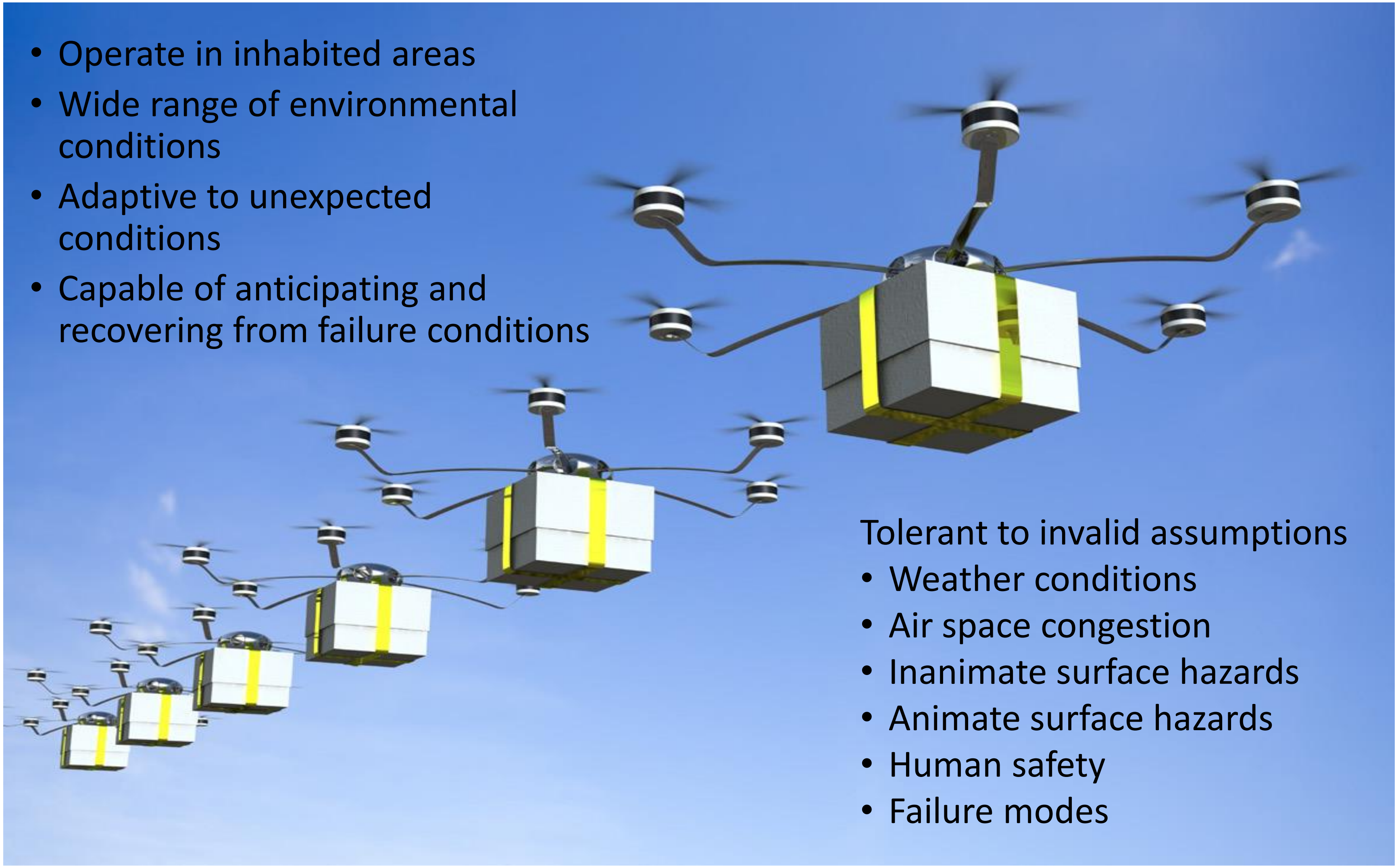
Interdisciplinary

- To engineer dependable, robust, pseudo-deterministic, mainly technological systems
- Requirements and operational concepts that:
  - Can be established early in the lifecycle
  - Are not expected to change (much) through life

Transdisciplinary

- To address resilient, adaptive systems and systems-of-systems that may be in a state of continual evolution (at least their operational environment, and probably the system as well)
- Systems of interest may be autonomous, possibly involving Artificial Intelligence, probably involving environmental aspects, and certainly involving social aspects as well as engineering and technology
- To address societal grand challenges related inter alia to the Sustainable Development Goals (SDGs)
- Such systems will still need dependable robust technological building blocks (which is why we say the focus “opens out” rather than “shifts”)

Resilient Design of Autonomous Systems



- Operate in inhabited areas
- Wide range of environmental conditions
- Adaptive to unexpected conditions
- Capable of anticipating and recovering from failure conditions

Tolerant to invalid assumptions

- Weather conditions
- Air space congestion
- Inanimate surface hazards
- Animate surface hazards
- Human safety
- Failure modes

INCOSE SE Vision 2025 - Imperatives

Expanding the APPLICATION of systems engineering across industry domains

Embracing and learning from the diversity of systems engineering APPROACHES

Applying systems engineering to help shape policy related to SOCIAL AND NATURAL SYSTEMS

Expanding the THEORETICAL foundation for systems engineering

Advancing the TOOLS and METHODS to address complexity

Enhancing EDUCATION and TRAINING to grow a SYSTEMS ENGINEERING WORKFORCE that meets the increasing demand

Expanding the APPLICATION of systems engineering across industry domains

Many traditional companies are adopting SE

- Transportation – public transit, intelligent transportation systems (ITS), automotive, agriculture, construction, autonomous vehicles
- Health – healthcare organizations, medical devices, pharma
- Energy & Power – oil & gas, power utilities, generating/ distribution
- Telecomms – critical infrastructure for first responders, municipalities, and utilities
- Water – water authorities

Reference: Personal communication with Anne O'Neil

What is creating the increased demand for SE?

1 Mission complexity is growing faster than our ability to manage it . . . increasing mission risk from inadequate specifications and incomplete verification.

2 System design emerges from pieces, rather than from architecture . . . resulting in systems that are brittle, difficult to test, and complex and expensive to operate.

3 Knowledge and investment are lost at project life cycle phase boundaries . . . increasing development cost and risk of late discovery of design problems

4 Knowledge and investment are lost between projects . . . increasing cost and risk: dampening the potential for true product lines.

5 Technical and programmatic sides of projects are poorly coupled . . . hampering effective project risk-based decision making.

6 Most major disasters such as Challenger and Columbia have resulted from failure to recognize and deal with risks. The Columbia Accident Investigation Board determined that the preferred approach is an "independent technical authority".

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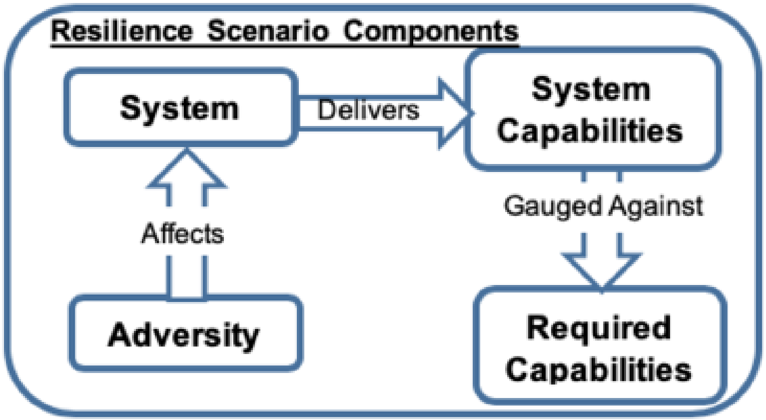
Embracing and learning from the diversity of systems engineering APPROACHES

Systems engineering methods used in commercial companies will differ from traditional defense applications

- Scalable to system and organizational complexity and size
- Tailored to the application domain
- Value driven to optimize project schedule, cost, and technical risk
- Built-in design drivers like cybersecurity and resilience

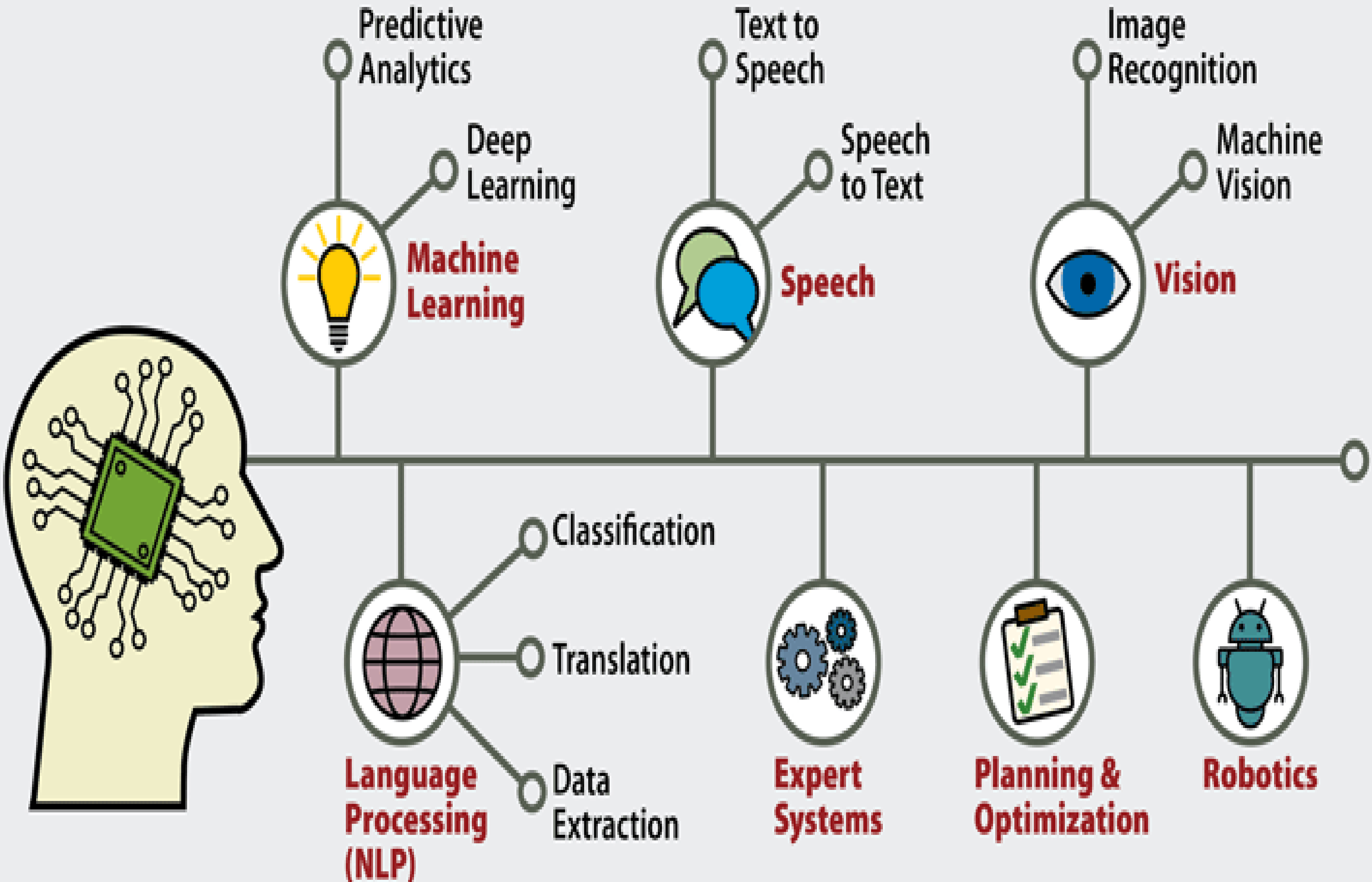
System Resilience

- The ability to provide the required capability in the face of adversity (avoid/withstand/recover)
  - Environmental sources
  - Component failure
  - Opponents, friendlies, neutral parties



- Key attributes of a resilient system
  - Robustness – ability to withstand a threat in the normal operating state
  - Adaptability – ability to restructure itself in the face of a threat
  - Tolerance – ability to degrade gracefully following an encounter with adversity
  - Integrity – ability to maintain cohesiveness under adversity

Artificial Intelligence



Agility

Agility is a capability exhibited by systems and processes that enables them to sustain effective operation under conditions of unpredictability, uncertainty, and change

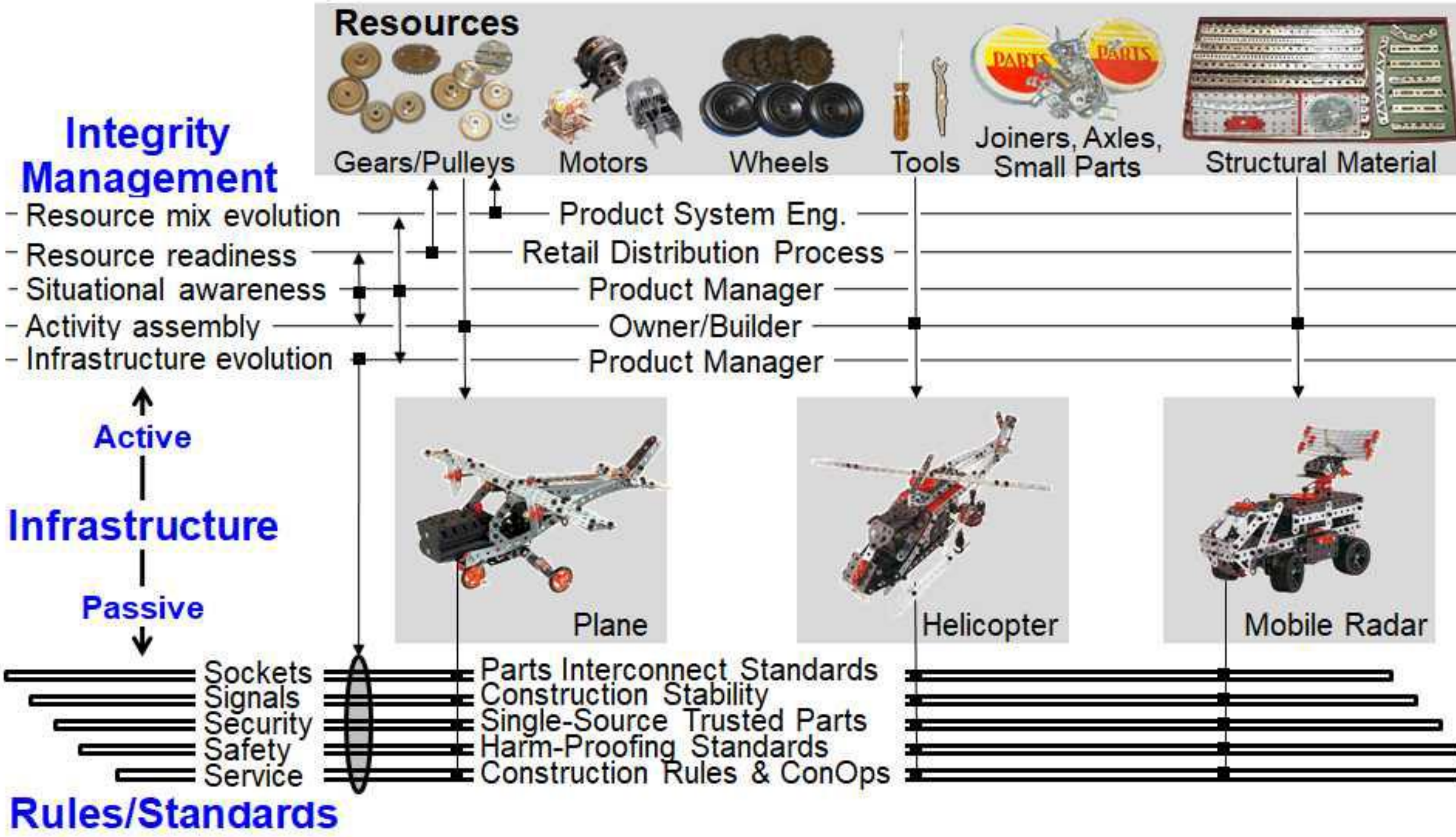
Agile systems

- Flexible, reconfigurable, extensible
- Scalable in the sense of capacity
- Flexible in terms of functions and performance levels (such systems can be modified after initial deployment by addition of modules or modification of performance levels)

Agile systems engineering

- Nimble, dexterous and swift
- Adaptive and response to new, sometimes unexpected, information that becomes available during product/system development
- Opposite the traditional belief in engineering design that requirements and design solutions should be frozen as early as possible

Erector Set - An Agile Hardware Engineering Example



"Fundamentals of Agile Systems Engineering – Part 1", Dove and La Barge

Applying systems engineering to help shape policy related to SOCIAL AND NATURAL SYSTEMS

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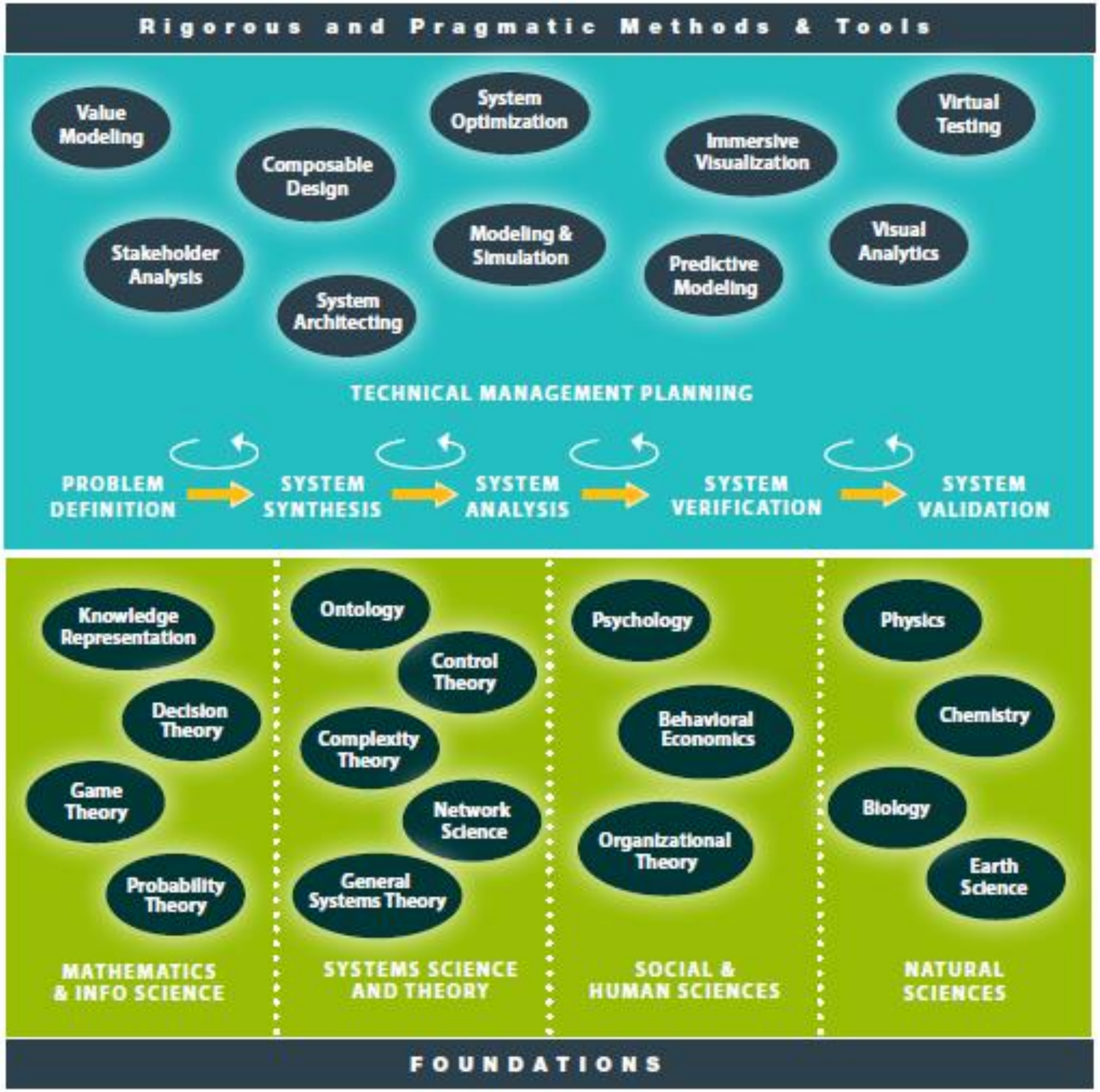
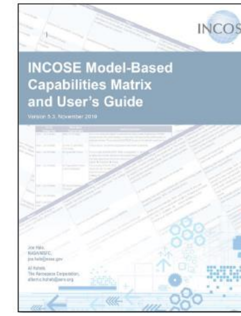
Expanding the THEORETICAL foundation for systems engineering



Advancing the TOOLS and METHODS to address complexity

Model-Based Systems Engineering – Maturity



- Rows: Organization modeling capabilities for an organization (42 capabilities)
- Columns: Increasing stages of capability
  - **Stage 0:** No MBSE capability or MBSE applied ad hoc to gain experience
  - **Stage 1:** Modeling efforts are used to address specific objectives and questions
  - **Stage 2:** Modeling standards are applied; ontology, languages, tools,
  - **Stage 3:** Program/project wide capabilities; model integrated with other functional disciplines, digital threads defined and digital twin
  - **Stage 4:** Enterprise wide capabilities: contributing to the enterprise, programs/projects use enterprise defined ontologies libraries, standards

CAPABILITY STATEMENTS	STAGE 0	STAGE 1	STAGE 2	STAGE 3	STAGE 4
CAP 1					
CAP 2					
CAP 3					
CAP 4					

INCOSE Model-Based Capabilities Matrix

DoD DE Strateg	Model-Based Capabilit	Stage 0	Stage 1	Stage 2	Stage 3	Stage 4
Goal 1. Use of Models	MBSE Use Strategy	No documented MBSE use strategy, or the strategy is described for ad hoc efforts. Each MBSE effort is stand-alone to address specific concerns.	Organization MBSE use strategy is documented as part of its overall organizational strategy at the system level. The strategy is related to the overall risk strategy.	Organization MBSE use strategy is documented as part of the organization's overall strategy at the system level. The strategy is related to the overall risk strategy. Modeling results used to inform systems engineers across system engineering phases and for all disciplines.	Organization MBSE use strategy is documented as part of the organization's overall strategy at the enterprise level. The strategy is related to the overall risk strategy. Modeling is integrated with business information tools and results used to inform systems engineers, program management, and all staff across the enterprise.	Organization MBSE use strategy is documented as part of the organization's overall strategy at the enterprise level. The strategy is related to the overall risk strategy. Modeling is integrated with business information tools and results are used to inform systems engineers, program management, and all staff across the enterprise. It manages a full range
Goal 1. Use of Models	Common DE and MBSE Terminology	Appropriate terminology defined for the project or program.	Common Glossary/Data Dictionary.	Top Tier terminology is defined for the enterprise.	Discipline and engineering specialty terminology is added to cover lower level models.	Common, tiered taxonomies are defined and consistent across enterprises and consistent with accepted community standards.
Goal 1. Use of Models	SE Agreement Process	Modeling is not incorporated as part of the agreement processes.	Given a clear business case, modeling is applied in an ad hoc manner across projects or programs.	Given a clear business case, modeling is applied in a consistent manner across projects or programs.	Consistent model business case descriptions are being practiced across an enterprise.	Consistent model business case driven planning guidance is in place and is being practiced across an
Goal 1. Use of Models	SE Organizational Project-Enabling Processes	Modeling is not incorporated as part of the Organizational Project Enabling processes.	Given a clear business case, modeling is applied in an ad hoc manner across projects or programs.	Given a clear business case, modeling is applied in a consistent manner across projects or programs.	Consistent model business case descriptions are being practiced across an enterprise.	Consistent model business case driven planning guidance is in place and is being practiced across an enterprise.
Goal 1. Use of Models	SE Technical Management Processes	Modeling is not incorporated as part of the Technical Management processes.	Modeling is part of the processes to improve quality and models contribute to the authoritative source of truth.	Modeling is the basis for the processes. Digital artifacts are used to make SE Technical Management decisions.	Modeling is the basis for the processes and is used to optimize results across the project or program.	Modeling is the basis for the processes and is used to optimize results across the enterprise.
Goal 1. Use of Models	Model Configuration Management	Model Configuration management is ad hoc.	Model configuration management is an assigned role.	Model configuration management adheres to a standard.	Model configuration management is applied to all models for a system.	Model configuration management is applied to all models for an enterprise.
Goal 1. Use of Models	Model Data Management	Model Data Management is ad hoc.	Model data management is an assigned role.	Model data management adheres to a standard.	Model data management is applied to all models for a system.	Model data management is applied to all models for an enterprise.
Goal 1. Use of Models	SE Technical Processes	Modeling is not incorporated as part of the Technical processes.	Modeling is part of the processes to improve quality and models contribute to the authoritative source of truth.	Modeling is the basis for the processes with digital threads covering some of the processes. Digital artifacts are used to make SE decisions.	Modeling is the basis for the processes with digital threads covering all selected processes. Digital artifacts and digital twins are used to make SE	Modeling is the basis for the processes with digital threads covering all processes. Digital artifacts, and digital twins are used to make SE decisions.
Goal 1. Use of Models	Modeling Stakeholder Requirements	Stakeholder requirements are not modeled.	Stakeholder requirements are in a requirements management tool.	Stakeholder requirements in a management tool are linked to enterprise and system models and are bi directional traceable. The requirements are linked model data that provide digital artifacts spanning the life cycle and depth of design information.	Enterprise and system stakeholder requirements are bi directional traceable.	Stakeholder requirements are traceable across enterprises.
Goal 1. Use of Models	Model-Based Verification and Validation	No plan for verifying or validating requirements in the models.	Plan for verifying and validating requirements in the models.	Verification and validation plan relies on model contents and analysis via requirements "analysis."	Modeling development processes have been established, modeling patterns, styles, and standards have been defined, and standard V&V procedures and programs have been formulated.	Modeling development processes have been established, modeling patterns, styles, and standards have been defined, and standard V&V procedures and programs have been formulated
Goal 1. Use of Models	SE-driven Model Plan	No documented MBSE plan.	Models are developed for parts of the system engineering or enterprise engineering processes or for only parts of the life cycle. Appropriate tools, environments, methods, and resources are provided.	Full System/Enterprise Models are developed and applied variously across the product life cycle and across Systems Engineering organizations. Appropriate tools, environments, methods, and resources are provided.	Multiple System Models are integrated for the enterprise. Consistent tool coverage and use within separate Systems Engineering Organizations. Appropriate tools, environments, methods, and resources are provided.	Consistent tool coverage within separate Systems Engineering Organizations across the enterprise. Multiple enterprise models are interfaced within or across mission areas. Appropriate tools, environments, methods, and resources are
Goal 1. Use of Models	Model Based Reviews, Management Program Reviews (MPR(s)), Milestone reviews, program reviews, technical reviews, audits	Reviews are not model based. Review and audit is set by calendar date against a contract event such as contract award. Digital artifacts aren't planned for use to satisfy entry/exit criteria.	Identification of model-based digital artifacts to satisfy entry/exit criteria. Model results called out explicitly as products with defined product quality. Use of digital artifacts allow for some criteria items to be addressed prior to the event.	Review process is still a scheduled event with known entrance and exit criteria as well as frozen baselines. Use of digital artifacts allow for some criteria items to be addressed prior to the event. Model-based digital artifacts to satisfy criteria along with linked narrative. Model content is identified that satisfies criteria are linked to external list of criteria	Review and audit is set by model data and information availability. Review process allows for more flexible reviews so that some criteria are acknowledged and accomplished before the scheduled review. Predominantly model-based digital artifacts with as-needed documents to satisfy criteria with linked narrative.	Enterprise organizations coordinate on common review criteria application, tailoring, and the use of specific digital artifacts to meet specific criteria. Models record the acceptance of criteria items. Rolling, frequent reviews of model contents of identified "Knowledge Points" allow stakeholders to accept that the review is complete for that
Goal 1. Use of Models	Model Metrics	Metrics are not used to manage the model development, quality, or effectiveness.	Available metrics are reported from the various modeling tools used.	Metrics, beyond those available from the tool configuration, are reported to address model development, quality, and effectiveness needs.	Metrics are used to manage the model development, quality, or effectiveness for a system or enterprise.	Consistent metrics are used across the enterprise to manage the model development, quality, or effectiveness with trend information kept and
Goal 1. Use of Models	Modeling Integration	Elements within a model are not integrated.	Elements within a model follow a structured approach (such as OOSEM).	Model elements not needed and that don't fit within the structured approach are removed. Model constraints are identified and model blocks	Integration across systems models for a project/program use the same structured approach. A Library of reusable SysML blocks is created and	Integration across systems models for an enterprise use the same structured approach. A Library of reusable SysML blocks is created and
Goal 1. Use of Models	Verification and Validation of Models	The organization has not stated model objectives – no basis for verification and validation of the models.	The organization has stated model objectives but not model requirements. Partial V&V evaluation of the resultant model is possible.	Model objectives and some general model requirements have been stated. Plans for V&V evaluation of the model traceable to the model requirements have been made.	Model objectives and some detailed model requirements for specific models have been stated. V&V evaluation of the model traceable to the model requirements is planned and includes V&V of modeling patterns, styles and standards, as well as having defined procedures.	Modeling development processes have been established, modeling patterns, styles, and standards have been defined, and standard V&V procedures and programs have been formulated (including associated automated scripts and tools). V&V of the model is performed and updates to the
Goal 1. Use of Models	Modeling Assurance	Model Assurance is not considered.	Model assurance is defined with known scales and methods.	Model assurance targets are identified in association with the effort schedule and cost.	Model assurance measurement and corrective actions are conducted for projects/programs.	Model assurance measurement and corrective actions are conducted for the enterprise.
Goal 1. Use of Models	Model Management	Model management is ad hoc.	Model management is an assigned role.	Model management adheres to a standard or to a defined approach.	Model management is applied to all models for a system.	Model management is applied to all models for an enterprise.
Goal 1. Use of Models	Distributed Database/Tool Interoperability	No interoperability between model based tools.	Model Based Tool-to-Tool has ad hoc interoperability.	Partial Federated Database Management System (FDBMS).	Main tools interoperable. Supporting tools interact through file transfer.	Fully Federated with standard "plug-and-play" interfaces. Data is interchanged among tools.
Goal 1. Use of Models	Model Based Data/Tool	Data/Tool independencies are not considered and	Data/Tool independencies are considered and	Data/Tool implementations independencies are	Data/Tool implementations independencies are	Data is independent of tools and allows for

Role-Based MBCM | MBCM-RB Capabilities | DE-Based MBCM | MBCM-DE Capabilities | OSD DE Strategy Goals

Model-Based Systems Engineering Trends

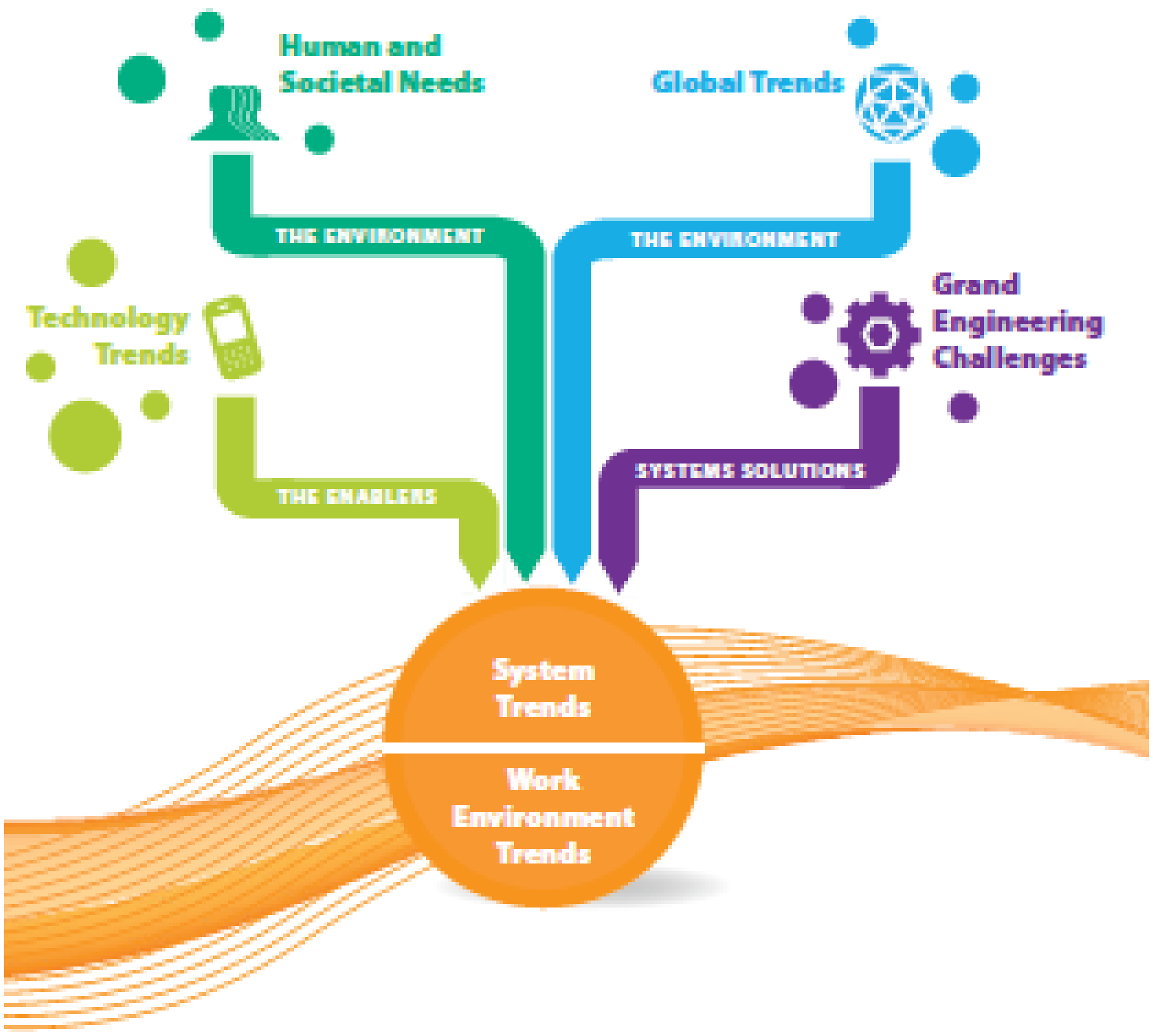
- MBSE is increasingly integrating technical, programmatic, and business concerns
- Tool suites, visualization and virtualization capabilities are maturing
- Model-based approaches will enable understanding of complex system behavior **much earlier in the product life cycle**
- Model-based visualization will allow **seamless navigation** among related viewpoints such as system, subsystem, component, as well as production and logistics
- Large scale virtual prototyping and virtual product integration based on integrated models will lead to **significant time-to-market reductions**

Enhancing EDUCATION and TRAINING to grow a SE WORKFORCE that meets the increasing demand

The worldwide demand for SE in all application domains is increasing the need for high quality SE education and training

- Increased use of systems thinking by non-engineers
- Increased understanding of systems engineering by all engineers
- Increased scope of knowledge, skills, and competencies by systems engineers, requiring life-long learning

The Global Context for Systems Engineering



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