Vision25
Systems Engineering

INCOSE
International Council on Systems Engineering

A WORLD IN MOTION*

Systems Engineering Vision • 2025

The purpose of the Vision 2025 is to ***inspire and guide*** the direction of systems engineering across diverse stakeholder communities, which include:

- Engineering Executives
- Policy Makers
- Academics & Researchers
- Practitioners
- Tool Vendors

This vision will continue to evolve based on stakeholder inputs and on-going collaborations with professional societies.

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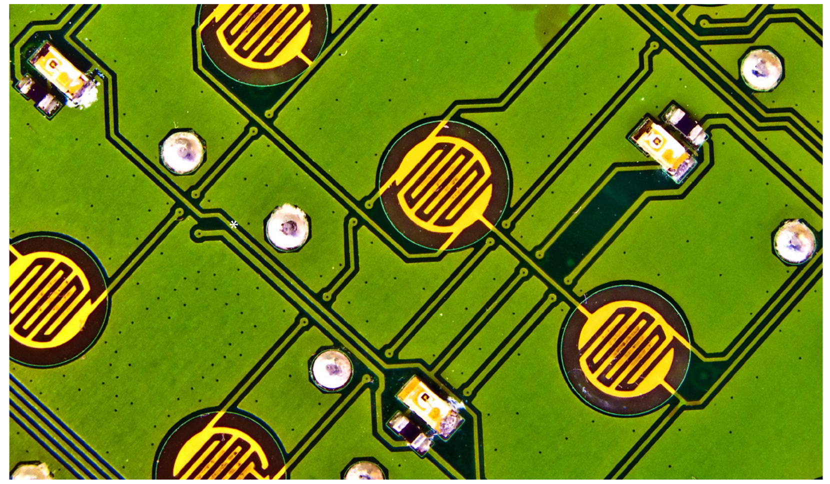
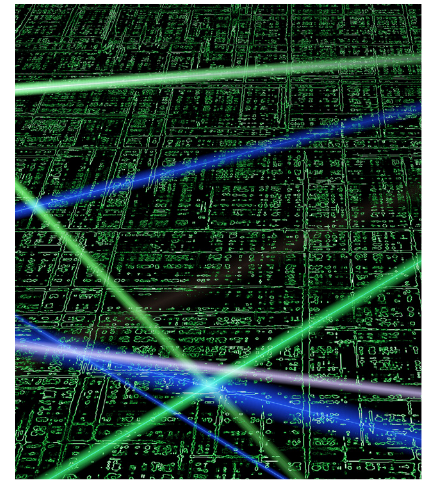
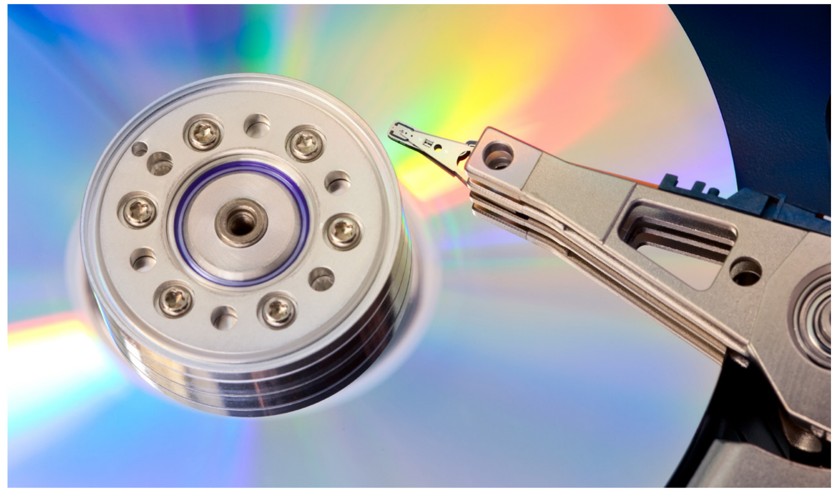
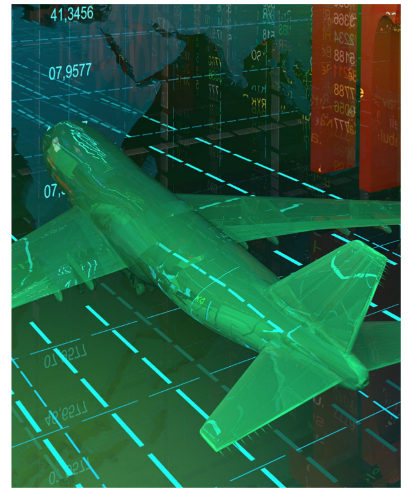


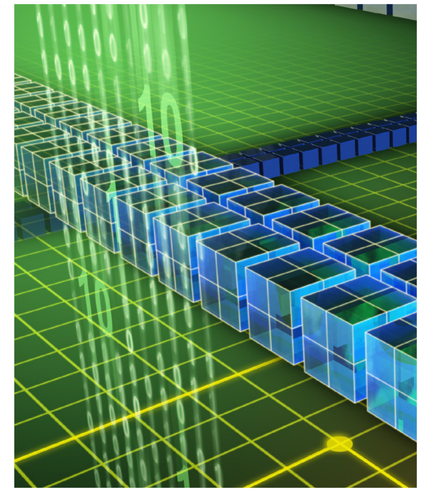
PROMOTE SYSTEMS ENGINEERING RESEARCH

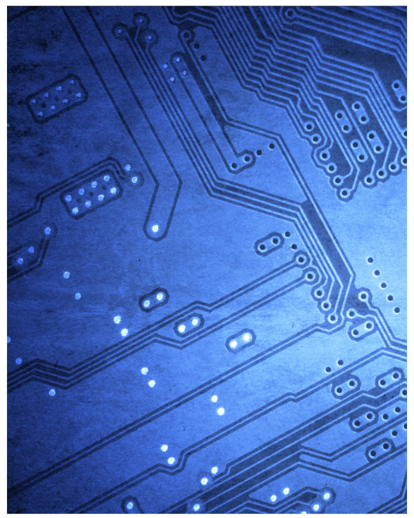


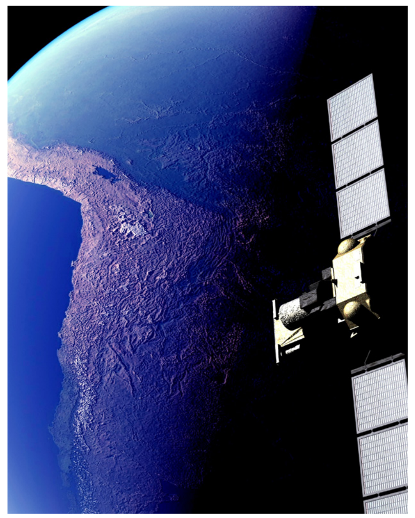
ALIGN SYSTEMS ENGINEERING INITIATIVES

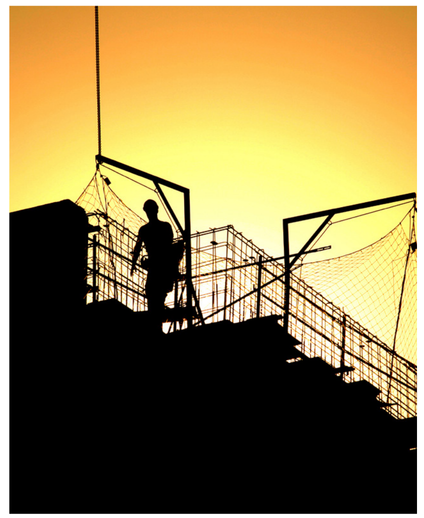




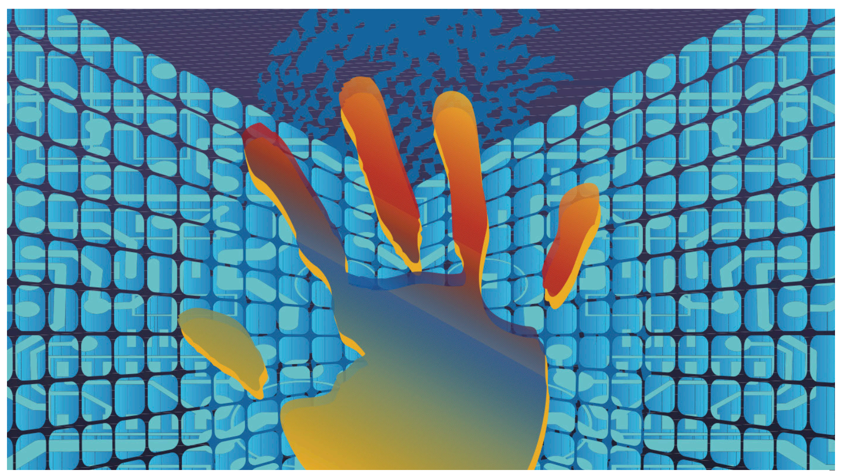




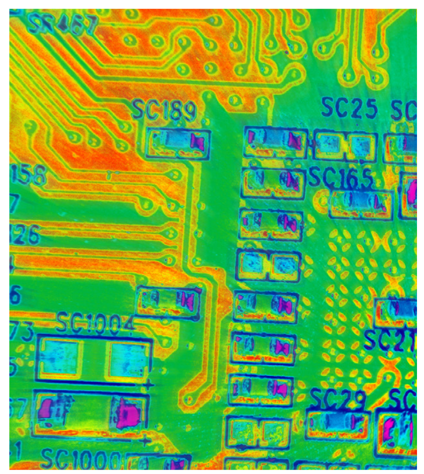


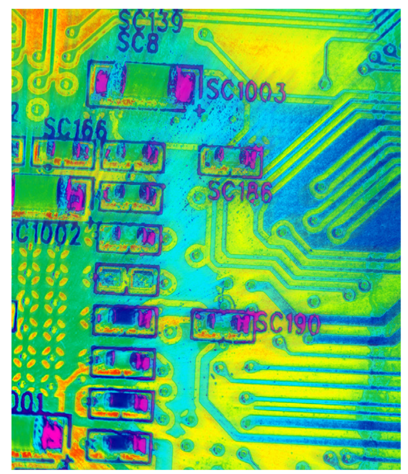


ADDRESS FUTURE SYSTEMS ENGINEERING CHALLENGES



BROADEN THE BASE OF SYSTEMS ENGINEERING PRACTITIONERS





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Systems Engineering

focuses on ensuring

the pieces work together

to achieve the

objectives of the whole.

Reference: Systems Engineering Body of Knowledge (SEBoK)

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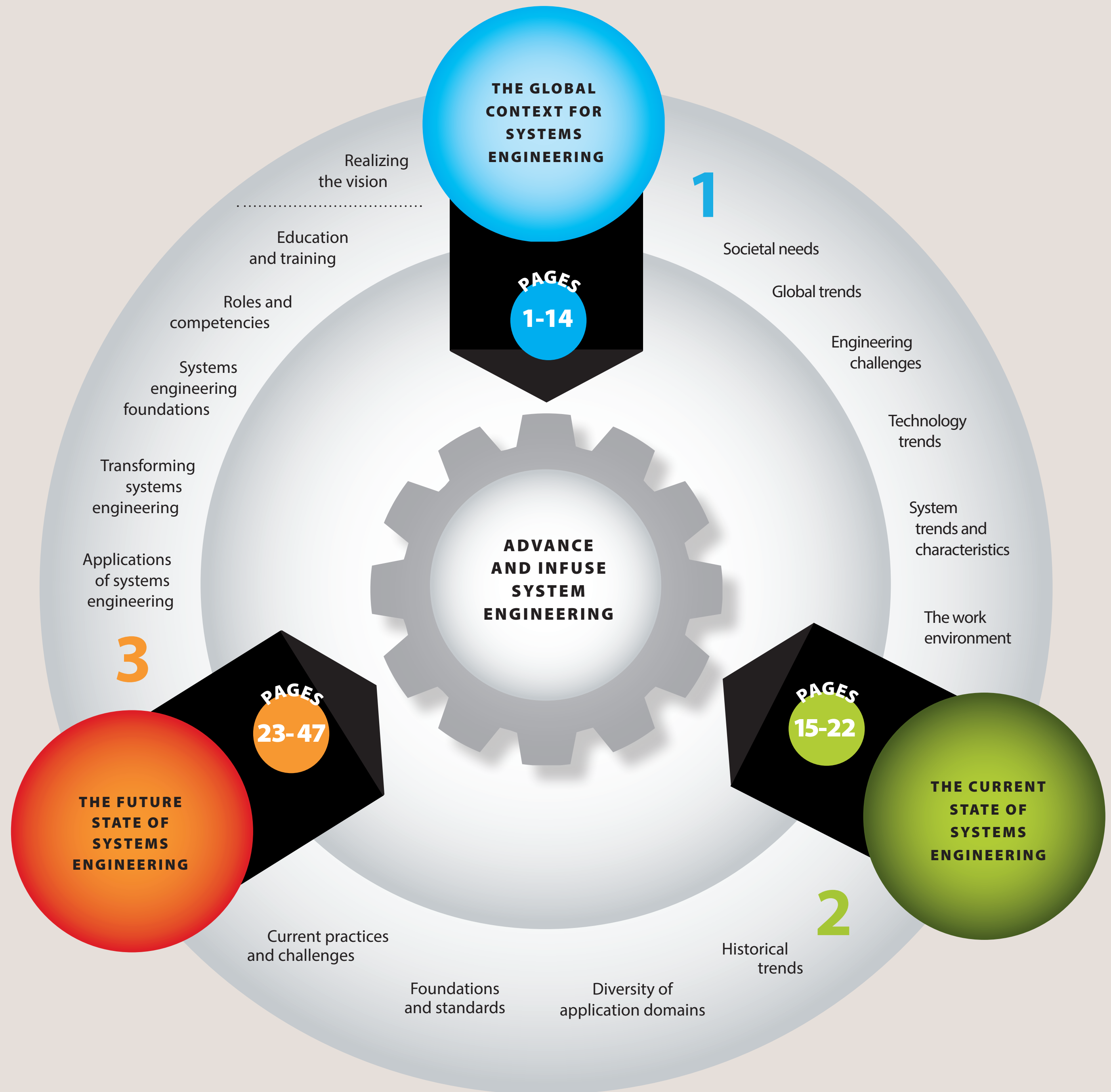

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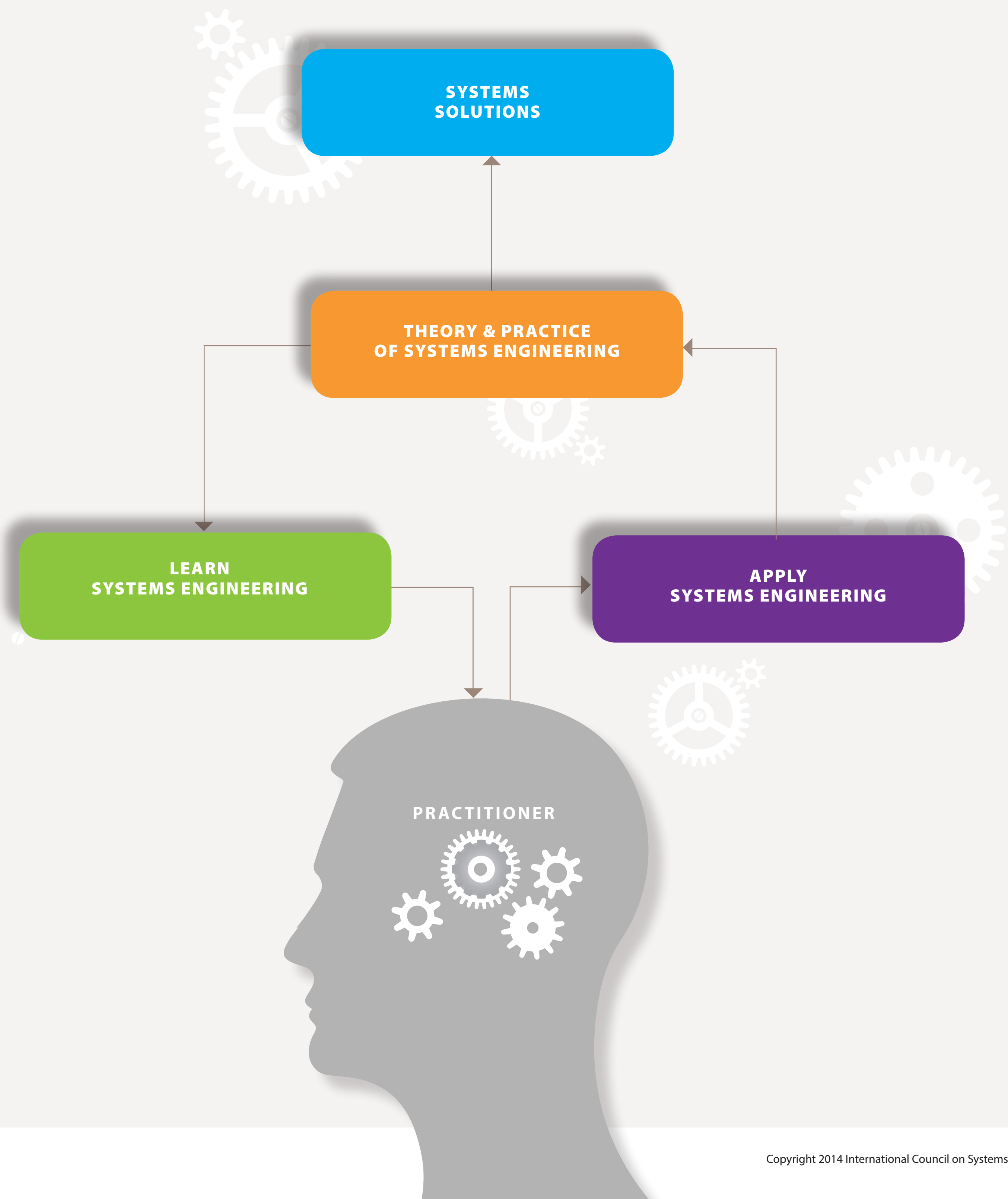
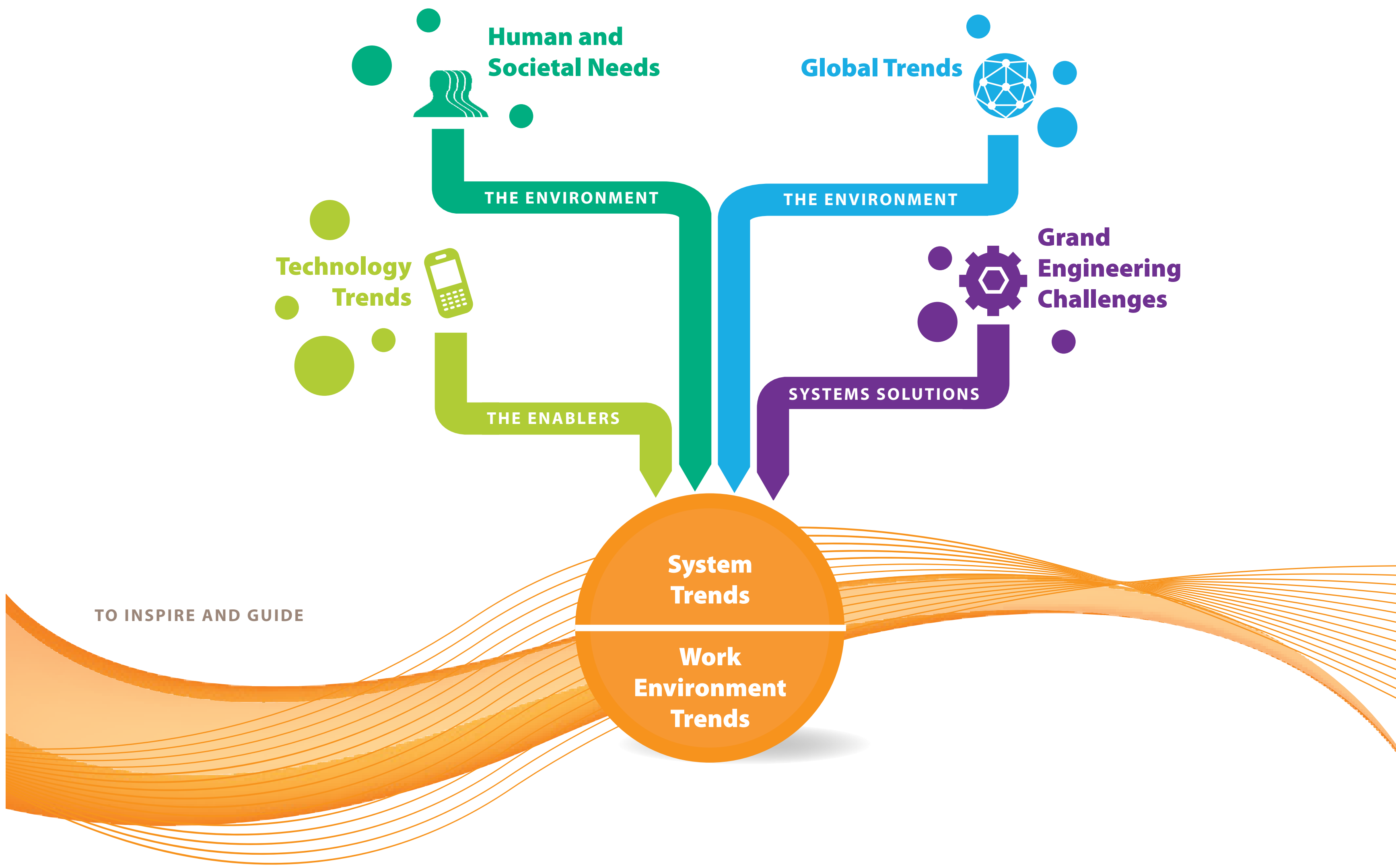


SYSTEMS ENGINEERING
IMPERATIVES

- 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.

1 The Global Context for Systems Engineering

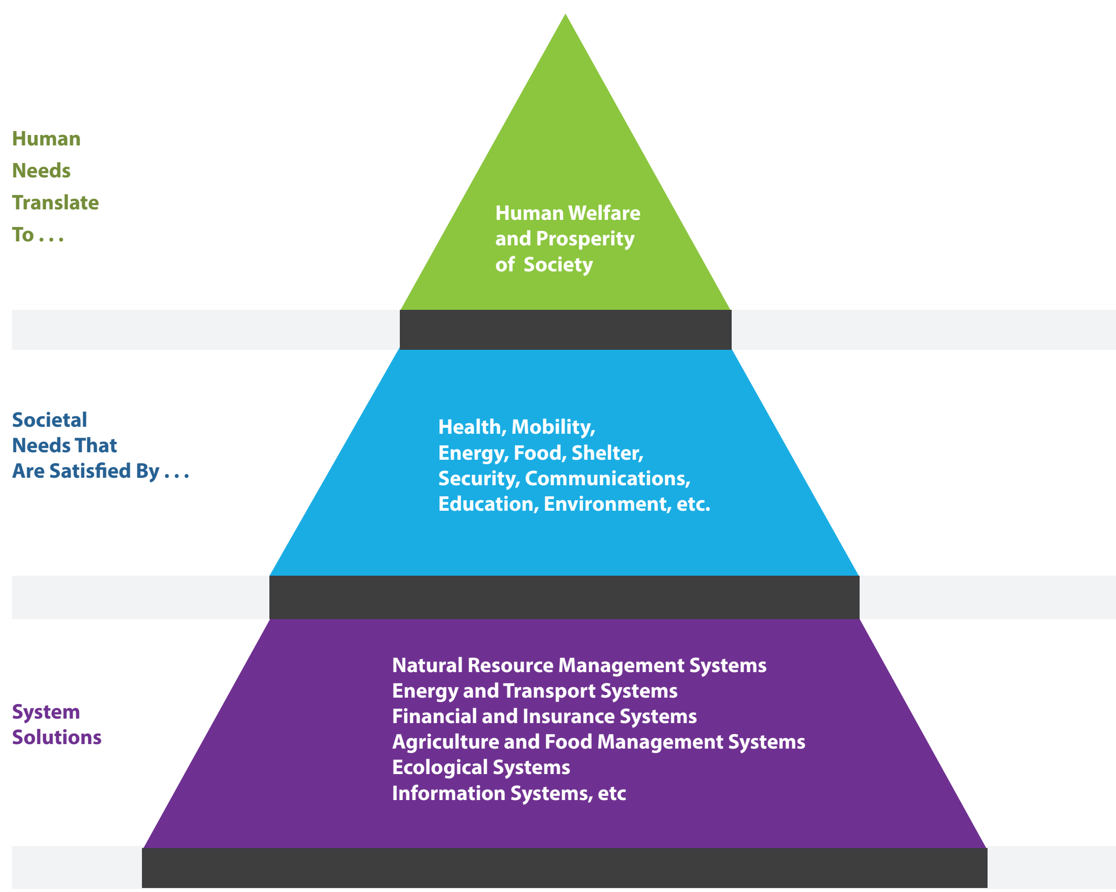
The vision for systems engineering in 2025 is shaped by the global environment, human and societal needs, policy and business challenges, as well as the technologies that underly systems. The evolving work environment, following global trends, both constrains and enables the manner in which systems engineering is practiced. In this section, we highlight the nature of evolving systems and the global context that systems engineering must respond to.



Human and Societal Needs Give Rise to Engineering Challenges

Humanity has always attempted, through engineering and technology, to make the world a better place. With our ever-evolving society, however, come new and ever greater challenges.

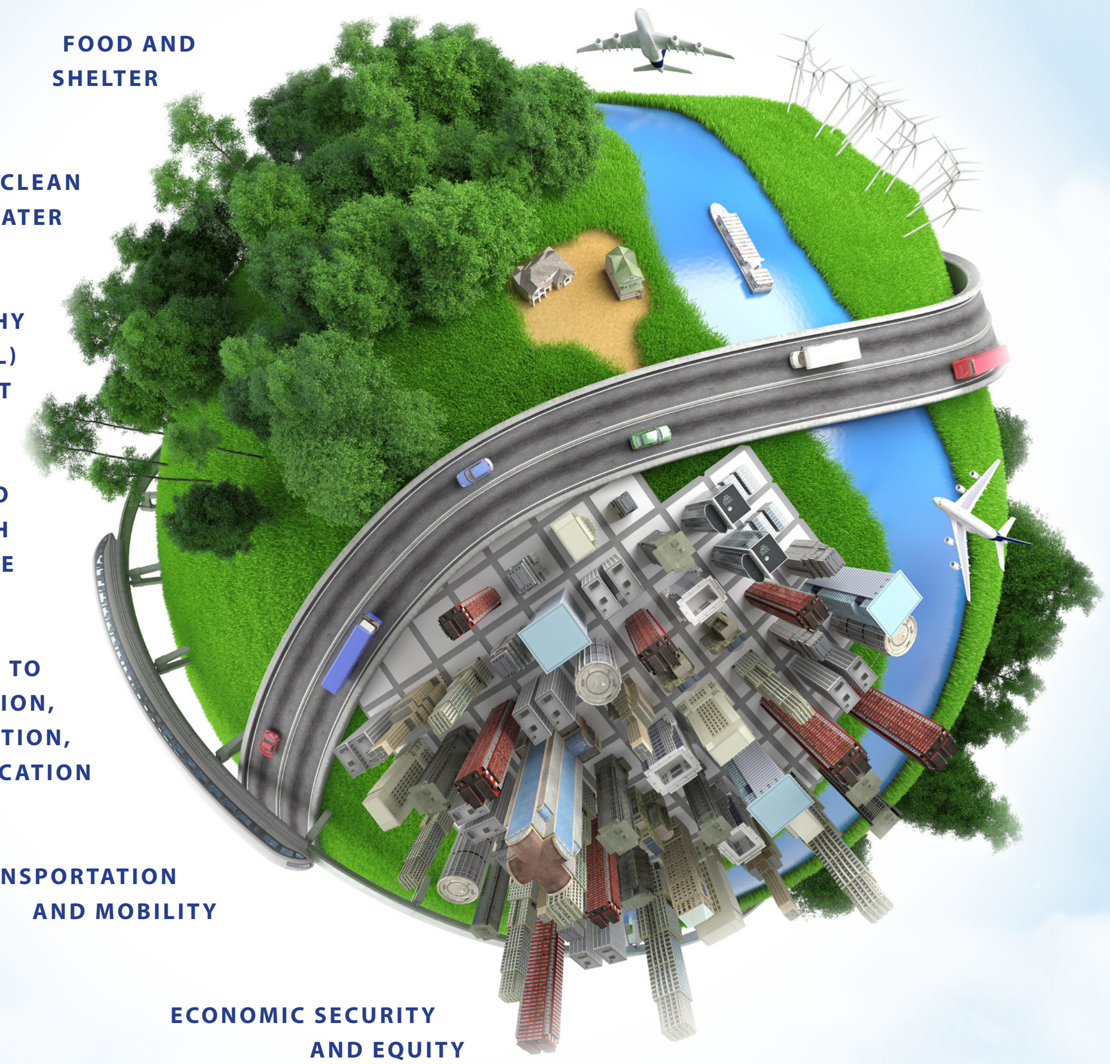
When we look for ways to meet fundamental human needs, we see that the solutions often lead to large and complex engineered systems — systems that can only be successful if they are socially acceptable and provide value to society.



Needs Drive Systems – Systems Satisfy Needs

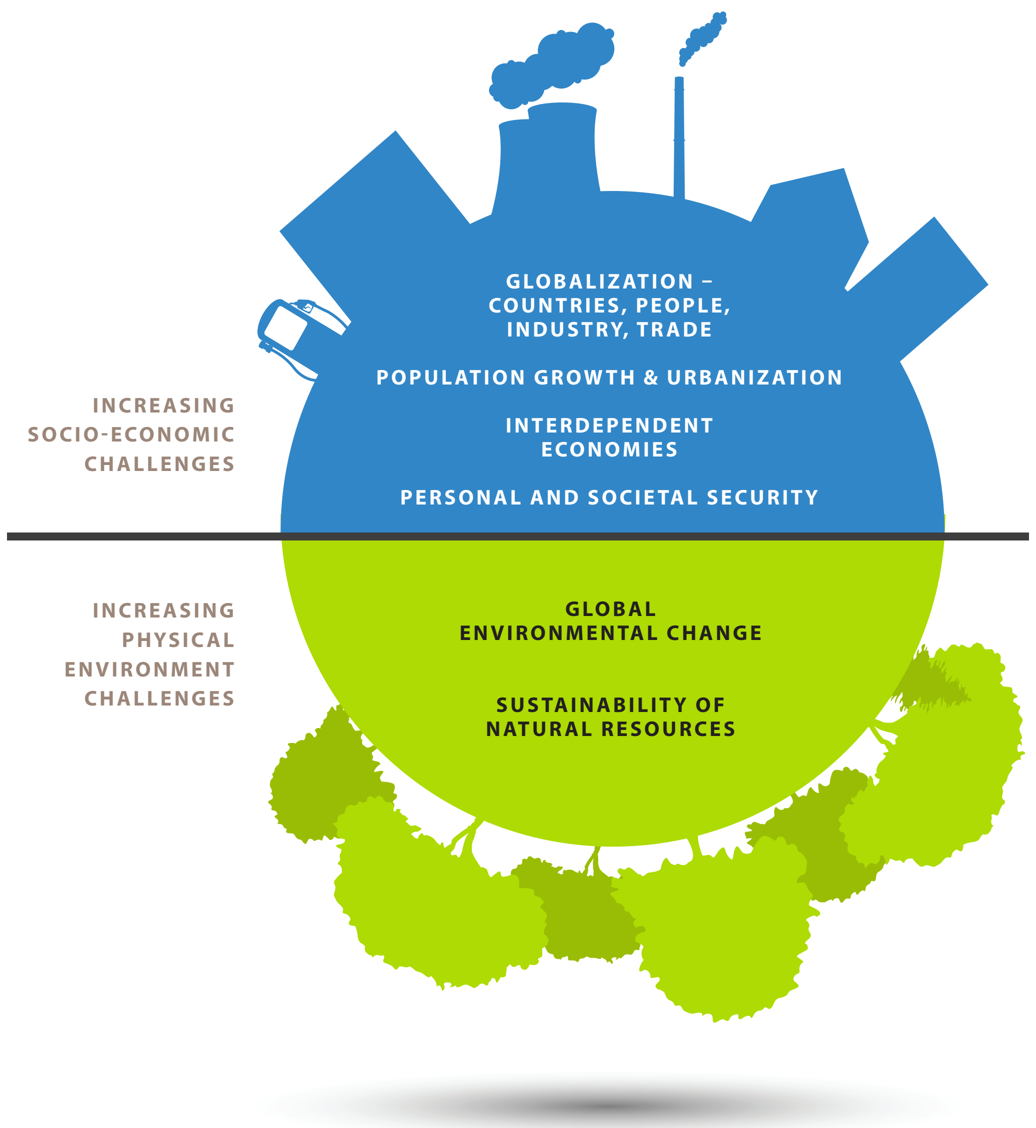
GENERAL HUMAN AND SOCIETAL NEEDS

Human needs have hardly changed over the centuries. Societal needs are similar throughout the world, and systems must respond to such needs.



Global Trends Shape the Systems Environment

Global trends include changes to both socio-economic conditions and changes in our physical environment. These global changes impose new demands on the types of systems that are needed, yet are often impacted by the very technology and system developments meant to satisfy the human needs. For example, increased population growth and urbanization impose new challenges on transportation, health, and other modern infrastructures, while at the same time, systems solutions and technology itself can adversely impact air and water quality. There are clearly many other examples of these interdependencies, both positive and negative. Global interdependence often amplifies the impact of these changes. The global community is calling for more attention to how systems can positively contribute to our social condition and natural environment to help advance our quality of life.



INCREASING STRESS ON THE SUSTAINABILITY OF NATURAL RESOURCES DUE TO

. . . consumption of non-renewable resources and higher demand resulting from population and economic growth require better global management, recycling, sustainable policies, and supporting systems

. . . creating system challenges for more efficient resource utilization, better use of renewable resources, waste disposal, and re-use opportunities.

ENVIRONMENTAL CHANGE

. . . results in major shifts in living conditions, and impacts biodiversity, weather, sea level, and the availabilty of water and other natural resources.

. . . which in turn is affected by water and other natural resources, global, regional and local policies and decisions to mitigate anthropogenic environmental impacts.

INCREASING GLOBALIZATION

. . . results in higher levels of political and economic interdependence, the need to share resources and interconnect systems for global partnerships

. . . but also results in new collaboration mechanisms and new system challenges for global disaster relief, information and communication security, and sharing of knowledge and technology.

INCREASING POPULATION GROWTH AND URBANIZATION

. . . results in changing population distributions, "smart" cities, larger markets and greater opportunities

. . . but also great societal stress, urban infrastructure demands, and increased system challenges for agriculture, environmental health and sustainability.

INCREASINGLY INTERDEPENDENT ECONOMIES

. . . have become globally intertwined, relying upon the effectiveness of national, regional and local infrastructure systems

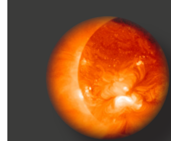
. . . but require improved coordination mechanisms and global policies to meet economic and financial system challenges while remaining balanced and equitable.

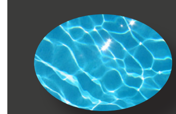
Engineering Challenges
Engineered Systems are Key to Satisfying Human and Societal Needs

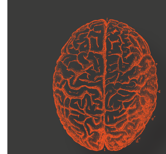
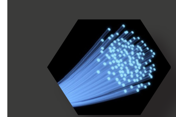
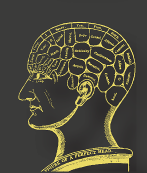
The US National Academy of Engineering (NAE) identified Grand Engineering Challenges for the 21st Century. Linking these to human and societal needs highlights the diversity and landscape of domains to which the discipline of systems engineering should contribute.

Large and often complex engineered systems are key to addressing the Grand Challenges and satisfying human and social needs that are physical, psychological, economic and cultural. However, these systems must be embedded in the prevailing social, physical, cultural and economic environment, and the technologies applied to system solutions must be tailored to the relevant local or regional capabilities and resources. Full life-cycle analyses and safe, robust and sustainable implementation approaches, along with stable governance environments are enablers for successful system solutions.

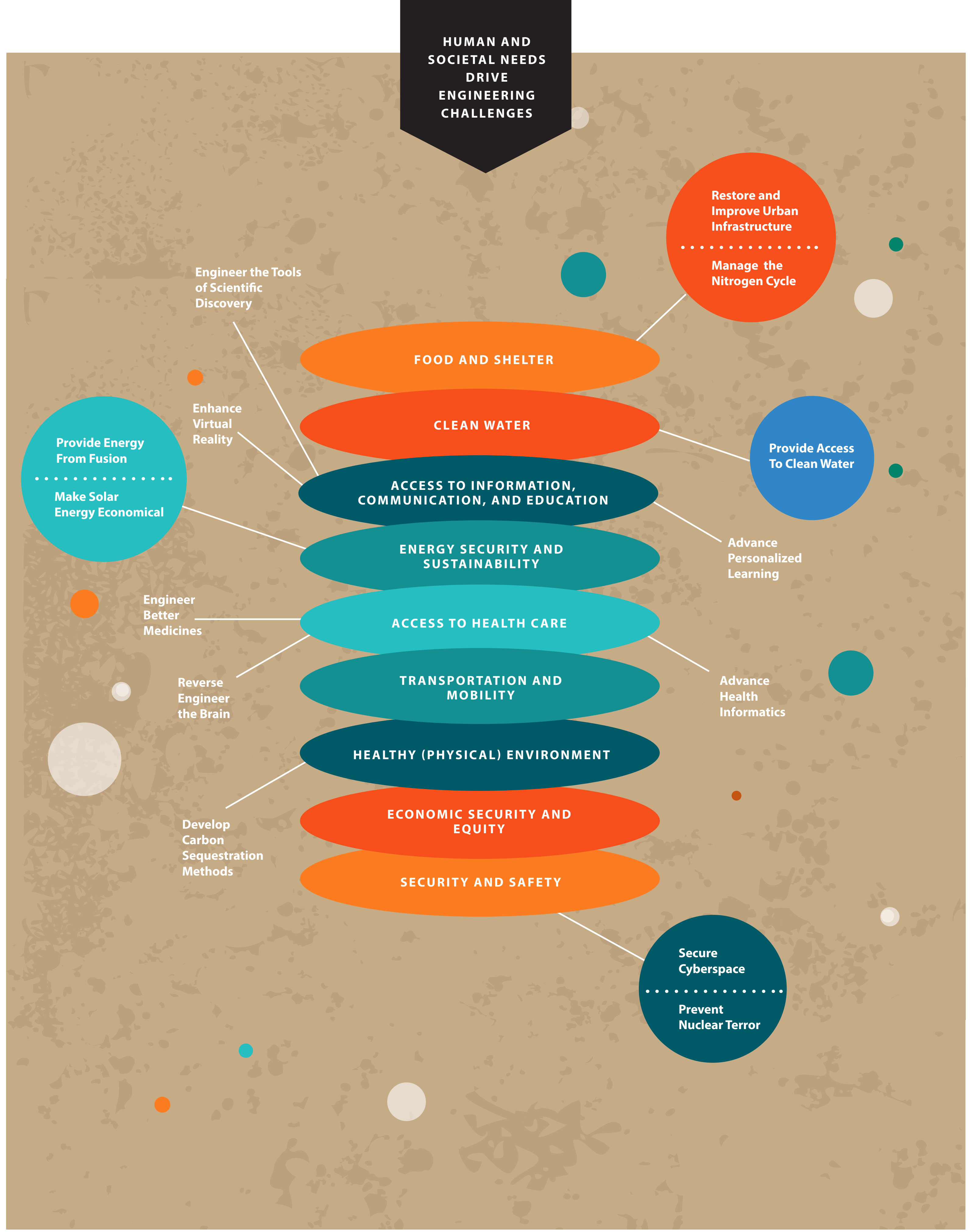
NAE ENGINEERING GRAND CHALLENGES



1. Make solar energy economical
2. Provide energy from fusion
3. Develop carbon sequestration methods
4. Manage the nitrogen cycle
5. Provide access to clean water
6. Restore and improve urban infrastructure
7. Advance health informatics
8. Engineer better medicines
9. Reverse-engineer the brain
10. Prevent nuclear terror
11. Secure cyberspace
12. Enhance virtual reality
13. Advance personalized learning
14. Engineer the tools of scientific discovery



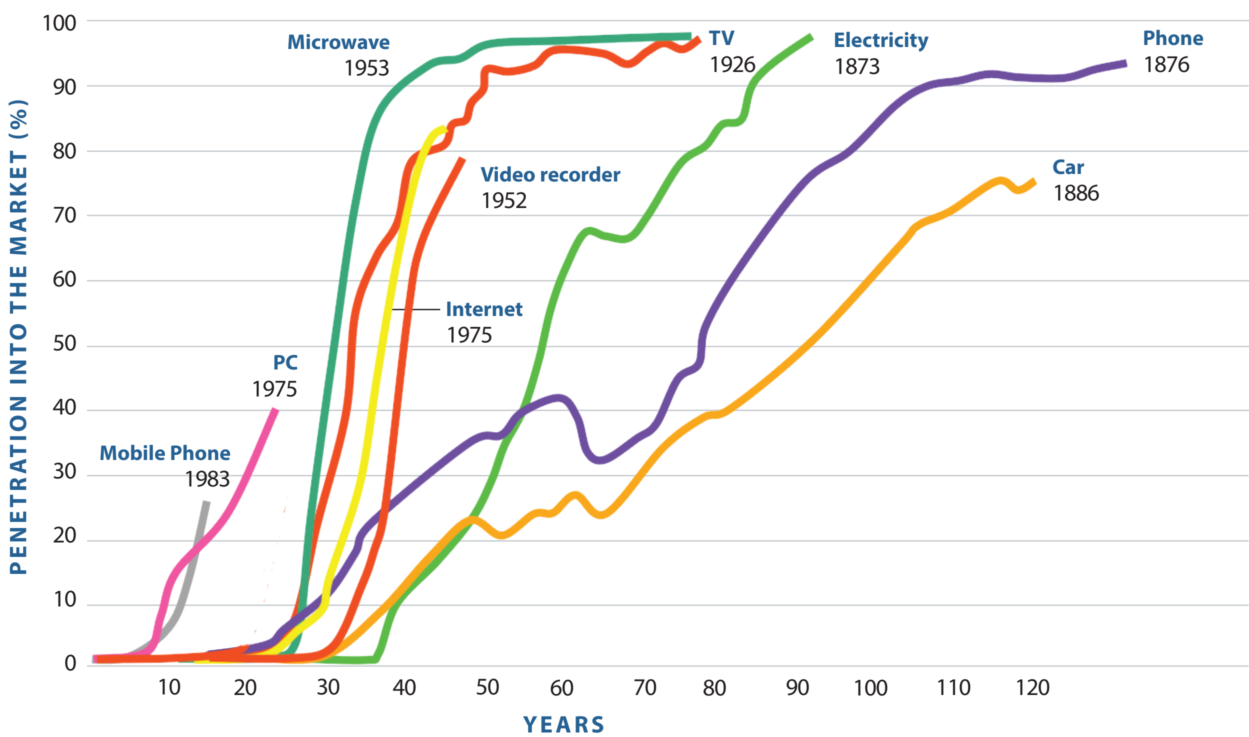
Technology Development and Infusion Impact the Nature of Future Systems

Technological advances in basic components, subsystems and infrastructure will produce innovations at an increasing pace, leading to sophisticated new services and products. The internet, for example, has progressed from an emerging technology to having a profound impact on commerce and our personal lives in just 20 years. These new services and products will both depend upon and result in new, evermore complex systems.

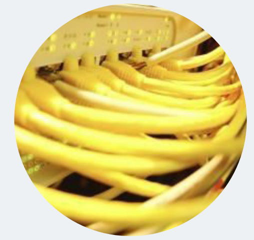
With technology infusion rates increasing, the pressure of time to market will also increase, yet customers will be expecting improved product functionality, aesthetics, operability, and overall value.

NEW TECHNOLOGIES CHANGE OUR DAILY LIFE AT AN EVER INCREASING RATE

Source: Forbes magazine



INFLUENTIAL TECHNOLOGY DEVELOPMENTS

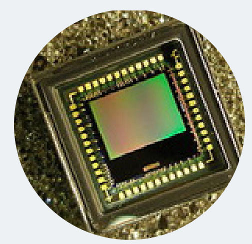


COMPUTATIONAL POWER

. . . 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.

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.

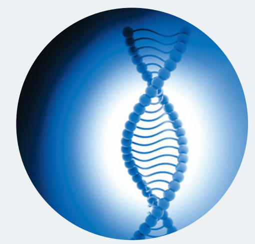


MINIATURIZATION

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

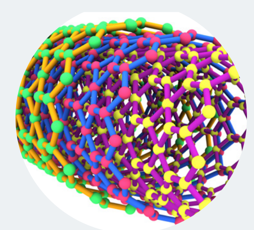
HUMAN-COMPUTER INTERACTION

. . . 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.



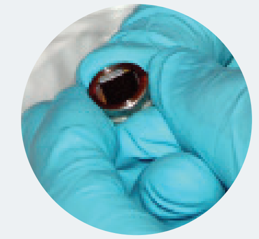
BIO-TECHNOLOGY

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



MATERIAL SCIENCE

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



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.

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.

System Trends

Stakeholder Expectations Drive System Trends

System performance expectations and many system characteristics will reflect the global societal and technological trends that shape stakeholder values. Examples of system stakeholders are:

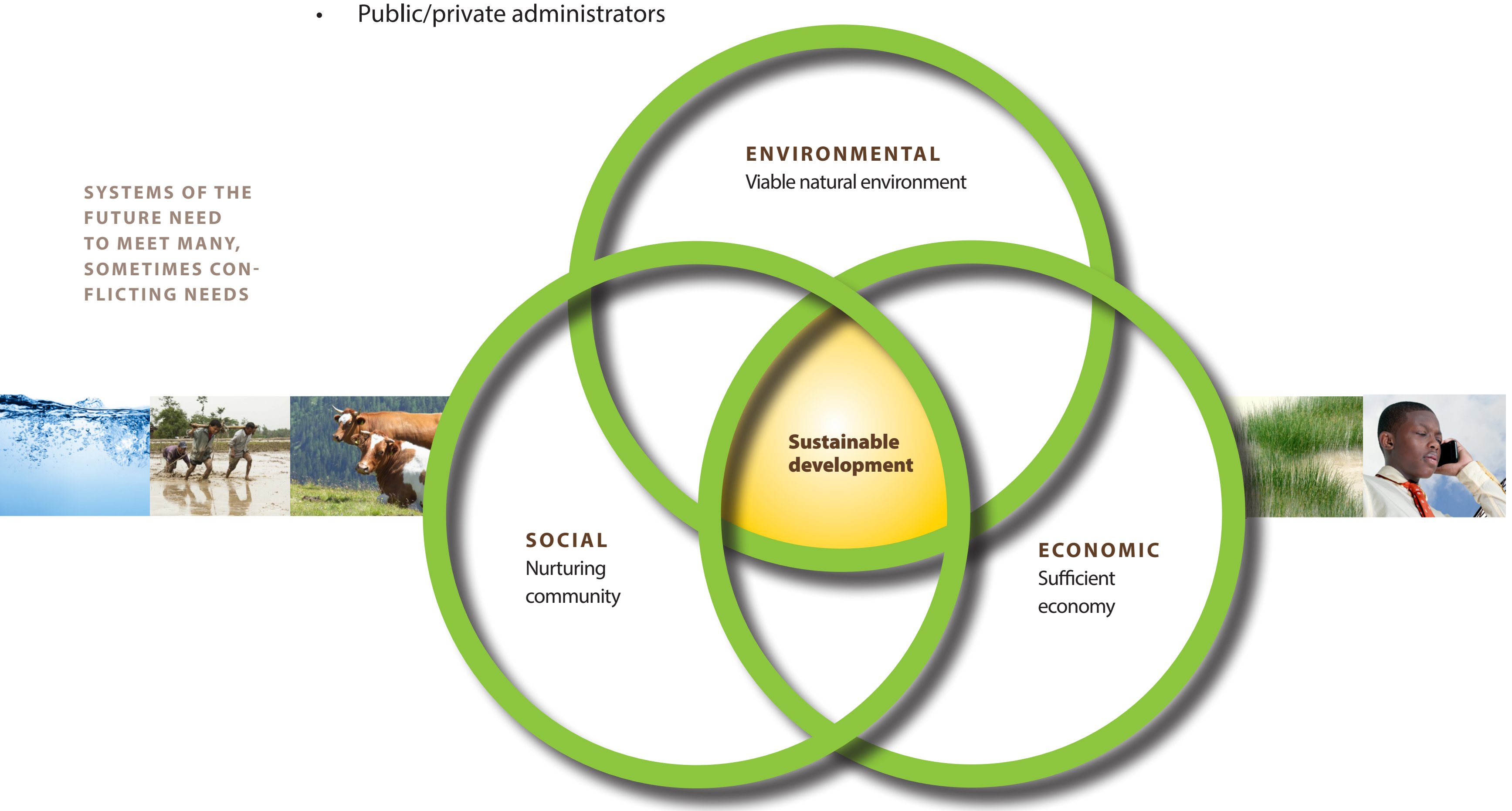
System Users
- The general public
- Public and private corporations
- Trained System Operators

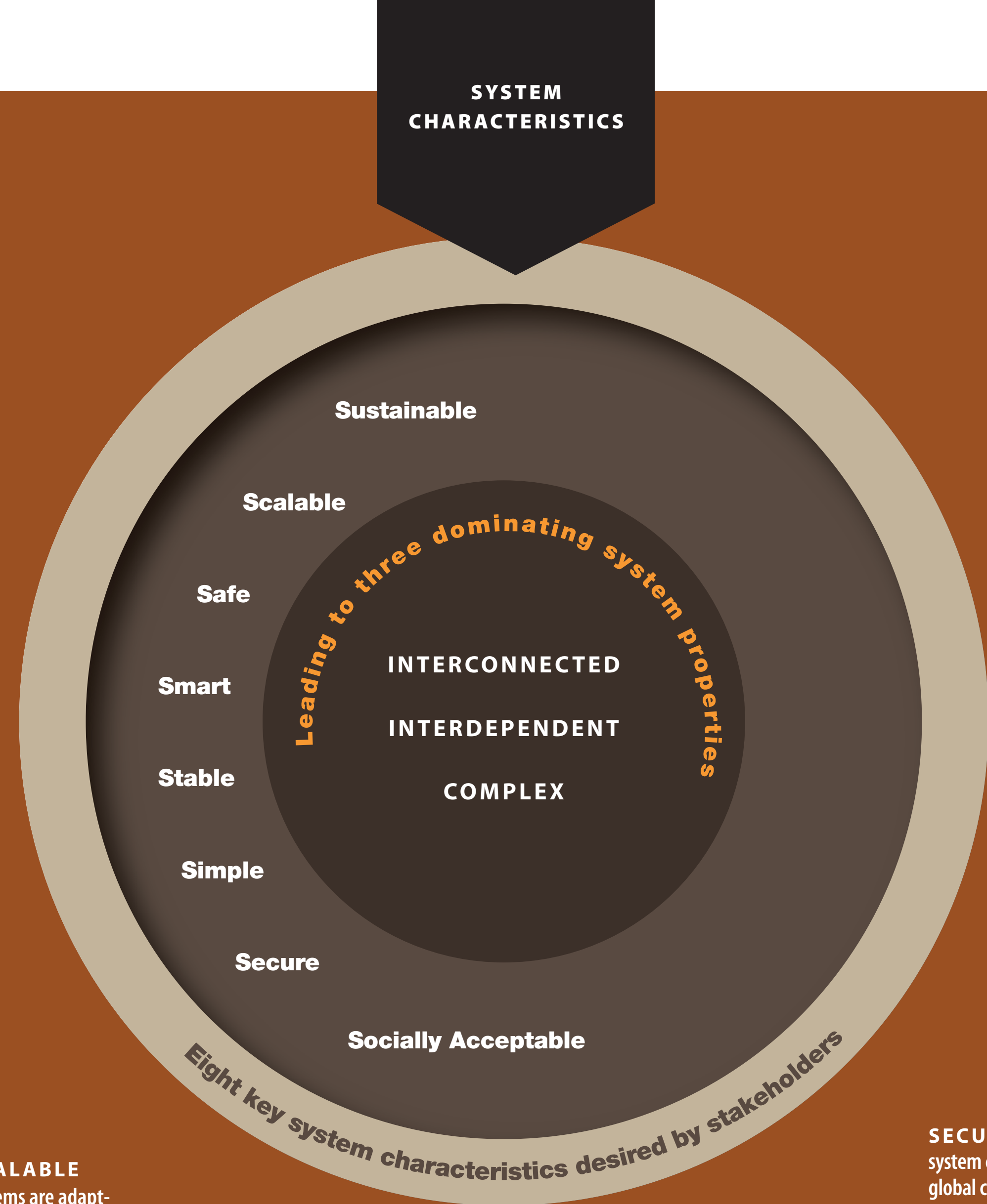
System Sponsors
- Funding organizations
- Investors
- Industrial leaders and politicians

Policy Makers
- Politicians
- Public/private administrators

Across a wide variety of domains, stakeholders are demanding increased functionality, higher reliability, shorter product life cycles, and lower prices. Stakeholders are also demanding environmentally and socially acceptable solutions that assure safety and personal security while delivering more value to the users. In maximizing value to stakeholders, systems engineers have to cope with greater levels of complexity and interdependence of system elements as well as cost, schedules and quality demands.

SYSTEMS OF THE FUTURE NEED TO MEET MANY, SOMETIMES CONFLICTING NEEDS





SUSTAINABLE systems take into account: acceptable cost of total ownership; full product life cycle management; management of product diversity; pre-planned product evolution; upgrades while operational; & conservation of natural resources.

Systems engineers must be able to balance sometimes contradictory demands.

SCALABLE systems are adaptable to a range of performance and system capabilities without breaking their fundamental architecture. This is an important trait because of the high cost associated with initial infrastructure investments or non-recurring engineering.

Systems engineers must deal with scalability and adaptability from the project start and reconcile the conflict with product optimization for single applications.

SAFE systems, driven by software-intensive designs, are increasingly being used in applications in which system safety is a significant concern.

Systems engineers must be able to assure ever-increasing levels of safety and resilience in the face of increasing systems complexity.

SMART systems are able to cope with a changing and unknown environment, assist human operators, or self-organize to provide unanticipated products & services.

Systems engineers must integrate social, functional and physical demands to create valuable system solutions that are resilient in their operational environment.

STABLE systems of the future must be stable and reliable in order to: meet key operational requirements and availability needs; achieve customer acceptance; operate efficiently; avoid liability; and provide expected system value.

Systems engineers must validate systems to be consistent with customer expectations across a wide variety of use cases and stress conditions.

SIMPLE systems are maintainable and avoid operator error.

Systems engineers must strive to find solutions that have simple architectures and interfaces, are understandably failure tolerant and easy to use.

SECURE system complexity, global connectivity and IT-dependence give rise to system vulnerabilities. The challenges for averting unwanted intrusions or for mitigating the results of intrusions have grown enormously.

Systems engineers must analyze cyber threats and contribute to global security policies ensuring cyber security and cyber defense against both ad hoc and organized threats.

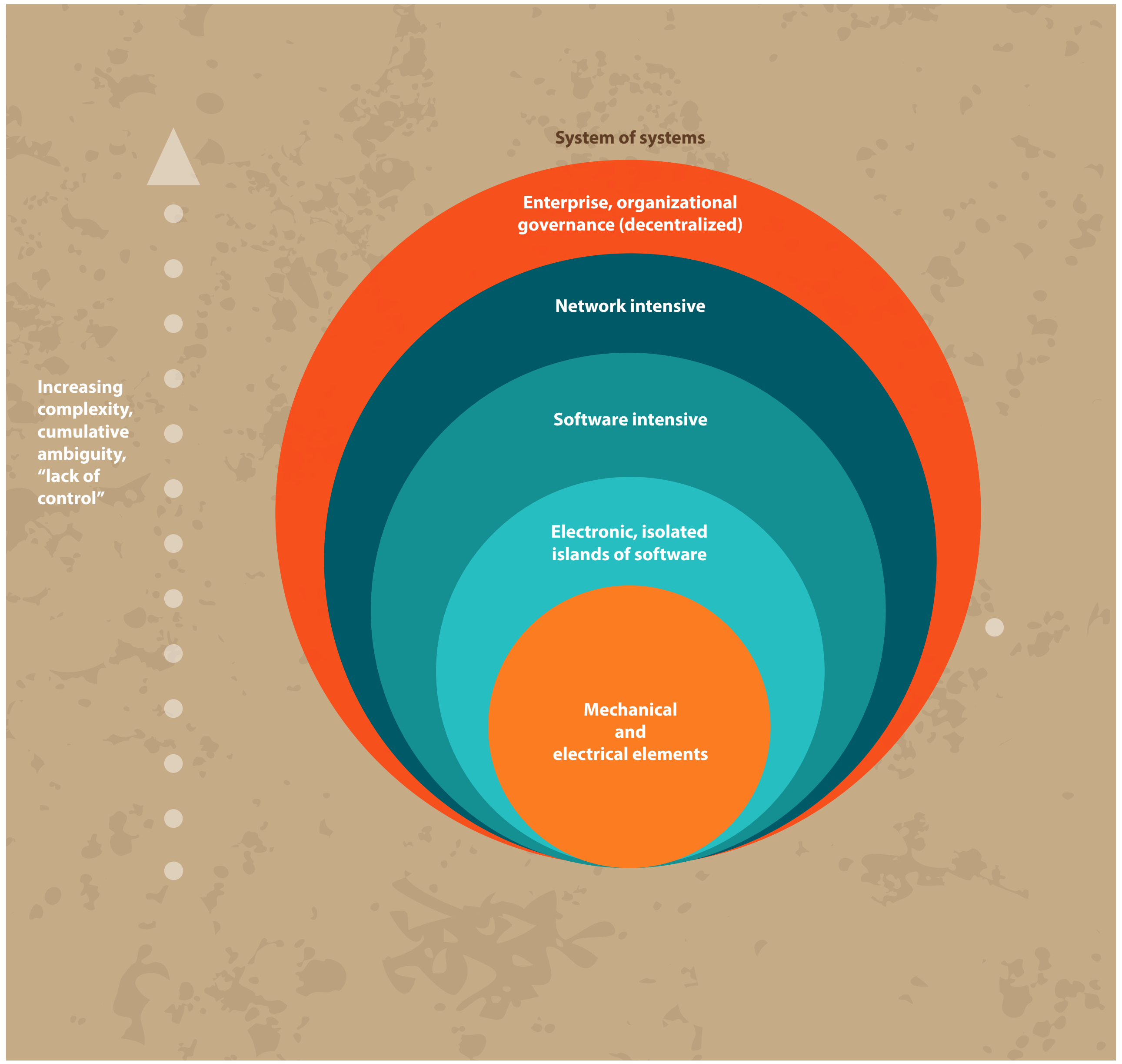
SOCIALLY ACCEPTABLE social, environmental and economic concerns interact.

Stakeholder acceptability of systems is increasingly influenced by socio-economic issues and concerns of sustainability.

Trends of Emerging System Properties

Inter-connectivity and interdependence are characteristics that, by themselves provide no instrinsic value. Value is gained by building systems with these characteristics to address stakeholder desires. In doing so, complexity, both necessary and unnecessary, emerges from the system designs because of the coupling. Interconnectivity produces vulnerabilities and risks that need to be analyzed and exposed for systems managers, sponsors and public policy decision makers. These properties will drive future systems design regardless of different markets and applications domains.

THE ROOTS FOR GROWING LEVELS OF SYSTEMS COMPLEXITY

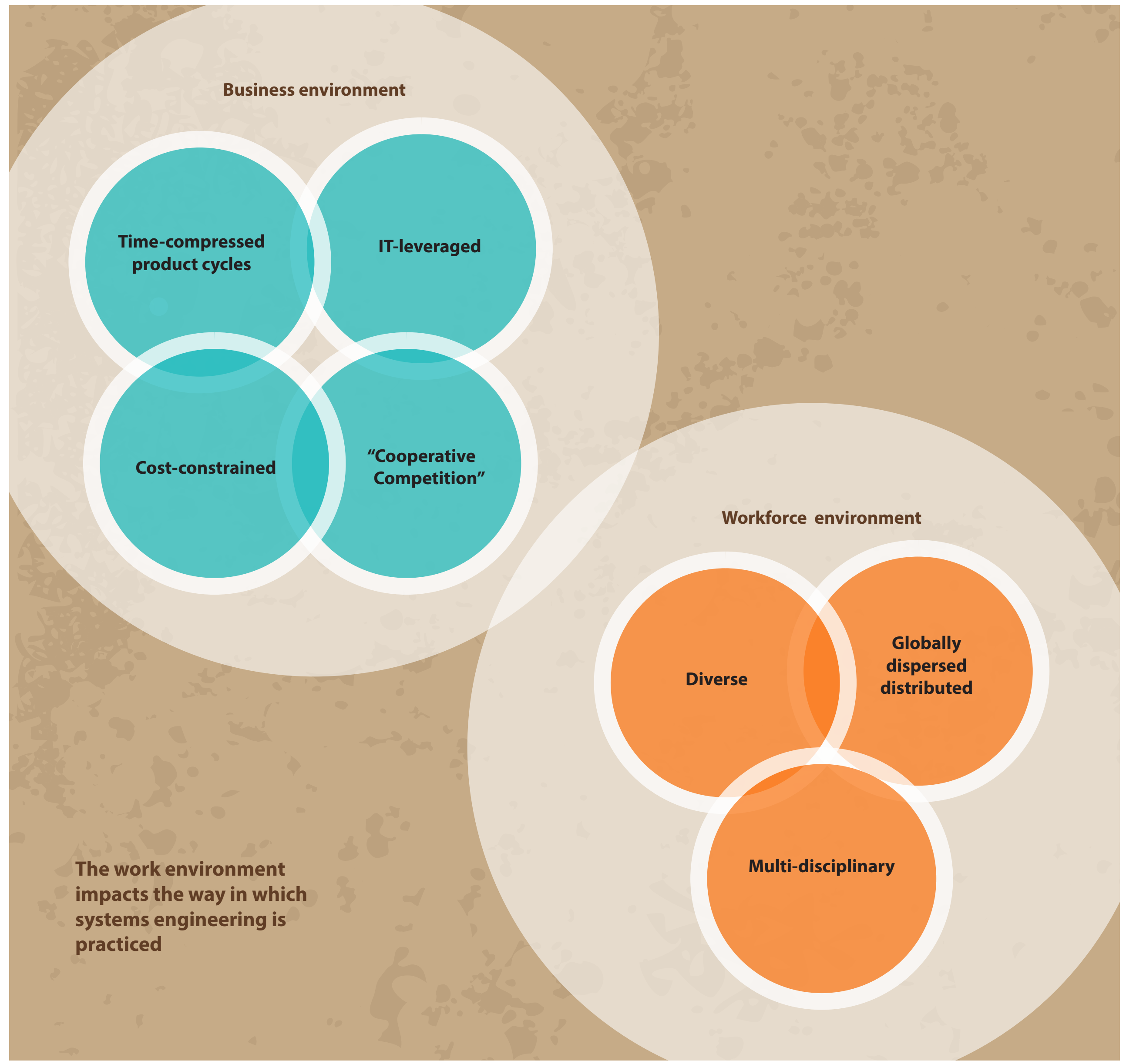


The Work Environment

Global competition drives innovation and enterprises. In the face of competition, industry collaboration, is increasing worldwide, with an emphasis on dispersed, multi-disciplinary teams. Collaborative engineering for global product development via international supply chain partnerships extends the scope of enterprises. Innovation in this competitive environment is driving industry to time-compressed product cycles.

The systems engineering workforce of the future is geographically dispersed, culturally diverse, gender agnostic, multi-disciplinary and trans-generational.

A new generation will be rapidly taking the place of retiring engineers as the "Baby Boomer" generation matures, requiring a strategy for transitioning knowledge



KEY ASPECTS OF THE EVOLVING SYSTEMS ENGINEERING WORK ENVIRONMENT

Adapted from the AFIS Vision

SUMMARY

THE SYSTEMS OF THE FUTURE

. . . need to respond to an ever growing and diverse spectrum of societal needs in order to create value

. . . need to harness the ever growing body of technology innovations while protecting against unintended consequences

. . . need to become smarter, self-organized, sustainable, resource-efficient, robust and safe in order to meet stakeholder demands

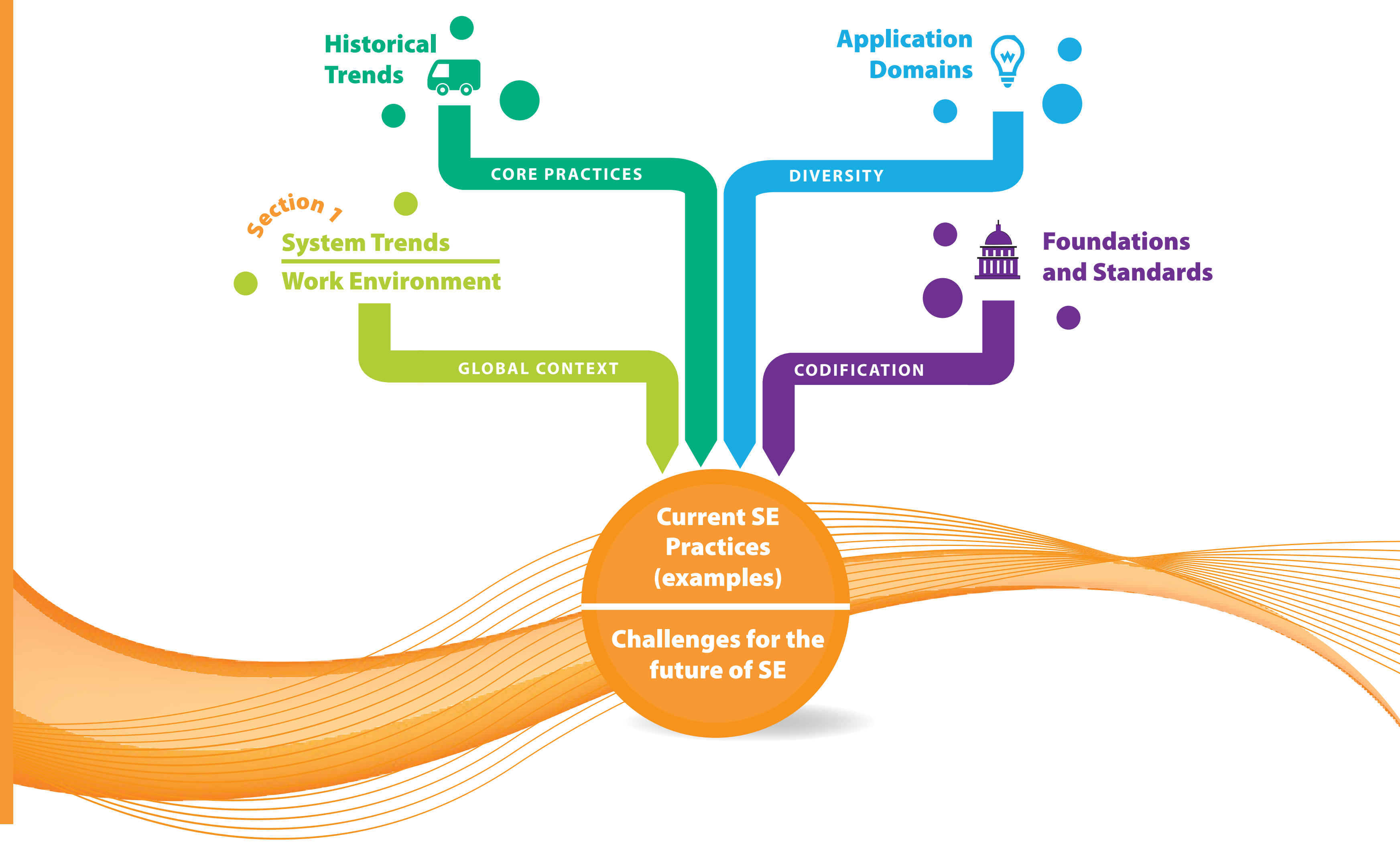
. . . need to be aligned with global trends in industry, economy and society, which will, in turn, influence system needs and expectations

. . . need to be engineered by an evolving, diverse workforce which, with increasingly capable tools, can innovate and respond to competitive pressures

2 The Current State of Systems Engineering

To understand the desired future state of systems engineering, it is essential to understand the current state. This section highlights key aspects of the current state of practice to help predict and guide its future directions.

The previous section provides a global context for systems engineering, by characterizing systems that systems engineers help develop and the work environment in which systems engineering is practiced. Today's systems engineering practices and challenges are greatly influenced by the global context. These practices have evolved differently across different industries but are built on common foundations and standards.



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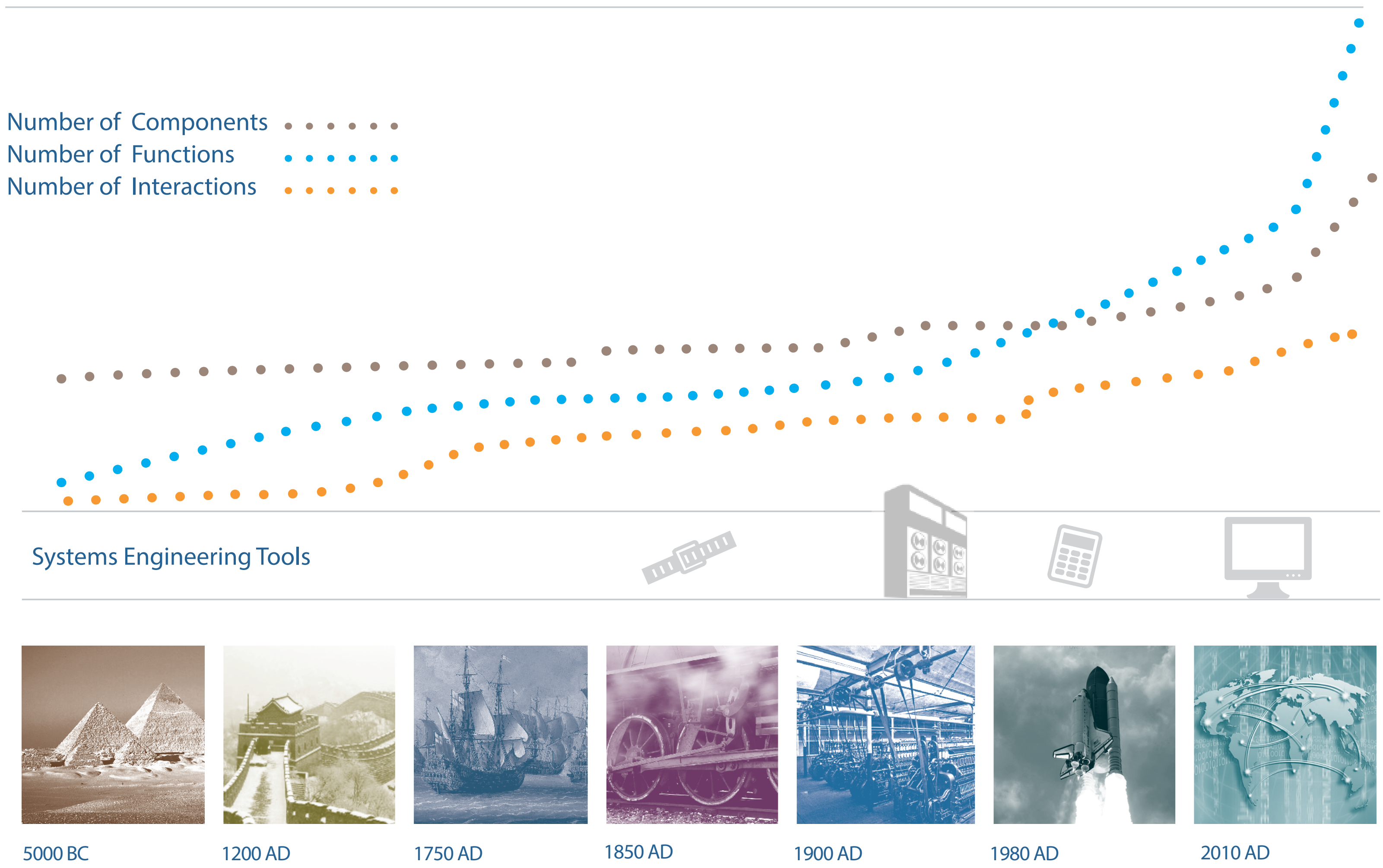
Historical Trends in Systems and Systems Engineering

Some consider systems engineering to be a young discipline, while others consider it to be quite old. Whatever your perspective, systems and the practice for developing them has existed a long time. The constant through this evolution of systems is an ever increasing complexity which can be observed in terms of the number of system functions, components, and interfaces and their non-linear interactions and emergent properties. Each of these indicators of complexity has increased dramatically over the last fifty years, and will continue to increase due to the capabilities that stakeholders are demanding and the advancement in technologies that enable these capabilities.

Other factors have impacted systems engineering. Advancements in technology not only impact the kinds of systems that are developed, but also the tools used by systems engineers. System failures have provided lessons that impact the practice, and factors related to the work environment remind us that systems engineering is a human undertaking. A look back in time can provide insight into the factors and trends that will impact the future directions of systems engineering.



A LOOK AT THE PAST SHEDS LIGHT ON THE FUTURE

Systems Engineering Across Application Domains

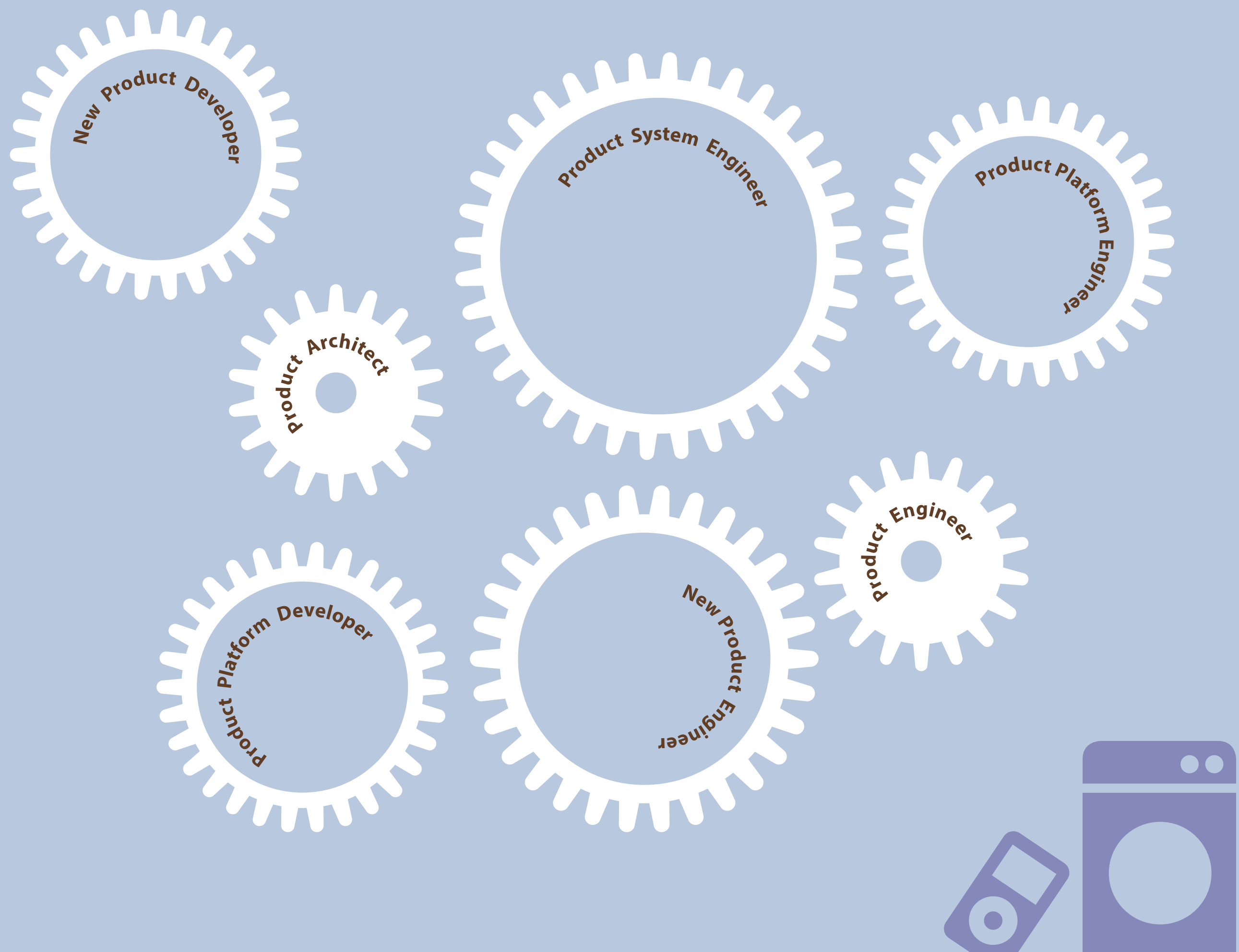
Systems engineering is an accepted practice in the aerospace and defense industry, and is gaining recognition as a discipline in other industries. Systems engineers have different names in these different industries, and each application domain may have unique drivers that impact the systems engineering practice. The extent to which the industry is market-driven or government-contracted, whether a product is delivered as a subsystem of a larger system or whether it is delivered as an end product or a service are all factors that influence the practice.

Systems engineering is being adapted to support many application domains in both common and industry-unique ways. Embracing the diversity of practice while leveraging practices that deal with common system challenges enriches the discipline.

SYSTEMS ENGINEERING IS PRACTICED DIFFERENTLY ACROSS MANY APPLICATION DOMAINS

DIVERSITY OF PRACTICE IN CONSUMER ELECTRONICS

WHAT SYSTEMS ENGINEERS ARE CALLED



WHAT SYSTEMS ENGINEERS CARE ABOUT

APPLIANCES

- Time to Market
- Optimize Against Variation
- Cost and Quality Balance
- Product Architecture Reuse

HOME ELECTRONICS

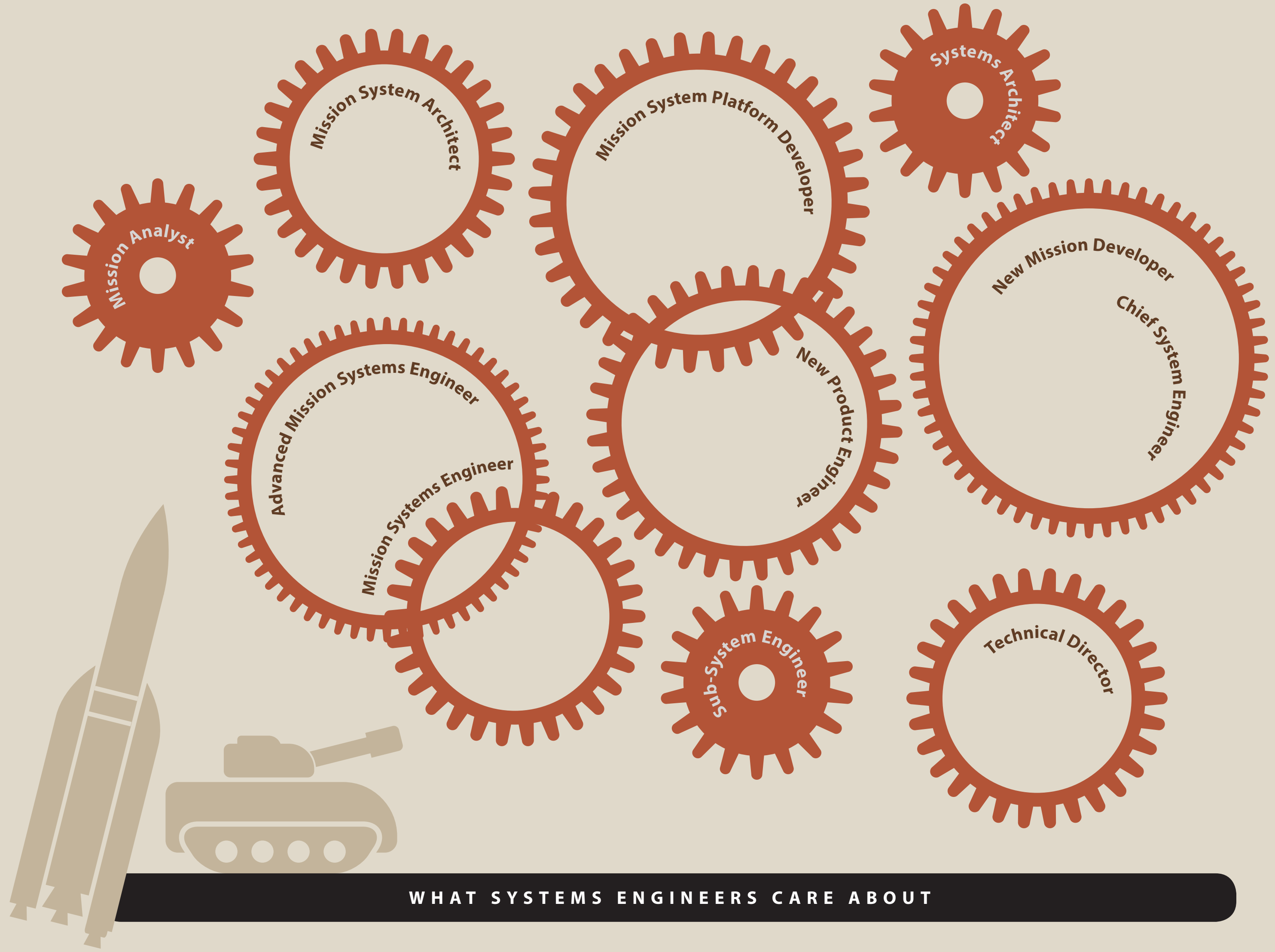
- Time to Market
- New Technology Infusion
- Modular Design
- Performance, Cost and Balance
- Consumer Configurable

MOBILE ELECTRONICS

- Time to Market
- New Technology Infusion
- Performance, Cost and Quality Balance

DIVERSITY OF PRACTICE IN AEROSPACE AND DEFENSE SYSTEMS

WHAT SYSTEMS ENGINEERS ARE CALLED



WHAT SYSTEMS ENGINEERS CARE ABOUT

COMMERCIAL

- Critical Mission Performance
- Survivability
- New Technology Integration of Innovation
- Product Cost vs. Operational Cost
- Product Architecture Reuse

SPACE

- Critical Mission Performance
- Survivability
- Enabling New Technology
- Safety, Performance, and Cost
- Product Architecture Reuse

DEFENSE

- Critical Mission Performance
- Survivability
- New Technology Integration
- Extensible Capability
- Performance vs. Operational Cost
- Product Architecture Reuse

Foundations and Standards

SYSTEMS ENGINEERING BODY OF KNOWLEDGE

Grown from the need to deal with complexity in the aerospace and defense industries, systems engineering practices have been based primarily on experience — trial and error. Over time, heuristics were developed to tackle complex problems systematically and holistically. This systems engineering body of knowledge today is documented in a broad array of standards, handbooks, academic literature, and web-resources, focusing on a variety of domains. A concerted effort is being made to continually improve, update and further organize this body of knowledge.

Today's researchers are revisiting current systems engineering practices to ground them in a sound foundation built on mathematical theory and science. Further development of this theoretical foundation is needed to allow systems engineering to expand into new domains and deal with increased complexity, without having to repeat a costly trial-and-error learning process.

Current Systems Engineering Practices and Challenges

Current systems engineering practice, based on well-defined processes and innovative analytic approaches, has demonstrated significant value to stakeholders, but in the future, the systems community must tackle many new fundamental interdisciplinary and integration-related challenges.

FIVE SYSTEMS ENGINEERING CHALLENGES

Adapted from Todd Bayer, Jet Propulsion Laboratory

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".**

CURRENT PRACTICE EXAMPLES

MODELING, SIMULATION, AND VISUALIZATION

When Boeing unveiled its latest jet, the 787 Dreamliner – it was a virtual rollout. Boeing virtually created parts, and integrated and assembled the system prior to cutting metal.

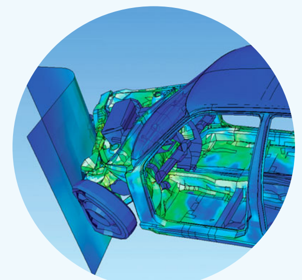
Visualization and simulation helped identify incompatibilities in interfaces and assembly processes early in design before hardware costs were fully committed, avoiding costly redesign late in the system design life cycle.

Source: http://www.pbs.org/newshour/bb/science/jan-june07/airplane_01-09.html

SYSTEM OF SYSTEMS ENGINEERING

The Thameslink Rail Capability Programme is a £5.5Bn rail upgrade program to improve North-South commuter traffic into London. It is led by Network Rail and overseen by the UK Department for Transportation. Systems engineering approaches have been applied to ensure that the rolling stock, signalling, new stations, and railroad can meet all needs (including number of passengers, target journey times, and system safety).

Understanding this complex system of systems requires the use of comprehensive systems approach to analyze not only the traditional technical issues, but also the policy issues and the human behavior of the users.



DESIGN TRACEABILITY BY MODEL-BASED SYSTEMS ENGINEERING

The software and electronics of modern automobiles are becoming increasingly complex. Ford Motor Company has been applying model-based systems engineering to manage design complexity including architecture, requirements, interfaces, behavior and test vectors.

Ford has established digital design traceability across their onboard electrical and software systems by applying multiple integrated modeling technologies including UML, SysML, Simulink with an underlying CM/PDM system.

Source: Presenter Chris Davey. http://www.omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:03-2013_incose_mbse_workshop-ford_automotive_complexity_v4.0-davey.pdf

PRODUCT-FAMILY AND COMPOSABLE DESIGN

Scania trucks is a Scandinavian company that provides customizable solutions for long haul, distribution, construction and special purpose trucking. Clients have the ability to customize their vehicle by selecting the cab, engine, chassis, engine, transmission and accessories.

Scania's composable approach starts at the component level – with common engine cylinders, push rods and combustion chambers to drive up parts interchangeability, and drive down variations for maintenance.

Source: http://www.scania.com/ products-services/trucks

SUMMARY

CURRENT STATE OF SYSTEMS ENGINEERING

Systems engineering continues to evolve in response to a long history of increasing system complexity.

Systems engineering is gaining recognition across industries, academia and governments.

Systems engineering practice varies across industries, organizations, and system types.

Systems engineering practices are still based on heuristics, but a theoretical foundation is being established.

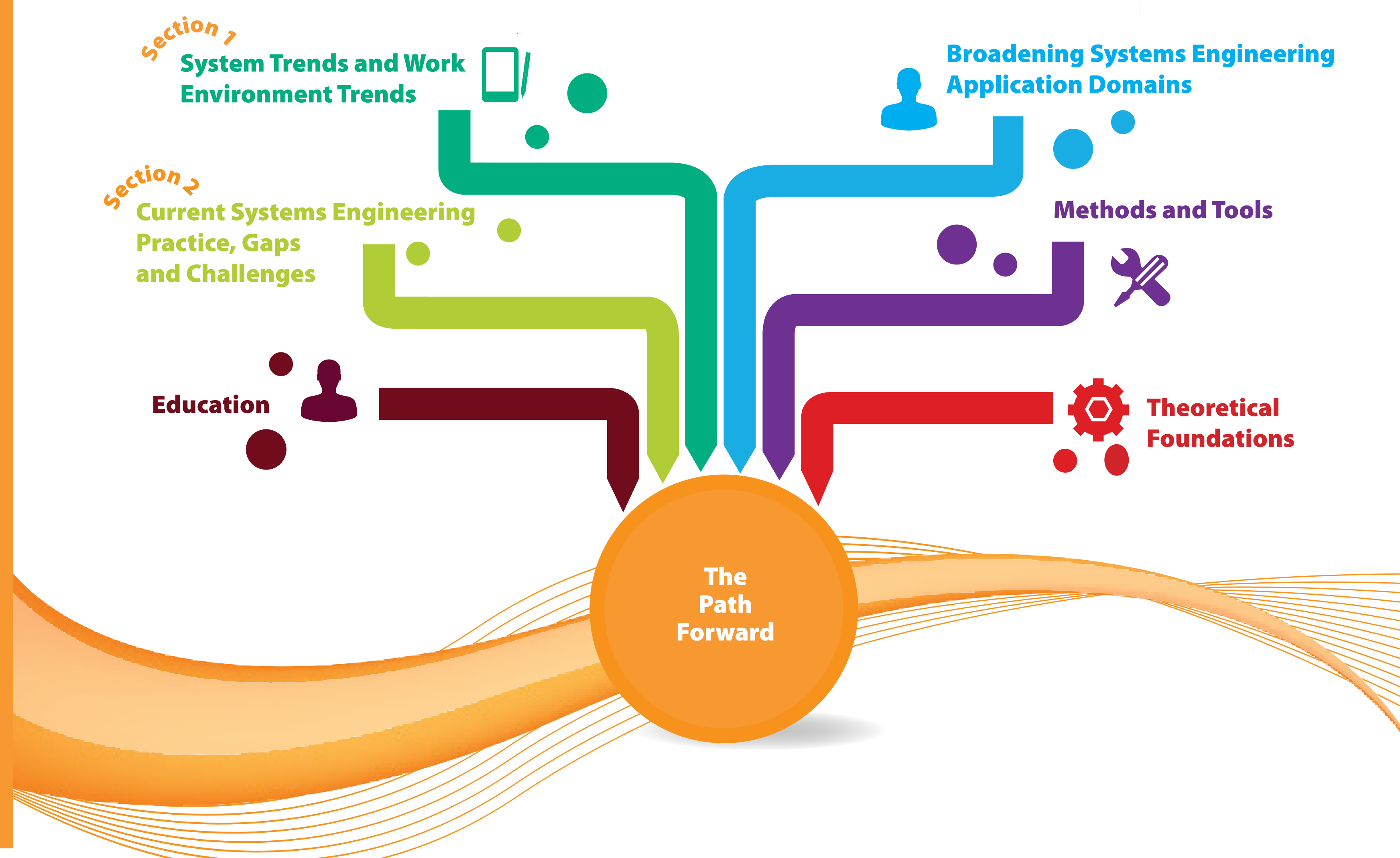
Cross fertilization of systems engineering practices across industries has begun slowly but surely; however, the global need for systems capabilities has outpaced the progress in systems engineering.

Integration across disciplines, phases of development, and projects represents a key systems engineering challenge.

3 The Future State of Systems Engineering

By 2025, Systems Engineering will have made significant strides in meeting the challenges and needs described in the Global Context for Systems Engineering. Its relevance and influence will go beyond traditional aerospace and defense systems and extend into the broader realm of engineered, natural and social systems.

Systems engineering will grow and thrive because it brings a multi-disciplinary perspective that is critical to system product innovation, defect reduction and customer satisfaction. Systems engineering will be recognized broadly by governments and industry as a discipline of high value to a wide spectrum of application domains because the above contributions, combined with assessment and management of risk and complexity, are key to competitiveness in many industries.



Transformative technologies are difficult to predict but one can be certain that disruptive technologies such as 3D printing, autonomous transportation systems, and new kinds of materials will impact both the nature of systems as well as the way in which systems are developed. Systems engineering practices will adapt to and be transformed by new technology as efforts become more IT-centric and globally distributed among diverse collaborating enterprises.

Changes in the social, economic and political environments in which emerging technologies are infused will impact the market drivers for system capabilities as well as the work environment where systems engineering is performed. Systems engineering will assist in the assessment of public policies designed to mitigate the negative aspects of technology on our social-physical systems and help shape the global societal trends of the future.

Systems engineering's theoretical foundations will advance to better deal with complexity and the global demands of the discipline, forming the basis for systems education as well as the methods and tools used by practicing systems engineers for system architecting, system design and system understanding.

Methods and tools, based on solid theoretical foundations, will advance to address the market demands of innovation, productivity, and time to market as well as product quality and safety by harnessing the power of advancements in modeling, simulation and knowledge representation, such as domain-specfic standard volcabularies, thereby meeting the needs of an increasingly diverse stakeholder community. The methods and tools will also keep pace with system complexity that continues to be driven by customers demanding ever increasing system interconnectedness, autonomy, ready access to information, and other technology advances associated with the digital revolution, such as "The Internet of Things" (reference IEEE Computer, Feb. 2013). Systems engineering will lead the effort to drive out unnecessary complexity through well-founded architecting and deeper system understanding.

Education and training of systems engineers and the infusion of systems thinking across a broad range of the engineering and management workforce will meet the demands for a growing number of systems engineers with the necessary technical and leadership competencies.

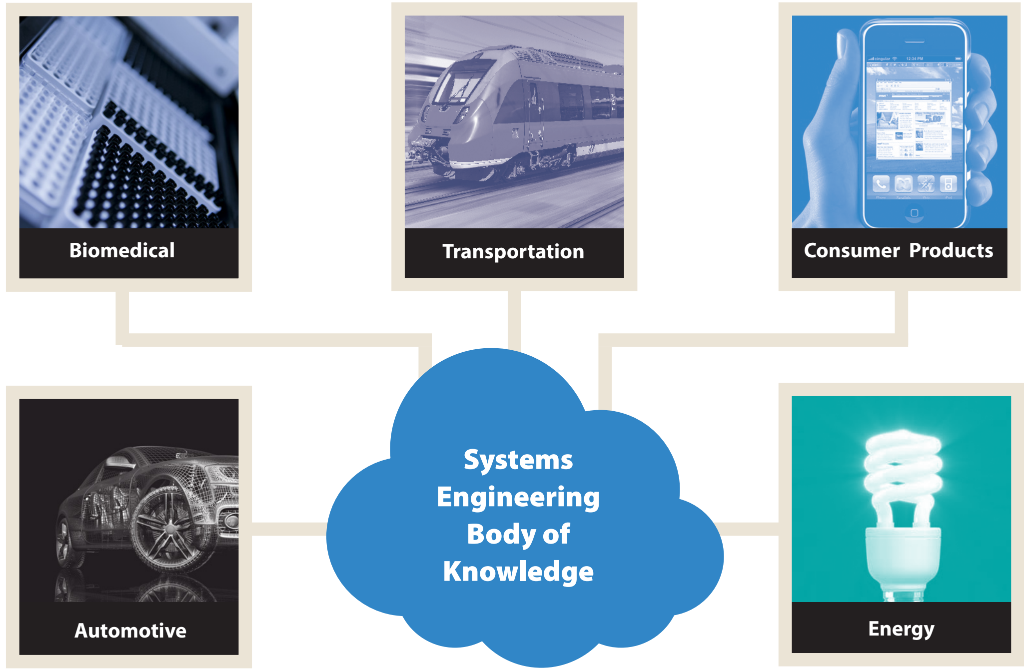
Applications of Systems Engineering

Applying Systems Engineering Across Industry Domains

FROM	TO
Systems engineering is a recognized discipline within Aerospace and Defense, and is applied in many other domains as well. However, it is only recently being recognized as a formal discipline in other industry domains such as automotive, transportation, and biomedical. The lack of recognition of systems engineering as a formal discipline in other industry domains limits the ability of systems engineering practitioners to share and mature their practices.	Systems engineering is broadly recognized by global economic and business leaders as a value-added discipline related to a wide variety of commercial products, systems and services, as well as government services and infrastructure. This broad community of practitioners result in the sharing and maturation of more robust systems engineering practices and foundations.

Systems engineering must scale and add value to a broad range of systems, stakeholders, and organizations with a diversity of size and complexity. In particular, the discipline will be increasingly relevant to global socio-technical and large-scale enterprise systems such as urban transportation and healthcare. Systems engineering will also contribute to assessments and analysis of socio-physical systems such as the global climate system to inform stakeholders and decision makers of the emergent impacts of organizational and public policy actions.

SHARING OF PRACTICES AND KNOWLEDGE ACROSS DOMAINS (AND ADDING VALUE TO EACH DOMAIN)



THE SYSTEM ENGINEERING DISCIPLINE WILL EXPAND ITS APPLICABILITY AND RECOGNITION ALONG SEVERAL FRONTS

- Diverse application domains such as consumer products, biomedical, healthcare, automotive, and energy production
- Geographic scope, both regionally and nationally
- Enterprises from small to medium to large
- Government projects and policy at international, national and local levels
- Breadth and scope of systems from individual systems to large scale system of systems.
- Increased emphasis on downstream life cycle phases such as sustainment

Applying Systems Engineering to Policy

FROM	TO
Public policy decisions are often made without leveraging a well-defined systems approach to understand the diverse set of stakeholder needs and the implications of various policy options.	Systems engineering takes its place with other systems-related, integrative disciplines such as economics, human ecology, geography, and economic anthropology to structure more objective cost, benefit and risk assessments of alternative policy executions. The addition of a formal systems approach helps decision-makers to select cost effective, safe, and sustainable policies that are more broadly embraced by the stakeholder community.

- Modeling and simulation is widely used to support integrated planning for a better representation of real-world constraints and solutions
- Capabilities for generating characterizations and visualizations for complex policy issues are greatly improved and are approachable by policy makers and other stakeholders
- Observational data sources and models are assessed for uncertainty and applicability for specific decision-making needs
- Tools and methods better integrate physical and socio-economic information into holistic and sustainable solutions

PERFORMING ASSESSMENTS TO SUPPORT POLICY MAKING

An assessment is produced by systems engineers to prepare knowledge from experts' and other stakeholder inputs for use by decision makers. This helps ensure decision makers have the information they need, and in a form they can act on.

Knowledge Certification . . . assesses the usability of expert knowledge by non-experts (e.g. policy makers).

Knowledge Assembly . . . provides knowledge from different sources, and is integrated to meet the needs of the decision maker.

Knowledge Translation . . . converts complex concepts into "decision-ready" forms that frame decision options and motivations for action in politically, economically, and culturally aware terms.

Knowledge Delivery . . . connects the knowledge to a government system, the forum by which decision makers can use the knowledge.

Earth Understanding On Demand

The state of the Earth system will be made widely available in near real time. Continuous awareness of the Earth system state will be communicated to decision makers and the public. By blending technologies, policies and institutions, a knowledge-dense cyber-infrastructure will provide an always-on management service that communities and industries everywhere can access on demand.

**Adapted from Knowledge Action Networks: Rethinking the Way We Think About Climate Change Assessments. Charles F. Kennel.*

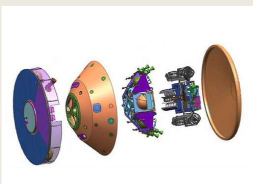
Transforming Systems Engineering

Value Driven Practices for Developing Systems in 2025 and Beyond

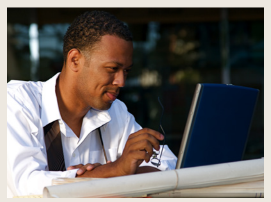
ADAPTABLE AND SCALABLE METHODS

Systems engineering methods will be scalable to system and organizational complexity and size. The methods will also be tailored to the application domain. Method selection will be value driven to optimize project schedule, cost, and technical risk. Methods and tools will scale from small and medium sized enterprises to multi-billion dollar projects.

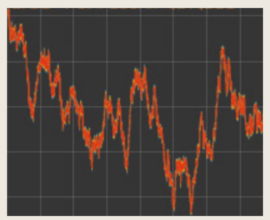
TAILORED TO THE DOMAIN



SCALED TO PROJECT SIZE



SCALED TO SYSTEM COMPLEXITY



Systems engineering practices will continue to evolve from current practice to meet the demands of complex systems and work environments of the 21st century. Leveraging information technology and establishing the theoretical foundations for value driven systems engineering practices will pave the way for meeting these demands to enhance competitiveness, manage complexity, and satisfy continuously evolving stakeholder needs.

The methods will be tailored to the domain and scalable to project and system size and complexity. Collaborative engineering across national boundaries, enterprises, and disciplines will be the norm. Systems engineering practice will deal with systems in a dynamically changing and fully interconnected system of systems context. Architecture design and analysis practices will enable integration of diverse stakeholder viewpoints to create more evolvable systems. Design drivers such as cyber-security considerations and resilience will be built into the solution from the beginning. Composable design methods will leverage reuse and validated patterns to configure and integrate components into system solutions. Decision support methods will support more rapid analysis of a large number of alternative designs, and optimization of complex systems with multiple variables and uncertainty. A virtual engineering environment will incorporate modeling, simulation, and visualization to support all aspects of systems engineering by enabling improved prediction and analysis of complex emergent behaviors.

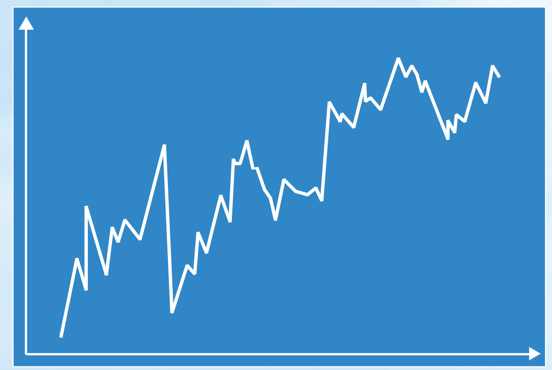
Complex System Understanding

FROM	TO
Today, stakeholders are demanding increasingly capable systems that are growing in complexity, yet complexity-related system misunderstanding is at the root of significant cost overruns and system failures. There is broad recognition that there is no end in sight to the system complexity curve.	In 2025 and beyond, standard measures of complexity will be established, and methods for tracking and handling complex system behaviors and mitigating undesired behaviors will be commonplace.

Systems engineering practices will include both formal and semi-formal methods for identifying emergent behaviors and dealing with unanticipated behaviors. Analytical techniques will be commonly used to explore huge system state spaces to identify and eliminate undesirable system states. Techniques will be developed to correlate a diverse range of system parameters as indicators of system health, similar to how a person's temperature and white blood count are used to indicate the presence of infection. Capitalizing on this understanding to develop systems that are more fault tolerant, secure, robust, resilient, and adaptable will be a fundamental part of systems engineering practices.

PREDICTING AND MONITORING COMPLEX BEHAVIORS

PREDICTING AND MONITORING SYSTEM HEALTH



MONITORING COMPLEX SYSTEMS FOR UNDESIRABLE STATES

Leveraging Technology for Systems Engineering Tools

FROM

Current systems engineering tools leverage computing and information technologies to some degree, and make heavy use of office applications for documenting system designs. The tools have limited integration with other engineering tools.

TO

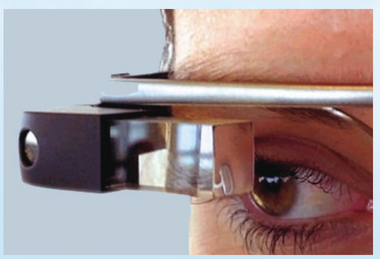
The systems engineering tools of 2025 will facilitate systems engineering practices as part of a fully integrated engineering environment. Systems engineering tools will support high fidelity simulation, immersive technologies to support data visualization, semantic web technologies to support data integration, search, and reasoning, and communication technologies to support collaboration. Systems engineering tools will benefit from internet-based connectivity and knowledge representation to readily exchange information with related fields. Systems engineering tools will integrate with CAD/CAE/PLM environments, project management and workflow tools as part of a broader computer-aided engineering and enterprise management environment. The systems engineer of the future will be highly skilled in the use of IT-enabled engineering tools.

TECHNOLOGY DRIVEN SYSTEMS ENGINEERING TOOLS

Cloud-based high performance computing supports high fidelity system simulations

Advanced search query, and analytical methods support reasoning about systems

Immersive technologies support data visualization



Net-enabled tools support collaboration

Collaborative Engineering: Integrating Teams and Organizations Across All Boundaries

FROM

Today, systems engineering processes are often not well integrated with program management and discipline-specific processes such as hardware, software, test, manufacturing, operations, and logistics support. As an example, program and product change processes require time consuming and manual coordination among development teams and supply chain participants.

TO

In 2025 and beyond, systems engineering will be a key integrator role for collaborative enterprise engineering that span regions, cultures, organizations, disciplines, and life cycle phases. This will result in multi-disciplinary engineering workflows and data being integrated to support agile program planning, execution, and monitoring. The collaboration will extend across the supply chain so that customers, primes, subcontractors, and suppliers are integrated throughout all phases of development.

COLLABORATIVE ENGINEERING PRACTICES

Automated workflow, data integration, and networked communications are critical to agile program execution, such as when implementing a change process.

System Design In a System of Systems Context

FROM

Limited technical guidance is available to engineer complex systems of systems and assure qualities of service. Current emphasis is on architecture frameworks and interoperability standards.

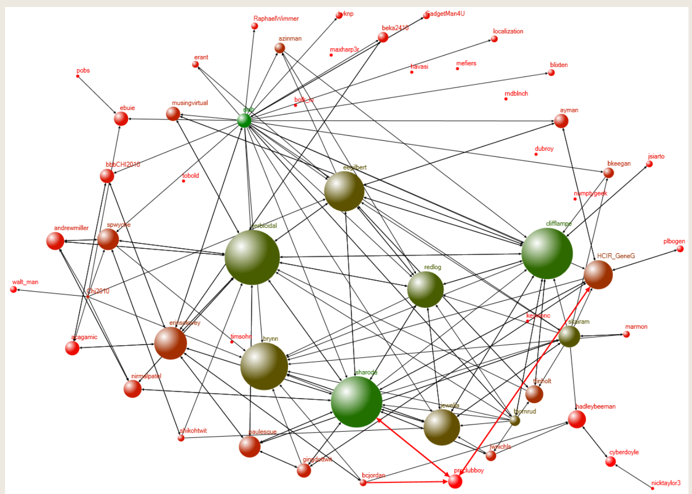
TO

The Internet of Things extends the SoS challenge beyond interconnected computers and users, to include increasingly interconnected systems and devices that monitor and control everything from household appliances to automobiles. A diverse set of stakeholders will increasingly demand SoS to provide information and services, leveraging value from the pieces.

System of systems engineering (SoSE) methods will be used to characterize and evolve the SoS, and include design for interoperability, analysis and prediction of emergent behaviors and quality of service, continuous verification, and methods for managing the integration of systems in a dynamic context with limited control.

SYSTEM OF SYSTEMS ENGINEERING PRACTICES

Techniques for analyzing interactions among independent systems and understanding emergent behaviors in SoS must mature and become commonplace (e.g., agent based simulation). New measures will be developed to characterize the SoS and its quality characteristics. SoSE will employ new continuous verification methods as changes occur without central control. Design of experiments is one such methodology for optimizing a verification program with many parameters and uncertainty. Requirements management will evolve to address even more diverse stakeholders, in the face of uncertain organizational authority. Methods for establishing evolutionary interoperability agreements among SoS constituents will become more robust.



"A SoS is an integration of a finite number of constituent systems which are independent and operable, and which are networked together for a period of time to achieve a certain higher goal."
— Jamshidi, 2009

Architecting Systems to Address Multiple Stakeholder Viewpoints

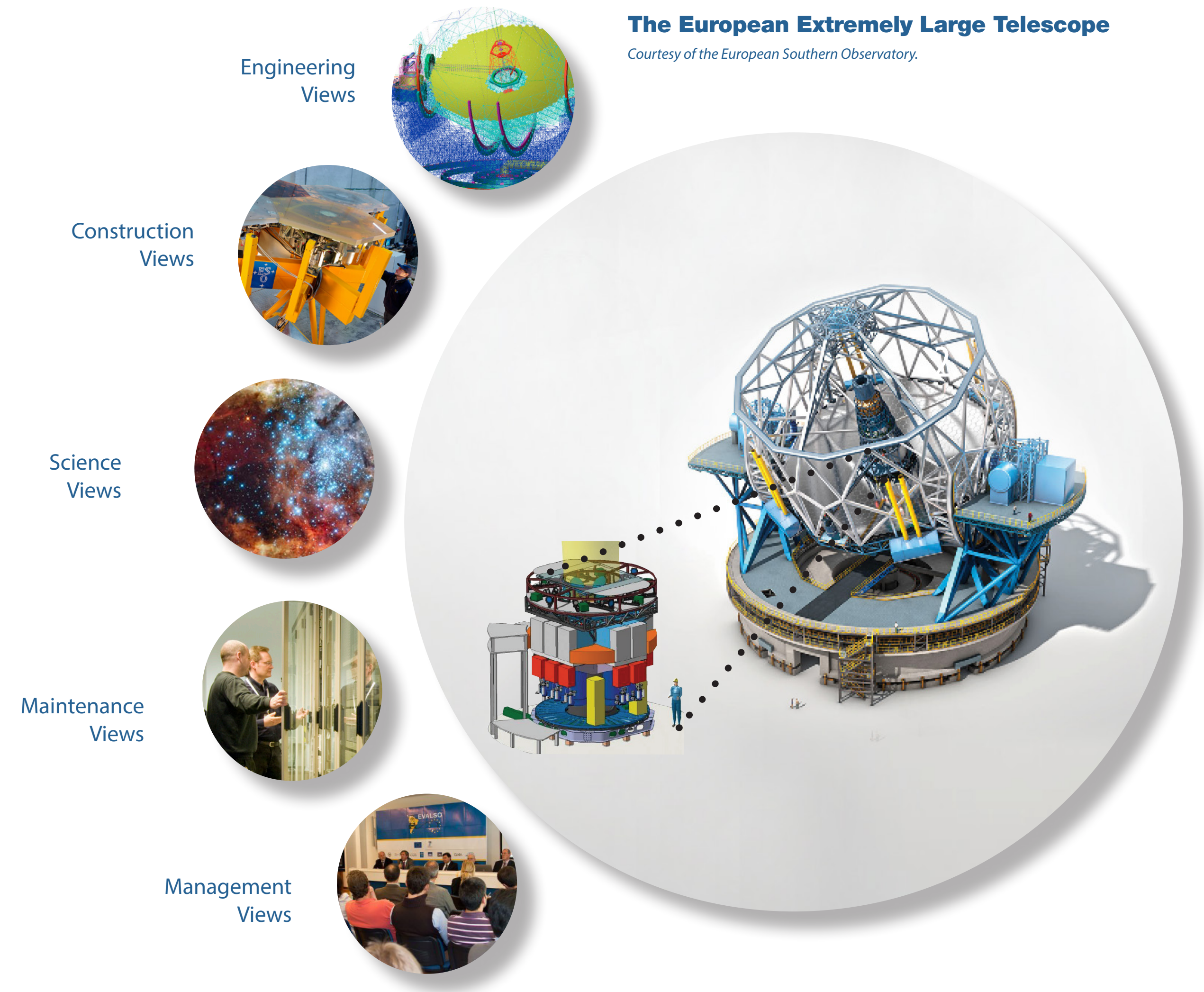
FROM

Systems architecting is often ad-hoc and does not effectively integrate architectural concerns from technical disciplines such as hardware, software, and security, nor does it fully integrate other stakeholder concerns.

TO

Systems architecting methods are well established and address broad stakeholder concerns associated with increasingly complex systems. System architecture, design and analysis is integrated across disciplines, domains and life cycle phases to provide a single, consistent, unambiguous, system representation. This ensures integrity and full traceability throughout the systems engineering process, and provides all stakeholders with multiple system views to address a broad range of concerns.

INTEGRATING STAKEHOLDER VIEWS

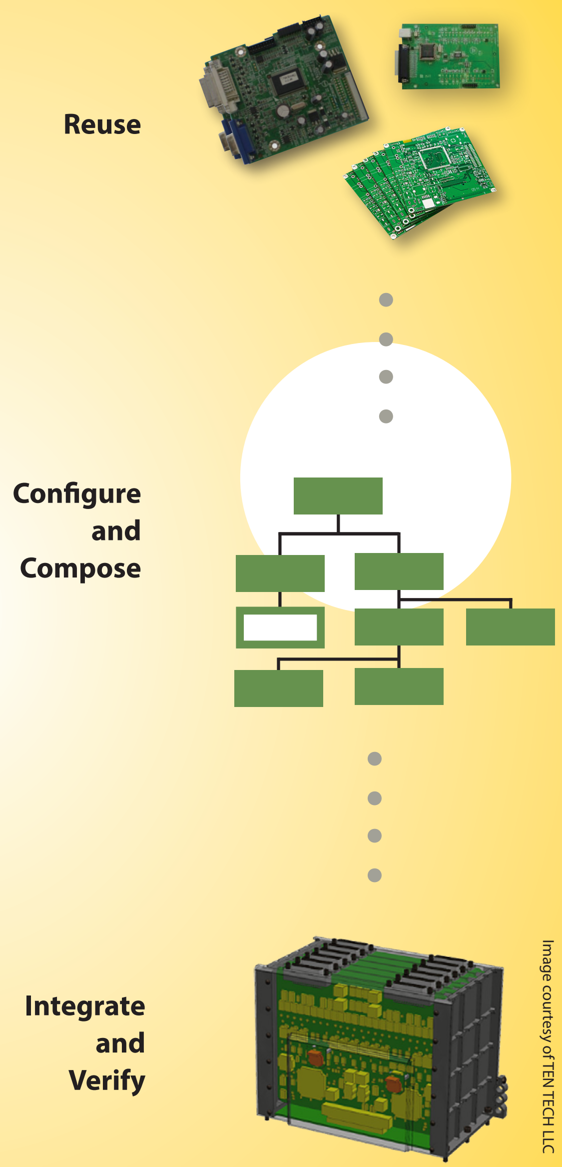


The European Extremely Large Telescope
Courtesy of the European Southern Observatory.

COMPOSABLE DESIGN: A KEY TO PRODUCTIVITY

Composable design methods in a virtual environment support rapid, agile and evolvable designs of families of products. By combining formal models from a library of component, reference architecture, and other context models, different system alternatives can be quickly compared and probabilistically evaluated. Composable design methods provide a systematic approach for capturing, selectively reusing, and integrating organizational intellectual assets that includes reference architectures and component specification, design, analysis, verification, manufacturing, and other life cycle data.

Composable design approaches are industry best practices in commercial electronics and building design, and will be adopted more broadly by the systems engineering community to drive cost effective solutions.



Architecting and Design of Resilient Systems

FROM

Fault detection, isolation, and recovery is a common practice when designing systems so they can recover from failures, and/or off nominal performance and continue to operate. Fault detection is based on a priori designation and characterization of off-nominal behavior.

TO

Architecting will incorporate design approaches for systems to perform their intended function in the face of changing circumstances or invalid assumptions.

Ref: Engineering Resilient Space Systems, Final Report, Keck Institute for Space Studies, Sept. 2013

RESILIENT DESIGN OF AUTONOMOUS SYSTEMS

The deployment of autonomous vehicles in transportation and delivery systems illustrates the need for resiliency.

Autonomous vehicles, especially those that operate in inhabited areas, must be designed to be robust to operate in a wide range of environmental conditions, adaptive to unexpected conditions, and capable of anticipating and recovering from failure conditions. In this example, the vehicle must be capable of assessing its current state and the state of its environment, and develop strategies to recover and return to normal operations.

The delivery system must be tolerant to invalid assumptions related to conditions such as:

- weather conditions
- air space congestion
- inanimate surface hazards
- animate surface hazards
- human safety
- failure modes

AIR DRONES IN FLIGHT

Cyber Security — Securing the System

FROM

Systems, personal and national security are increasingly being compromised due to the digitally interconnected nature of our infrastructure. Engineers are hard pressed to keep up with the evolving nature and increasing sophistication of the threats to our cyber-physical systems. Cyber-security is often dealt with only as an afterthought or not addressed at all.

TO

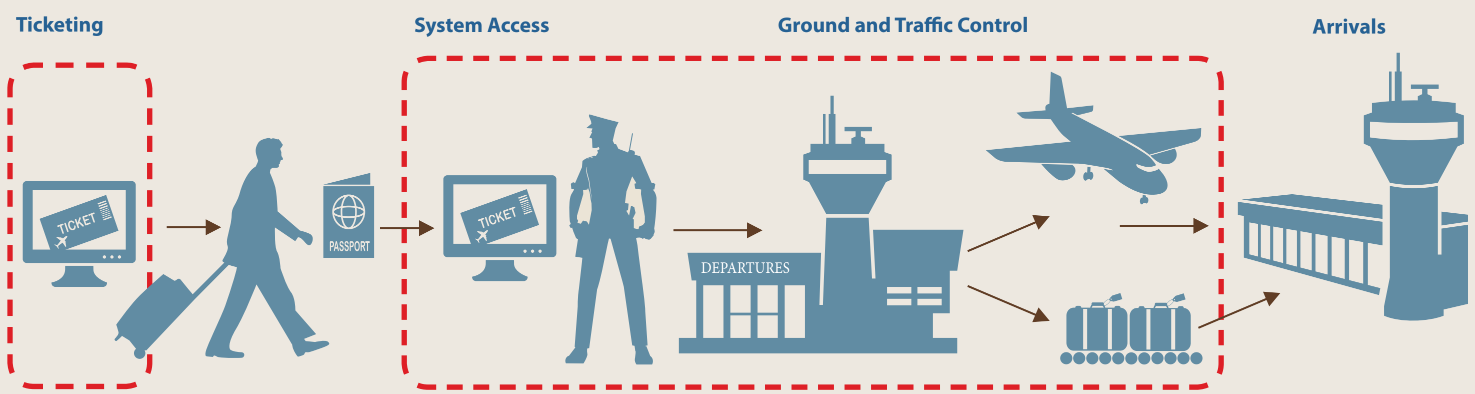
Systems engineering routinely incorporates requirements to enhance systems and information security and resiliency to cyber threats early and is able to verify the cyber defense capabilities over the full system life cycle, based on an increasing body of strategies, tools and methods. Cyber security is a fundamental system attribute that systems engineers understand and incorporate into designs using the following strategies:

- Continuous threat and system behavior monitoring
- Management of access rights and privileges
- Use of testbeds for assessing new threats in fielded systems
- Supply-chain diligence
- Certification and accreditation standards
- Formal methods for identification of vulnerabilities

CYBER THREATS

Addressing security concerns in modern systems and systems of systems requires understanding the boundary of the system and analyzing what portions of that boundary need to be protected. This protection comes at a price, often with systems engineering needing to trade performance for security. In context of the air travel system of systems, physical and cyber security is traded for passenger convenience and cost.

Understanding and characterizing threats, the system boundary, and trades among key performance parameters and security, is critical for achieving the right balance of security and overall capability.



Decision Support

Leveraging Information and Analysis for Effective Decision Making

FROM

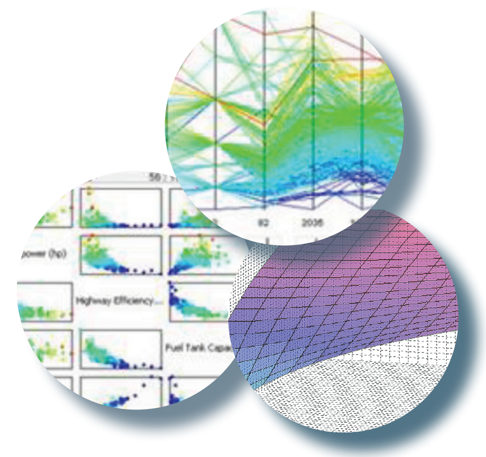
Systems engineers explore a limited number of design alternatives primarily based on deterministic models of performance, physical constraints, cost and risk.

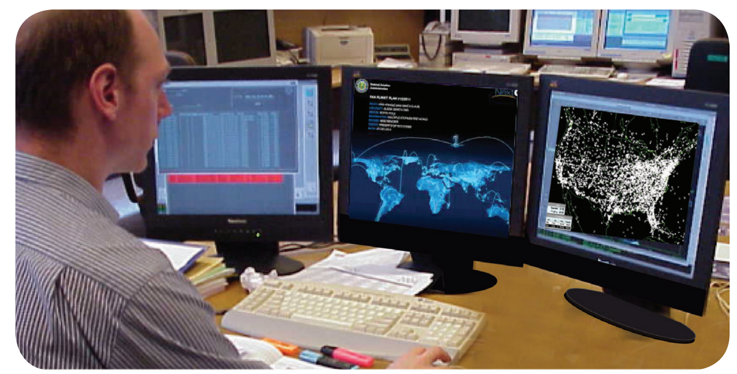
TO

Systems engineers rapidly explore a broad space of alternatives to maximize overall value, based on a comprehensive set of measures including performance, physical constraints, security, resilience, cost and risk.

Decision support tools must comprehensively support each aspect of the decision making process. Through composition of reference components and scenarios, a much broader set of system architectures will be defined and considered. A decision support dashboard will assist the systems engineer in using sensitivity and uncertainty analysis to analyze a system design from all relevant perspectives across the entire life cycle. While adding fidelity to models, adapting modeling formalisms, and combining multiple concurrent modeling efforts, systems engineers will be able to perform increasingly detailed trade studies and analyses. Optimization tools will be used broadly, taking advantage of vast, inexpensive cloud-computing resources to identify system alternatives that are most likely to maximize life cycle value under uncertainty. Visualization tools will enable interactive analysis from many different stakeholder-specific viewpoints, allowing decision makers to gain new insights, perform what-if analyses, and make decisions with confidence.

DECISION MAKERS WILL HAVE MORE INFORMATION, AND OPTIONS FROM WHICH TO DRAW CONCLUSIONS.





Virtual Engineering
Part of The Digital Revolution

FROM

Model-based systems engineering has grown in popularity as a way to deal with the limitations of document-based approaches, but is still in an early stage of maturity similar to the early days of CAD/CAE.

TO

Formal systems modeling is standard practice for specifying, analyzing, designing, and verifying systems, and is fully integrated with other engineering models. System models are adapted to the application domain, and include a broad spectrum of models for representing all aspects of systems. The use of internet-driven knowledge representation and immersive technologies enable highly efficient and shared human understanding of systems in a virtual environment that span the full life cycle from concept through development, manufacturing, operations, and support.

- Systems modeling will form the product-centric backbone of the digital enterprise which incorporates a model-centric approach to integrate technical, programmatic, and business concerns.
- Model-based approaches will extend beyond product modeling to enterprise-level modeling and analysis .
- Tool suites, visualization and virtualization capabilities will mature to efficiently support the development of integrated cross-disciplinary analyses and design space explorations and optimizations, comprehensive customer/market needs, requirements, architecture, design, operations and servicing solutions.
- Model-based approaches will move engineering and management from paper documentation as a communications medium to a paperless environment, by permitting the capture and review of systems design and performance in digital form.
- 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.
- Models will be used not only to capture design but to embody design rationale by linking design to top level customer and programmatic concerns
- Large scale virtual prototyping and virtual product integration based on integrated models will lead to significant time-to-market reductions.

Simulation and Visualization

Modeling, simulation, and visualization enable complex system understanding that help us anticipate and verify solutions and their cost before building them. As systems become more complex, understanding their emergent behavior due to increasingly complex software, extreme physical environments, net-centricity, and human interactions becomes essential for successful systems development.

Modeling, simulation and visualization will become more integrated and powerful to cope with the systems challenges in 2025.

Integrated Model-based Approaches

Model-based Systems Engineering will become the "norm" for systems engineering execution, with specific focus placed on integrated modeling environments. These systems models go "beyond the boxes", incorporating geometric, production and operational views. Integrated models reduce inconsistencies, enable automation and support early and continual verification by analysis.

DARPA's Adaptive Vehicle Make program is setting the vision for the future of an integrated, model-based tool chain.

Transforming Virtual Model to Reality

A shift towards an integrated, digital engineering environment enables rapid transformation of concepts and designs to physical prototypes through the application of additive manufacturing technologies, such as 3D printers. This capability enables engineers to rapidly and continually assess and update their designs prior to committing costs to production hardware. The Boeing 777 virtual design process establishes a point of departure for the future of highly integrated, virtual design and production. Systems engineering practices will leverage this capability to rapidly assess alternative designs in terms of their form, fit and function.

Digital printing and related technologies enable rapid iterations from concept to hardware prototype and even production.

Systems Engineering Foundations

Shoring Up the Theoretical Foundation

FROM

Systems engineering practice is only weakly connected to the underlying theoretical foundation, and educational programs focus on practice with little emphasis on underlying theory.

TO

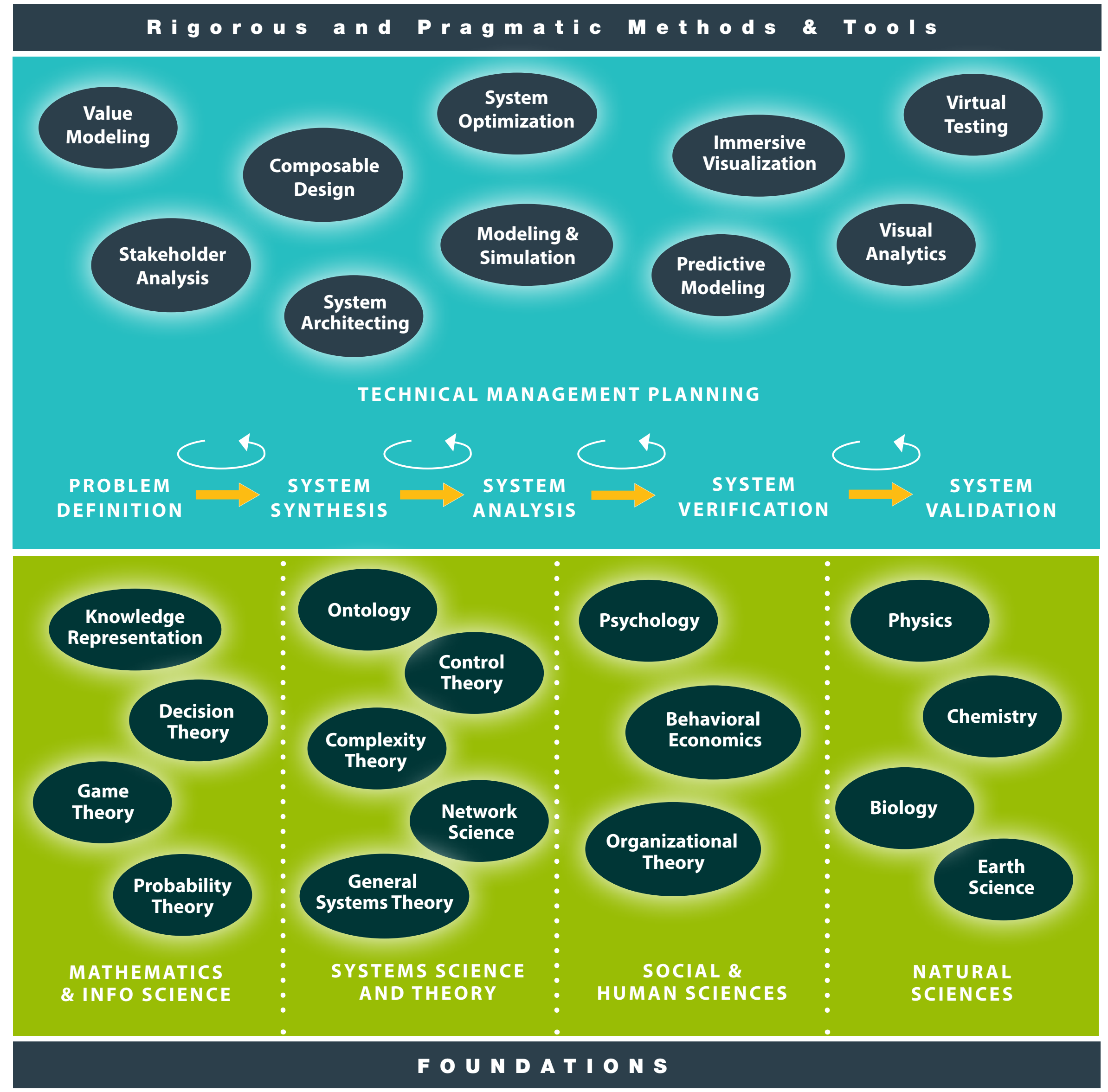
The theoretical foundation of systems engineering encompasses not only mathematics, physical sciences, and systems science, but also human and social sciences. This foundational theory is taught as a normal part of systems engineering curricula, and it directly supports systems engineering methods and standards. Understanding the foundation enables the systems engineer to evaluate and select from an expanded and robust toolkit, the right tool for the job.

The theoretical foundation will provide a scientific basis for improved methods that must be both rigorous and pragmatic. It must allow for effective adaptation of systems engineering practices to ever increasing system complexity, to a broad range of application domains, and to new enabling technologies. The theoretical foundation will build on systems science to expand our understanding of the system under development and of the environment in which it operates. The foundations will encompass the mathematics of probability theory, decision theory and game theory to ensure methods that lead to the selection of a system design that maximizes value under uncertainty. In addition, social, organizational and psychological sciences will support the development of systems engineering methods and tools that are in tune with human nature.

Systems Engineering Body of Knowledge

Systems engineering knowledge and practices will be grounded in a more rigorous foundation of mathematics and science. Building on this common foundation, knowledge and practices will be defined and codified in domain-specific guidance and standards.

SHORING UP THE THEORETICAL FOUNDATION OF SYSTEMS ENGINEERING



Systems Theories Across Disciplines

Engineered systems increasingly derive their behavior from complex interactions between tightly coupled parts, covering multiple disciplines. It is therefore important to develop a scientific foundation that helps us to understand the whole rather than just the parts, that focuses on the relationships among the parts and the emergent properties of the whole. This reflects a shift in emphasis from reductionism to holism. Systems Science seeks to provide a common vocabulary (ontology), and general principles explaining the nature of complex systems.

Roles and Competencies

The Broadening Role of the Systems Engineer

FROM

A typical systems engineering role varies from managing requirements to being the technical leader on a project.

TO

The roles and competencies of the systems engineer will broaden to address the increasing complexity and diversity of future systems. The technical leadership role of the systems engineer on a project will be well established as critical to the success of a project. The systems engineering role also supports and integrates a broader range of socio-technical disciplines, technologies, and stakeholder concerns in an increasingly diverse work environment. Systems engineers will integrate programmatic and socio-technical concerns that span global and cultural boundaries as well as system-of-system boundaries. Systems engineers will understand systems of increasing complexity that include emergent behaviors associated with system interdependence and human interactions. Systems engineers will address concerns such as security, economic viability and sustainability that span broader disciplines, applications and technical domains.

All leaders need to be systems thinkers. All engineers should have some education and training in systems and systems engineering, and systems engineers need to be well versed in a broad set of socio-technical and leadership skills, serving as a central, multi-disciplinary focal point for systems development with stakeholders from all walks of life.

SYSTEMS ENGINEERING IS BROADLY APPLICABLE

- Systems thinking is used by many.
- Systems engineering is understood and embraced by all engineers.

- Systems engineering is a career for a few.

Essential Systems Engineering Competencies

FROM

The competency of today's systems engineer vary significantly in the depth and breadth of their systems engineering knowledge. Their competencies are often based on their domain specific engineering background, an understanding of the specific practices that are employed at their organization, and the lessons learned from applying this approach on projects.

TO

The expected competencies of a systems engineer will be more consistently defined and broadened to support the expanded systems engineering roles. The competencies will include leadership skills to enable team effectiveness across diverse organizational, physical and cultural boundaries; mastery of systems engineering foundations and methods related to knowledge representation, decision analysis, stakeholder analysis, and complex system understanding; deep knowledge in the relevant application and technical domains; experience across the full system life cycle including development, operations, and sustainment; and skills in the use of software-based tools needed to support the application of systems engineering to the domain.

The systems engineering practitioner will have the leadership skills, coupled with deep system, socio-technical and domain understanding to effectively support the evolving systems engineering roles. The need to understand and embrace the so-called soft skills necessary for leadership and the social sciences required for a more complete understanding of the system's operation and impact is a qualitative departure from what have traditionally been a set of mainly technical competencies.

THE BREADTH OF SYSTEMS ENGINEERING COMPETENCIES

Education and Training

Building the Systems Engineering Workforce for 2025 and Beyond

FROM	TO
The worldwide demand for systems engineering in all application domains is increasing the need for high quality systems engineering education and training. A growing number of academic institutions are offering graduate-level programs in systems engineering. *There are increasing numbers of universities that teach systems engineering at the graduate level, although the total number is still small relative to other engineering disciplines. The Graduate Reference Curriculum for Systems Engineering (GRCSE) has recently been defined as part of an international effort to standardize the requirements for a systems engineering curriculum at the graduate level. Many practicing systems engineers have not had formal systems engineering education, but have learned systems engineering "on the job".*	The worldwide demand for systems engineering is well understood, and an educational, training, and mentoring life-long learning pipeline is in place to support it with individuals and teams of the required quantity and multi-disciplinary capabilities. *Systems thinking is formally introduced in early education. Systems engineering is a part of every engineer's curriculum and systems engineering at the university level is grounded in the theoretical foundations that spans the hard sciences, engineering, mathematics, and human and social sciences.*

The Systems Engineering Curriculum

Educational and training programs will provide to the systems engineers of 2025 the broad competencies described previously. These include the socio-technical, leadership, and domain-specific knowledge to engineer complex systems that span a broad range of application domains. Systems engineering will be seen as a meaningful career, one which affects people broadly and has positive impact on addressing the most critical of society's challenges. As such, the systems engineering curriculum will expand to include socio-political learning (e.g., economics, sociology, public policy, law).

Systems engineering skills cannot be limited to a small number of systems engineers, but will be embraced by numerous discipline-centric practitioners. As a result, systems engineering education and training will be integrated into discipline-specific engineering curriculums. Systems engineering will be widely recognized as an important complement to domain specific education and taught for awareness in most other fields of engineering and social/economic/policy educational areas.

To have impact, systems engineers will have leadership enabling skills which include a wide range of soft skills, particularly those needed to integrate across a multi-disciplinary environment that spans regions, organizations, and industries.

For continuing relevance, systems engineering education and training will stay abreast of the advancing processes, methods and tools while providing grounding in the theoretical foundations. This imposes requirements on the curriculum, instructional methods, and the instructor competencies. This field will be continually enriched by extensive theoretical elements from physics/engineering, sociology/anthropology and economics/political science. Educational and training programs will also become more pervasive to support the broadening applications of systems engineering, and the increased demands on the number of systems engineers.

Lifelong Learning

Education and training is a lifetime endeavor in which the systems engineers of the future will be actively engaged. This lifelong pursuit is necessary to build the initial foundations for systems engineering, later to stay abreast of advances in technology and practices and to share their experiential knowledge with others that follow. Throughout this lifetime of education, systems training will leverage technology through knowledge representation, simulation, computation and visualization.

Systems thinking will be introduced early in education to complement learning in sciences, technology, engineering, and mathematics.

Early education will also develop skills necessary for working together in teams to create solutions that satisfy stakeholder needs.

Later formal education will teach basic systems engineering concepts fundamental to sound engineering, as a part of all engineering instruction, such as: soliciting and understanding stakeholder's needs, identifying and evaluating conceptual alternatives before arriving at a solution, considering full life cycle impacts, and understanding and validating sources of data. Instruction will be practical, based on relevant real world experiences, to motivate students to acquire the requisite mathematical and scientific knowledge to support analyses and decision-making.

LIFE-LONG SYSTEMS ENGINEERING EDUCATION AND TRAINING

Workplace-based continuous learning programs will be individualized. In early to mid-career, training and education will provide the practitioner the opportunity to learn the latest systems capabilities and analytical techniques as well as specific institutional practices and standards. Greater in-depth analysis of domain-specific challenges and approaches will be provided for the professional practicing systems engineer or aspiring systems engineer to move from a discipline-specific or limited scope role into a broader systems engineering role. Systems engineering certification programs will enable validation and self-assessment of systems engineering competencies throughout one's career.

SUMMARY

SYSTEMS ENGINEERING IN THE FUTURE WILL BE . . .

- Relevant to a broad range of application domains, well beyond its traditional roots in aerospace and defense, to meet society's growing quest for sustainable system solutions to providing fundamental needs, in the globally competitive environment.
- Applied more widely to assessments of socio-physical systems in support of policy decisions and other forms of remediation.
- Comprehensively integrating multiple market, social and environmental stakeholder demands against "end-to-end" life-cycle considerations and long-term risks.
- A key integrating role to support collaboration that spans diverse organizational and regional boundaries, and a broad range of disciplines.
- Supported by a more encompassing foundation of theory and sophisticated model-based methods and tools allowing a better understanding of increasingly complex systems and decisions in the face of uncertainty.
- Enhanced by an educational infrastructure that stresses systems thinking and systems analysis at all learning phases.
- Practiced by a growing cadre of professionals who possess not only technical acumen in their domain of application, but who also have mastery of the next generation of tools and methods necessary for the systems and integration challenges of the times.

Realizing the Vision

This vision for systems engineering is not intended to simply be a prediction of the future, but rather a prescription for the evolution of systems engineering to meet the needs and challenges of an evolving global environment. The vision is intended to inspire and guide the direction of systems engineering to meet these needs and challenges and must require broad participation from the systems engineering community at large to develop and execute the path forward to realize the vision.

The path forward includes establishing grand challenges for systems engineering that can be used to focus and gauge progress towards the vision. Addressing these challenges will help us solve complex socio-technical problems. The path forward also includes roadmaps for research, education, and standards. The research roadmap will mature systems thinking and the theoretical foundations as a basis for advanced systems engineering methods and tools. The education roadmap will help build the competencies for the workforce of 2025 and include both curriculum and instructional methods starting in early education. A third roadmap will identify, develop, and evolve standards for codifying the practice of systems engineering, which can contribute to the systems engineering body of knowledge.

A successful path forward must have the active engagement of industry, academia and government. This engagement will be structured as a collaboration between representatives from diverse industry and other application domains. Each domain, such as automotive, healthcare and biomedical, power and energy, transportation, and many others, can develop their domain specific vision using this vision as a starting point. The collaboration will provide the opportunity to synergize investment and other resources across domains, while focusing on the unique needs of each domain.

INCOSE will engage other professional societies that span application domains and regions, as well as researchers, educators, and tool vendors. The collaboration will evolve a master plan to integrate the domain specific roadmaps and detailed plans for the shared activities, to help guide the incremental evolution and implementation of the shared vision.

GRAND CHALLENGES FOR SYSTEMS ENGINEERING 2025

A core body of systems engineering foundations is defined and taught consistently across academia.

System complexity and associated risk is appreciated, characterized and managed.

Systems engineering provides the analytical framework for designing and predicting the behavior for trusted, resilient systems.

Model-based systems engineering is a standard practice and is integrated with other modeling and simulation as well as digital enterprise functions.

Systems engineering is recognized across industries, governments, and academia as providing significant value for innovation and competitiveness.

Systems engineering is established as an indispensible discipline for technology assessment and policy analysis.

Systems thinking is taught at all levels of education.

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