A Preview of the Systems Engineering Vision 2035

INCOSE IW 2021

January 31, 2021

SE Vision Core Team

Agenda

Introduction - S. Friedenthal

Global Context For SE - Dave Nichols, Heinz Stoewer

Current State of SE – Sky Matthews, Paul Nielsen

Future State of SE – Chris Oster, Chris Davey

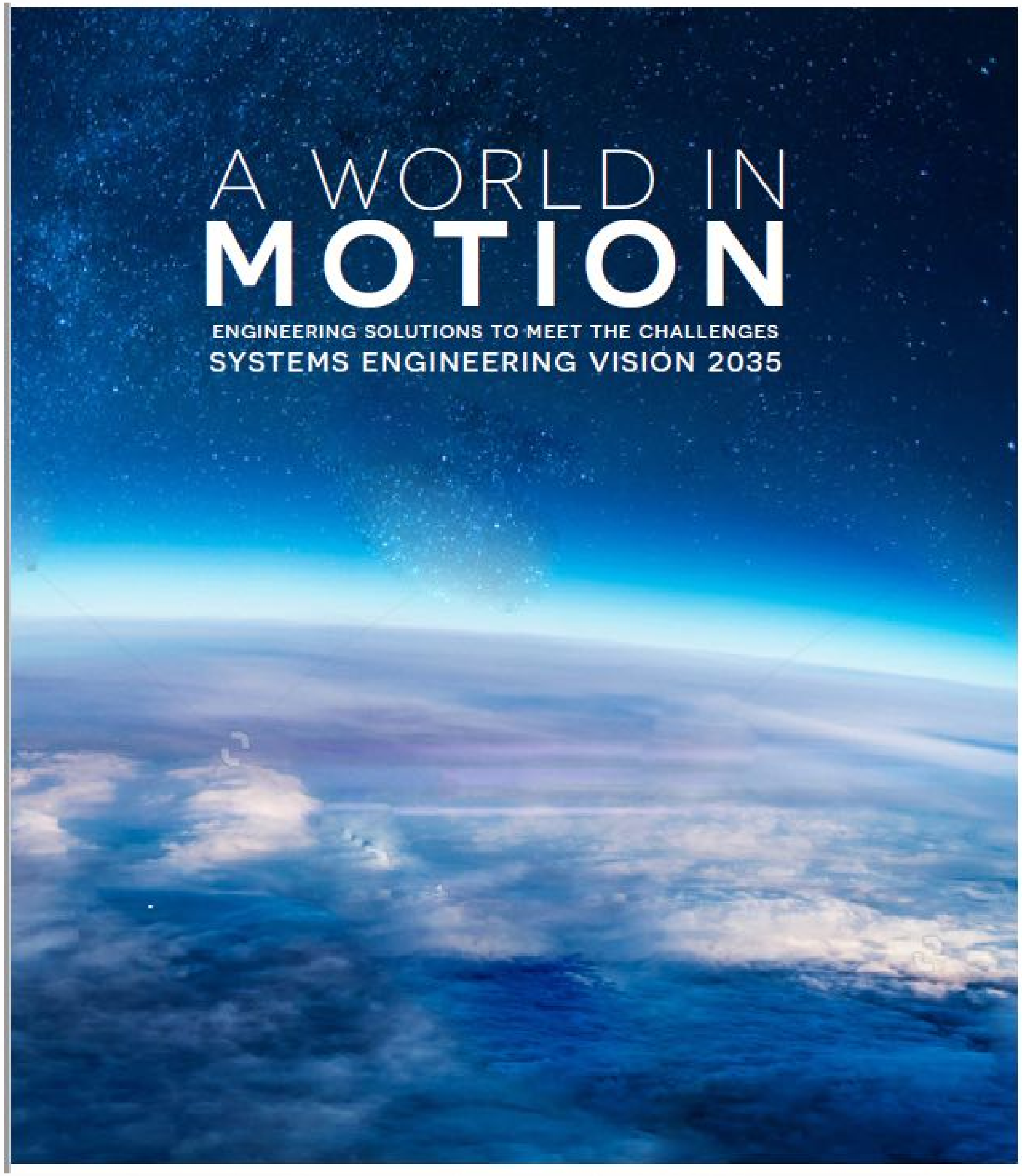
Realizing the Vision – Garry Roedler, Troy Peterson

Preliminary Review Plan – Paul Schreinemakers

Closing – Heinz Stoewer

SE Vision 2035 Background & Milestones

- SE Vision **2025** rollout at the INCOSE IS on July 3, 2014
- INCOSE BoD decision to pursue update in August, 2019
- SE Vision Core Team kickoff on January 26-27, 2020
- SE Vision 2035 Preliminary Review to begin on February 1, 2021
  - ***Current vision is a preliminary draft***
- SE Vision 2035 Final Review planned for August, 2021 (TBC)
- SE Vision **2035** Planned Rollout at INCOSE IW, January 2022


A WORLD IN
MOTION
ENGINEERING SOLUTIONS TO MEET THE CHALLENGES
SYSTEMS ENGINEERING VISION 2035

SE Vision Team

- Core Team
  - Chris Davey (Ford Motor Company)
  - Sanford Friedenthal (*Lead*) (SAF Consulting)
  - Sky Matthews (IBM)
  - David Nichols (NASA/Jet Propulsion Laboratory California Institute of Technology)
  - Paul Nielsen (Carnegie Mellon University Software Engineering Institute)
  - Christopher Oster (Lutron Electronics)
  - Troy Peterson (System Strategy, Inc.)
  - Garry Roedler (INCOSE)
  - Paul Schreinemakers (*Review Team Lead*) (How2SE)
  - Heinz Stoewer (*CTO*) (Space Associates and TU Delft)
- Support Team members
  - To be listed
- Graphics Design
  - Taylor Riethle

SE Vision Purpose & Objectives

- **Purpose:** inspire and guide the direction of systems engineering across diverse stakeholder communities, which include:
  - Engineering & Executive Leadership
  - Engineering Practitioners
  - Policy Makers
  - Professional Organizations
  - Researchers, Academics, & Students
  - Standard Bodies
  - Tool Vendors
- **Objectives**
  - Align Systems Engineering Initiatives
  - Address Future Systems Engineering Challenges
  - Broaden the Base of Systems Engineering Practitioners
  - Promote Systems Engineering Research
- **Evolution:** This vision will continue to evolve based on on-going collaborations with the stakeholder community

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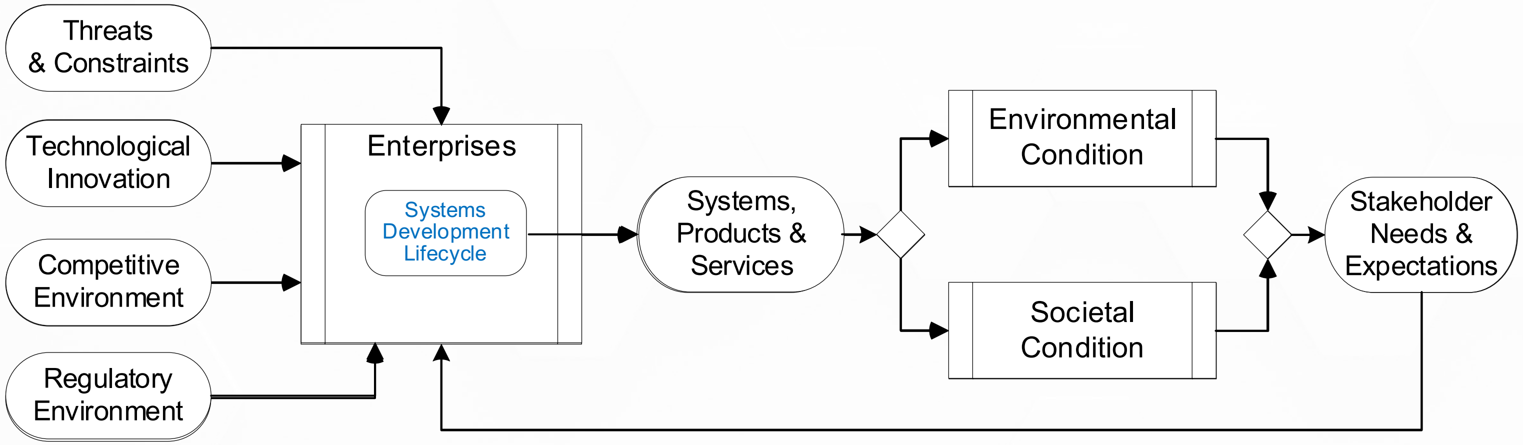
Vision35 Systems Engineering

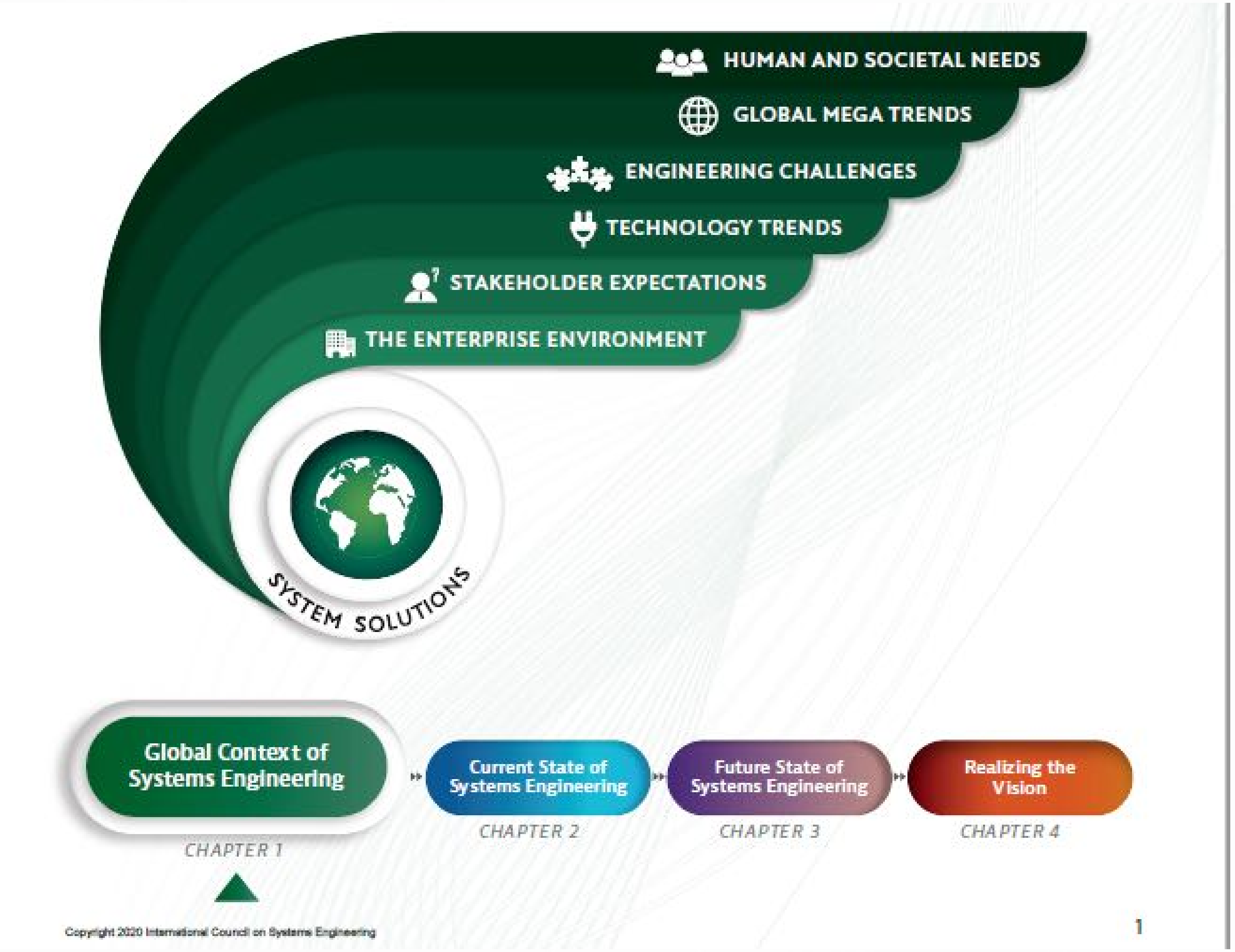
CONTENTS

Influencing Factors on Systems Engineering Practice



- SE Practices to meet these challenges
  - Collaborative environments that enable agility
  - Use of AI to assist the systems engineer in routine tasks
  - Data science methods to make sense of large data sets
  - Model-based SE leverages the digital transformation to address system complexity
  - SoS practices to address interconnected & distributed systems
  - Architecting practices to ensure system trust, safety, and resiliency
  - Reuse and product line engineering practices to leverage investment across enterprise
  - Human system integration practices to enable effective human-machine interactions

Chapter 1
Global Context for Systems Engineering



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

General Human and Societal Needs

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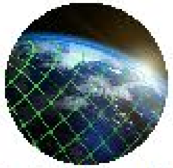
Global Mega-Trends Shape the Systems of the Future

Vision35 Systems Engineering

Global Mega-Trend 1

Priority of Environmental Sustainability



Global Mega-Trend 2

Interconnected & Independent World

Global Mega-Trend 3

Digital Transformation

KEY ATTRIBUTES OF GLOBAL SOCIO-ECONOMIC CHANGE INFLUENCING THE NATURE OF SYSTEMS

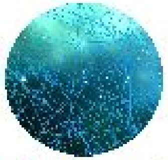
- DECREASES IN EXTREME POVERTY
- IMPROVED ACCESS TO HEALTHCARE
- LOWERING OF FERTILITY RATES AND INFANT MORTALITY
- INCREASE IN INCOME LEVELS
- IMPROVEMENT IN EDUCATION LEVELS, ESPECIALLY FOR WOMEN
- WIDESPREAD ELECTRIFICATION
- IMPROVED NUTRITION
- REDUCED FATALITIES FROM NATURAL DISASTERS, ACCIDENTS AND WARS
- DECREASED USE OF FOSSIL FUELS
- INCREASED RELIANCE ON SOCIAL COMMUNICATION COMMUNITIES FOR INTERCONNECTING AND INFORMING (AND MISINFORMING) PEOPLE.
- INCREASED ACCESS TO THE INTERNET

Global Mega-Trend 4

Industry 4.0 - Society 5.0

Global Mega-Trend 5

Complexity Explosion



Global Mega-Trend 6

Proliferation of Smart Systems

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.

Technologies Shape the Nature of Systems

Key Technology Advancements Impacting the Nature of Systems

Advanced modeling and simulation

Materials science and manufacturing

Bio/Life Science and nano-technologies

Autonomy and artificial intelligence

Communications

Geolocation-based technologies

Power generation, storage and conversion

Edge computing

Growing Stakeholder Expectations

- *Stakeholders are system users, sponsors and policy makers*

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

1. 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.

2. 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.

3. 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.

4. 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.

5. 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.

6. 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.

7. Socially Acceptable
Social, environmental and economic concerns interact.

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

8. Affordable
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.

9. 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.

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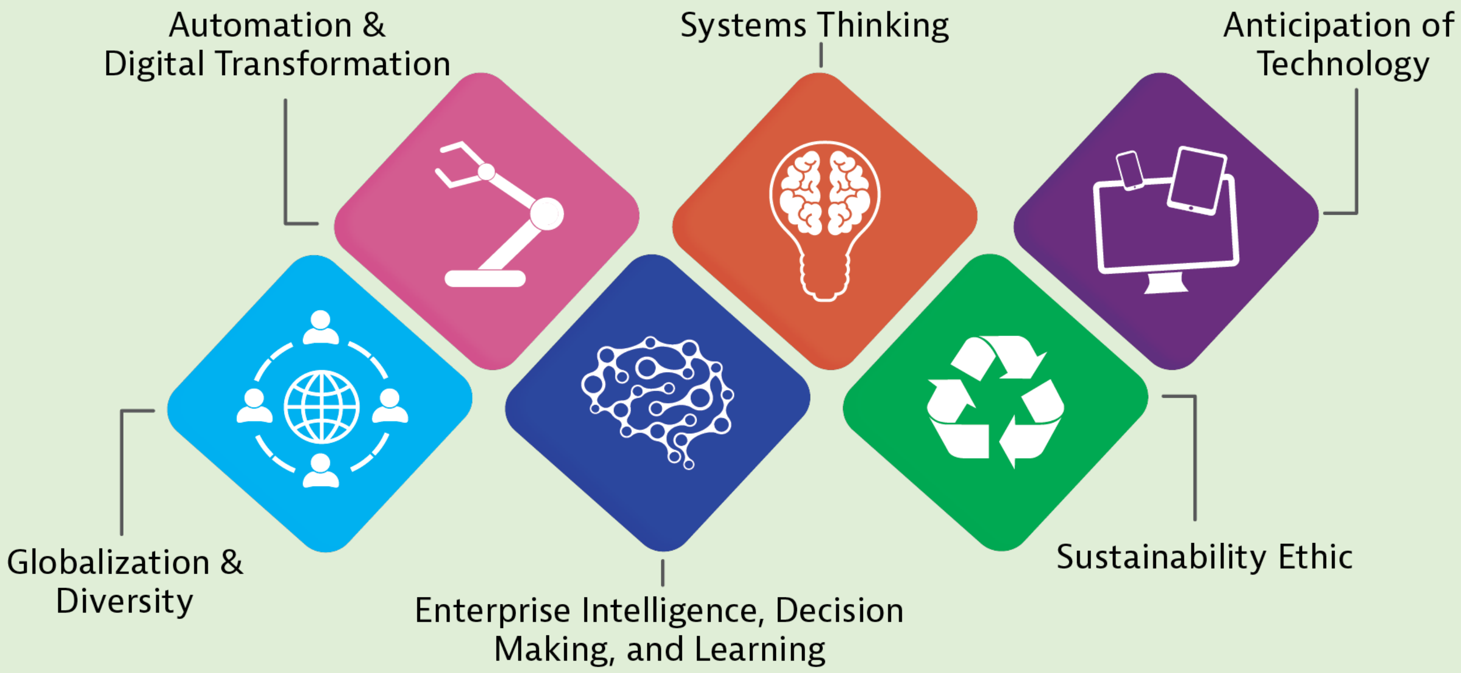
Vision35 Systems Engineering

The Enterprise Work Environment

ENTERPRISE & WORKFORCE TRENDS



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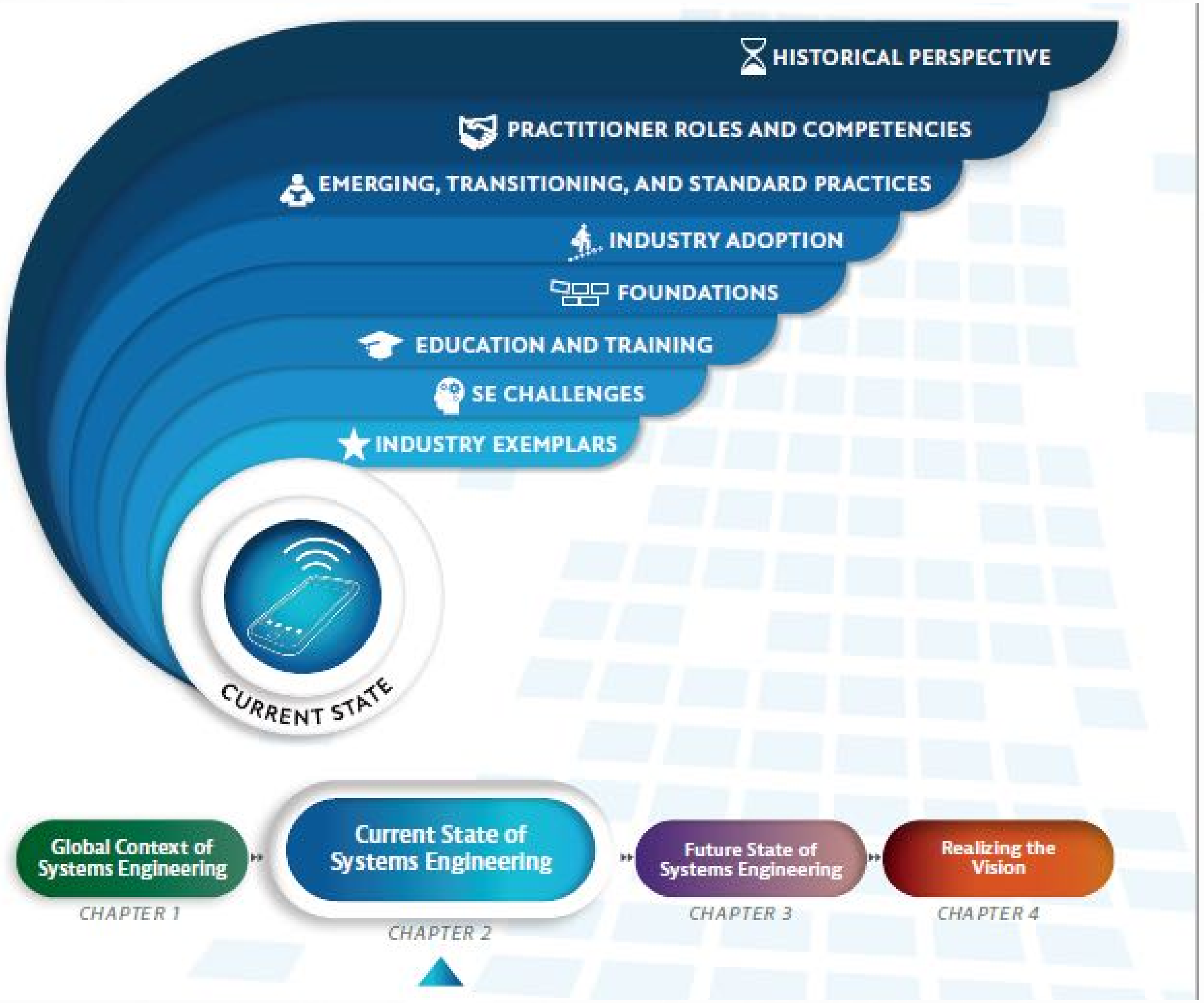
Vision35
Systems Engineering

Influencing Factors for Systems Solutions

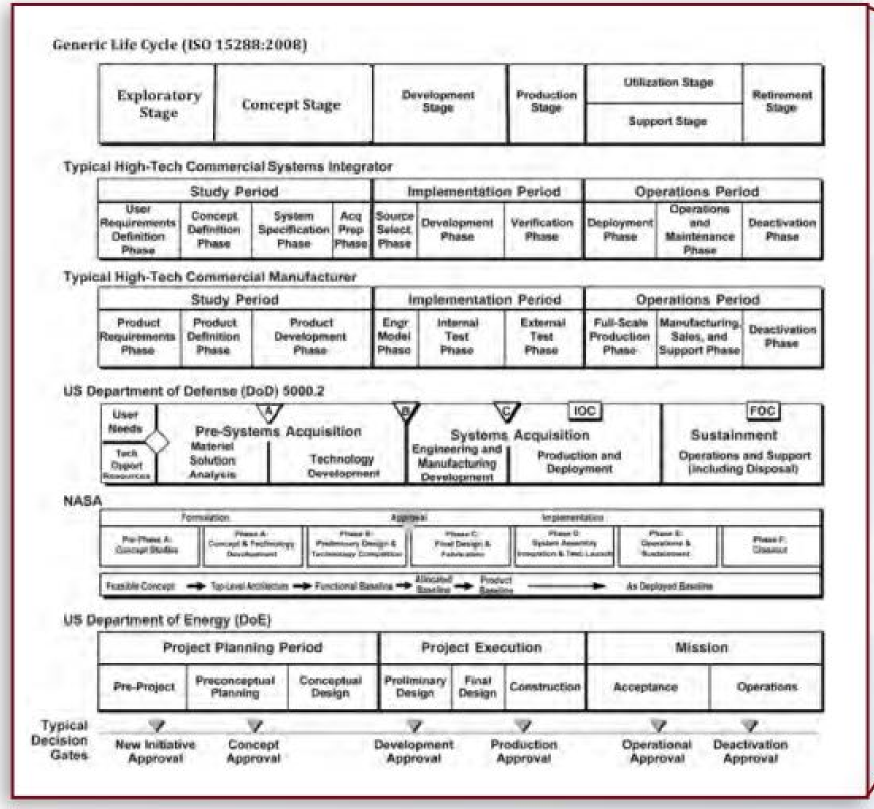
Chapter 2
Current State of Systems Engineering



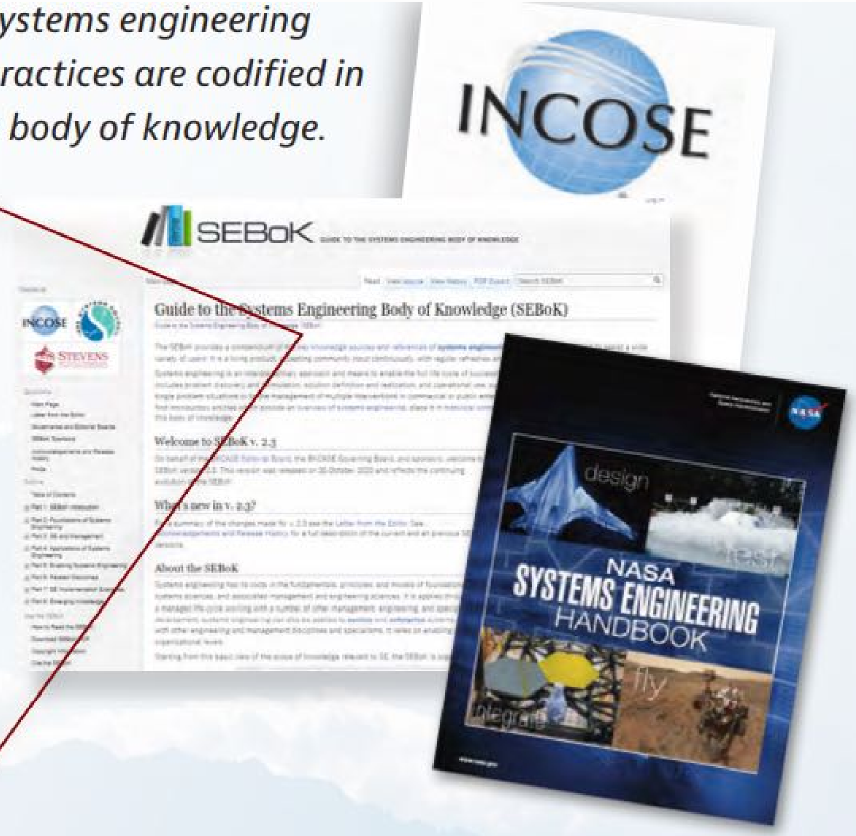
Practitioner Roles and Competencies

Emerging, Transitioning, & Standard Practices

Systems engineering practices are adapted to different industries



Systems engineering practices are codified in a body of knowledge.



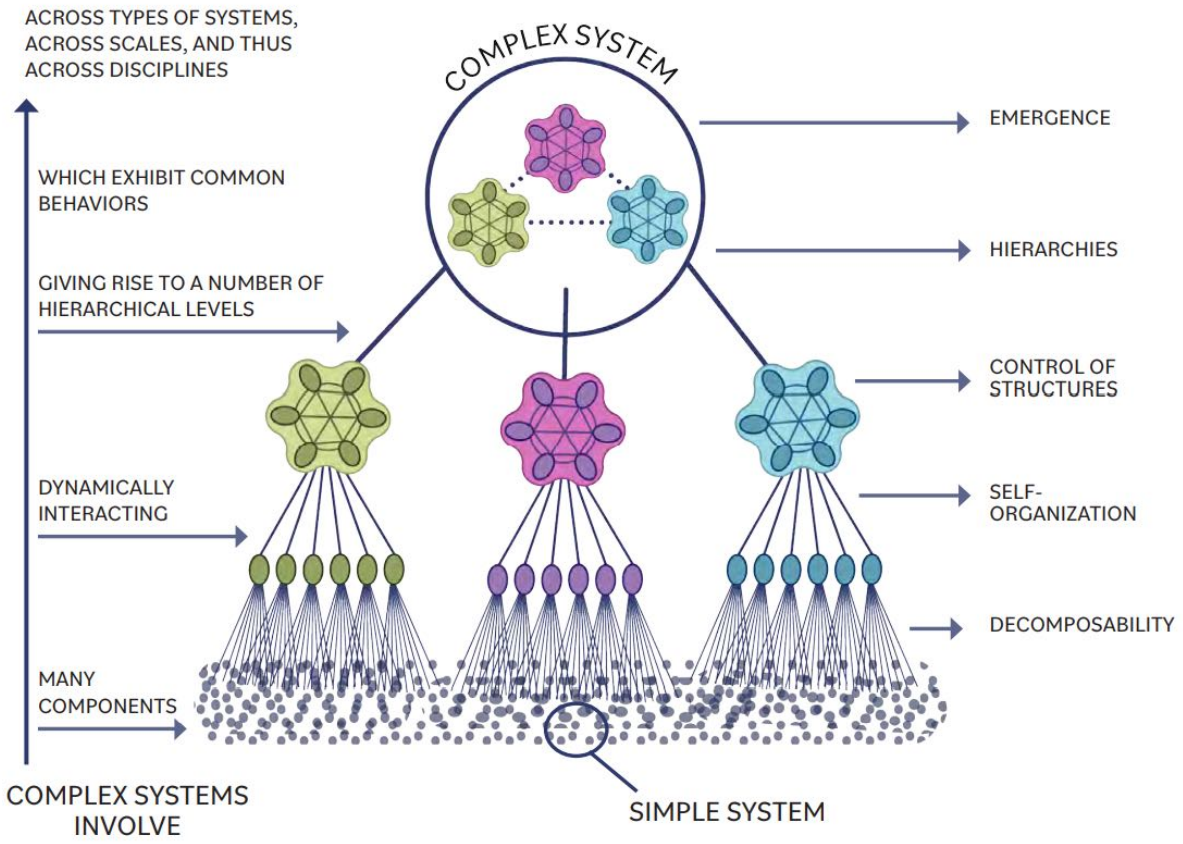
SE Practices are incorporated in to domain-specific processes covering the solution lifecycle from cradle to grave.

Many SE practices are now considered standard, while others are still emerging and not applied consistently across domains. Every SE practice can be thought of as having a maturity curve.

Foundations

- **Theoretical Foundations**
- **Standards,**
  Bodies of Knowledge
- **Complexity Theory,**
  Emergent Behavior

CHARACTERISTICS OF COMPLEX SYSTEMS

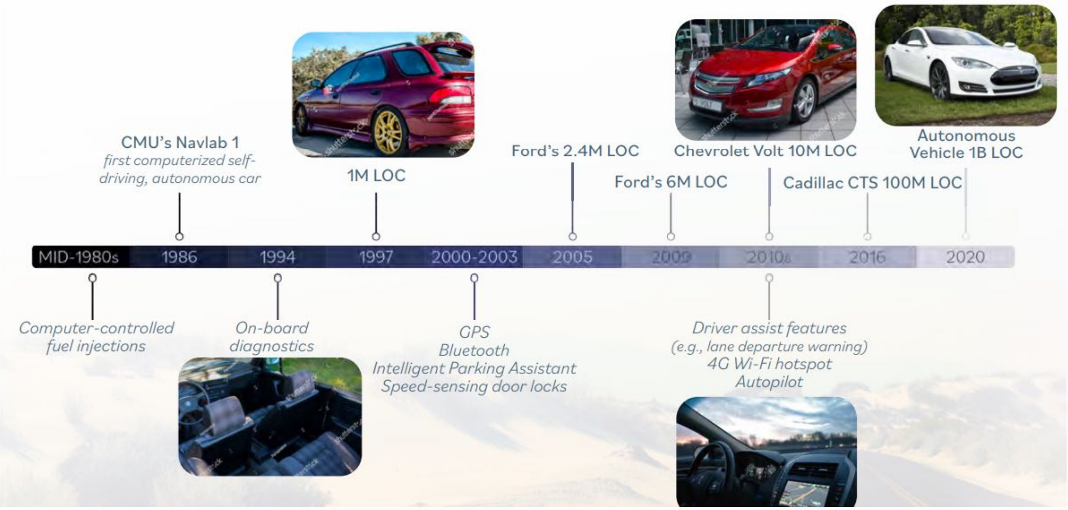


Source: Marshall Clemens, https://necsi.edu/visualizing-complex-systems-science

Systems Engineering Challenges

- **Tools and Data Integration**
- **Systems and Software Integration**
- **Impact of AI and Autonomous Systems**
- **Agility/Responding to Change**

Integration of tools and data from different specialties and different vendors via the OASIS Open Services for Lifecycle Collaboration standard: https://open-services.net



Industry Exemplars

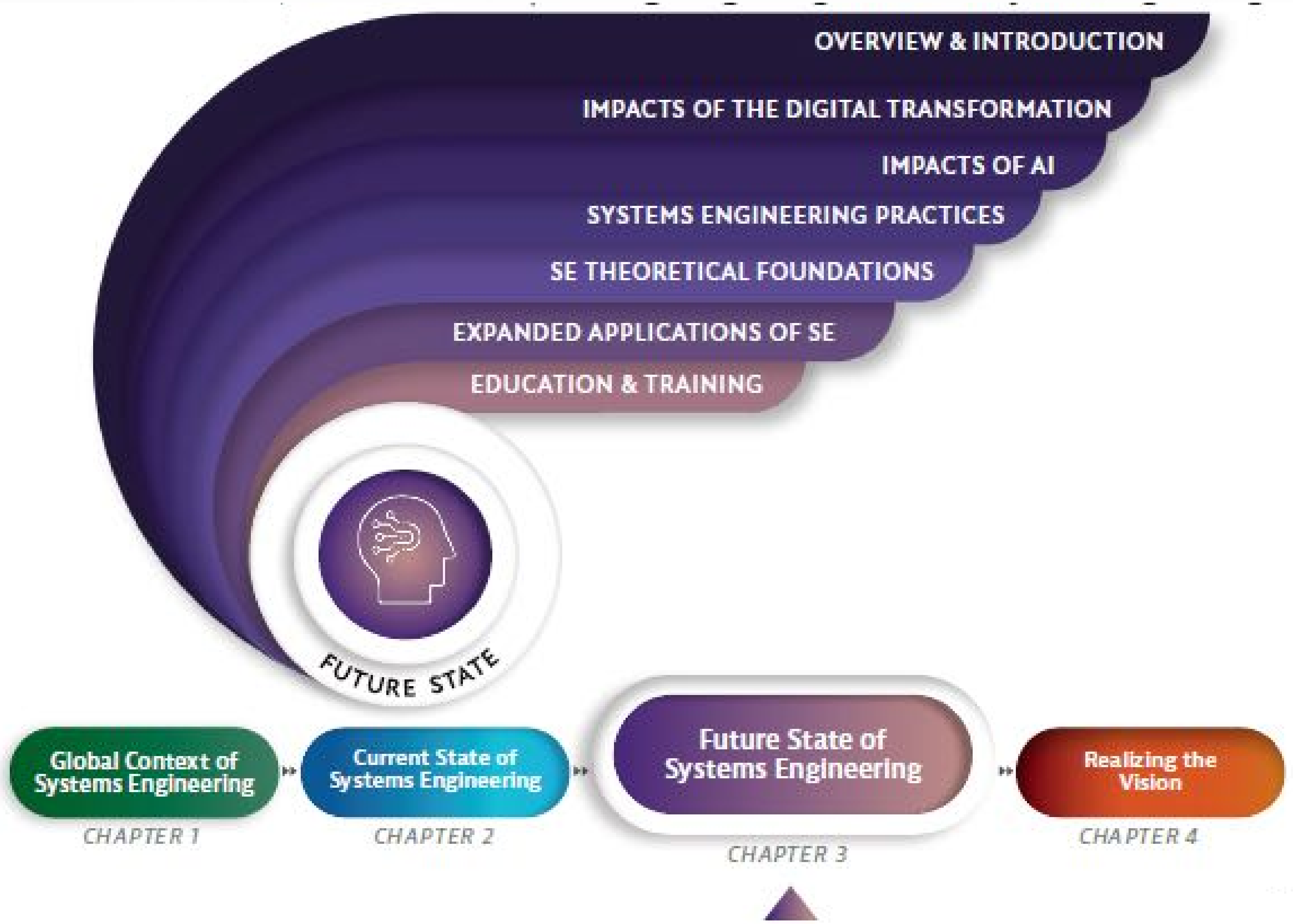
New Amsterdam Metro Line

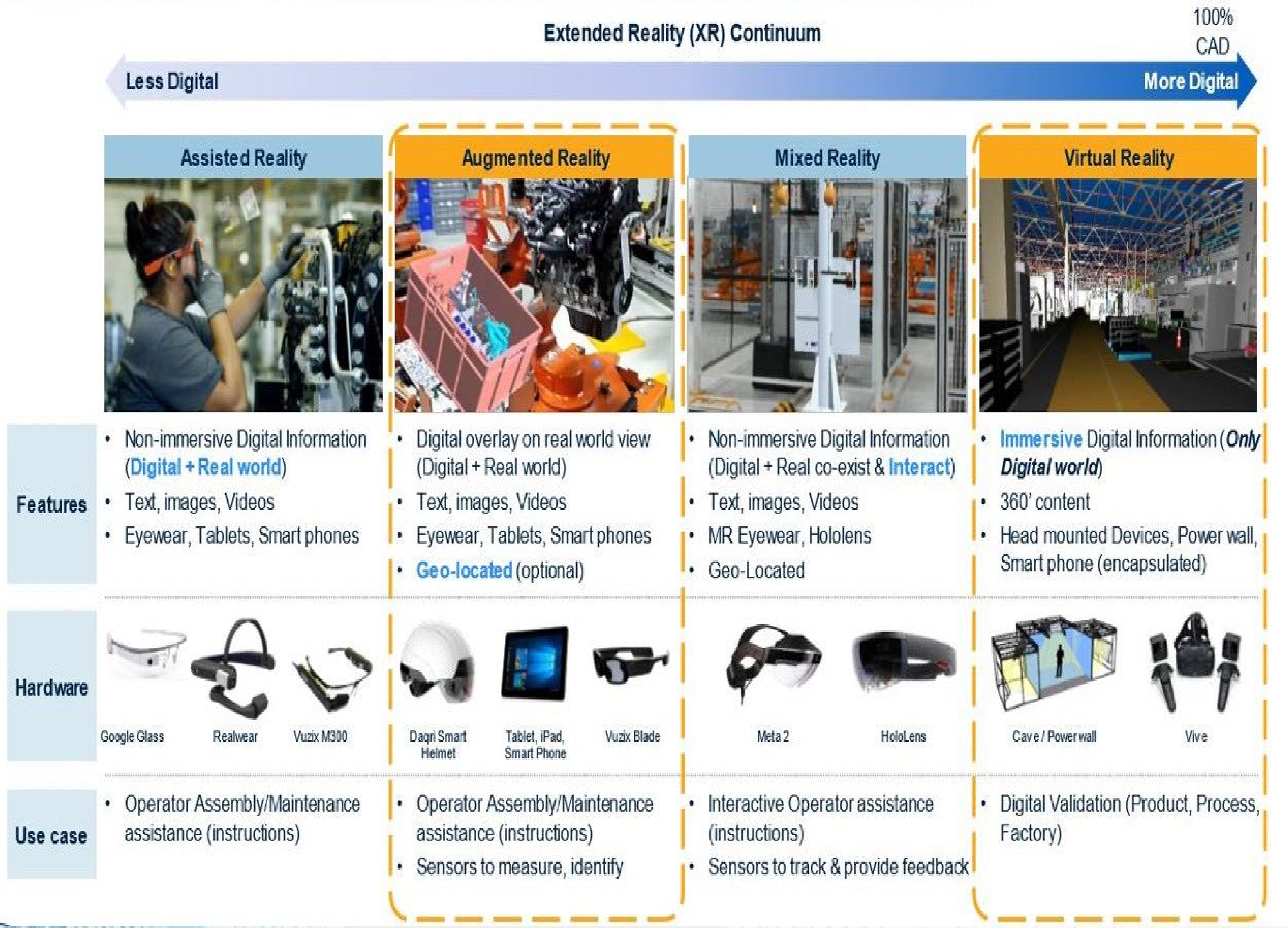
Thirty Meter Telescope

Others to add:

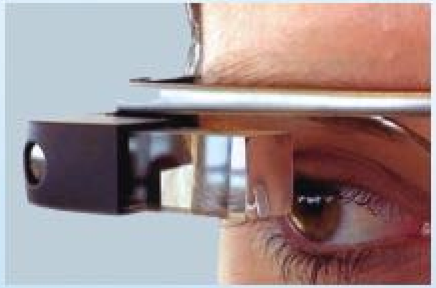
- **A2100 Satellite Family (Inc GPS III)**
- **Medical device**

Chapter 3
Future State of Systems Engineering





Immersive technologies support data visualization



Cloud-based high performance computing supports high fidelity system simulations

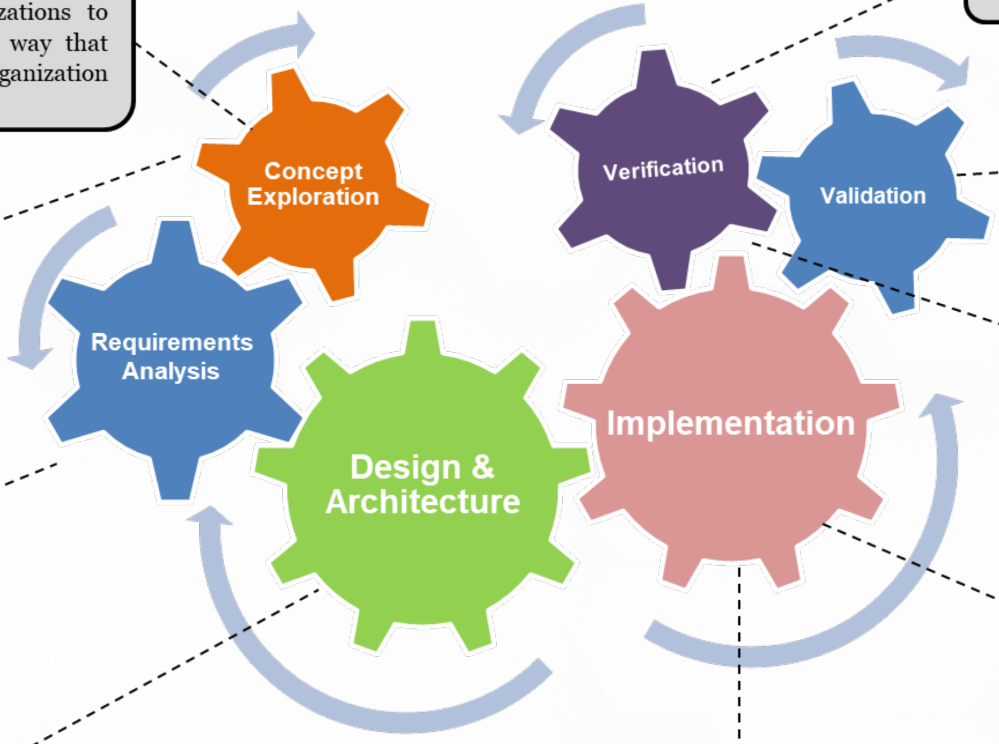
Ubiquitous, low cost, and nearly unlimited compute capacity available on demand, will allow systems engineers to evaluate an un-precedented number of alternatives, at any fidelity required to answer the questions central to understanding the system of interest.

The Impacts of AI on Systems Engineering

There will be new AI techniques joining neural and symbolic methods allowing SE organizations to describe the design domain in such a way that algorithms can tailor support for the organization and system of interest.

SEs will play a critical role in setting the context, and encoding domain concepts in such a way that AI powered design tools can leverage to generate alternative designs for evaluation and tradeoff.

NLP techniques will be used to help SEs write better specifications, removing ambiguity, identifying incompatible requirements and assessing the impact of requirements on the final design.



AI enabled tools will help identify and optimize the required testing to build confidence in a system.

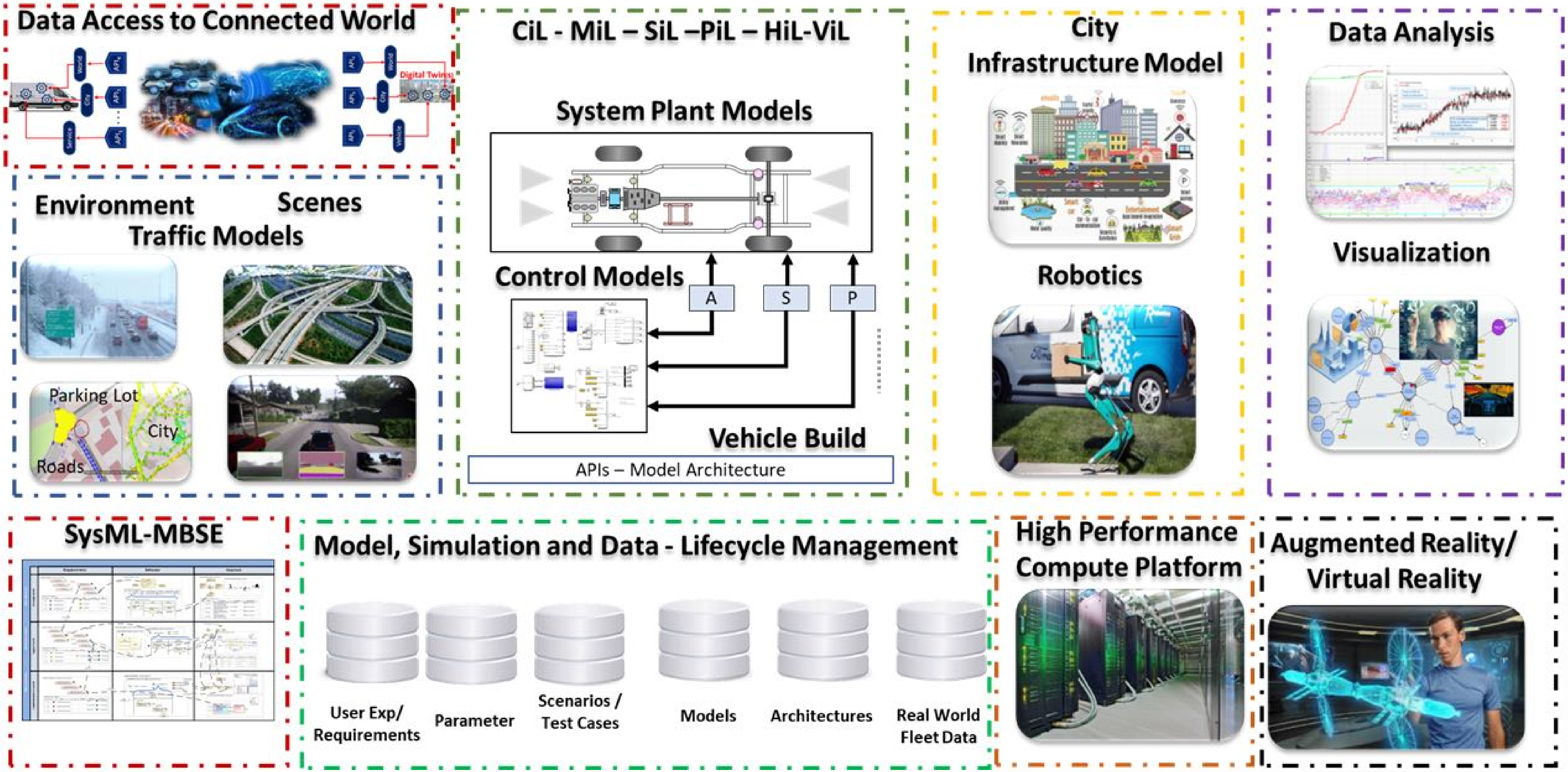
SEs will have to ensure algorithms are not biased as part of the validation process

SEs will need to adapt how they plan and execute tests to gain sufficient coverage and trust on non-deterministic systems without relying on brute force methods.

The SE community will need to become more versed in AI and Machine Learning methods as systems begin to leverage more components enabled by these algorithms.

AI enabled tools help to drive design activities in collaboration with the SE and help avoid bad design choices that do not support the design intent.

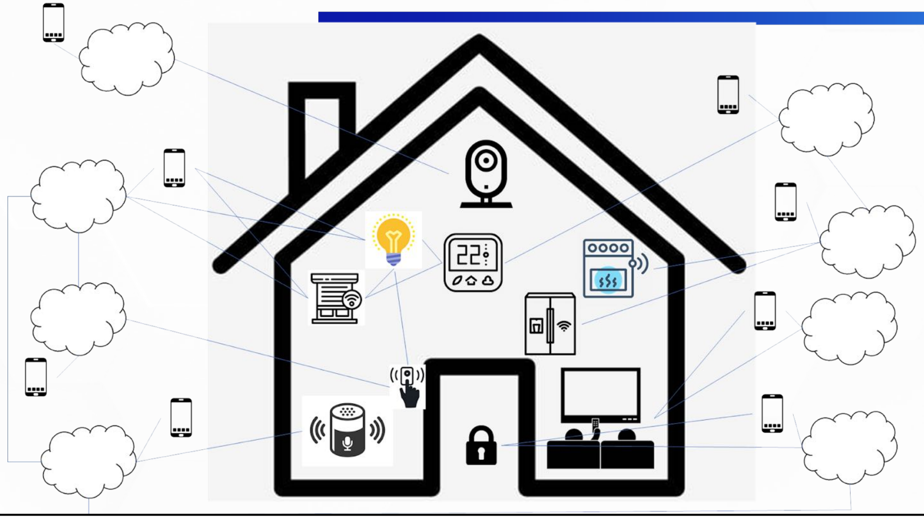
SEs will have a new role in building and evaluating training and testing data for algorithms to help ensure the data is balanced and representative of the real environment the system will operate in.

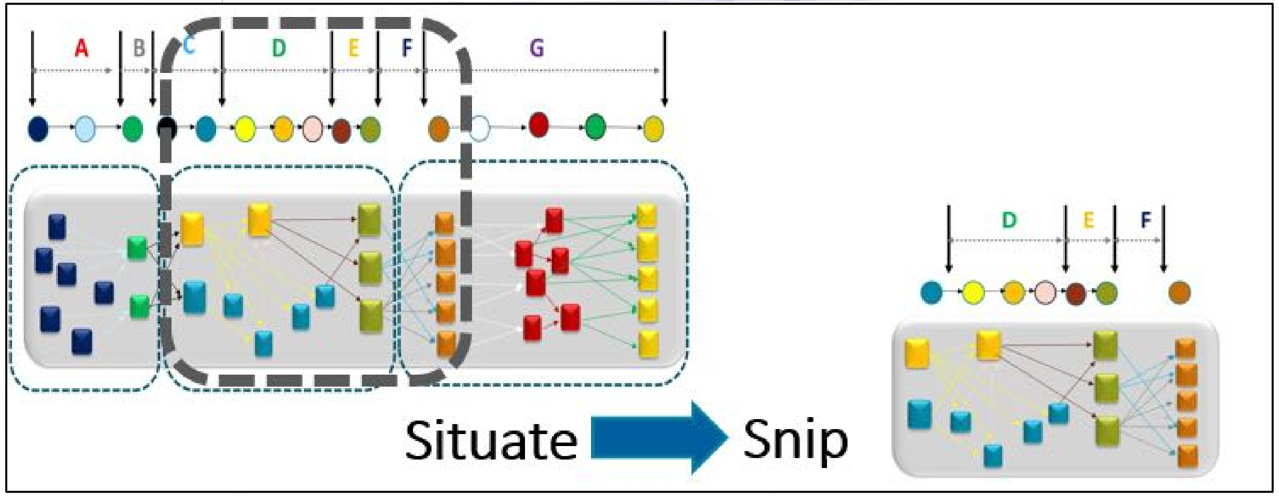

Data Access to Connected World
Digital Twins
CiL - MiL – SiL –PiL – HiL-ViL
System Plant Models
Control Models
A
S
P
Vehicle Build
APIs – Model Architecture
City
Infrastructure Model
Robotics
Data Analysis
Visualization
Environment
Scenes
Traffic Models
Parking Lot
City
Roads
SysML-MBSE
Model, Simulation and Data - Lifecycle Management
User Exp/
Requirements
Parameter
Scenarios /
Test Cases
Models
Architectures
Real World
Fleet Data
High Performance
Compute Platform
Augmented Reality/
Virtual Reality

The Future is Model-Based

- The descriptive MBSE model framework needs to be seamlessly and dynamically linked to the dynamic simulation model framework.
- Each framework needs to be extended upstream to enable efficient capture, modelling, simulation and analysis of User Experiences. They need to be extended downstream to include Manufacturing, Service Updates and Decommissioning.
- High bandwidth, bi-directional connectivity must be established between the model frameworks. This must support both fresh data ingestion, segmentation and object/scene identification as well as agile deployment of exploratory ghost features and services to obtain just in time customer usage specific trend data.
- Efficient usage of integrated AR, VR and hybrids supported by 3D visualization spaces that configure to the operational domain spaces being studied.
- Full integrated xLM (ALM, PLM, MLM, SLM) asset management systems that support Continuous Integration, Build, Validation and Publication

System of Systems Engineering





- In 2035 the SoSE community has grown to include practitioners across a diverse set of domains including Government-Policy, Civil and Commercial.
- This community has defined new SoSE Patterns that are leveraged to design and implement extensible, robust and adaptive SoS solutions.
- By 2035, these communities have identified the collective advantage of working together and treating the aggregate set of separately owned and operated technical and nontechnical systems and applying a broad-based systems approach despite the lack of a 'top level authority'. This opens new opportunities for implementing SoSE across domains.

Evolving & Emerging Practices

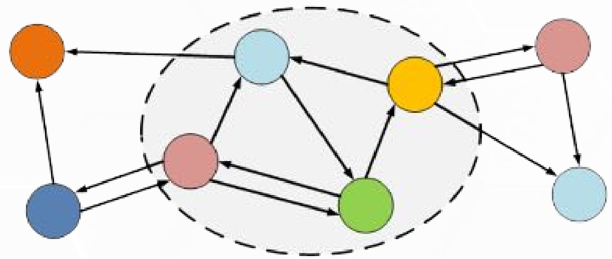
- Feature-based Product Line Engineering
- Architecting for Resiliency and Flexibility
- Engineering Trusted Systems
- Complex Systems Analysis
- System of Systems Design & Analysis
- Human Systems Integration
- Collaborative Design & Acquisition
- …

SE Theoretical Foundations

Systems Engineering has become a practice based on theoretical foundations concerning Observable Phenomena in the engineered systems and their environment:

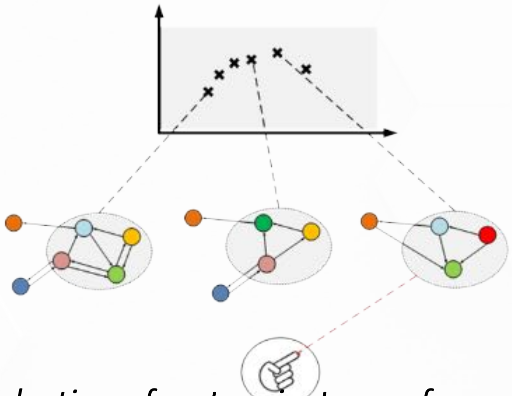
- **The System Phenomenon**
- **The Value Selection Phenomenon**
- **The Model Trust by Groups Phenomenon**

1. The System Phenomenon



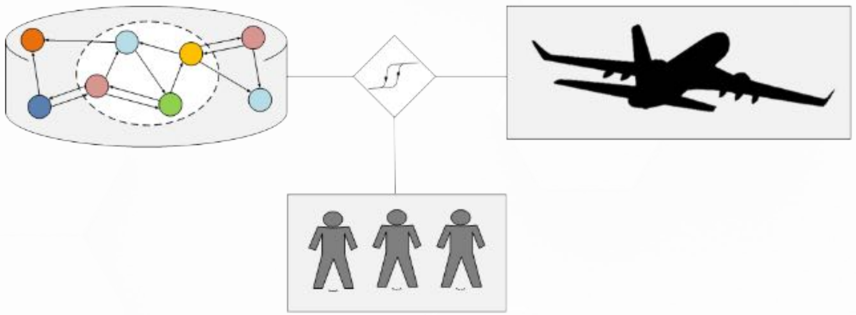
Interacting system components, IO exchange, state dependency and impact, emerging system parameters and behaviors

2. The Value Selection Phenomenon



Selection of system instance, form, and parameter values

3. The Model Trust by Groups Phenomenon



Model improvement based on empirical observation, shared learning, managed model uncertainty, shared human trust across a group in a model of a system.

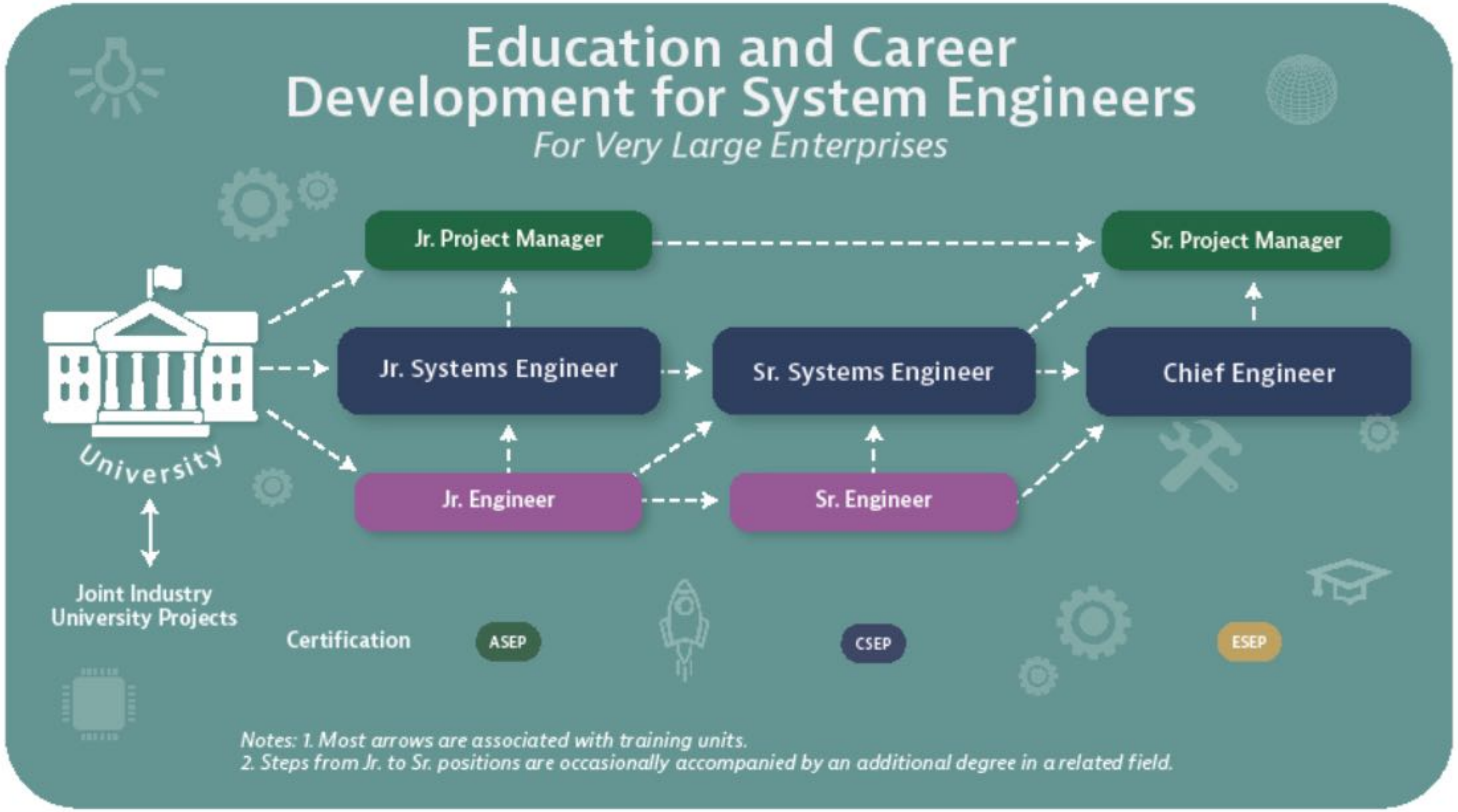
SE Education & Training

Re-engineering our engineering education

"There has never been a better time to be an engineer with special skills or the right education, because these people can use technology to create and capture value.

However, there has never been a worse time to be an engineer with only "ordinary" skills and abilities to offer: Employability competition is worldwide. Engineering students all over the globe, computers, virtual assistants and other thinking machines are acquiring these skills and abilities at an extraordinary rate." Brynjolfsson and McAfee (2014)

- **Schools and primary education will be continuously adapted**
- **Universities are destined for substantial change**
- **Training providers & employers have an important role**
- **Life-long learning will be critical**



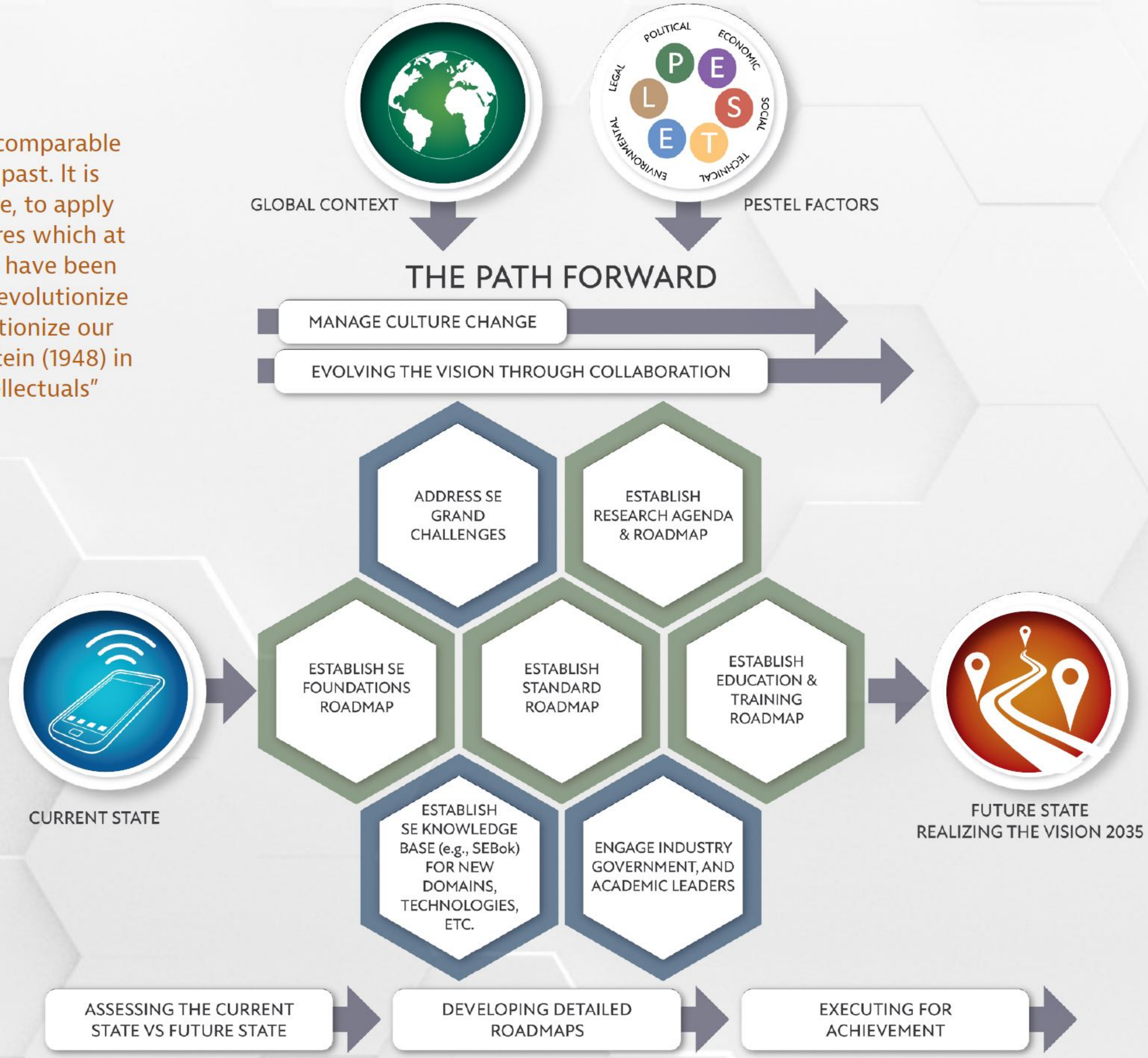
Summary

- The Future of SE Is Model Based, Enabled by a major Digital Transformation
- Systems Engineering will incorporate material from other disciplines such as Data Science to help manage the growth in data
- Formal SE Theoretical Foundations will be codified leading to new research and development in the next generation of SE methods and tools
- AI will both impact the SE practice and the types of systems designed by the SE community
- There will be a step change in SE education starting with early education with a heavy focus on lifelong learning

Chapter 4
Realizing the Vision

Path Forward

Our situation is not comparable to anything in the past. It is impossible, therefore, to apply methods and measures which at an earlier age might have been sufficient. We must revolutionize our thinking, revolutionize our actions… Albert Einstein (1948) in "A Message to Intellectuals"



Collaboration: An Essential Element

Organizational Change Management and Culture Change with Incremental Objectives are also Essential Elements

SE Grand Challenges – Outcomes needed for Success

CATEGORY	SE GRAND CHALLENGES
APPLICATIONS	1. SE contributes innovative solutions to major societal challenges. 2. SE is recognized for providing value to an increasing number of enterprises and domains.
PRACTICES	3. Systems engineering anticipates and effectively responds to an increasingly dynamic and complex environment. 4. Model-based systems engineering, integrated with simulation, multi-disciplinary analysis, and immersive visualization environments is standard practice. (i.e., SE is Model-based) 5. Systems engineering provides the analytic framework to analyze, specify, design, and realize increasingly complex systems. 6. Systems engineering has widely adopted reuse practices such as product-line engineering, patterns, and composable design practices.
TOOLS & ENVIRONMENTS	7. Systems engineering tools and environments enable seamless, trusted collaboration and interactions as part of the digital ecosystem.
RESEARCH	8. Systems engineering practices are based on accepted theoretical foundations and taught as part of the systems engineering curriculum.
COMPETENCIES	9. Systems engineering education is part of the standard engineering curriculum, and is supported by a continuous learning environment.

SE Grand Challenges reflect necessary accomplishments that must be addressed for Systems Engineering to evolve and be prepared for the future

Specific Recommendations (to the SE Community) - Roadmaps for Progress

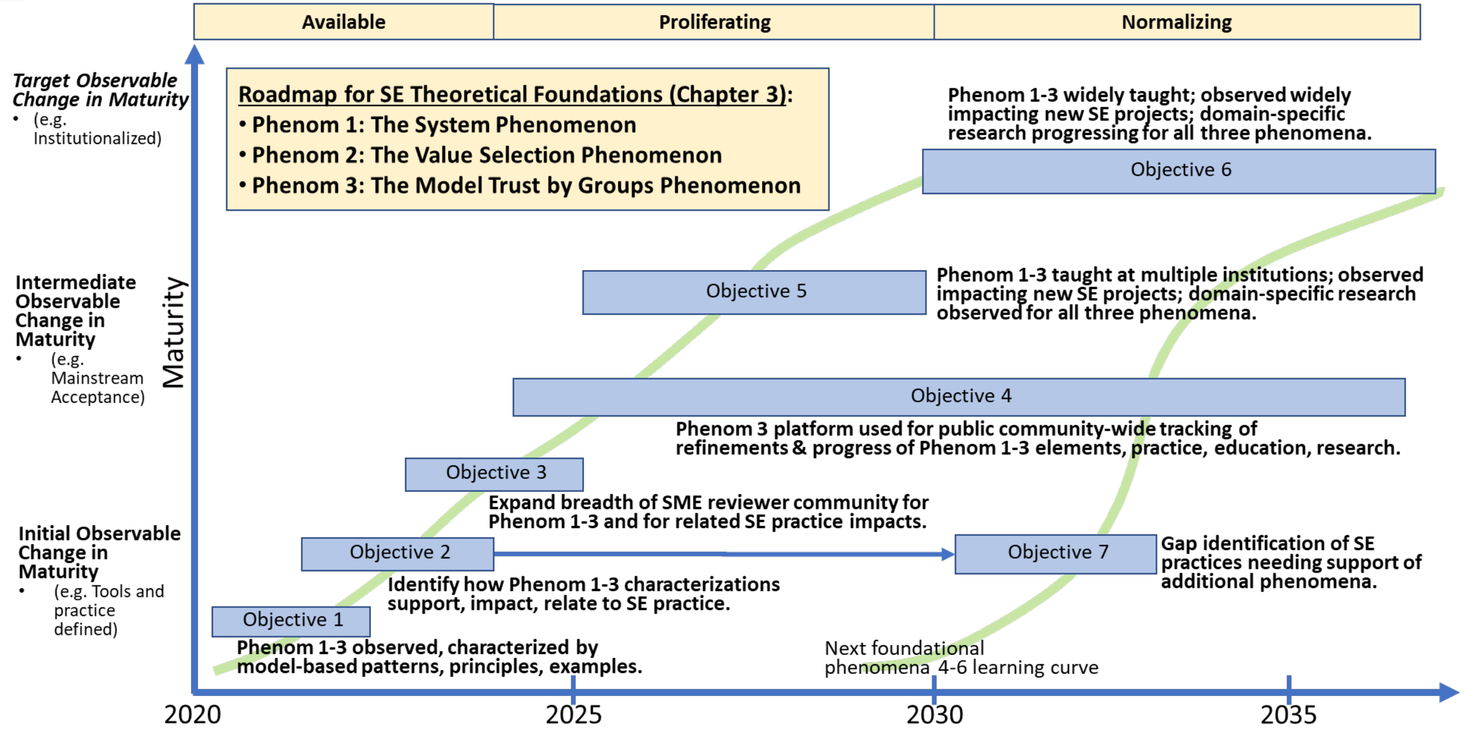
SE Grand Challenge Category: Research

SE FOUNDATIONS AND RESEARCH

CHANGE NEEDED ▸▸ Balance new foundations, concepts, and technologies with existing requirements

CHANGE NEEDED ▸▸ Incorporate foundations into SE education and practice and add SE concepts/ system thinking to all engineering disciplines

Example format – roadmap content is not complete



SHIFTING PERSPECTIVES

Achieving the future view of Systems Engineering will require managing the organizational change and the associated culture change.

SE Vision 2035 Preliminary Review

Paul Schreinemakers, ESEP
Chair of the Review Support Team
Date: Jan 2021

Current planning

- January 2021
  - Final Core-Team review of Chapters
  - Core-Team meeting during IW2021
  - Introduce SE Vision 2035 during the IW2021 Town Hall meeting (Sunday Jan 31st)
- February 1 or 2 → Send Review letter to all reviewers
- February 1 – March 15 → review executed by the reviewers
- March 16 – April 14 → Processing the review comments by the RST*
- April 15 → submit review results to the editorial team
- 2021 Q3 – Q4 → release of updated SE Vision document for final Review
- 2022 → release of Final Version of the SE Vision 2035

Smartsheet Collection of review data

SE Vision 2035 Portal

Systems Engineering Vision 2035

Document Review Portal

Number of Registered Reviewers
8

Number of Comments Submitted
17

General Messaging

Welcome!

Please follow the below instructions to participate in the review process:

1. Decide on your comment return plan (web form or Excel bulk upload)
2. Register for document access and your unique Reviewer ID using the form to the right.
3. Download the SE Vision 2035 document and review the content.
4. Submit comments via the web form, linked below. *This is the preferred method.* (**Deadline: March 15, 2021**) OR,
5. Collect comments in bulk using the Excel form provided, and then upload the comment form. (Deadline: March 15, 2021)

Submit Reviewer Comments

Reviewer Comment Submittal Web Form

Bulk Comment Upload

Editor Team Links

- **SE Vision 2035 Editor Dashboard**
- SE Vision 2035 User HELP
- Sheet - Team & Editors & Invited Reviewers
- Sheet - Registered Reviewers and Bulk Commenting
- Sheet - Metrics
- Sheet - Master Comment Collection
- Process Diagrams

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Reviewer Registration Form

Submit this form to register as a reviewer for the Systems Engineering Vision 2035 draft document and to receive your unique Reviewer ID for use when submitting comments.

A link for PDF download will be emailed to the address provided.

Reviewer Data

Any data collected on behalf of International Council on Systems Engineering is being electronically handled for the purpose of providing you the ability to participate in this review service. Please refer to INCOSE Privacy Notice at https://www.incose.org/privacy-notice for more details.

Name *

Email *

Organization *

Org Type *
Select

INCOSE Membership *
Select

Global Sector *
Select

Country
of residence

Comment Submittal Plan

Smartsheet web form submittal is the preferred comment method. An Excel form for bulk collection and upload may be requested.

Comment Method
Web form (online)

Submit

INCOSE

SE Vision 2035 Reviewer Comment Submission Form

Instructions for review

Commenter Reference

Comments without a valid Reviewer ID will not be considered.

Reviewer ID is provided in the SE Vision 2035 document access email.

You can re-register to obtain a new Reviewer ID at https://app.smartsheet.com/b/form/253f76ed0c8a4a189c76bfeab646c165

Reviewer ID *
Format: XX-XXX
(example: Mo-137)

Comment Reference

Chapter *
Select

Page *

Line

Figure

Table

Comment

Comment Type *
Select

Comment *

Proposed Text *
Enter "N/A" if no proposed text.

Proposed Graphic
Include description and/or hyperlink to suggestion

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Review steps for reviewers (1)

- Register as reviewer via the secure website: http://..........
  - While registering, INCOSE members will be asked about the constituency(s) they belong to
  - Indicate whether you will submit review comments in bulk (spreadsheet) or at the online form
  - You will receive a confirmation e-mail after registering
- Download the SE Vision 2035 via the link provided after registering
  - PLEASE DO NOT DISTRIBUTE THIS DRAFT VERSION TO OTHERS THAN THE INTENDED REVIEWERS!!!!!!!
- Review the entire document or those chapters that are of your interest
  - Please make sure that you take notice of the dedicated reviewer's instructions at the beginning of each chapter.
  - For each observation its mandatory to register: Chapter #, Page, Comment type and Proposed alt. text
  - Suggestions and comments may be related to existing text, missing information or regarding proposed graphics to be used in the document.
  - Please avoid statements like "This chapter is rubbish" → Preferably point to a specific observation and provide a specific suggestion (text and or graphic) for improvement

Review steps for reviewers (2)

Individual reviewers (invited)

- Submit your review comments via the online ‘Review Comment Submission Form’
- ….or in bulk via the dedicated spreadsheet

Group reviews

- PoC distributes the Vision document to the intended reviewers.
  - We suggest that you let all reviewers use a dedicated spreadsheet to capture comments
- PoC gathers all review comments of their organization (Chapter, CAB org, University or Working Group)
  - Do a first sanity check of the comments gathered and take out doublings, inconsistencies or request missing information from the individual reviewer.
  - Merge all comments into a single spreadsheet
- Submit the review comments in bulk via the dedicated spreadsheet

Thank You

Your review efforts will be very appreciated!!

Paul Schreinemakers
www.incose.org
paul.schreinemakers@incose.net

Closing

by Heinz Stoewer