Transdisciplinarity and the Future of Engineering
B.R. Moser et al. (Eds.)

doi:10.3233/ATDE220707

The Future of Systems Engineering: Realizing the Systems Engineering Vision 2035

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Abstract. The International Council on Systems Engineering (INCOSE) in January 2022 has published the *Systems Engineering Vision 2035: Engineering Solutions for a Better World*. The *Vision* recognizes the scale, interconnectedness, and non-determinism of 21st Century systems. The *Vision* has been reviewed by peer organizations throughout the engineering and systems communities and is freely available for download at www.incose.org. The *Vision* addresses the global context for systems engineering, the current state of systems engineering, the future state of systems engineering, and realizing the vision. The *Future of Systems Engineering (FuSE)* is the engineering and systems communities initiative to realize the *Vision* in a holistic and comprehensive transdisciplinary manner that addresses both the enablers and impediments, taking into account the political, economic, social, technical, environmental, and legal (PESTEL) factors. The challenges span applications, practices, tools and environment, research, and competencies. The path forward must address the set of challenges while inspiring collaboration and managing the culture change required to shift mindsets and approaches from the current state to the future state in the engineering of systems. *FuSE* is framing the realization of the *Vision* and measures to assess progress to proactively engage stakeholders.

Keywords. Future of systems engineering, PESTEL factors, systems engineering challenges, systems engineering vision, transdisciplinary

Introduction

The International Council of Systems Engineering (INCOSE) periodically publishes a vision document for the systems engineering discipline looking out 10 or more years into the future. The *Systems Engineering Vision 2020* was published in 2007 and the *Systems Engineering Vision 2025* was published in 2015. INCOSE released the *Systems Engineering Vision 2035: Engineering Solutions for a Better World* in early 2022 [1]. The Vision is available in print, PDF, and an interactive online web format. The executive summary is also available as a separate document in print and PDF.

The emergence of significant trends and strongly coupled interplay among political, economic, social, technical, environmental, and legal (PESTEL) factors are the drivers for the updated *Vision* looking out further into the future beyond 2025 towards 2035. For example, the *Vision 2025* did not foresee the disruptive effects of AI/machine learning across multiple domains, effects of globalization on national psyches, and the SARS COVID-19 pandemic. A conclusion is that the systems engineering discipline that evolved in the period from the 1930s to the 1970s to meet the challenges of that time period is no longer *fit for purpose* in the current and future ecosystem and therefore needs to be revitalized.

The *Vision 2035* is organized into an executive summary and four chapters:

1. The Global Context for Systems Engineering
2. The Current State of Systems Engineering
3. The Future State of Systems Engineering
4. Realizing the Vision.

The document ends with the summary of systems enginerering by 2035.

This paper overviews each of the four chapters of the *Vision* and then focuses on the future of systems engineering (*FuSE*) initiative to realize the *Vision* [2]. The *FuSE* initiative was initiated in 2019 ahead of the initiation of the *Vision 2035* effort, accounting for both PESTEL factors, and the *Systems Engineering Vision 2025,* as a baseline. Emerging technologies were of interest in the PESTEL factors. The *FuSE* team participated in the reviews of the *Vision 2035* drafts throughout its development. Major thrusts of the FuSE intiative have been in the following broad areas:

- Science foundations for systems engineering (SF4SE) [3]
- Systems engineering for artificial intelligence (SE4AI) and artificial intelligence for systems engineering (AI4SE) [4] [5]
- Human systems integration
- Systems security
- Agile systems.

With the release of the *Vision 2035*, *FuSE* is also focused on validating the *Systems Engineering Vision 2035* recommendations and roadmap in Chapter 4 and deriving measures to assess progress and be proactive where needed in achieving the *Vision*.

1. Systems engineering vision 2035

The intent of the *Systems Engineering Vision 2035* is to *inspire and guide the strategic direction of systems engineering for the global systems community. This community includes leaders of organizations, practitioners, and students, and others serving this community that includes educators, researchers, professional organizations, standards bodies, and tool vendors. It is intended to apply to a broad range of application domains including biomedical, defense, healthcare, power and energy, telecommunications, transportation, and many others.*

This vision can be used to develop strategies to evolve the systems engineering capability of an enterprise or project. The vision can also be used to help direct investments and support collaborative efforts to advance the discipline and grow the skill base to meet current and future challenges related to systems development. The reader will also gain insights on trends that impact enterprise competitiveness and how systems engineering will respond to these trends, which include the digital transformation, sustainability, smart systems and complexity growth, and advancements in modeling, simulation, and visualization.

The value statement for the Vision 2035 is that *systems engineering aims to ensure the pieces work together to achieve the objectives of the whole, including*

- *Architect balanced solutions that satisfy diverse stakeholder needs for capability, dependability, sustainability, social acceptability, and esse of use*

- *Adapt to evolving technology and requirements*
- *Manage compexity and risk.*

1.1. The Global context for systems engineering

Chapter 1 *summarizes some of the key trends and influencing factors that are expected to drive changes in the practice of systems engineering. These factors include:*
• the societal and environmental condition,
• technology,
• nature of systems,
• stakeholder expectations,
• enterprises and the workforce.

Goode and Machol [6] recognized in the 1950s the challenge of complexity growing exponentially and the value of systems engineering in addressing this complexity. The two case studies throughout their text are the airline reservation system and the Bell telephone system. In our current era, Morris [7] characterizes exponentially growing complexity across 83 changes.

1.2. The current state of systems engineering

Chapter 2 *highlights the current state of systems engineering including systems engineering competencies, practices, foundations, and current challenges. It points to the fact that basic elements of systems engineering apply to all kinds of systems, small and large, but that there is significant variation in maturity across industries and organizations.*

The current state of the systems engineering discipline is described in the *INCOSE Systems Engineering Handbook* [8] and the Systems Engineering Body of Knowledge (SEBoK) [9]. INCOSE offers systems engineering proessional certification based on the handbook, https://www.incose.org/systems-engineering-certification.

1.3. The future state of systems engineering

Chapter 3 *describes the future state of systems engineering needed to address the changing global context and the current challenges. It addresses the digital transformation and the direction towards a fully model-based systems engineering environment. It touches upon theoretical foundations, and the education and training needed to develop the competent systems engineering work force of the future. It also provides an example of how the daily life of a systems engineer could look in 2035.*

A transdisciplinary perspective is critical to successful engineering of systems for product innovation ensuring reduction of defects, agility, and security [10].

1.4. Realizing the Vision

Chapter 4 describes what is needed to realize the vision. It identifies a set of engineering challenges and specific recommendations addressing the challenges and the high-level roadmaps needed to transition the engineering of systems from the current state to the future state. It also highlights the need for collaboration among the global systems community to evolve and implement the roadmaps. The specific categories are

- Applications
- Practices
- Tools and environments
- Research
- Competencies.

The challenges and recommendations for the practices categories are shown in Table 1 to illustrate the criticality of transdisciplinary engineering to achieve the *Vision*. The complete set of challenges and recommendations across all the categories are provided in the *Vision* document. The roadmaps are discussed in the next section on the *FuSE* initiative.

Table 1. Systems engineering challenges and specific recommendations – practices.

Systems Engineering Challenges	Specific Recommended Changes Needed
Systems engineering anticipates and effectively responds to an increasingly dynamic and uncertain environment.	• Data standards are developed and adopted enabling effective data interconnection and exchange. • Methods and tools for dealing with product variation and variability are widely adopted. • Knowledge Management and incremental learning are integrated with systems engineering practice • Systems engineering incorporates dynamic feedback into solutions across the life cycle (such as Agile practices). • Increasing technology assistance for human tasking is incorporated including automated workflows.
Model-based systems engineering, integrated with simulation, multi-disciplinary analysis, and immersive visualization environments is standard practice.	• Use and management of models, architecture, and digital thread mature, including digital twins. • Immersive visualization with modeling and simulation is incorporated. • Trusted digital environments with broad span are established. • Trusted data is managed as an essential asset. • Effective semantic integration of digital assets is applied, including knowledge representation. • MBSE is supported by AI/ML to aid development of solutions.
Systems engineering provides the analytic framework to define, realize, and sustain increasingly complex systems.	• Advanced data science, AI/ ML, augmentation, and visualization are integrated to support analyses for improved understanding of system behavior. • Standards and regulations are integrated in the framework. • Capability to analyze a broader set of elements across the life cycle (such as, sustainability and social acceptability) is developed. • Effective synthesis capabilities are matured, including for systems of systems. • Knowledge is increased of natural systems and how they embody and deal with complexity.
Systems engineering has widely adopted reuse practices such as product-line engineering, patterns, and composable design practices.	• Commonality of practice across a range of systems engineering use cases is understood and applied. • Patterns and unified models that account for variations are established. • Effective reuse practices evolve and become widely applied across domains (Product Line Engineering and Composable Design).

2. Future of systems engineering

FuSE is a systems community initative facilitated by INCOSE to address the emerging challenges in engineering 21st Century systems. A holistic action model for *FuSE* is represented by the systemigram in Figure 1.

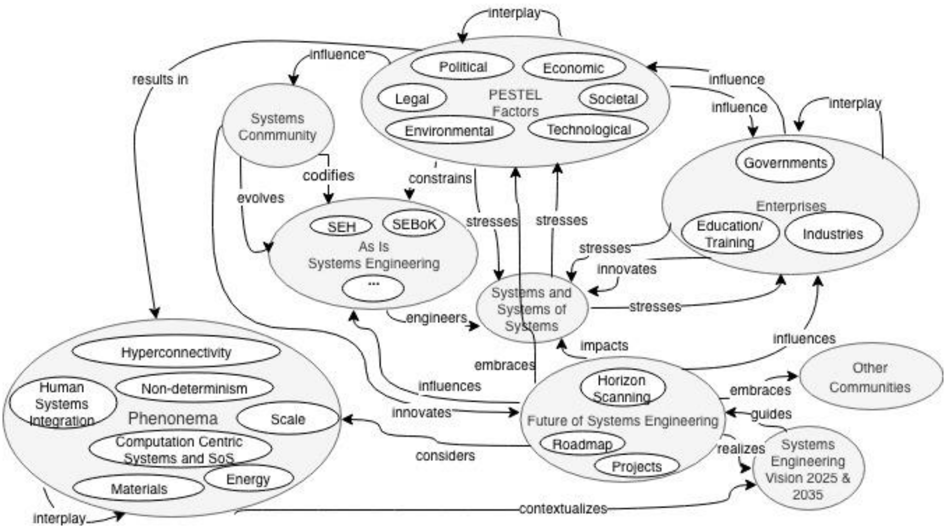

Figure 1. Future of systems engineering systemigram.

2.1. Emerging challenges

The future environment is becoming:

- More dynamic and nondeterministic
- Increasingly evolutionary, with an accelerating rate of change
- Resource constrained driving a need for sustainability
- Highly interactive among individuals, communities, organizations, and systems.

There are growing expectations for system engineering solutions:

- Increased level of functionality providing more comprehensive solutions
- Higher order of intelligence and adaptability augmenting human performance
- Greater level of connectivity and interoperability across and between systems
- Trust, safety, and cybersecurity of digital representations
- Increased inclusivity, growing the scale and scope of solutions.

Emerging technologies provide both challenges to the engineering of systems and opportunities to enhance the engineering of systems:

- Machine Learning
- Autonomous Physical Systems
- 3D Printing, Genomics
- Quantum and Nano Technology
- Biomimicry

- Complexity Science
- Systems Sciences
- Data Science (Big Data)
- Smart Everything
- Connected Everything (IoT)
- Artificial Intelligence
- Cybersecurity.

Many of these emerging technologies are addressed in initiatives such as digital engineering [11] (including digital threads and digital twins), Industry 4.0, and Society 5.0. A technological challenge of digital twins is insufficient computing throughput to execute them both spatially, that is, fidelity, and temporally, both individually and on the scale of a large number of assets in a class of systems. West and Pyster [12] found that available computing throughput was insufficient to achieve the objective fidelity and computing time for the digital twin of a single instantiation for a military aircraft. West and Blackburn [13] later addressed achievable fidelity and computing time given the constraint of available computing throughput. Gaps in computing power stimulate innovation in computing architectures to meet unfulfilled needs as evidenced in computing advances for big data and machine learning.

2.2. Future of systems engineering charter

The purpose of *FuSE* is to evolve the practice, instruction and perception of system engineering to:

1. Position systems engineering to leverage new technologies in collaboration with allied fields
2. Enhance systems engineering's ability to solve the emerging challenges
3. Promote systems engineering as essential for achieving success and delivering value.

Goal: Create a road map that drives the evolution of systems engineering to:

1. be increasingly adaptable, evolvable and fit for purpose
2. account for human abilities, needs as an integral system element and their interactions with a system
3. be more responsive in resolving increasingly challenging societal needs
4. realize and enhance the *Systems Engineering Vision 2035* and other visionary inputs.

Scope: Identify the needs, priorities and means for transforming SE including:

1. underlying foundations, systems theory and principles
2. people, methods, tools, processes, education and training
3. the future social and ethical duties, contributions, and responsibilities of future systems engineers.

2.3. Objective Outcomes

- The systems community is focused on realising the *Systems Engineering Vision 2035* and beyond
- The systems community is aligned to the common goals of the *FuSE* road map
- Our road map is the point of differentiation for the future of systems engineering

- Our road map forms the focal point for systems engineering transformational activities
- INCOSE is positioned to monitor progress against the road map and adapts it to the emerging needs of the systems community.

2.4. Systems Engineering Vision 2035 roadmap goals

The roadmap goals for the systems engineering vision 2035 are shown in Table 2. The challenges and goals need to be addressed in an integrated and holistic manner. They are not entirely independent of each other and reflect only the most significant challenges. The FuSE initiative is currently deriving a set of measures to assess progress towards achieving the roadmap goals and an interaction model of their influences on each other. Preferences for the types of measures are shown in Table 3. Natural measures are preferred to constructed measures and direct measures are preferred to proxy measures [14]. Proxy measures are associated with the attainment of an objective that is not directly measurable; a proxy measure provides a surrogate.

Table 2. Systems engineering vision roadmap goals by category.

Systems Engineering Roadmap Goals by Category
Applications: **2025 Goal:** Expand domain application: Address growing societal challenges. Influence policy across enterprises. **2030 Goal:** Impactful application across domains underpinned by SE foundations and best practices supported by education and research. **2035 Goal:** SE is the 'go to' discipline across domains to solve engineering and societal grand challenges. Synthesizing cross disciplinary practices, models, and tools.
Practices: **2025 Goal:** Normalize community of practice with common SE foundations, definitions, and ontologies. Underpin knowledge management strategies to provide real time reuse of SE assets. **2030 Goal:** Formalize and standardize approaches underpinned by SE foundations across domains. Collaborate with academia and industry to embed knowledge further enhancing knowledge management. **2035 Goal:** Integration of practice across domains with majority adoption and institutionalization of tools and practices.
Tools & Environment: **2025 Goal**: Moving toward standardization with agreed language and terminology supported by open standard architectures enabling cross domain application. **2030 Goal:** Democratized systems language widely used and supporting multi domain application. Working towards standardized libraries. **2035 Goal:** Evidence of wide reuse with system generative design underpinned by standardized libraries.
Research: **2025 Goal:** Expand Research rooted in theoretical foundations in and improve practice. Propagate strong examples and principles. **2030 Goal:** SE theoretical foundations taught at multiple institutions across domains driving the research agenda and opening up wider funding opportunities.**2035 Goal:** Broad implementation of SE theoretical foundations acro guiding future research and applications.
Competencies: **2025 Goal**: Practitioner-based competencies with supporting bodies of knowledge and curricula. Provide support through certification and create greater standardization of practice and pull through to education. **2030 Goal:** Support STEM uptake through systems building blocks across educational levels and programs. Create continuous learning opportunities and embed practice. **2035 Goal:** SE embedded at all educational levels and across disciplines supported by innovative education and training approaches.

Table 3. Types of measures and their order of preference where a 1 has a higher order of preference than a 4.

Types of Measures	Direct	Proxy
Natural	1	3
Constructed	2	4

3. Summary

The intent of the *Systems Engineering Vision 2035* is to *inspire and guide the strategic direction of systems engineering for the global systems community.* The *FuSE* systems community initiative is currently validating the *Systems Engineering Vision 2035* roadmap goals and deriving measures for assessing progress and determining proactive actions to achieving the *Vision*.

Acknowledgement

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