Digital Transformation: Drivers, Challenges, and Opportunities

Troy Peterson

SSI Vice President &
INCOSE FUTURE & Transformation Lead

www.sercuarc.org

July 16, 2020

Digital Transformation

Wikipedia:
Digital Transformation is the use of new, fast and frequently changing digital technology to solve problems. It is about transforming processes that were non digital or manual to digital processes.

CIO and Leading Digital
Digital transformation marks a radical rethinking of how an organization uses technology, people and processes to fundamentally change business performance, says George Westerman, MIT principal research scientist and author of *Leading Digital: Turning Technology Into Business Transformation*.

DIGTIAL

It's more than bits of information in digital formats. Its about how the bits can be combined to provide new insight, capability and value.

TRANSFORMATION

It's more than modernization or continuous improvement, it's game changing, >10x improvement

DIGTIAL TRANSFORMATION

It's across all sectors driving profound change all around us.

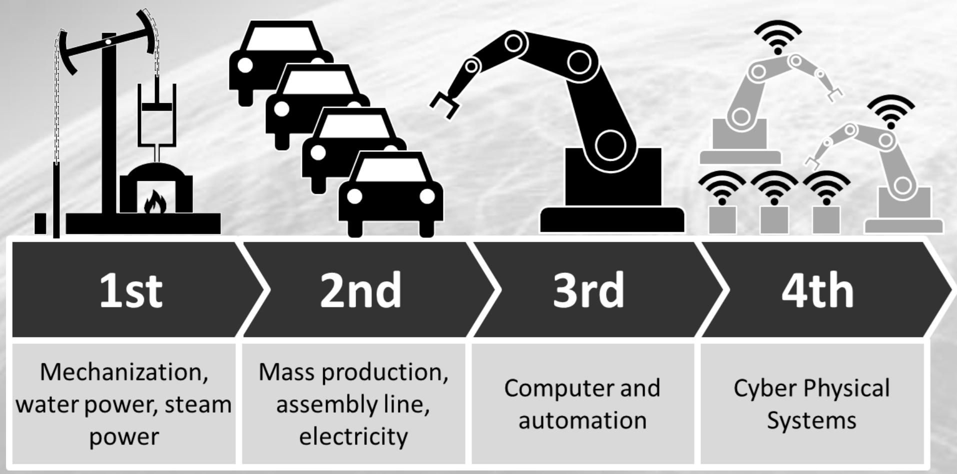
It connects, links and relates information in ways that can provide new insight, predictive capacity and value. Models underpin digital transformation

The Next Industrial Revolution and Digital Engineering

Fourth Industrial Revolution

“The world is entering the Fourth Industrial Revolution. Processing and storage capacities are rising exponentially, and knowledge is becoming accessible to more people than ever before in human history. The future holds an even higher potential for human development as the full effects of new technologies such as the Internet of Things, artificial intelligence, 3-D Printing, energy storage, and quantum computing unfold.”

The Global Information Technology Report
Innovating in the Digital Economy - 2016
World Economic Forum



Industry 4.0 Design Principles

Interconnection:

- The ability of machines, devices, sensors, and people to connect and communicate with each other via the Internet of Things (IoT)

Information transparency:

- The transparency afforded by Industry 4.0 - vast amounts of useful information to make full life cycle decisions concept to retirement.

Technical assistance:

- The ability of the systems to assist humans in decision making

Decentralized decisions:

- The ability of cyber physical systems to make decisions on their own

Digital engineering is defined as “an integrated digital approach that uses authoritative sources of systems’ data and models as a continuum across disciplines to support lifecycle activities from concept through disposal [1].”
https://www.dau.mil/glossary/pages/3626.aspx.

Furthermore, it…combines model-based techniques, digital practices, and computing infrastructure…”

Drivers: Trends Affecting Digital Transformation

WORLD ECONOMIC FORUM
COMMITTED TO IMPROVING THE STATE OF THE WORLD

As a foundation to its work, the council sought to identify the software and services megatrends which are shaping society, and their associated opportunities and risks.

People and the internet
How people connect with others, information and the world around them is being transformed through a combination of technologies. Wearable and implantable technologies will enhance people's "digital presence", allowing them to) interact with objects and one another in new ways.

Computing, communications and storage everywhere
The continued rapid decline in the size and cost of computing and connectivity technologies is driving an exponential growth in the potential to access and leverage the internet. This will lead to ubiquitous computing power being available, where everyone has access to a supercomputer in their pocket, with nearly unlimited storage capacity.

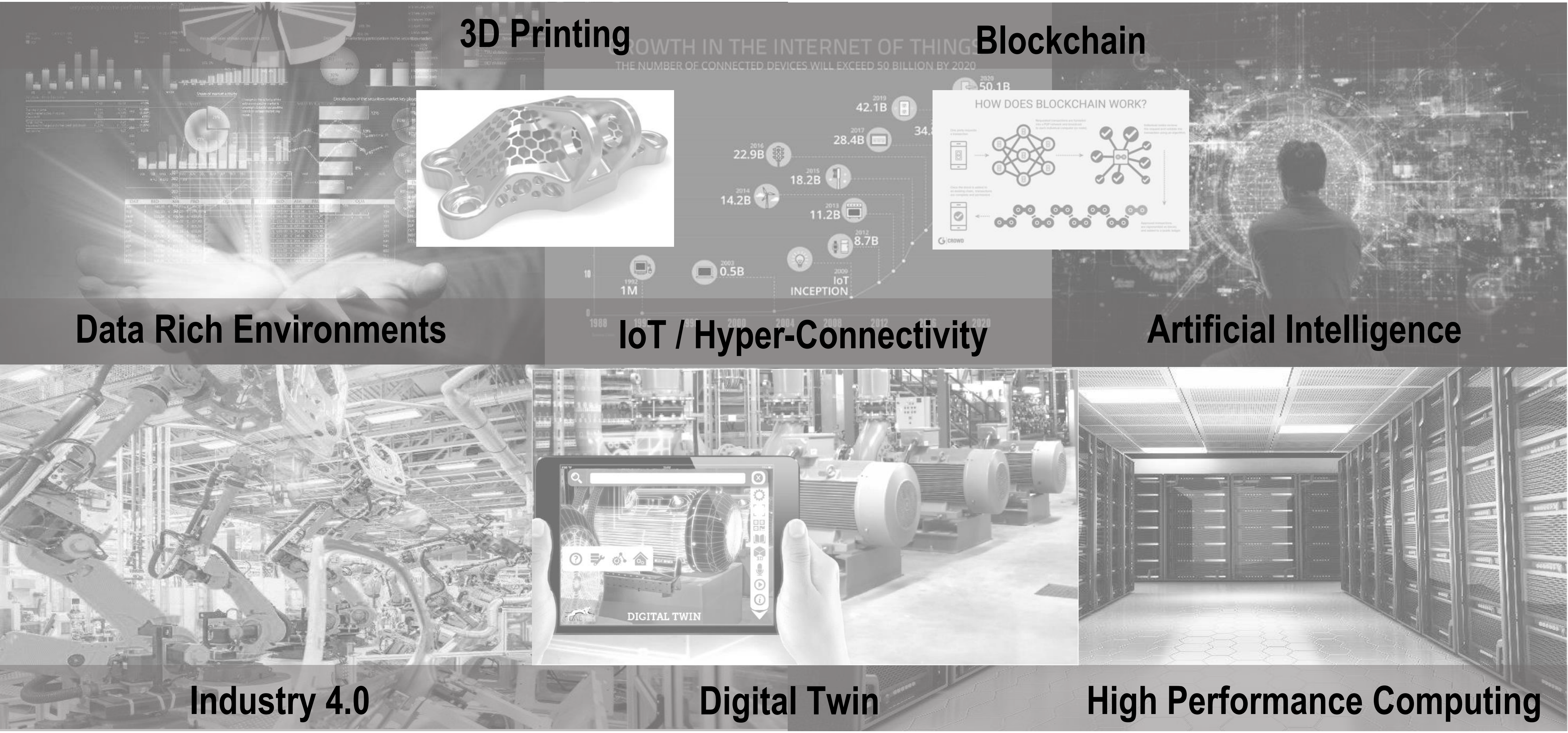
The Internet of Things
Smaller, cheaper and smarter sensors are being introduced - in homes, clothes and accessories, cities, transport and energy networks, as well as manufacturing processes.

Artificial intelligence (AI) and big data
Exponential digitization creates exponentially more data - about everything and everyone. In parallel, the sophistication of the problems software can address, and the ability for software to learn and evolve itself, is advancing rapidly.
This is built on the rise of big data for decision-making, and the influence that AI and robotics are starting to have on decision-making and jobs.

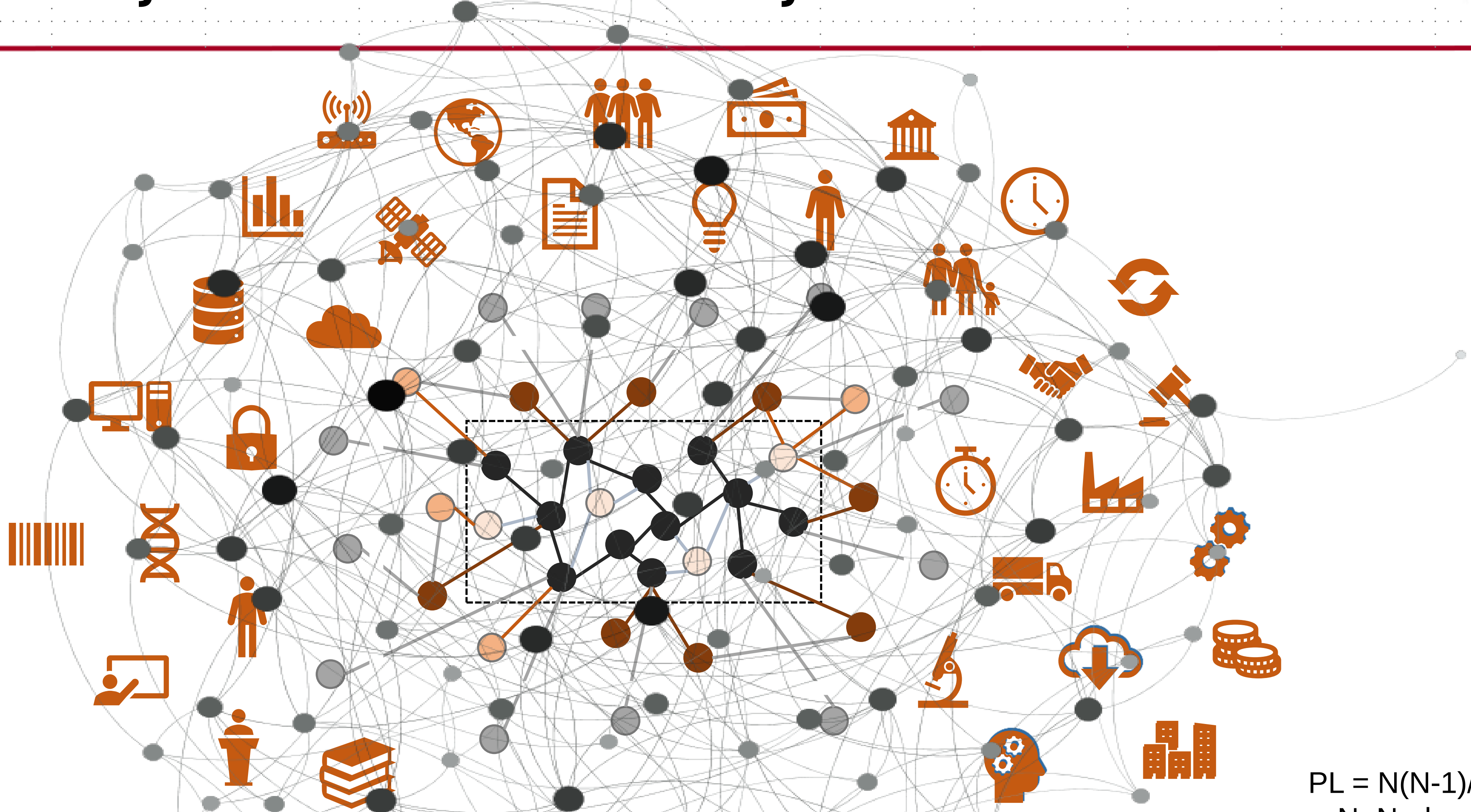
The sharing economy and distributed trust
The internet is driving a shift towards networks and platform-based social and economic models. Assets can be shared, creating not just new efficiencies but also whole new business models and opportunities for social self organization. The blockchain, an emerging technology, replaces the need for third-party institutions to provide trust for financial, contract and voting activities.

The digitization of matter
Physical objects are “printed" from raw materials via additive, or 3D, printing, a process that transforms industrial manufacturing, allows for printing products at home and creates a whole set of human health opportunities.

Drivers: Rapidly Evolving Enabling Technologies



Drivers: Systems and Interconnectivity



System Elements & Interactions
External Elements & Interactions
Increased Density of System Elements & Interactions
Increased Density of System External Elements & Interactions
Increased Interactions Between External Elements
Expanding System Domain Boundary Increasing Interactions

PL = N(N-1)/2
N=Nodes
PL=Potential Links
Potential System Configurations = 2^{PL}
N=20, PL =190, PSC = 2^{190*}

**Number of known atoms in the universe ~ 2^{158} and 2^{246}*

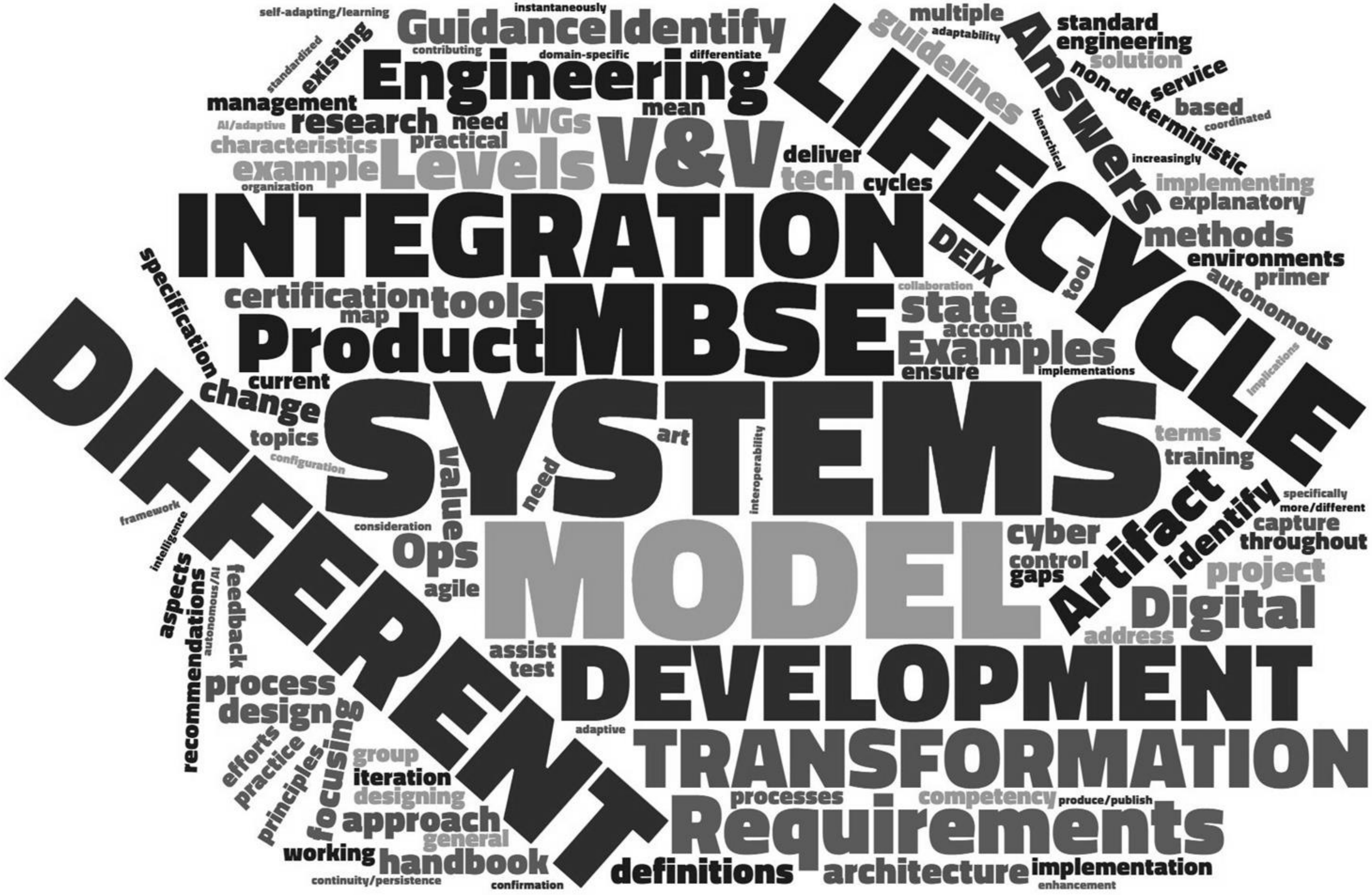
Drivers: Specialized Systems of Growing Complexity

Drivers: INCOSE Corporate Advisory Board Smart Goals

INCOSE
International Council on Systems Engineering

CAB SMART Goals:
Top Work Uses

19	SYSTEMS
14	MODEL
13	DIFFERENT
12	LIFECYCLE
11	V-MODEL
11	MBSE
10	INTEGRATION
10	DEVELOPMENT
10	V&V
7	TRANSFORMATION



Challenges: The Need to Address Speed and Complexity

"Today more and more design problems are reaching insoluble levels of complexity."[1]

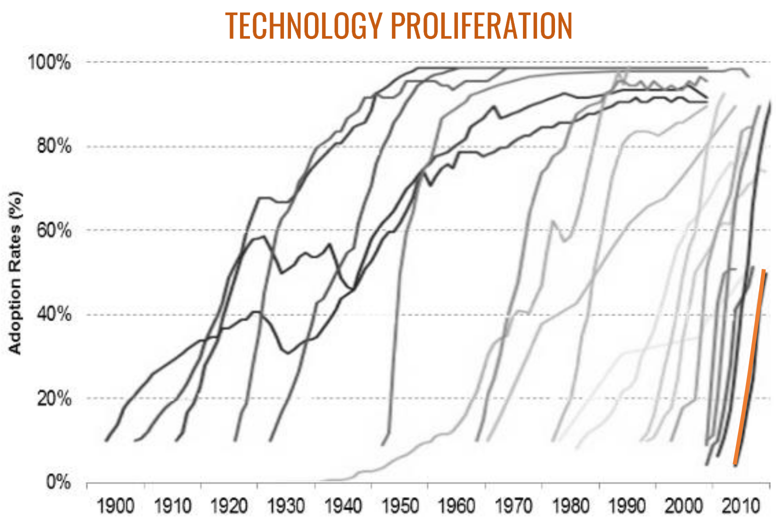
"At the same time that problems increase in quantity, complexity and difficulty, they also change faster than before."[1]

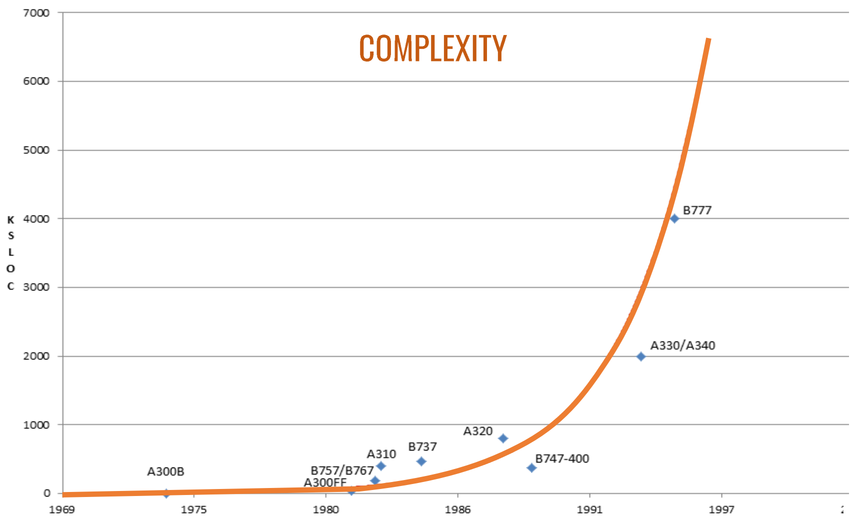
"Trial-and-error design is an admirable method. But it is just real world trial and error which we are trying to replace by a symbolic method. Because trial and error is too expensive and too slow."[1]

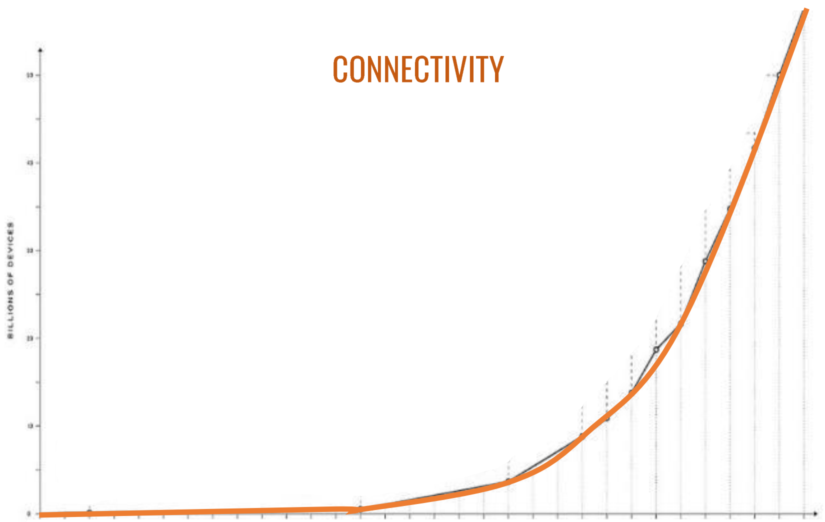
1. Christopher Alexander, "Notes on the Synthesis of Form" Harvard University Press, Cambridge Massachusetts, 1964

Challenges: Growing Complexity

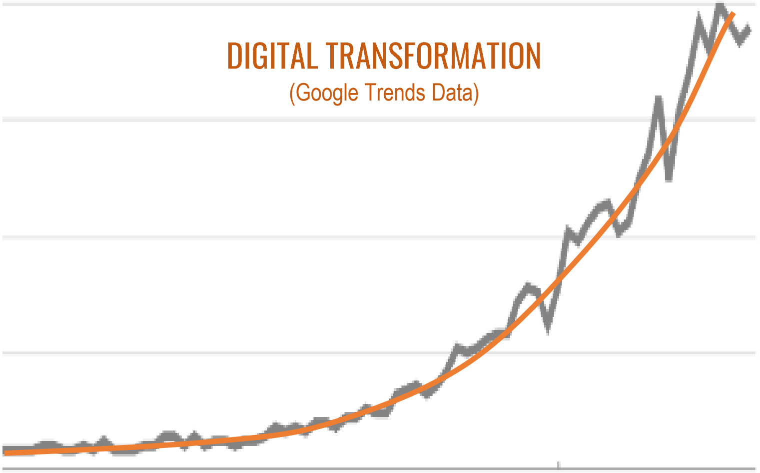
Contextual Challenges

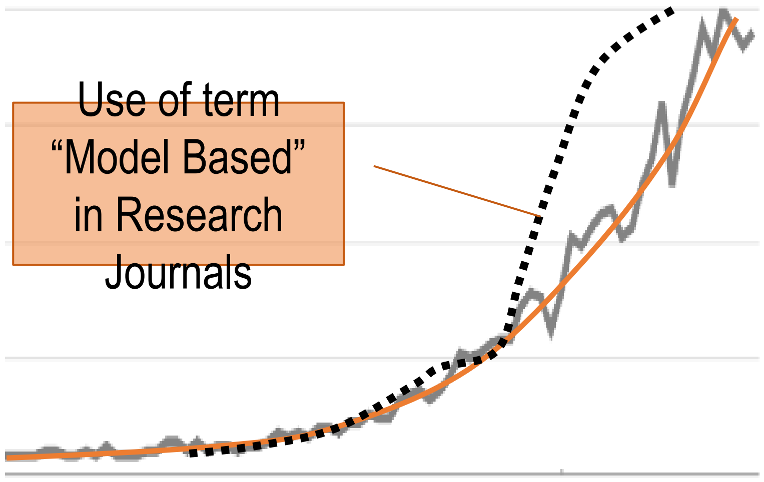


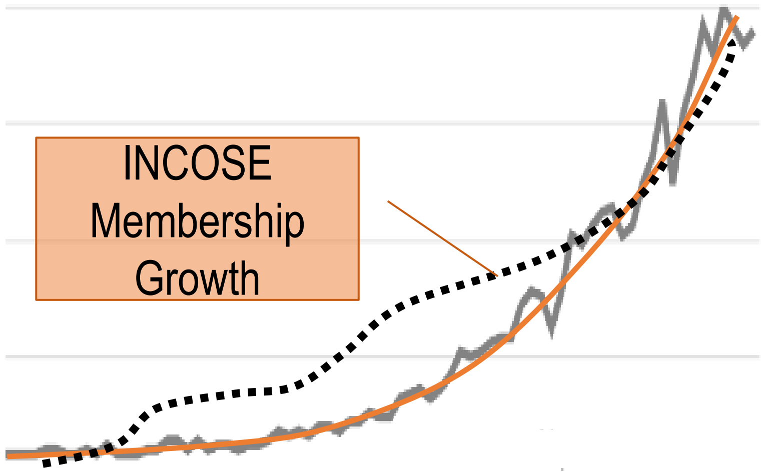




Solution Seeking

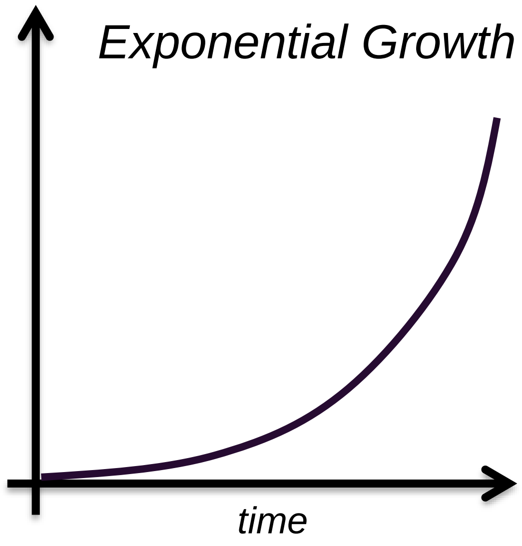


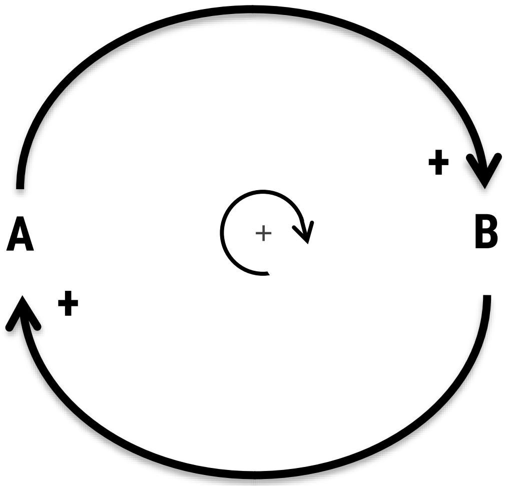


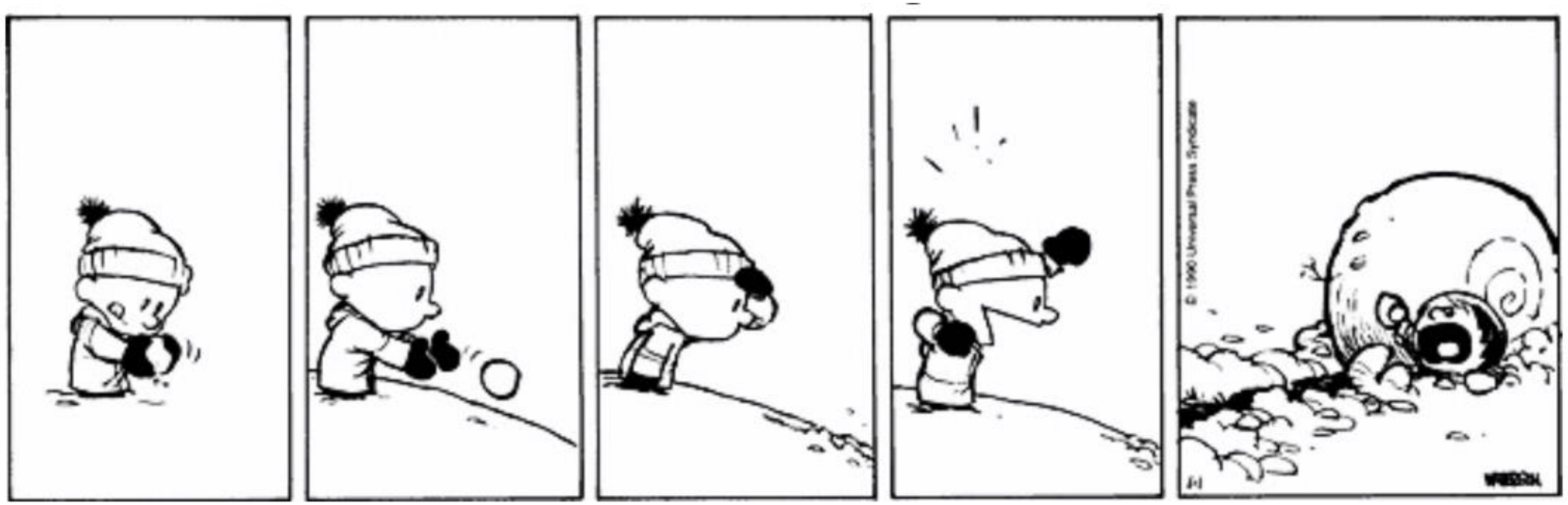


Challenges: Understanding Exponential Growth

- *Connected Devices*
- *Software /LOC*
- *Tech Adoption*
- *Automation*
- *Usage of Sensors*
- *Electronics Integration*
- *Autonomous Systems*



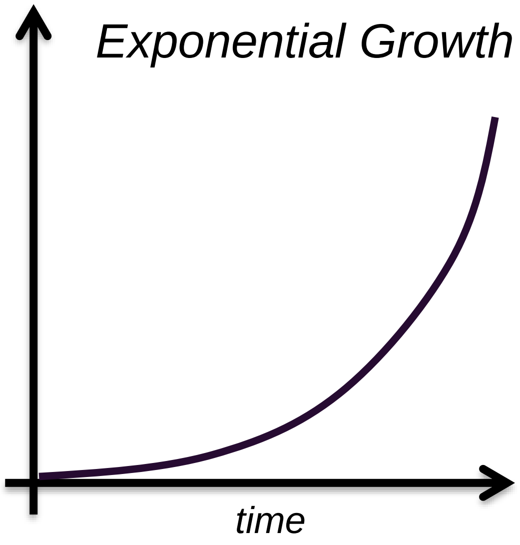


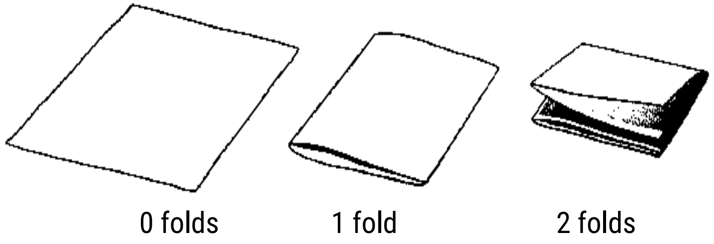


Challenges: Magnitude and Underestimation

Traditional development methods do not adequately address the complexity of systems today

The explosive growth of cyber-physical systems has rapidly and dramatically increased complexity all around us. Seamlessly intertwining computational algorithms and physical components, these systems have significantly increased the demands on engineering rigor to ensure safety, quality, security, sustainability, adaptability, and more, all while delivering products more rapidly.





We routinely underestimate the power of exponential growth.

What is the thickness of a piece of paper after folding it 42 times? What about 100 times?

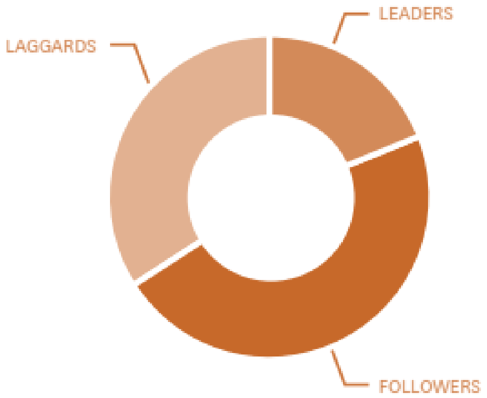
42x = 440,000 km thick
100x = 850T * distance to our sun

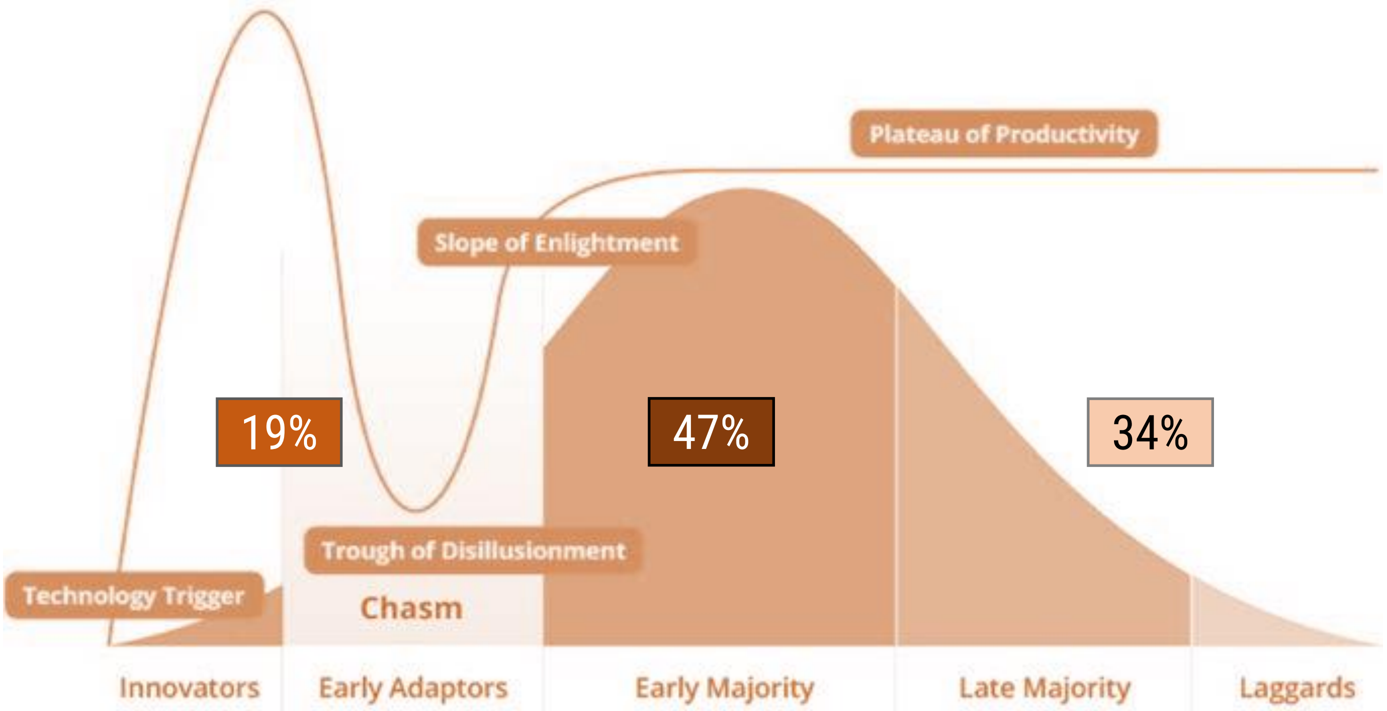
Challenges: Rate of Change

"When the rate of external change exceeds the rate of internal change, the end of your business is in sight."

Jack Welch

Challenges: Organizational Change





Rating of company's digital maturity in leadership and management[5]

More than 80% of respondents are either followers or laggards

Acceleration is very much about sharing, communicating and learning

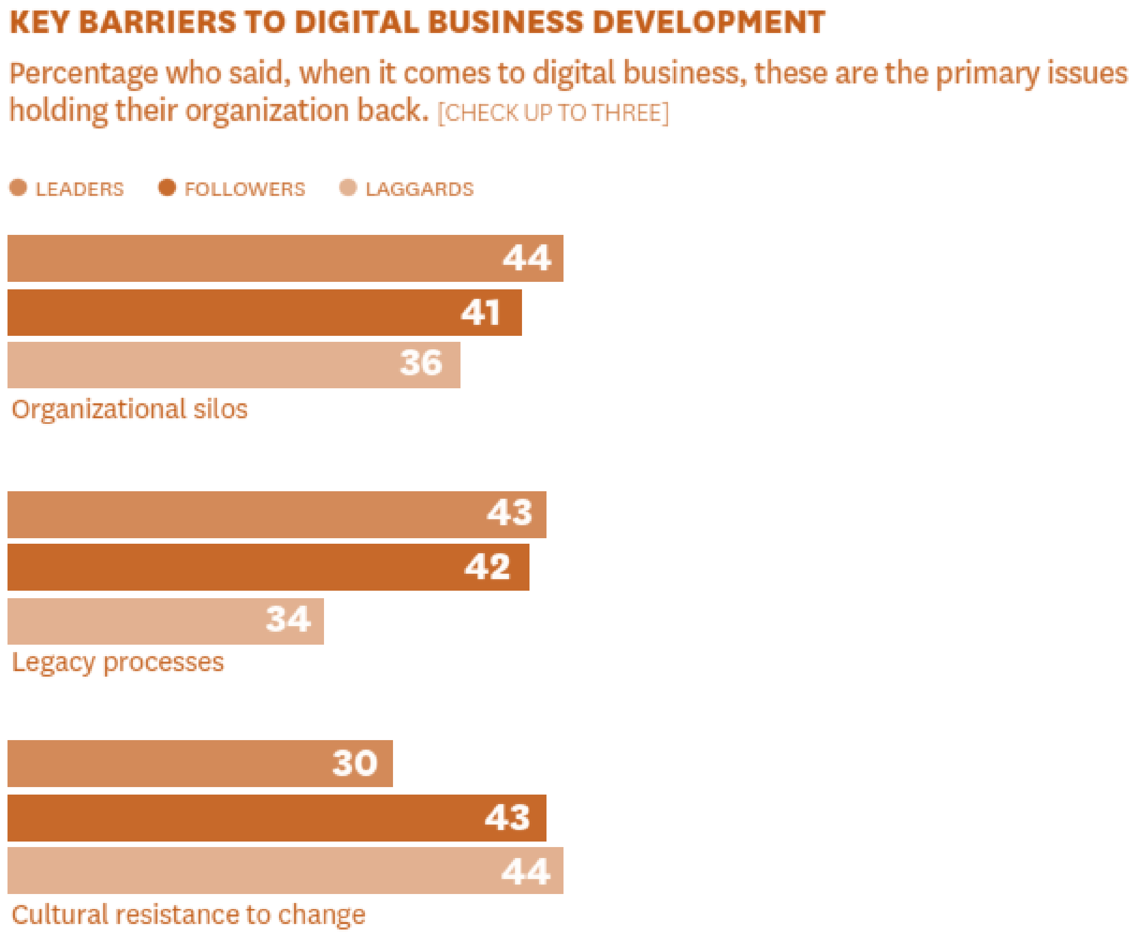
Where would you plot your organization today?

1. Hype Cycle is a branded graphical presentation developed and used by IT research and advisory firm Gartner
2. Hype Cycle Graphic: https://en.wikipedia.org/wiki/Hype_cycle
3. Moore, Geoffrey A. "Crossing the Chasm – and Beyond" Strategic Management of Technology and Innovation Third Edition 1996
4. Hype Cycle, Chasm Combined Graphic: http://www.datameer.com/blog/big-data-analytics-perspectives/big-data-crossing-the-chasm-in-2013.html
5. Driving Digital Transformation: New Skills for Leaders, New Role for the CIO, Harvard Business Review

Challenges: Driving Digital Transformation[1]

Keys to Digital Transformation (HBR Report)

- Start from the customers perspective
- Digital leadership starts at the top
- Engage in a discussion of trends
- Think about agile
- Use examples to make it real
- Need a foundation of trust
- Use KPIs for sharing knowledge
- Break down walls wherever possible
- Need digital coaches or maters
- Create appropriate learning forums



1. Driving Digital Transformation: New Skills for Leaders, New Role for the CIO, Harvard Business Review

Challenges: Cross Functional Nature of Transformation

Integrate dimensions of change

Addresses dimensions in parallel

Concurrency and dimensional trades

Build grass-roots ownership

Obtain top leadership support

Consider:

ABP = CM(OE + PR + IT)

- ABP = Achieving Breakthrough Performance
- OE = Organizational Environment
- BPR = Business Process Reengineering
- IT = Information Technology
- CM = Change Management

Transformation is very much a people focused endeavor.

Challenges: INCOSE CAB MBSE Top Needs and Obstacles

Documents to Models

Needs / Obstacles

- Translate models into decision maker language
- Ability to analyze quickly, proper level of fidelity
- Change management best practices
- Models need to answer stakeholder questions
- Connect modeling to programmatic success
- Demonstration how modeling speeds innovation
- Why change, what is the ROI
- Inability to know if model used is reliable; VVUQ
- Up front costs in resources, time to learn etc.

Process / Methods

Needs / Obstacles

- Clearly demonstrate the value of system model(s)
- Models uncover errors in existing artifacts
- Aid an early adopter with a pain point
- Systems engineering and domain ontologies
- Common MBSE methods and practices
- Better ability to review model quality/accuracy
- Contracting, Intellectual Property and Policy
- Use of requirements documents versus models
- Benefits are not obvious but they should be

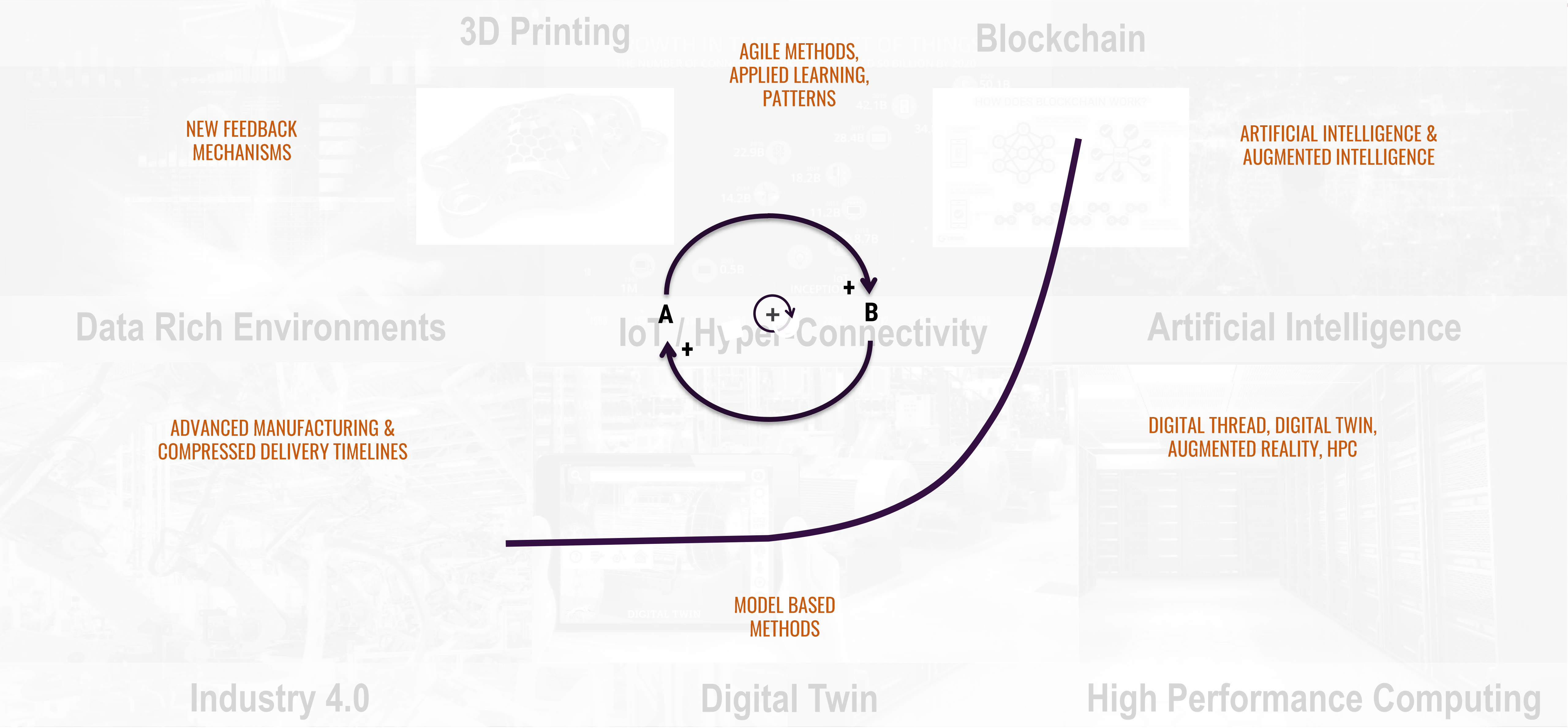
Model Based ROI

Needs / Obstacles

- Seeing through the "Mystique" of MBSE
- Framework to view ROI by process area
- Capitalizing models as intellectual property
- Baseline to compare MBSE application
- Weak Systems Engineering foundation for MBSE
- Lack of understanding; one size does not fit all
- Expressing "Soft" versus "Hard" ROI for MBSE
- Perceived ROI from various stakeholders
- Covering all of the ISO 15288 process areas

Findings from 2015 INCOSE International Workshop Corporate Advisory Board Breakout Sessions

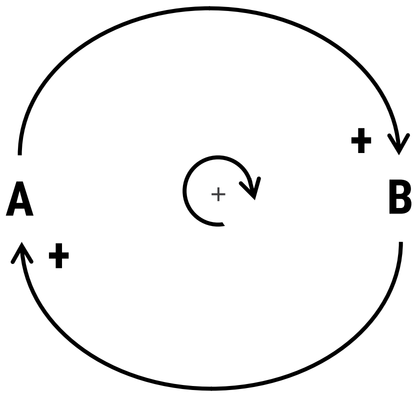
Opportunity: Reinforcing Nature of Advancements



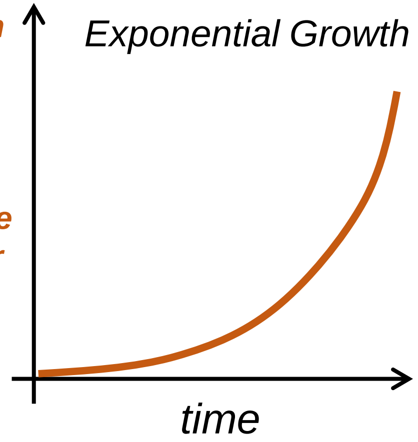
Opportunity: Technological Advancements

Leverage new digital technologies within a MBSE framework to transform how organizations innovate

While the explosive growth of digital technologies introduces many challenges, it also provides significant opportunity. Traditional methods are insufficient, and organizations must transform to use systems and model based methods to meet the challenge. Are you leveraging this exponential growth to transform how you innovate and manage your products, systems and services? the most value added part of your business –?



- *Digital Xformation*
- *Model Based Research*
- *Interest in MBSE*
- *Industry 4.0*
- *Global Datasphere*
- *Computing Power*
- *AI, ML, NLP use*



Opportunity: The Power of Models, Feedback Loops and Learning

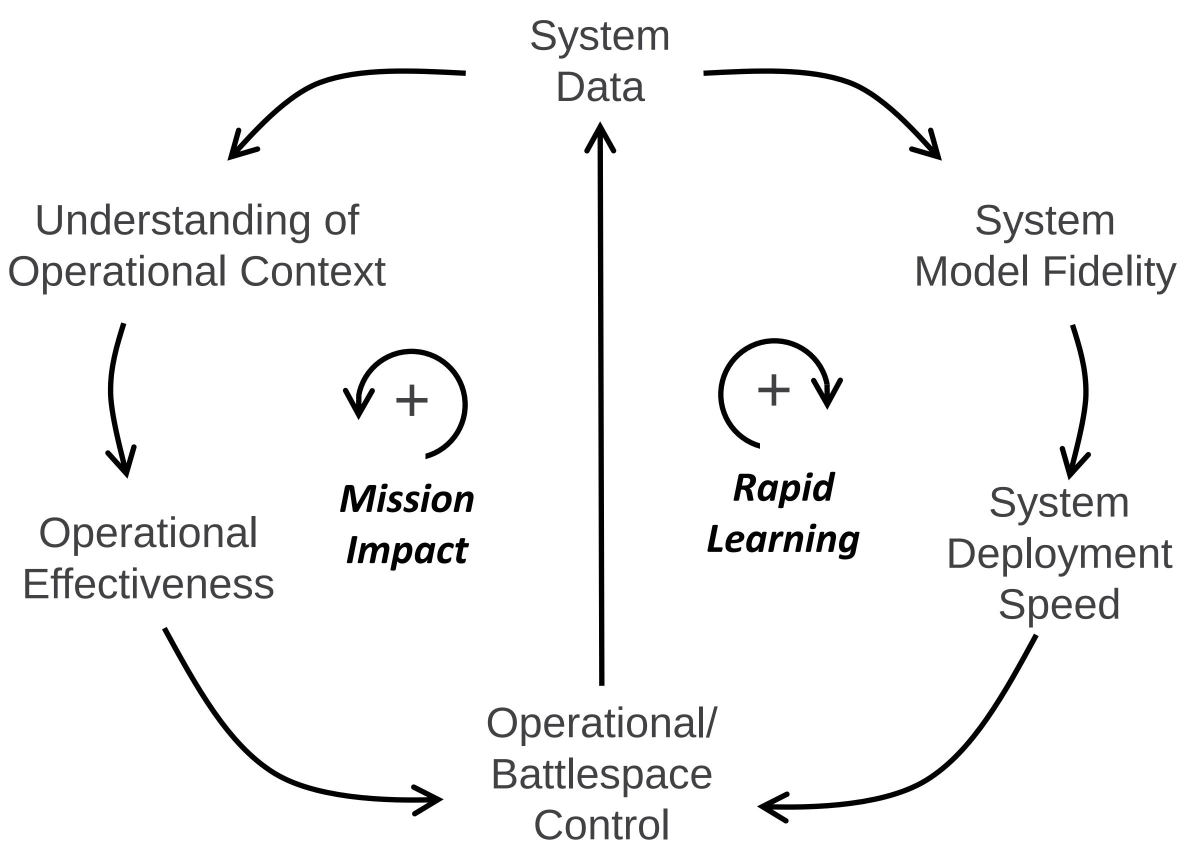
THE WALL STREET JOURNAL

Models Will Run the World

By Steven A. Cohen and Matthew W. Granade – August 19, 2018

- There is no shortage of hype about artificial intelligence and big data, but models are the source of the real power behind these tools.
- Model based business products get better, allowing them to collect more data, which allows them to build better models, making their products better…
- Are there missing feedback loops, can we improve existing ones. Is there unnecessary delay in feedback?
- Exponential growth in speed, scale and complexity of operations requires exponential responses in how we innovate

What happens when our models are right?



What happens when our models are wrong?

Opportunity: The Application of Systems Engineering

model based

Systems Engineering

is the essential discipline for Digital Transformation

Opportunity: INCOSE Vision 2025 - Transformation

Transforming
Systems Engineering

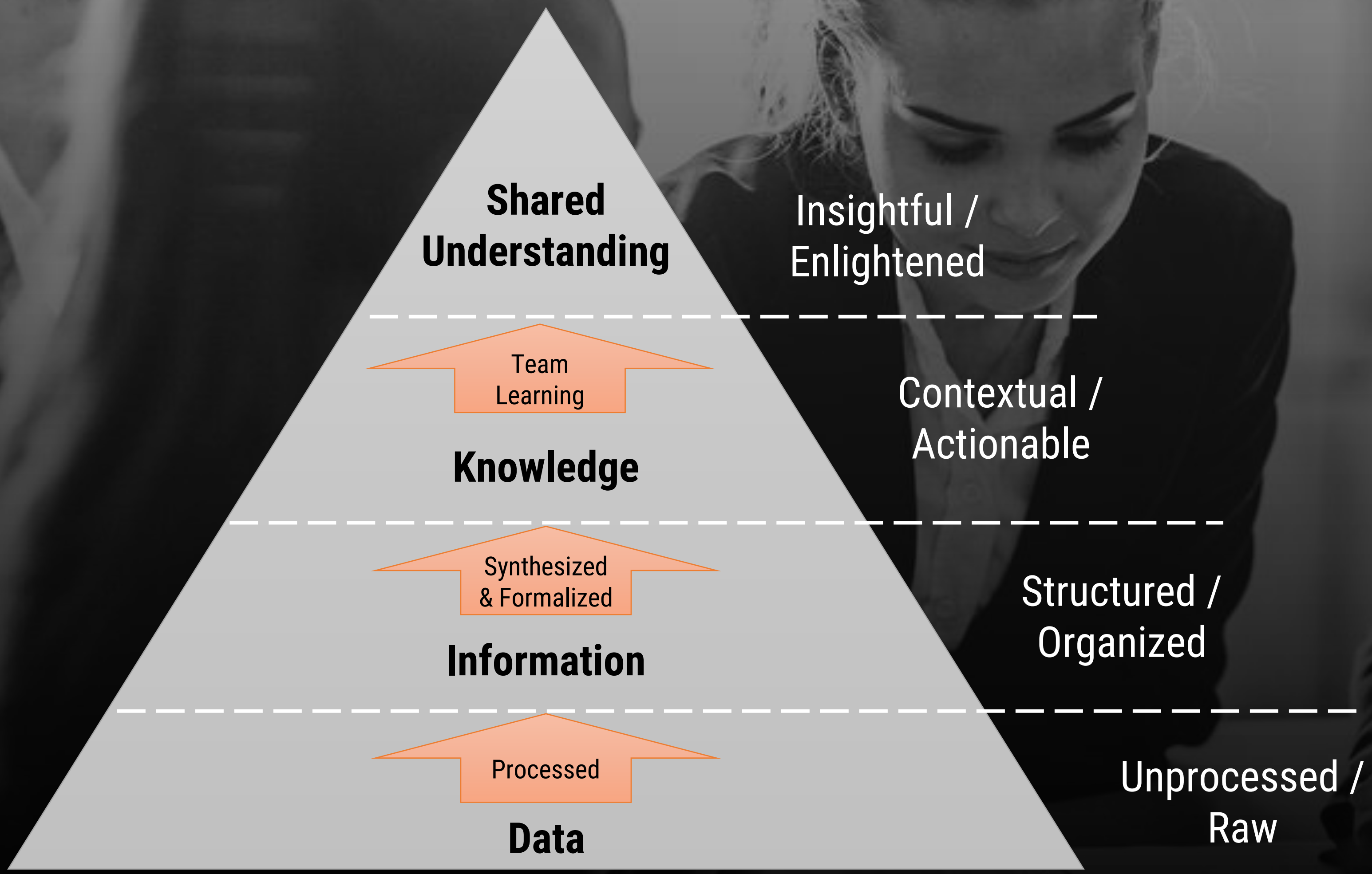
Systems engineering will lead the effort to **drive out unnecessary complexity** through well-founded architecting and deeper system understanding

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.

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.

https://www.incose.org/docs/default-source/aboutse/se-vision-2025.pdf?sfvrsn=b69eb4c6_4

Opportunity: Better Knowledge Management and Shared Understanding



From: …Limitations of document-based approaches, but is still in an early stage of maturity similar to the early days of CAD/CAE.

To:…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.

Executing Knowledge Management in Support of Mission Command, A Primer for Senior Leaders - Army Bulletin No 18-02 (Nov 2017)

INCOSE Vision 2025 www.incose.org

Opportunity: Central Role of KM in SE

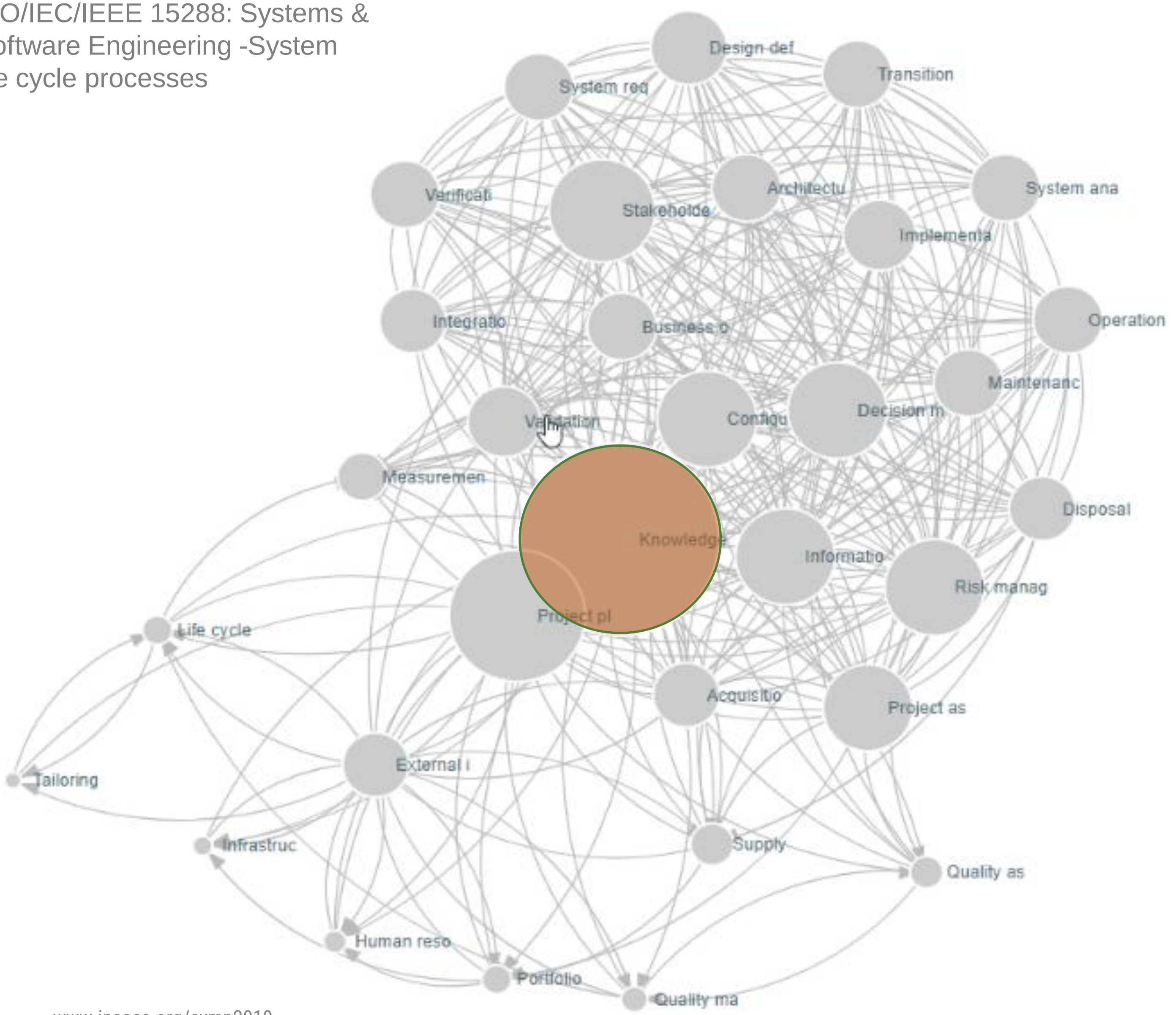
Agreement Processes
- Acquisition Process (6.1.1)
- Supply Process (6.1.2)

Organization Project-Enabling Processes
- Life Cycle Model Management Process (6.2.1)
- Infrastructure Management (6.2.2)
- Project Portfolio Management (6.2.3)
- Human Resource Management (6.2.4)
- Quality Management (6.2.5)
- Knowledge Management Process (6.2.6)

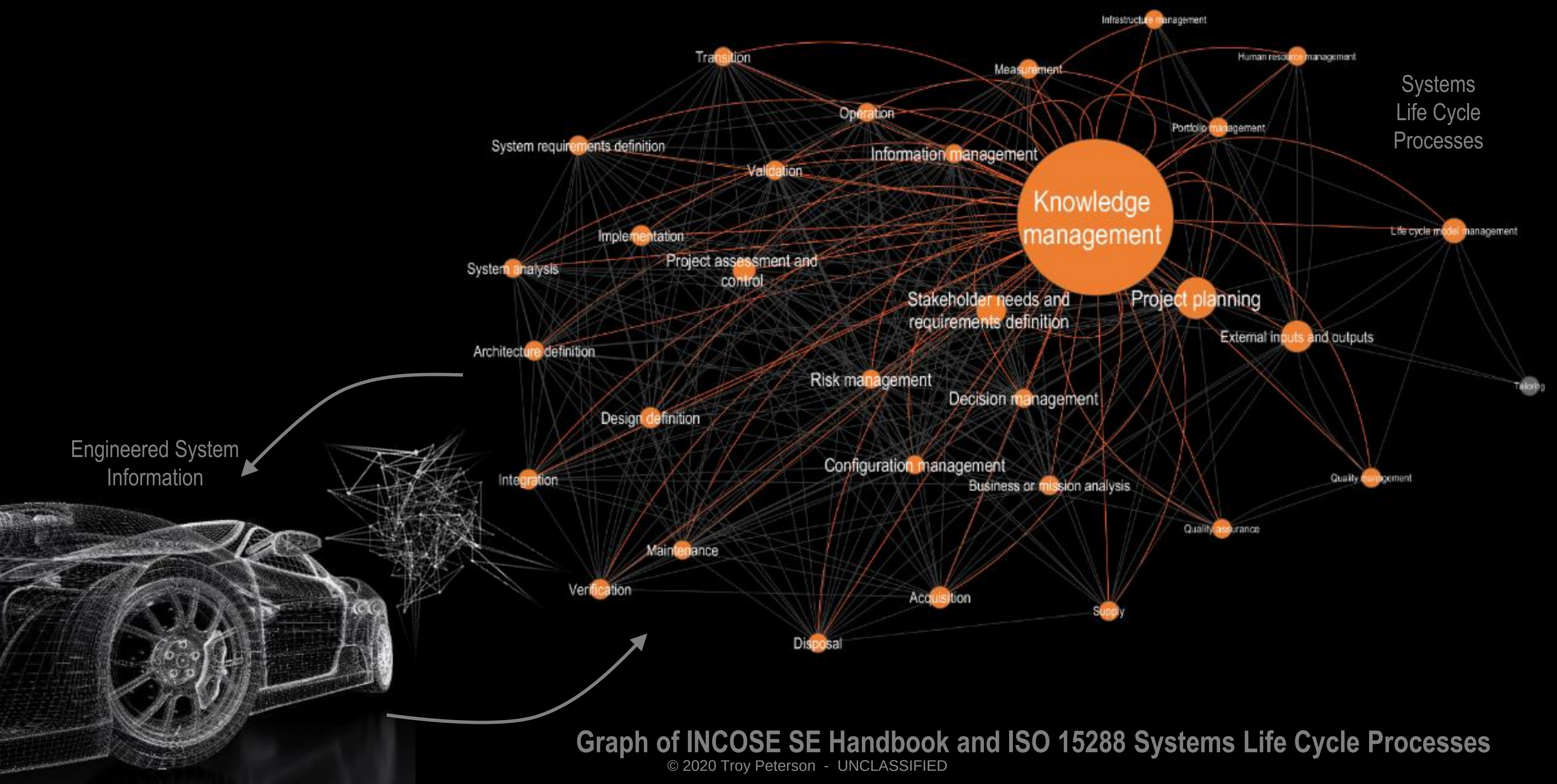
Technical Management Processes
- Project Planning Process (6.3.1)
- Project Assessment and Control Process (6.3.2)
- Decision Management Process (6.3.3)
- Risk Management Process (6.3.4)
- Configuration Management Process (6.3.5)
- Information Management Process (6.3.6)
- Measurement Process (6.3.7)
- Quality Process (6.3.8)

Technical Processes
- Business or Mission Analysis Process (6.4.1)
- Stakeholder Needs & Requirements Definitions Process (6.4.2)
- System Requirements Definition Process (6.4.3)
- Architecture Development Process (6.4.4)
- Design Definition Process (6.4.5)
- System Analysis Process (6.4.6)
- Implementation Process (6.4.7)
- Integration Process (6.4.8)
- Verification Process (6.4.9)
- Transition Process (6.4.10)
- Validation Process (6.4.11)
- Operation Process (6.4.12)
- Maintenance Process (6.4.13)
- Disposal Process (6.4.14)

ISO/IEC/IEEE 15288: Systems & Software Engineering -System life cycle processes

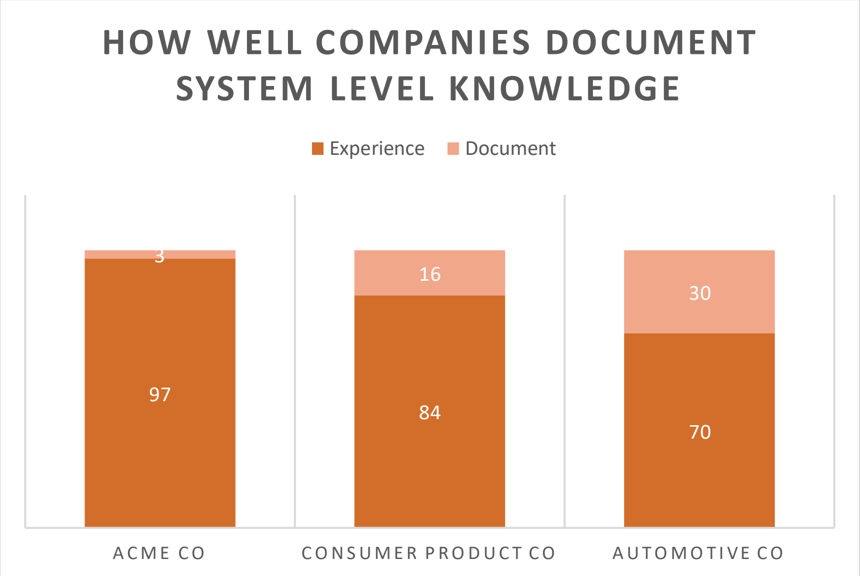


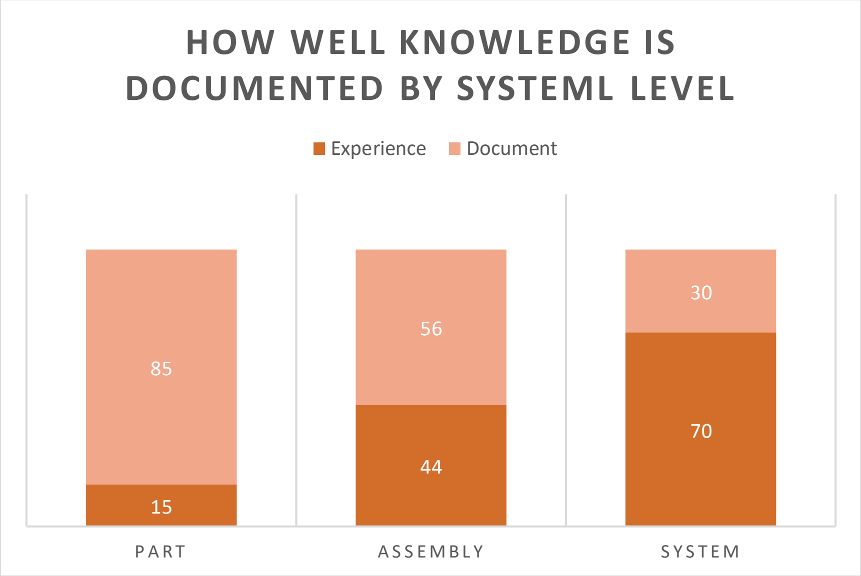
Opportunity: Capture and Formally Model Knowledge



Graph of INCOSE SE Handbook and ISO 15288 Systems Life Cycle Processes

Opportunity: Transform Tacit to Explicit Model Based Knowledge

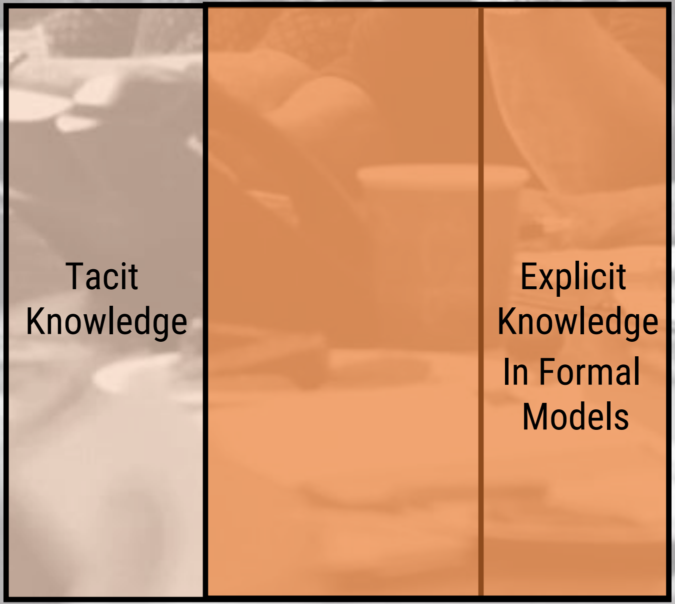




Knowledge Documentation Data from MIT Systems Engineering ESD.33 June 2010

"Domain experts" internalize patterns:

Human experts influence our projects, using their experience, intuition, informed judgment.



Engineers explicitly model knowledge

Data, information and knowledge used to overcome bias and identify opportunities.

Lewis, Michael. Moneyball: The Art of Winning an Unfair Game. 2003. | Movie: Moneyball, Columbia Pictures presents ; Michael de Luca Productions Culver City, CA : Sony Pictures Home Entertainment, [2012].

Opportunity: Develop Learning Organizations – Change the Engineering Ecosystem

Intelligent Networked Enterprise Systems

Model Based / Digital

Accumulate Learning

Encode Learning

Accelerate Execution

Improve Outcomes

Intelligent Networked Target Systems

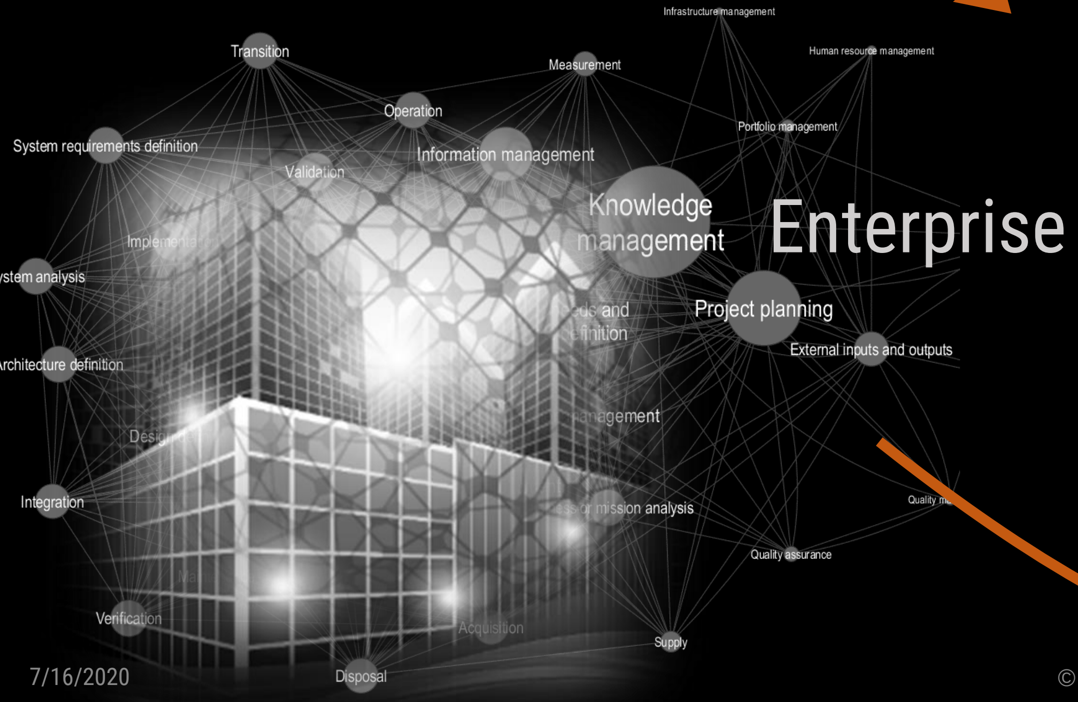
Interconnected & Intelligent

Provide Feedback

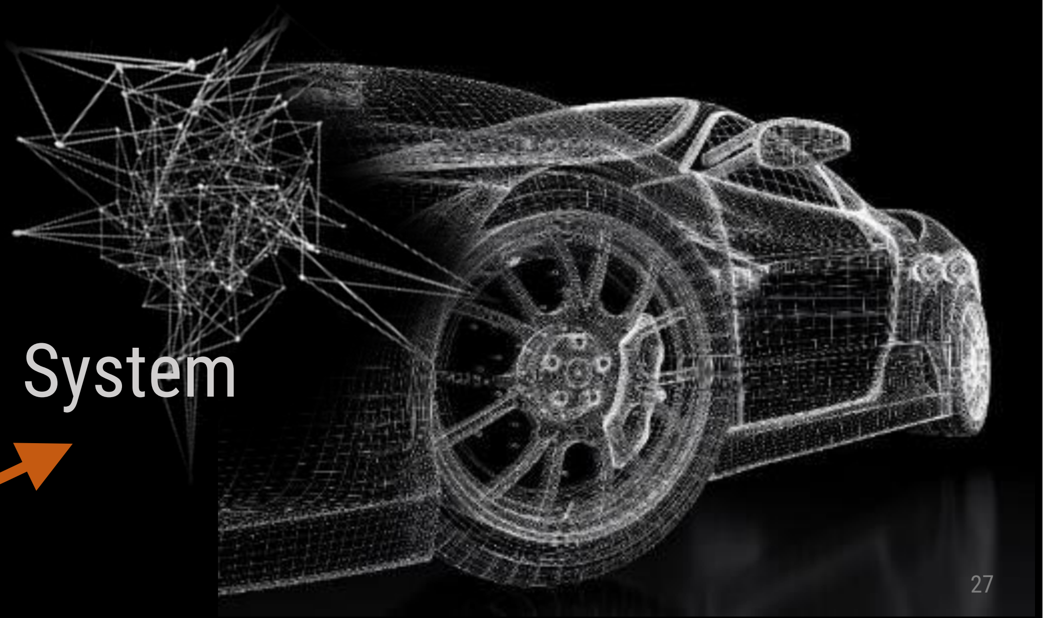
Non-deterministic

Agile, Flexible, Adaptable

Require rapid updates



Accelerate Learning and Execution for Improved Outcomes



Opportunity: Framing the Digital Engineering Ecosystem

S3

Life Cycle Management of System 2

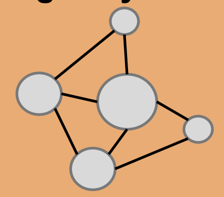
- Advancing & Adapting
  - System Development
  - Support Processes
  - Manufacturing
  - Production
  - Distribution
  - Marketing

S2

Life Cycle Management of System 1(Target System)

- System Development
- Support Processes
- Manufacturing
- Production
- Distribution
- Marketing

Target System S1



Target System Operating Environment

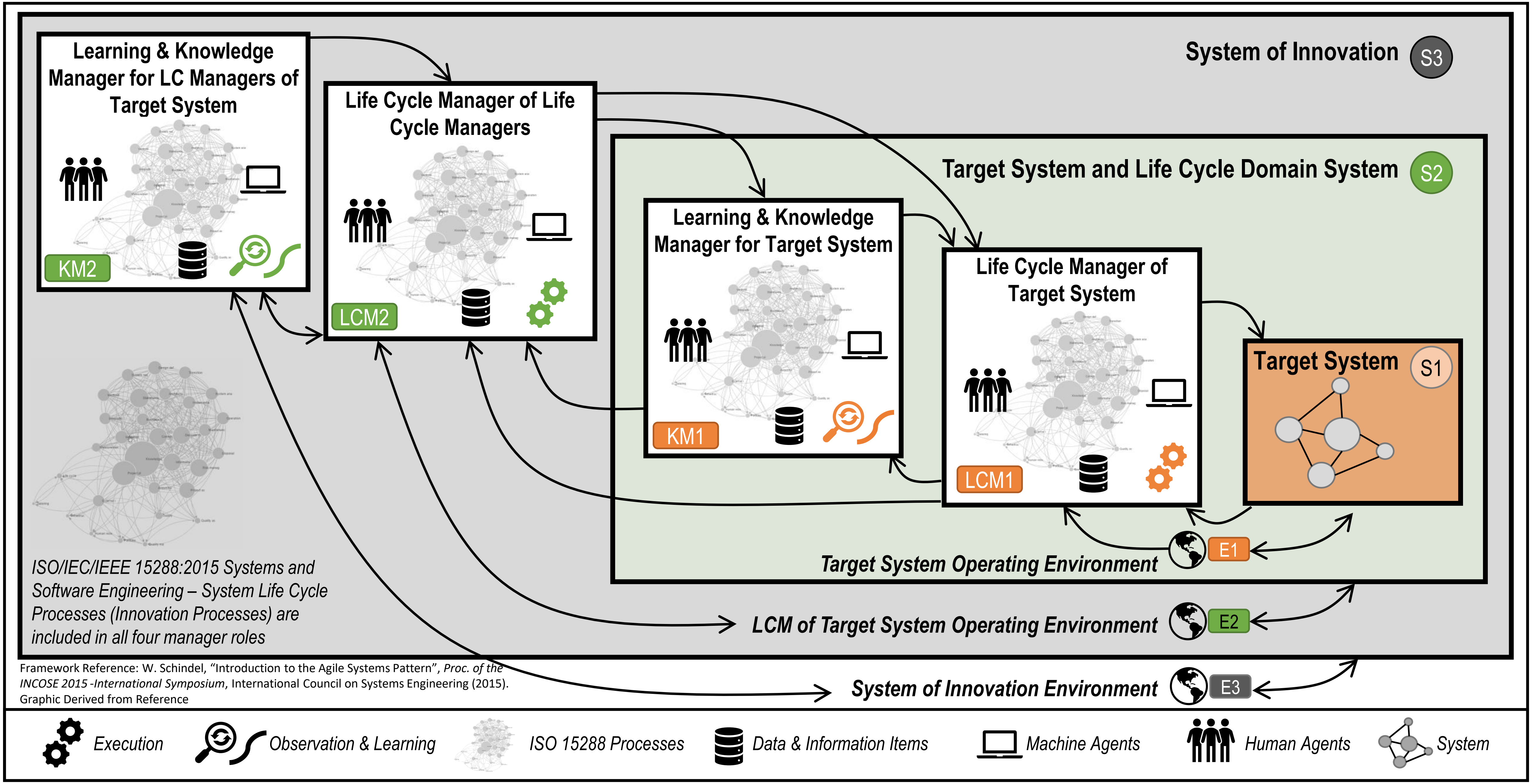
LCM of Target System Operating Environment

System of Innovation Environment

Agile SE Life Cycle Management Model (ASELCM) Ecosystem Pattern

Schindel, W., and Dove, R., "Introduction to the Agile Systems Engineering Life Cycle MBSE Pattern", *Proc. of INCOSE 2016 IS*, Edinburg, UK, 2016.

Opportunity: Leverage the Agile Systems Engineering Life Cycle Management Model (ASELCM) Ecosystem Pattern



Framework Reference: W. Schindel, "Introduction to the Agile Systems Pattern", *Proc. of the INCOSE 2015 -International Symposium*, International Council on Systems Engineering (2015).
Graphic Derived from Reference

Opportunity: Mimic Human System Cognition, Thinking Fast and Slow

We have two cognitive systems

- —Fast (Unconscious)
  - Works easily and automatically with low effort
  - makes quick judgements based on familiar patterns
  - It's rapid and involuntary - instinct and intuition.

- —Slow (Conscious):
  - Takes more effort and time, requires intense focus
  - Operates methodically – analytical rigor formal logic.

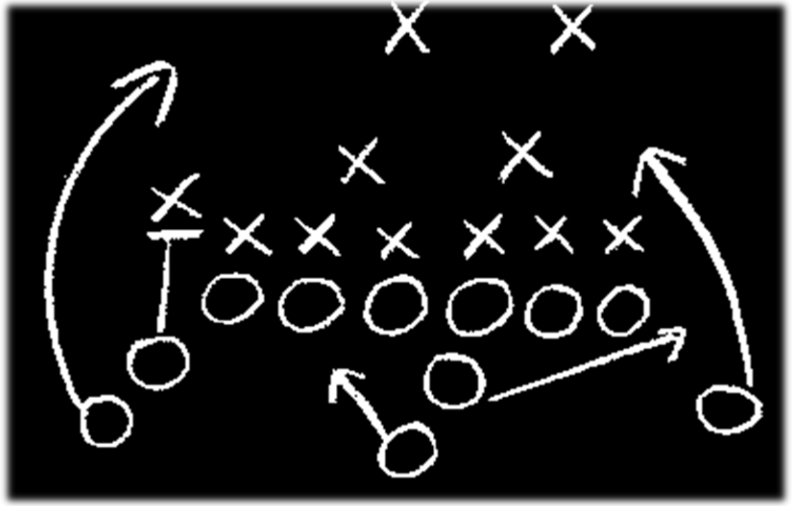
- —These two systems interact continually, stitching between conscious and unconscious modes of thinking based on context

Kahneman, Daniel. Thinking, Fast and Slow. New York: Farrar, Straus and Giroux, 2011. | Gladwell, Malcolm. Blink: The Power Of Thinking Without Thinking. New York : Little, Brown And Co., 2005. Print.

Opportunity: Develop Enterprise System Cognition: Apply Patterns & Analysis

Learning Organizations Combine Fast and Slow Thinking

- —Use both intuition and analysis
- —Have both a playbook and allow for adaptable play
- —Manage a fixed part (fast) and a variable part (slow)



Model Based Pattern Awareness Helps Organizations:

- —Identify repeatable structural and behavioral patterns
- —Recognize when a situation has changed
- —Know the best alternate pattern configuration
- —Chunk large amounts of information into patterns or principles particular to a given problem, discipline, domain or context.
- —Have more time for deeper analysis and study of new problems

Opportunity: The Case for Digital Engineering

"Success does not go to the country that develops a new technology first, but rather, to the one that better integrates it and more swiftly adapts its way of fighting."

Need to operate at the "Speed of Relevance"

The Engineer's Role in the National Defense Strategy

Remarks by Secretary Mattis on the National Defense Strategy, Jan. 19, 2018

"It is incumbent upon us to field a more lethal force if our nation is to retain the ability to defend ourselves and what we stand for."

"We will modernize key capabilities, recognizing we cannot expect success fighting tomorrow's conflicts with yesterday's weapons or equipment. Investments in space and cyberspace, nuclear deterrent forces, missile defense, advanced autonomous systems, and resilient and agile logistics will provide our high-quality troops what they need to win."

"To keep pace with our times, the department will transition to a culture of performance and affordability that operates at the speed of relevance. Success does not go to the country that develops a new technology first, but rather, to the one that better integrates it and more swiftly adapts its way of fighting. Our current bureaucratic processes are insufficiently responsive to the department's needs for new equipment. We will prioritize speed of delivery, continuous adaptation and frequent modular upgrades."

Distribution Statement A: Approved for public release; distribution is unlimited. 5

28th Annual INCOSE international symposium
Washington, DC, USA
July 7 - 12, 2018

Reference: "Delivering Systems in the Age of Globalization", Ms. Kristen Baldwin - INCOSE IS 2018

Opportunity: Shifting the focus to System Information

1 Content

Key system information that must be produced, consumed and maintained consistently across the life cycle

2 Process

Interrelated activities that direct what information goes where, when and to whom

3 Automation

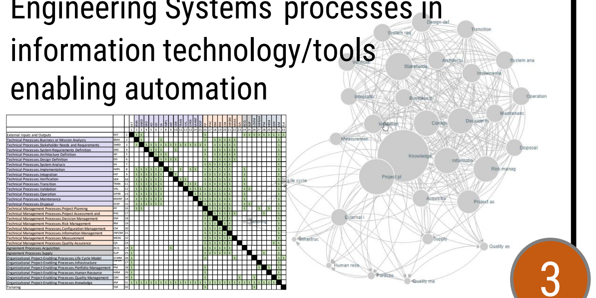
Digital federation, integration, automation through the use of tooling, standards, common interfaces etc.

Engineering Process Consumes and Produces information Iteratively

2 Engineering Process (ISO 15288)

1 Target System Information produced and consumed by Process

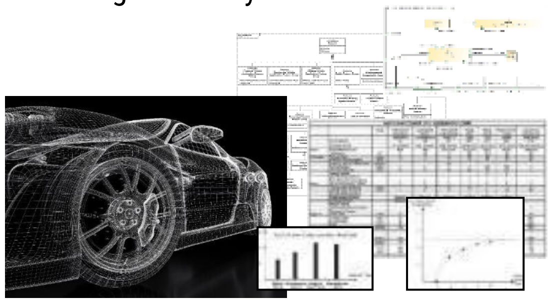
Engineering Systems processes in information technology/tools enabling automation



3

Engineered System Information

3



http://www.omgwiki.org/MBSE/doku.php?id=mbse:pbse

2. Processes

- Leverage existing ISO 15288 Systems Engineering Life Cycle Management Processes
- Design and modeling the Systems Engineering Process and Environment for MBSE.

1. System Information

- Domain Models
- A strong underlying metamodel
- Ensuring the essential system concepts underpin our models
- Science, Engineering, Math…

Remember: Automating junk, makes more junk automatically

Opportunity: Trusted Model Repositories and Consistency Management

Control Model Element Change History ~ Hashed Blockchain – Time phased graph

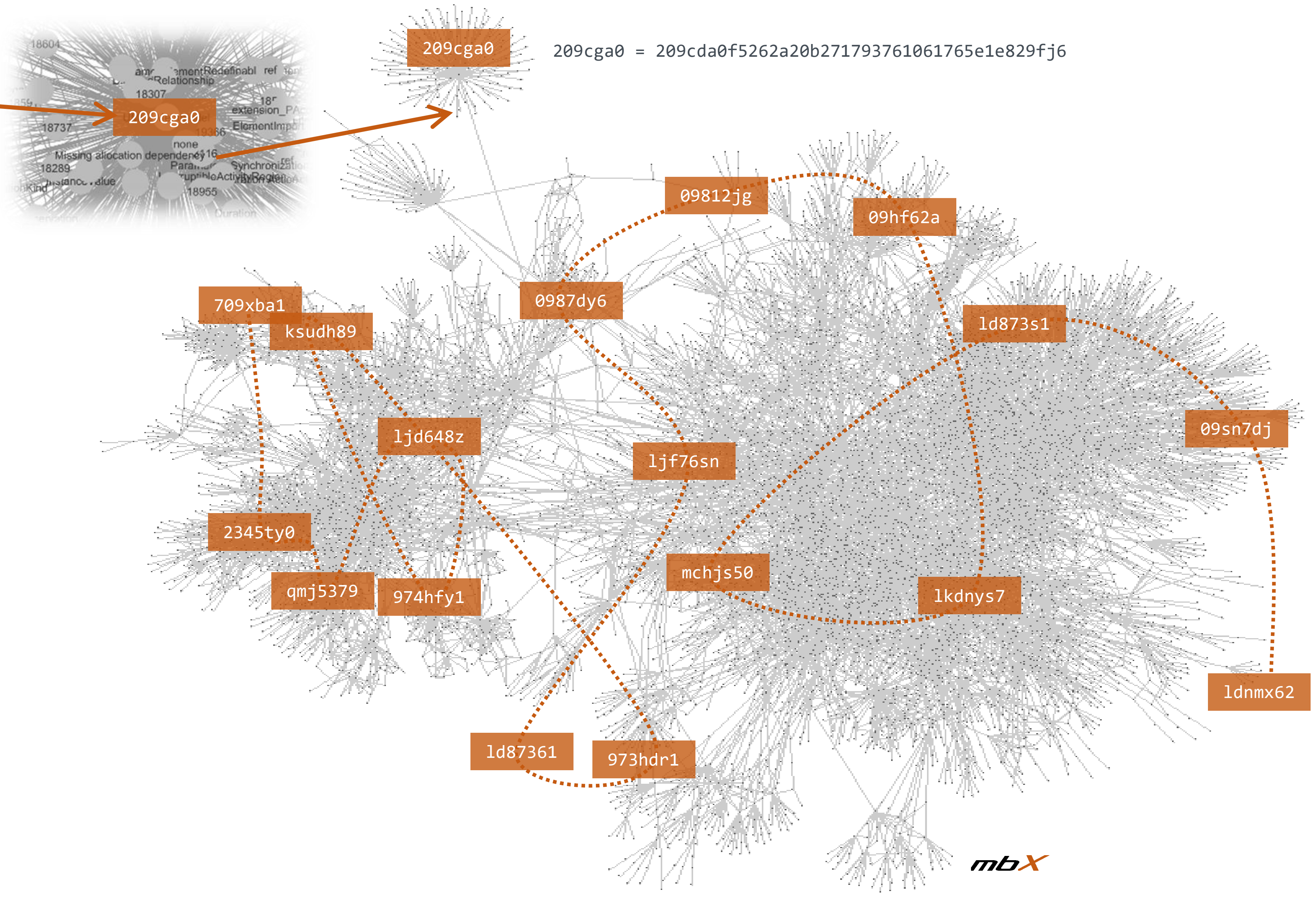
```
209cga0 = 20190829: Updated mass property of XYZ
345rha4 = 20190715: Element name to conformance
678yqa6 = 20190501: Published V&V version of model
976eya9 = 20190425: Added subcomponent property N
129qka4 = 20180105: Pattern configured for Sys1
```

Digital Thread of a particular analysis ~ Hashed Blockchain Architecture

709xba1	Authenticated Signed Version/Changes
2345ty0	Authenticated Signed Version/Changes
qmj5379	
ljd648z	
⋮	
ldnmx62	

Tool Neutral Model, Data, Knowledge Representation

ljd648z	MagicDraw: Vehicle Parameter Model
0987dy6	Excel: Cost Model
mchjs50	Matlab: Mechanics Model
lkdnys7	Creo: CAD model attribute: Mass



Opportunity: Employ *Augmented* Intelligence (AuI)

- Reinforce knowledge in formal models and pattern based methods with AuI
- Maximize Human + Machine Collaboration
- Allocate work based on strengths
- The Human + Machine combined "team" is more effective than either in isolation.
- Keep the Human in the loop, automate carefully

Remember: AuI = Human + AI
AuI > Human
AuI > AI

Kasparov's Law

weak human + machine + better process
beats
strong human + machine + inferior process.

Opportunity: Use Models to Improve Outcomes

"Would you tell me, please," Alice asks the cat, "which way I ought to go from here?"

"Well", responds the Cheshire Cat, "That depends a good deal on where you want to get to."

"Oh, I don't much care where –" says Alice.

The Cheshire Cat responds "If you don't care where you are going, then it really doesn't matter which way you go."

What is the Objective of your Model?
Know where you want to go…

The model is not the end game
Care about improved outcomes…

Poor SE dooms MBSE
MBSE multiplies good SE

Know the objective and requirements of your model, and what questions it should answer

Opportunity: Seek and Economical Description

"…All models are wrong, but some are useful"

"Since all models are wrong the scientist cannot obtain a "correct" one by excessive elaboration. On the contrary following William of Occam he should ***seek an economical description*** of natural phenomena. Just as the ability to devise simple but evocative models is the signature of the great scientist so ***overelaboration and over parameterization*** is often the mark of mediocrity."

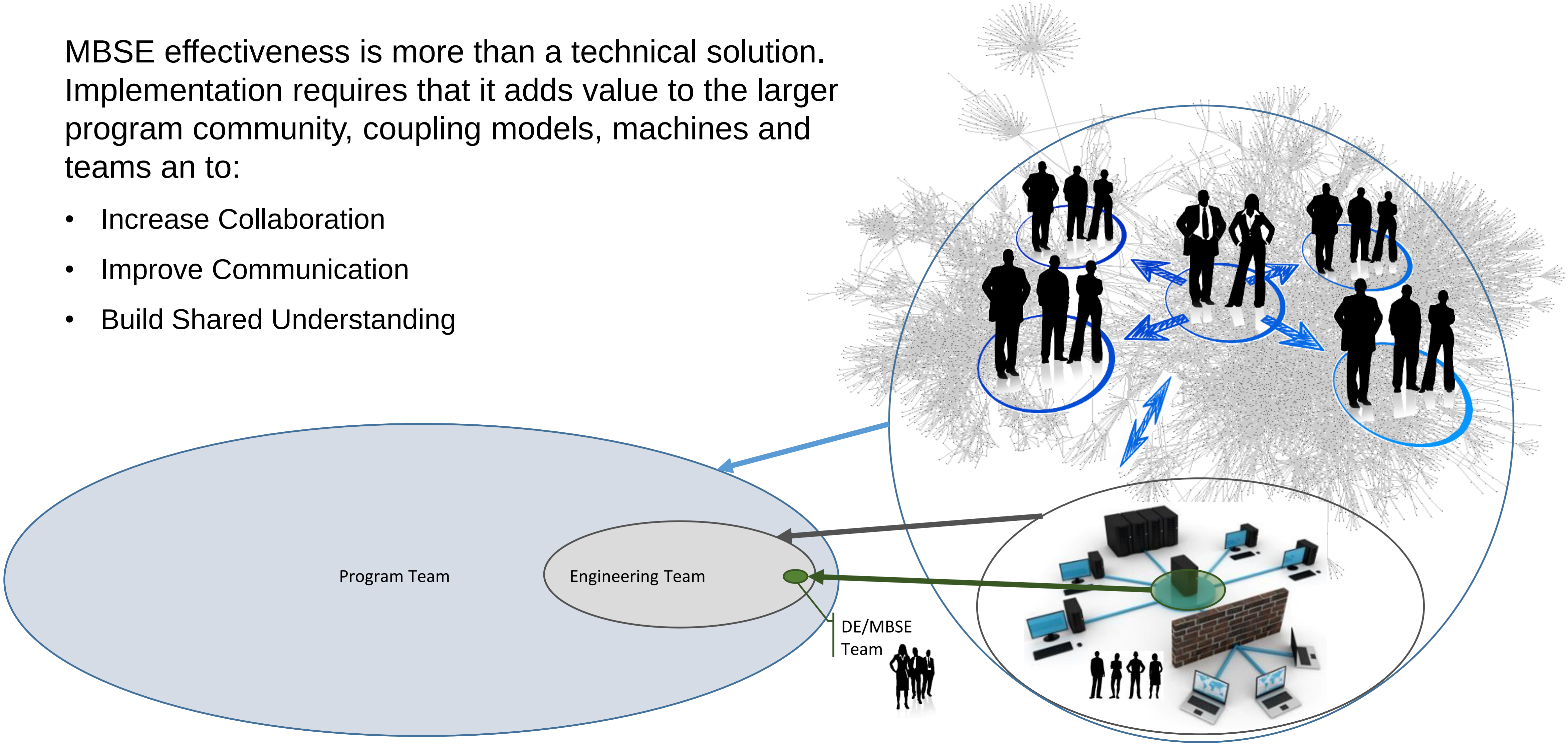
George E. P. Box

"…seek an economical description…"

Opportunity: Add Value to the Larger Stakeholder Community

MBSE effectiveness is more than a technical solution. Implementation requires that it adds value to the larger program community, coupling models, machines and teams an to:

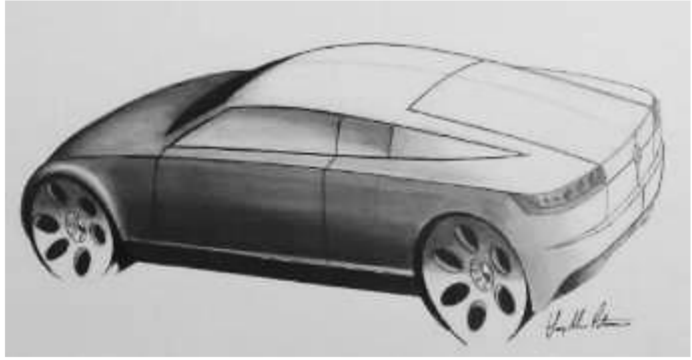
- Increase Collaboration
- Improve Communication
- Build Shared Understanding

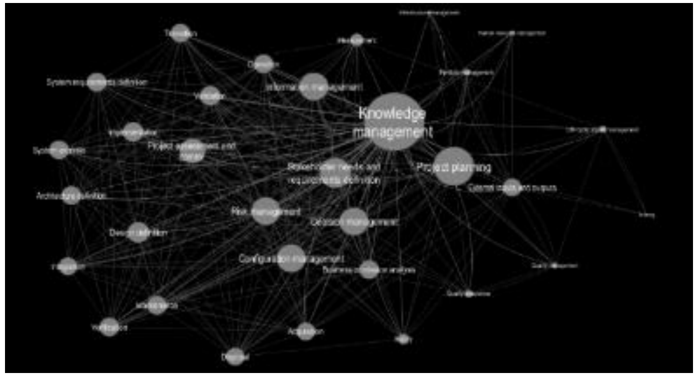


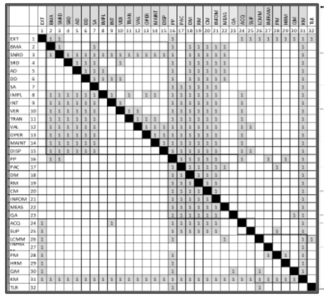
Opportunity: Use Lots of Models, Use Differing Viewpoints

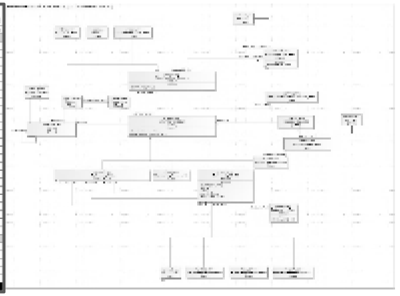
Evidence shows that people who think with models consistently outperform those who don't. And, moreover people who think with lots of models outperform people who use only one.

Scott E. Page "Model Thinking" Course Description

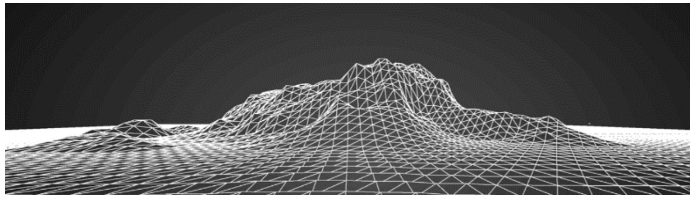








Models are powerful; they help us understand our systems, they provide a path forward for our ideas, and they invoke action.

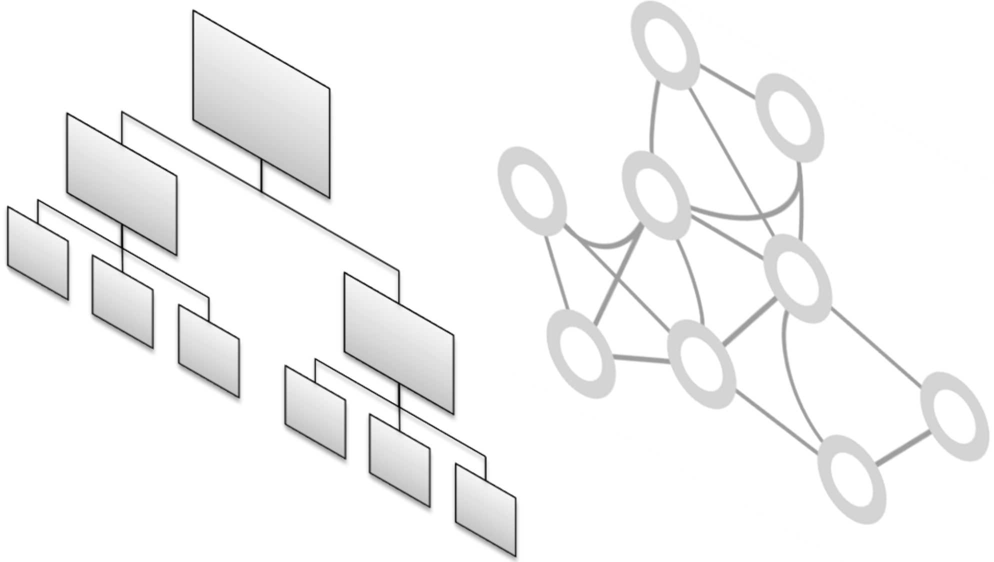


Opportunity: Create a Sense of Urgency

Leading Change: John P. Kotter

Eight-Step Process for undertaking major change.

1. ***Creating a Sense of Urgency***
2. Building a Guiding Coalition
3. Developing a Strategic Vision and Initiatives
4. Expanding the Network of Change Agents
5. Empowering Broad-Based Action
6. Generating Short-Term Wins
7. Consolidating Gains and Producing More Change
8. Instituting Change in the Culture



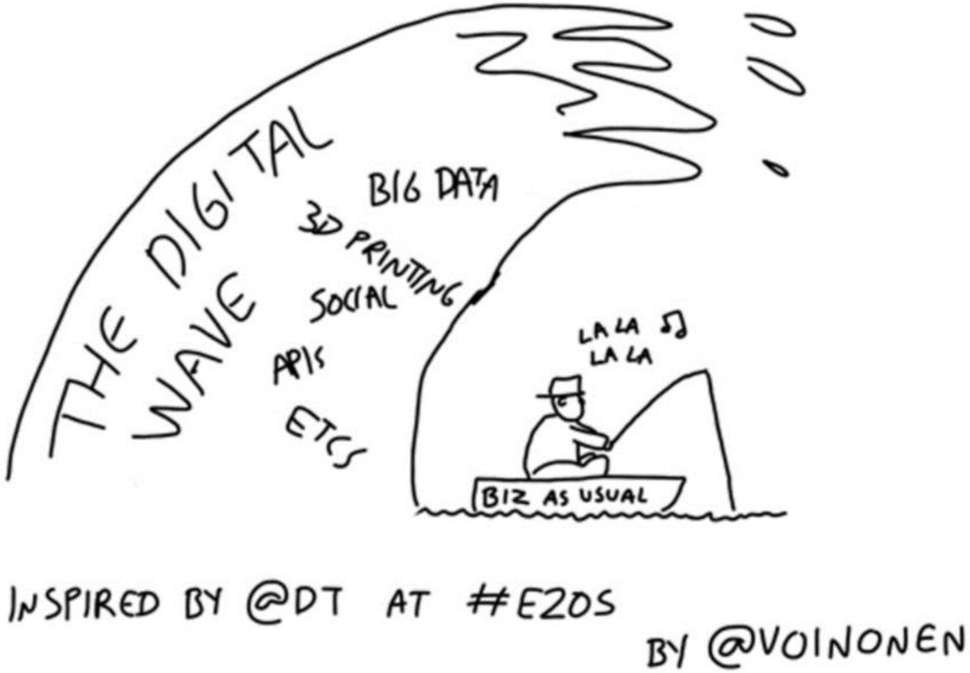
Accelerate: John P. Kotter

Kotter's new book *Accelerate* refines principals and adds the concept of a "dual operating system".

- One operating system is characterized by management, hierarchy and driven toward efficiency
- The other is characterized by leadership, networks, strategic acceleration and driven to innovate.
- Operating systems align nicely with the System of Innovation framework used in INCOSE's Agile and Patterns Working Groups where we see the distinct roles of executing and managing systems development and managing knowledge and what is learned in execution.

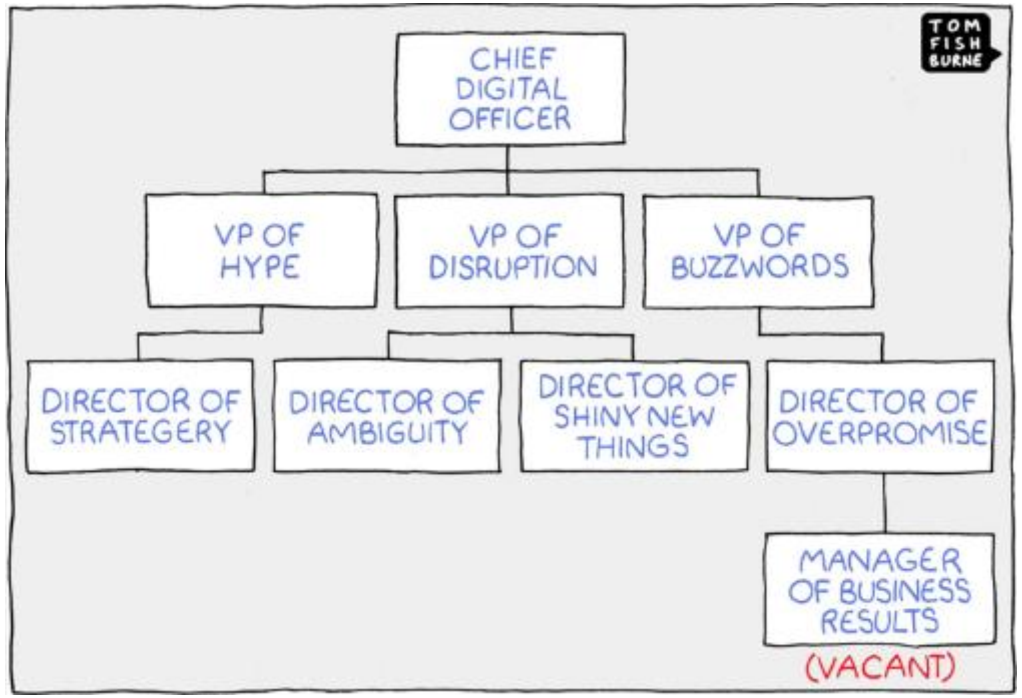
Opportunity: Be Aware and Be Real, Avoid the Hype

STATES OF DIGITAL TRANSFORMATION



DIGITAL DENIAL

MEANINGFUL TRANSFORMATION



DIGITALLY ZEALOUS

- It’s a paradigm shift
- The previous state is unrecognizable
- It doesn’t happen overnight, it takes time, and effort

“It is not necessary to change. Survival is not mandatory.”

W. Edwards Deming

INCOSE’s Transformation Strategic Objective: http://www.incose.org/about/strategicobjectives/transformation

Systems Engineering: Cracking the Code of Digital Transformation

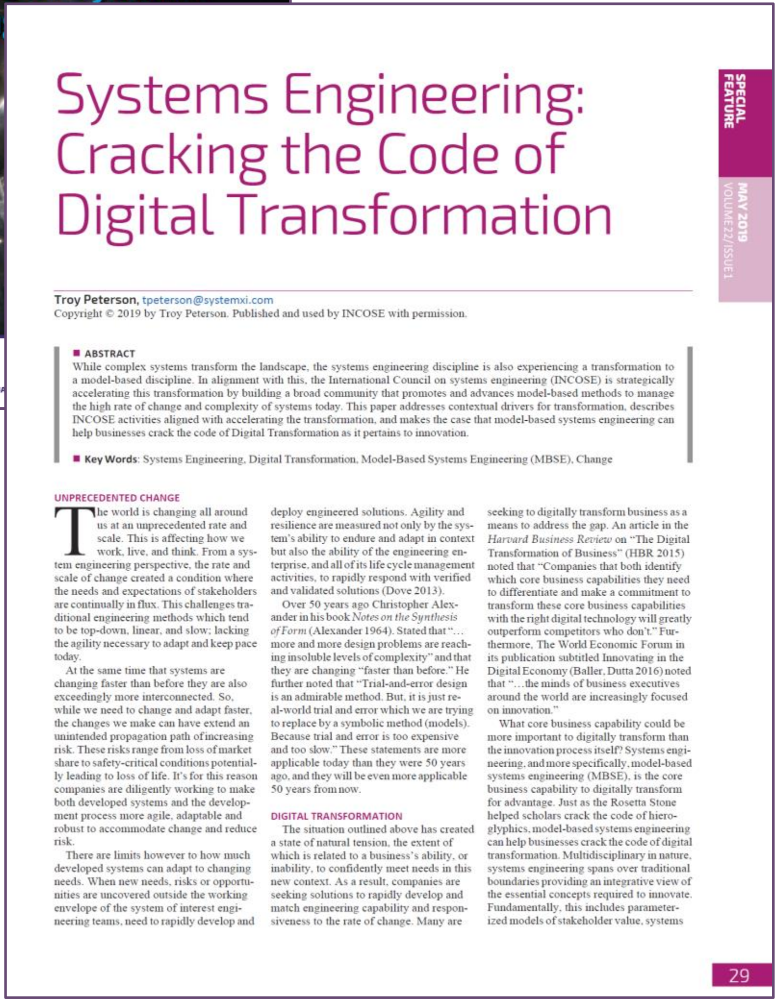
SYSTEMS ENGINEERING RESEARCH CENTER

Unprecedented change and growing systems complexity is diving the need for digital transformation and most notably in how we innovate or perform systems engineering.

INCOSE is leading many activities to help accelerate the necessary transformation, some of these include:

- FuSE
- Transformation Initiative
- MBSE Incubator
- SysML v2
- Semantic Technologies for Systems Engineering (ST4SE)
- MBSE Patterns Working Group (WG)
- Digital Engineering Information Exchange WG
- Augmented Intelligence for Systems Engineering Challenge Team (CT)
- Model Based X Ecosystem Challenge Team (CT)
- Model Based Enterprise Capabilities Matrix (CT)
- Systems Engineering Foundations
- Vision 2035
- Organizational Change
- …

It is an exciting time for systems engineers and the discipline of systems engineering. We are at a tipping point, and a timely one.



SPECIAL FEATURE

MAY 2019 VOLUME 22/ISSUE 1

Systems Engineering: Cracking the Code of Digital Transformation

Troy Peterson, tpeterson@systemxi.com
Copyright © 2019 by Troy Peterson. Published and used by INCOSE with permission.

■ ABSTRACT
While complex systems transform the landscape, the systems engineering discipline is also experiencing a transformation to a model-based discipline. In alignment with this, the International Council on systems engineering (INCOSE) is strategically accelerating this transformation by building a broad community that promotes and advances model-based methods to manage the high rate of change and complexity of systems today. This paper addresses contextual drivers for transformation, describes INCOSE activities aligned with accelerating the transformation, and makes the case that model-based systems engineering can help businesses crack the code of Digital Transformation as it pertains to innovation.

■ Key Words: Systems Engineering, Digital Transformation, Model-Based Systems Engineering (MBSE), Change

UNPRECEDENTED CHANGE

The world is changing all around us at an unprecedented rate and scale. This is affecting how we work, live, and think. From a system engineering perspective, the rate and scale of change created a condition where the needs and expectations of stakeholders are continually in flux. This challenges traditional engineering methods which tend to be top-down, linear, and slow; lacking the agility necessary to adapt and keep pace today.

At the same time that systems are changing faster than before they are also exceedingly more interconnected. So, while we need to change and adapt faster, the changes we make can have extend an unintended propagation path of increasing risk. These risks range from loss of market share to safety-critical conditions potentially leading to loss of life. It's for this reason companies are diligently working to make both developed systems and the development process more agile, adaptable and robust to accommodate change and reduce risk.

There are limits however to how much developed systems can adapt to changing needs. When new needs, risks or opportunities are uncovered outside the working envelope of the system of interest engineering teams, need to rapidly develop and deploy engineered solutions. Agility and resilience are measured not only by the system's ability to endure and adapt in context but also the ability of the engineering enterprise, and all of its life cycle management activities, to rapidly respond with verified and validated solutions (Dove 2013).

Over 50 years ago Christopher Alexander in his book *Notes on the Synthesis of Form* (Alexander 1964). Stated that "… more and more design problems are reaching insoluble levels of complexity" and that they are changing "faster than before." He further noted that "Trial-and-error design is an admirable method. But, it is just real-world trial and error which we are trying to replace by a symbolic method (models). Because trial and error is too expensive and too slow." These statements are more applicable today than they were 50 years ago, and they will be even more applicable 50 years from now.

DIGITAL TRANSFORMATION

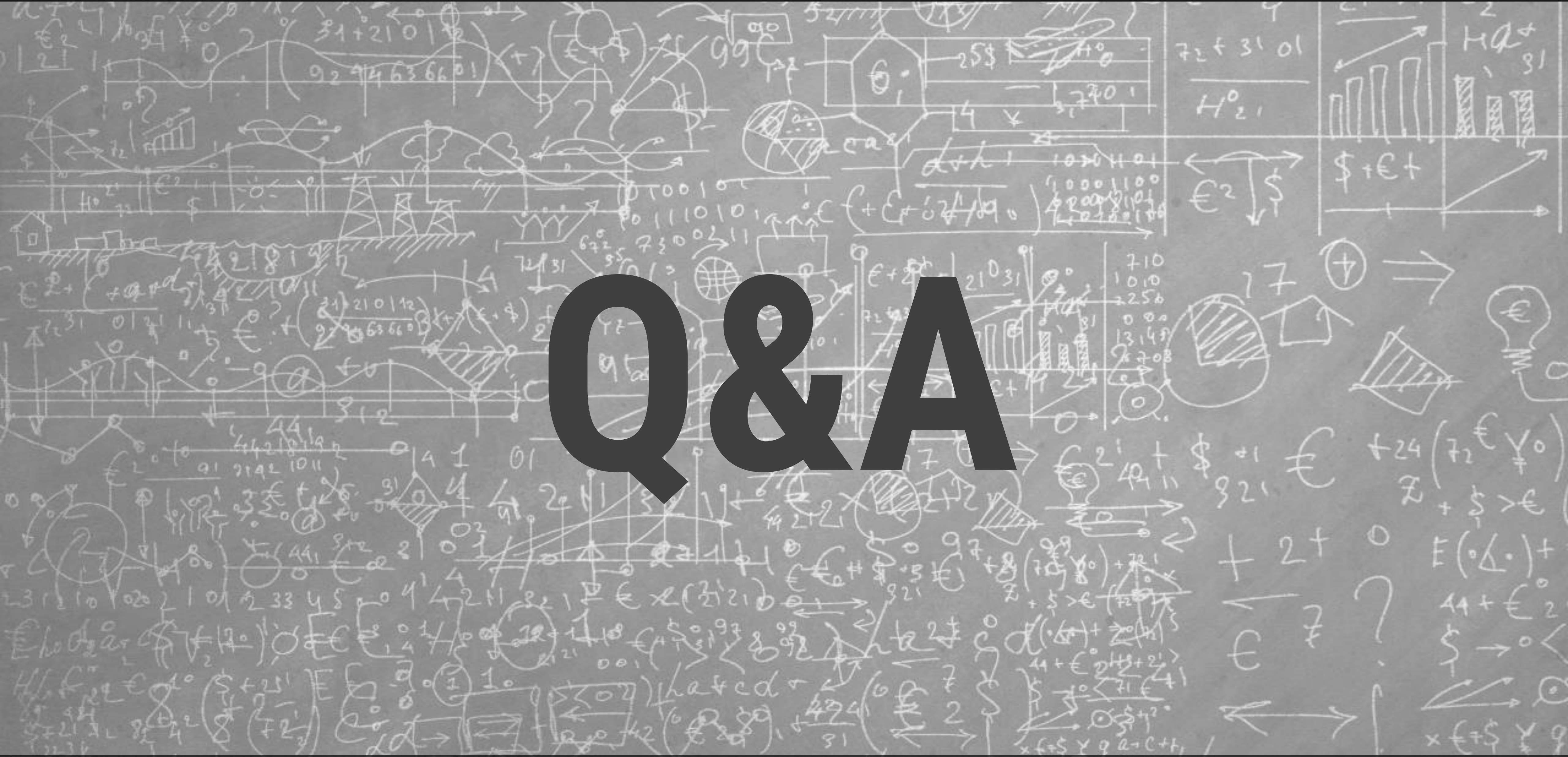
The situation outlined above has created a state of natural tension, the extent of which is related to a business's ability, or inability, to confidently meet needs in this new context. As a result, companies are seeking solutions to rapidly develop and match engineering capability and responsiveness to the rate of change. Many are seeking to digitally transform business as a means to address the gap. An article in the *Harvard Business Review* on "The Digital Transformation of Business" (HBR 2015) noted that "Companies that both identify which core business capabilities they need to differentiate and make a commitment to transform these core business capabilities with the right digital technology will greatly outperform competitors who don't." Furthermore, The World Economic Forum in its publication subtitled Innovating in the Digital Economy (Baller, Dutta 2016) noted that "…the minds of business executives around the world are increasingly focused on innovation."

What core business capability could be more important to digitally transform than the innovation process itself? Systems engineering, and more specifically, model-based systems engineering (MBSE), is the core business capability to digitally transform for advantage. Just as the Rosetta Stone helped scholars crack the code of hieroglyphics, model-based systems engineering can help businesses crack the code of digital transformation. Multidisciplinary in nature, systems engineering spans over traditional boundaries providing an integrative view of the essential concepts required to innovate. Fundamentally, this includes parameterized models of stakeholder value, systems

29

INCOSE
International Council on Systems Engineering

Q&A



Speaker Bio

Troy Peterson

Vice President & Fellow
tpeterson@systemxi.com
313.806.3929

Troy Peterson, SSI Vice President, and INCOSE Transformation and FUTURE Champion is a recognized leader in developing model based solutions to speed innovation and solve complex systems challenges. He has led the delivery of numerous complex systems and methodologies as a Vice President at SSI, Booz Allen Fellow and Lead Engineer at Ford Motor Company. His experience spans academic, non-profit, commercial and government environments across all lifecycle phases. Troy received a BS in Mechanical Engineering from Michigan State University, an MS in Technology Management from Rensselaer Polytechnic Institute and an advanced graduate certificate in Systems Design and Management from Massachusetts Institute of Technology. He also holds INCOSE CSEP, PMI PMP, and ASQ Six Sigma Black Belt Certifications.

Abstract

Systems continue to reach new heights of complexity and autonomy. They seamlessly intertwine computational algorithms and physical components, providing organizations tremendous opportunity while also exposing them to significant risk. The problem is that while systems become more interconnected, and intelligent development methods are lagging behind, not keeping pace with contextual and technological change. Many organizations still follow a traditional document-based approach, which is fragmented, slow, and error-prone, lacking the agility and scalability required today. Other organizations are beginning to apply model based methods; however, the approach is often ad-hoc and mirrors the document-based approach using model-based tools that usually do not scale to the broader enterprise. Many organizations are now asking how to advance development methods through model-based methods and new approaches to overcome the significant mismatch between the complexity of the systems and our ability to manage and mitigate the associated risks

For the Department of Defense, this led to the release of the Digital Engineering Strategy and subsequent engagement with the services to transform how they deliver capability. Digital Transformation underpinned by model based methods is now the fundamental approach being pursued across industry and government domains to address system complexity and provide the order of magnitude improvements called for by today's dynamic environment and systems. While models underpin the path forward to apply advanced methods and enable the digital enterprise to respond with the necessary speed, scale, and agility, many challenges still exist and must be addressed by the engineering community.

This presentation will outline some of the fundamental drivers for Digital Transformation, why Digital Engineering is the key to the broader Digital Transformation, as well as share some best practices, lessons learned, and activities underway to help pave the path forward for Digital Engineering.

Copyright for INCOSE Vision 2025 use and references

INCOSE Efforts & Backup

INCOSE Model Based Systems Engineering

INCOSE Definition

- Model-based systems engineering (MBSE): The formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases.
- MBSE is part of a long-term trend toward model-centric approaches adopted by other engineering disciplines, including mechanical, electrical and software.

SEBOK

- Purpose of a Model: Models are representations that can aid in defining, analyzing, and communicating a set of concepts. Some of the purposes that models can serve throughout the system life cycle are:
    - Characterizing an existing system
    - Mission and System Concept Formulation Flowdown
    - System Design Synthesis and Requirements Flowdown
    - Support System Integration and Verification
    - Support for Training
    - Knowledge Capture and System Design Evolution

The model must be scoped to address its intended purpose

MBSE Wiki

http://www.omgwiki.org/MBSE/doku.php

https://www.sebokwiki.org/wiki/Why_Model%3F

INCOSE FUTURE Strategic Objective

INCOSE FUTURE Strategic Objective: INCOSE leads the community in shaping the future of Systems Engineering

- Engage with and Align FUTURE related INCOSE activities
  - FuSE
  - Transformation Initiative
  - MBSE Incubator
  - Organizational Change Management
  - MBSE Benchmarking Study
  - Virtual Models Community Network
  - MBSE Value Briefing
- Engage Larger External Community – Collaborate
  - Transformational Working Groups, MBSE Incubator, Challenge Teams,

Collaborating Organizations

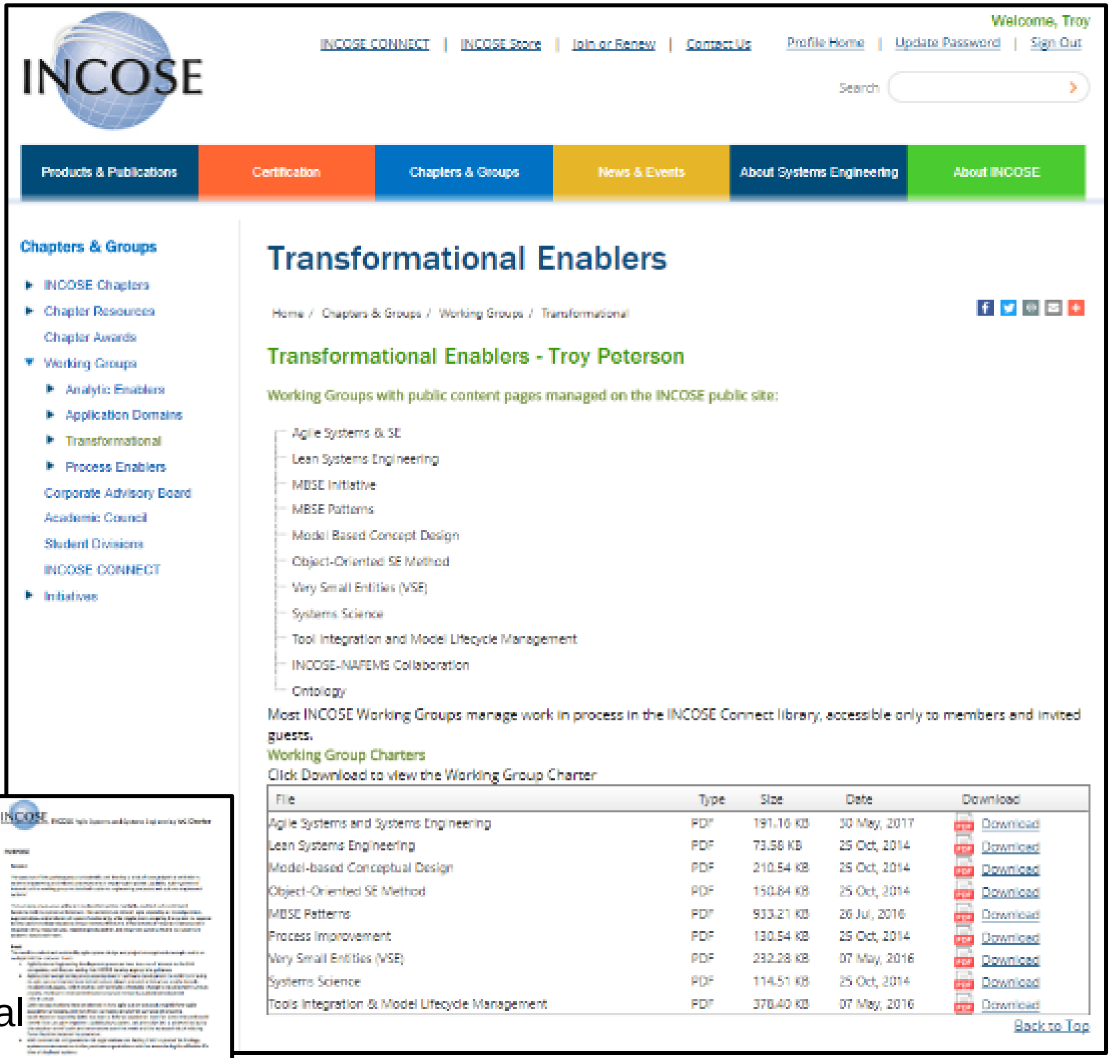
INCOSE Transformational Enablers Working Groups

Transformational Working Groups (WG)

- Agile Systems and Systems Engineering
- Digital Engineering Information Exchange (DEIX)
- Lean Systems Engineering
- Model Based Systems Engineering Initiative
- Model-based Conceptual Design
- Object-Oriented SE Method
- MBSE Patterns
- Very Small Entities (VSE)
- Systems Science
- Tools Integration & Model Lifecycle Management
- INCOSE-NAFEMS Collaboration
- Ontology

Visit site for WG charters and to learn more

http://www.incose.org/ChaptersGroups/WorkingGroups/transformational



Continuing to build upon INCOSE resources to build understanding of the practical implications of MBSE.

- INCOSE / OMG MBSE Wiki
  - Proceedings of ~10 years of the MBSE Workshop and IW content
  - Overviews/Summaries of MBSE methodologies
  - MBSE Challenge Teams addressing leading issues
  - MBSE related working groups and products

- SEBoK, SE Journal and INSIGHT
- INCOSE Event Proceedings
- INCOSE Community and more…

Challenge/Activity Team	Challenge/Activity Team Lead
Augmented Intelligence in Systems Engineering	Mark Petrotta
MBX Ecosystems	Russell Peak
Model-Based Engineering (MBE) Manifesto	Chris Schreiber
Model-Based Enterprise Capabilities Matrix	Joe Hale and Al Hoheb
Production and Logistics Systems Modeling	Tim Sprock
Telescope Modeling	Robert Karban

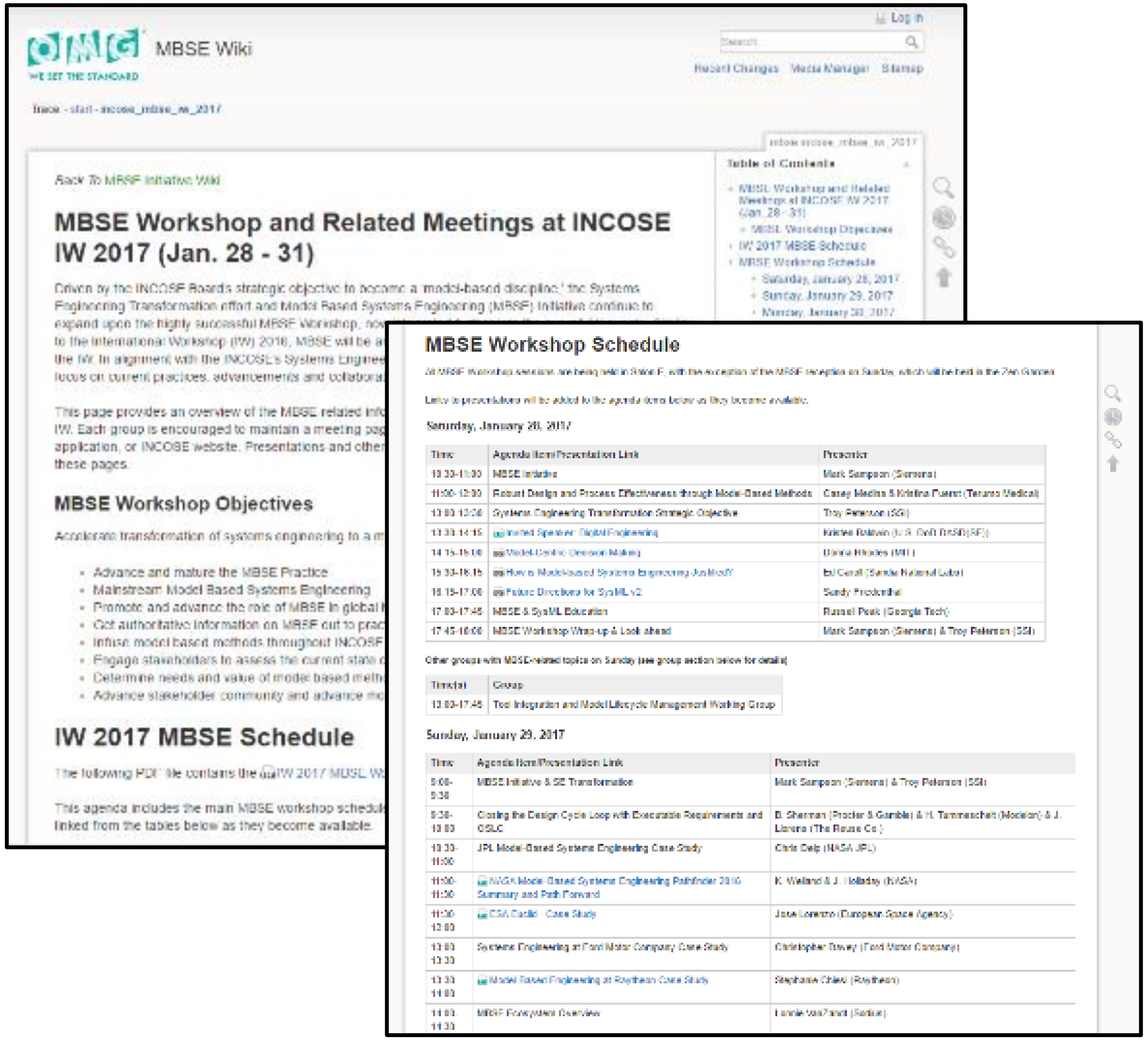
MBSE Initiative as an Incubator and Transformation Agent

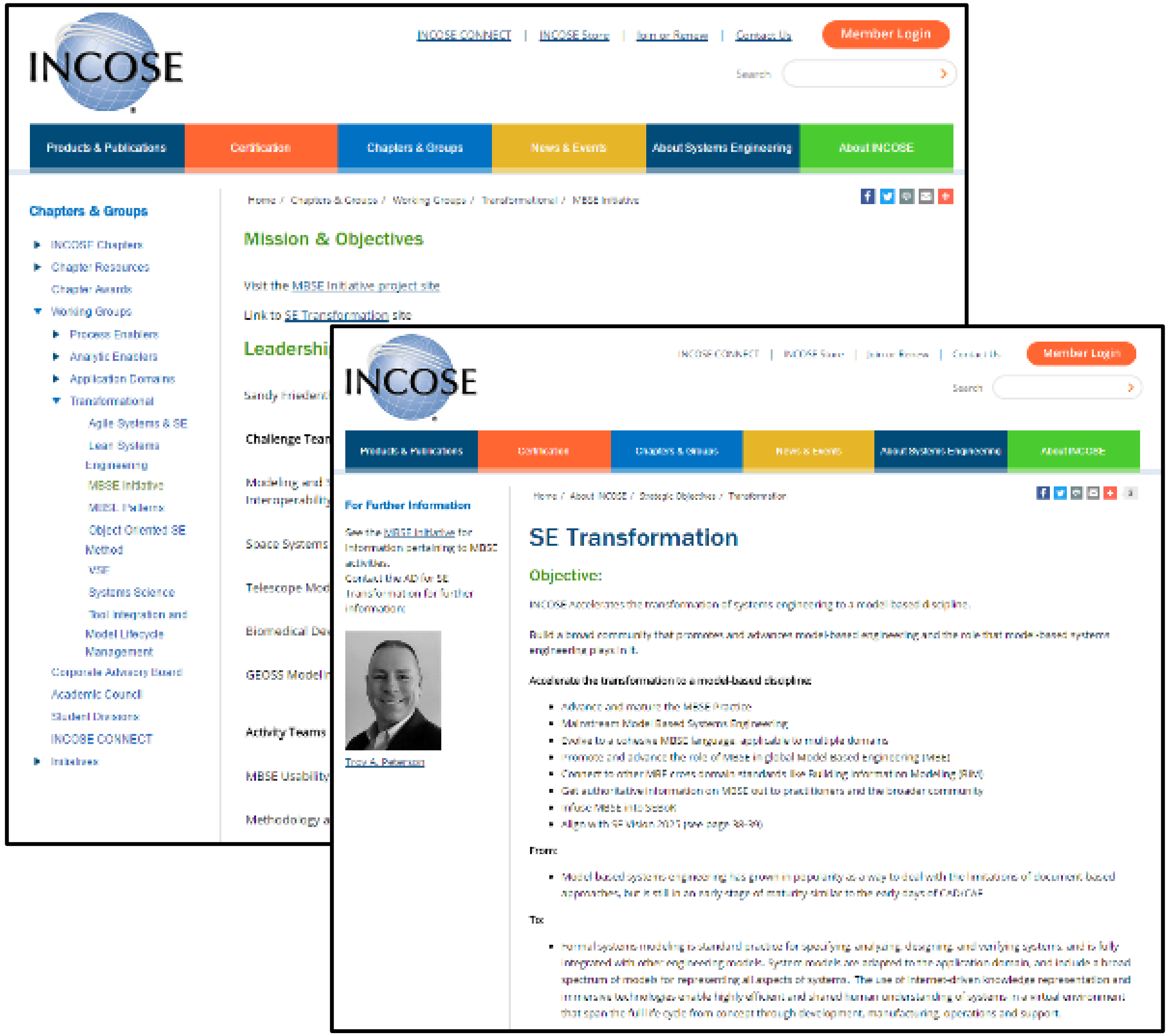
- **Digital Artifacts Challenge Team -> Digital Engineering Information Exchange WG:**
  - Identifying and characterizing MBSE digital artifacts across the lifecycle
- **Augmented Intelligence in Systems Challenge Team**
  - How can machine learning and AI aid systems engineering in the innovation process
- **Production and Distribution Systems Challenge Team**
  - Connecting models across the lifecycle – Industry 4.0, Supply Chain, Logistics
- **V&V of models (Potential Collaboration ASME, INCOSE, NAFEMS)**
  - Verification and Validation of Models – tied to ASME VV50 standards project
- **Model Based Enterprise Capabilities Matrix**
  - Developing self-assessments and gap analysis, strategic planning, project progress aids

Generic life cycle (ISO/IEC/IEEE 15288:2015)

Concept stage	Development stage	Production stage	Utilization stage / Support stage	Retirement stage

MBSE Wiki and Website





http://www.omgwiki.org/MBSE/doku.php?id=mbse:incose_mbse_iw_2017

http://www.incose.org/about/strategicobjectives/transformation

Production and Logistics Modeling Challenge Team

Model-Based Industrial and Systems Engineering Playbook
Manufacturing Edition, Electronics Assembly example

George Thiers[1,2], Leon McGinnis[1], Timothy Sprock[3], Conrad Bock[3], Greg Pollari[4], Eugenio Rios[4], and Adam Graunke[5]

[1]Georgia Tech ISyE, Atlanta, GA 30332
[2]MBSE Tools, Inc., Alpharetta, GA 30009
[3]NIST, Gaithersburg, MD 20899
[4]Collins Aerospace, Cedar Rapids, IA 52402
[5]Boeing, Seattle, WA 98108

A Value Proposition for MBSE for Manufacturing Systems

George Thiers
MBSE Tools, Inc.
Alpharetta, GA, USA

Leon McGinnis
Georgia Tech ISyE
Atlanta, GA, USA

Timothy Sprock
Bock, Conrad
NIST
Gaithersburg, MD, USA

Greg Pollari
Rios, Eugenio
Collins Aerospace
Cedar Rapids, IA, USA

Adam Graunke
Boeing Research & Technology
Seattle, WA, USA

Abstract

MBSE for product development has the benefits of shorter time-to-market, improved product quality, and lower program cost. [Hedberg et al., 2016; Nichols and Lin, 2014; Bayer, 2018] A manufacturing system can be regarded as just another product and subject to conventional MBSE, which is "the formalized application of modeling to support system requirements, design, analysis, verification, and validation activities" throughout all life-cycle phases. [INCOSE, 2007] However, to the best of the authors' knowledge, this is far from contemporary practice. This paper explores contemporary practices for design, diagnosis, and improvement of manufacturing systems throughout their lifecycle, the reasons why MBSE is not contemporary practice, and the value proposition its adoption.

Current Goals:

- Develop a **"how to do it" guide** for production and logistics systems modelers;
- Articulate a **value proposition** for adopting MBSE for production and logistics
- Document **case studies** applying MBSE methods to production and logistics systems

Current Projects:

- Playbook Draft:
  https://v2.overleaf.com/read/rsjqhqzmxtxq
- Value Proposition Draft:
  https://v2.overleaf.com/read/pjjpsvkskgvn

How to get involved:

- Weekly meeting at 11 am (Eastern) Fridays.
  https://bluejeans.com/252469214
- http://www.omgwiki.org/MBSE/doku.php?id=mbse:prodlog
- Point of Contact: timothy.sprock@nist.gov

MBSE Methodologies

List of Methodologies and Methods

Methodologies Surveyed in INCOSE 2008 Report

http://www.omgsysml.org/MBSE_Methodology_Survey_RevB.pdf

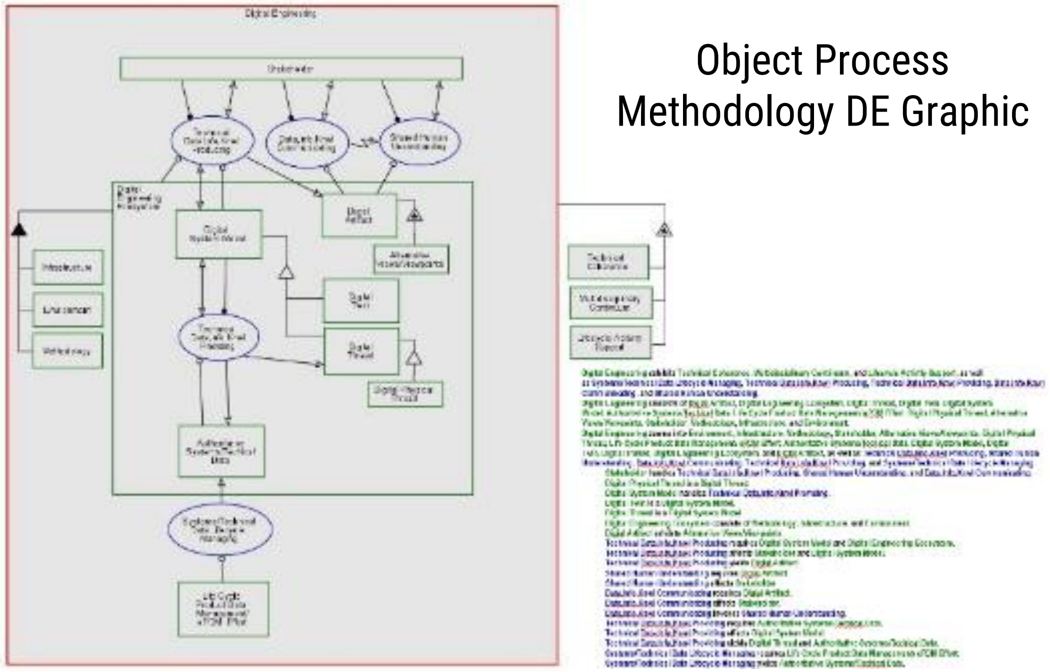
Name	Primary Point of Contact
INCOSE Object-Oriented Systems Engineering Method (OOSEM)	safriedenthal@gmail.com
IBM Rational Telelogic Harmony-SE	peter.hoffmann@telelogic.com
IBM Rational Unified Process for Systems Engineering (RUP-SE)	mcantor@us.ibm.com
Vitech Model-Based Systems Engineering (MBSE) Methodology|Vitech	jlong@vitechcorp.com
JPL State Analysis (SA) Methodology|JPL State Analysis (SA)	Robert.D.Rasmussen@jpl.nasa.gov
Dori Object-Process Methodology (OPM)	dori@ie.technion.ac.il

Additional Methodologies Identified as Gaps Since 2008 INCOSE Survey

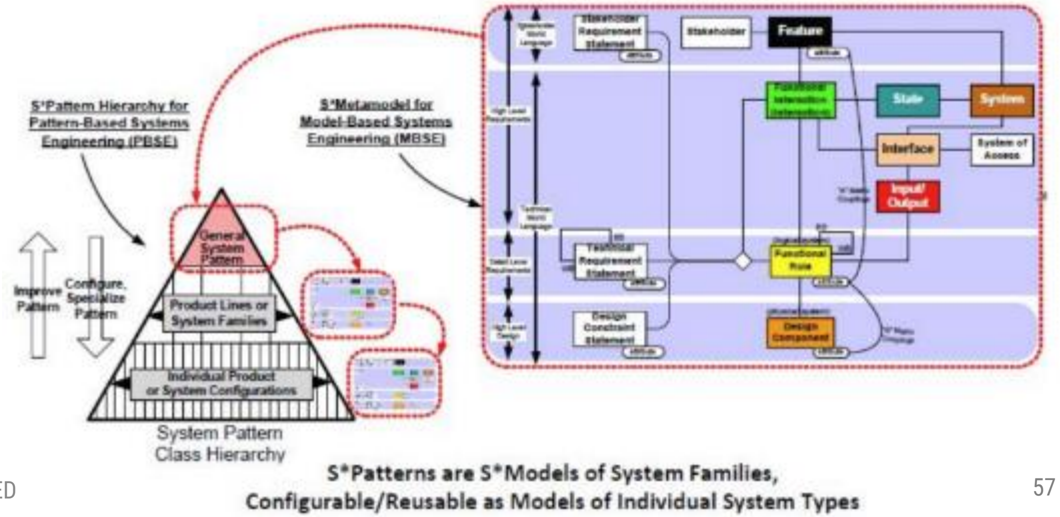
Name	Primary Point of Contact
Weilkiens Systems Modeling Process (SYSMOD)	Tim.Weilkiens@oose.de
Fernandez Process Pipelines in OO Architectures (PPOOA)	joselfernandez@telefonica.net
An Ontology for State Analysis: Formalizing the Mapping to SysML	nicolas.f.rouquette@jpl.nasa.gov
ISO-15288, OOSEM and Model-Based Submarine Design	Paul.Pearce@deepbluetech.com.au
Alstom ASAP methodology	marco.ferrogalini@transport.alstom.com
Pattern-Based Systems Engineering (PBSE)	schindel@ictt.com
Arcadia, a model-based engineering method	Polarsys/Capella

http://www.omgwiki.org/MBSE/doku.php?id=mbse:methodology#incose_links

Object Process Methodology DE Graphic



Pattern Based Systems Engineering



MBX Ecosystem

Challenge Team Wiki @ INCOSE/OMG Site

https://www.omgwiki.org/MBSE/doku.php?id=mbse:ecosystems

OMG WE SET THE STANDARD MBSE Wiki

Search

Recent Changes Media Manager Sitemap

Trace: · ecosystem

MBX E

Purpose

This challeng
manage their
IW17, and IW

In simple terr
systems/prod

But an ecosy
ecosystems t
ecosystems,

If these type

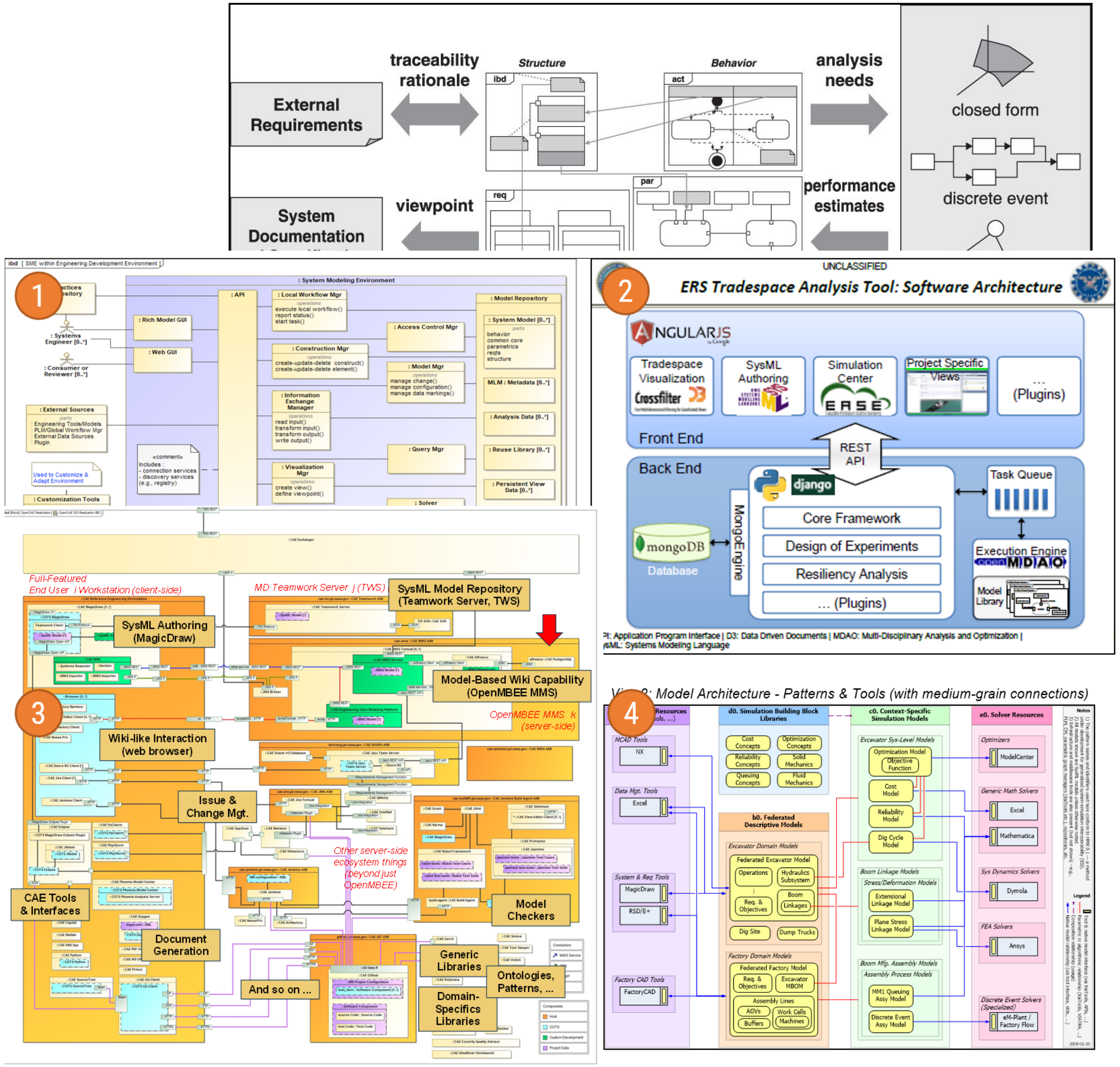
MBX = mode
..., enterprise

Context & Terminology (Informal)

MBX Ecosystem Management

- MBX, where X = MBE, MBSE, MBM, ...
- Ecosystem = combined system of tools, models, products, repositories, interconnections, people, processes, workflows, ... [a "system of systems" - largely computer-based]
  - Level 1 – Overall ecosystem for organization X
  - Level 2 – Division sub-ecosystems
  - Level 0 – Level 1 in a global ecosystem with interfaces to ecosystems of customers, suppliers, regulators, ...
- Management = handling all ecosystem lifecycle phases
  - Vision/concepts, prototype, preliminary design, detailed design, deployment, maintenance, updates, migration, decommissioning
- Therefore, treat your MBX ecosystem as a system!
  - Apply systems engineering principles ("Alpo" approach) w/ ecosystem know-how
- Similar terms: system development environment, decision support system, modeling & simulation framework, ...

 SysML and MBSE: A Quick-Start Course 101.20 5

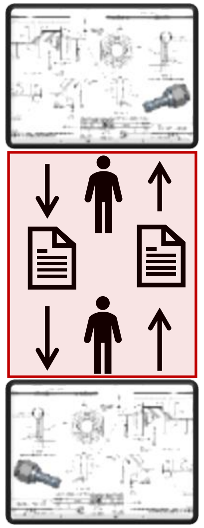


Digital Engineering Information Exchange WG Overview

Problem Statement:

Despite advances in the digital era, there are significant inefficiencies when suppliers and acquirers and internal team members exchange engineering information following a traditional document-based approach.

Ambiguity | Risk | Rework | Error Prone

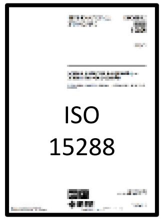


Primary Goal:

To establish a finite set of digital artifacts which stakeholders (acquirers, suppliers, internal teams et al.) should use to exchange digital engineering information.

Efforts:

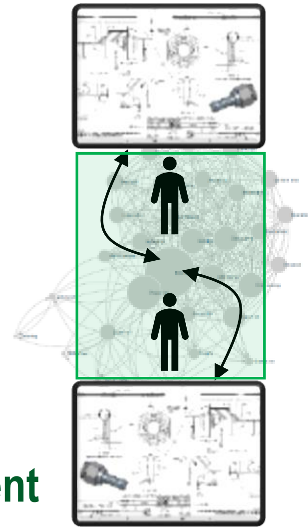
- Define a Finite Set of Digital Artifacts
- Develop Constructs for assembling of Digital Artifacts
- Leverage and Influence Standards to Improve DEIX
- Adopt a Common Lexicon



Opportunity:

Leverage new digital technologies, forms of media and means of interaction to provide enriched system representations. Shared information, knowledge and understanding

Understanding | Speed | Efficiency | Consistent



Participants:

Stakeholder Representatives/Advisors:

- Phil Zimmerman: OSD OUSD R-E
- Troy Peterson: INCOSE
- Chris Schreiber: NDIA
- David Allsop: NDIA
- Frank Salvatore, INCOSE
- John Coleman, DASD(SE) SETA

http://www.omgwiki.org/MBSE/doku.php?id=mbse:digitalartifacts#incose_iw_2018_summary

INCOSE Model-Based Enterprise Capabilities Matrix

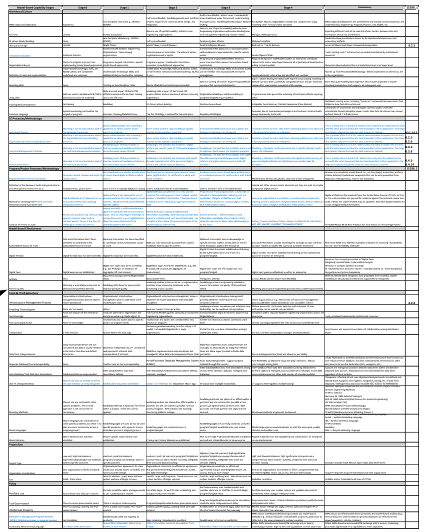
SSI

Model-Based Capability Dimensions
• Workforce/Culture
• SE Processes/Methodology
• Program/Project Processes/Methodology
• Model Based Effectiveness
• Tools & IT Infrastructure
• Project Use
• Policy

Objective:
Define a method of characterizing the current capability of one or more domains/attributes for a Model-Based Enterprise

General Approach:
Assess the current Stage of Implementation by capability maturity of the Organization for one or more relevant attributes. Highlight the attained Stage of Implementation maturity level cell and all calls to the left of the attained level Stage for all assessed relevant attributes.

MBSE Maturity Levels	Level 0	Level 1	Level 2	Level 3	Level 4
Tools & IT Infrastructure					
Collaboration	E-mail, telecom.	System Model File Exchange.	Various organizations working on different parts of model. Full model integrated by a single organizations.	Partial On-line, real-time collaboration amongst distributed teams	On-line, real-time collaboration amongst distributed teams
Disparate Database/Tool interoperability	None	Tool-to-Tool, ad hoc interoperability	Partial Federated Database Management System (FDBMS)	Main tools interoperable. Supporting tools interact through file transfer.	Fully Federated w/ standard "plug-and-play" interfaces. Data is interchanged among tools
Inter-Database/Tool Data Item Associations	Databases/tools are independent	Inter-Database/Tool Data Item associations defined	Inter-Database/Tool Data Item associations defined, captured, managed	Inter-Database/Tool Data Item associations among all data items defined, captured, managed, and traceable	Inter-Database/Tool Data Item associations among all data items defined, captured, managed, and traceable where changes in one data source alerts owners of other data sources of intended updates
User IF, Viewpoint/Views	N/A	Doc Gen	UI draws from Model app	UI draws from multiple models/DBs	UI supports Interrogation; multiple configs



Augmented Intelligence for Systems Engineering

Description & Purpose

- Augmented Intelligence describes the approaches and best practices for "team play" – where engineer and machine intelligence (such as AI, Machine Learning) can coordinate to develop transparent, traceable, and understandable system designs that are better than either human or algorithmic approaches could develop alone
- The team seeks to develop a collaboration framework where computational approaches can effectively pair with engineers to measurably improve the systems engineering effort

AuI = Human + AI
AuI > Human
AuI > AI

Goals

- Develop technical paper on augmented intelligence capabilities applicable to systems engineering, and conceptual applications and uses cases for how augmented intelligence could improve systems engineering
- Technical Paper

weak human + machine + better process
beats
strong human + machine + inferior process.

Major Technology Areas

- Human Machine Interface, Visualization, AI, Machine Learning, MBSE

Charter and Wiki

- Chartered February 2018
- http://www.omgwiki.org/MBSE/doku.php?id=mbse:augmented

Related Projects

- Agile SE

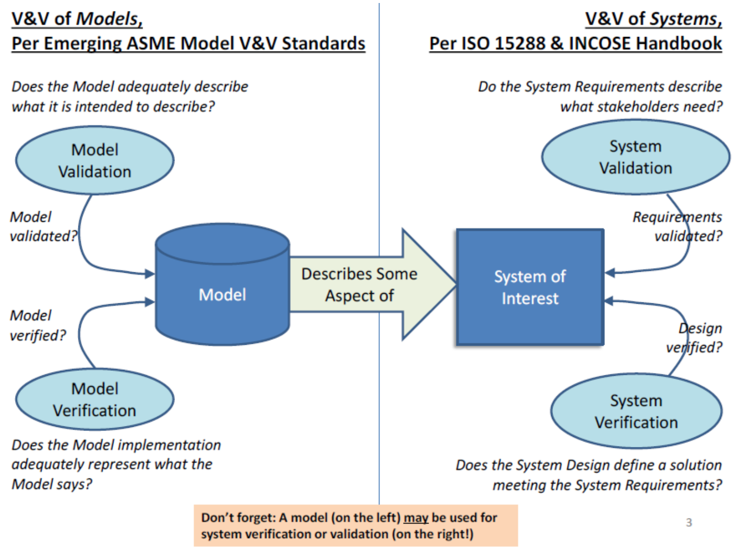
Model Credibility – Verification and Validation

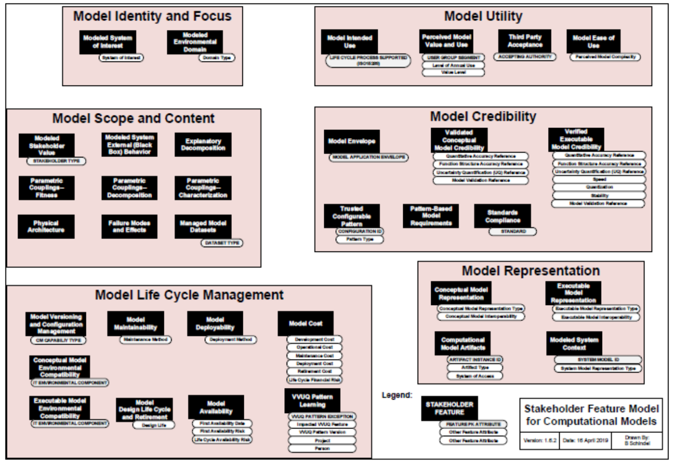
Solutions to Validation and Verification (V&V) Questions:

- ASME INCOE Collaboration on VVUQ – focused on V&V of models. ASME V&V10-60.
- Expand standards to encompass VVUQ of broad ISO 15288 scope of models
- Model Characterization Pattern
- Model Life Cycle Management Process: Establish, Develop, Deploy, Use, Maintain, Retire
- Model Curation

Goals

1. Scale up volume of models and people.
2. Manage models over entire life cycles.
3. Increase use of what was already learned.
4. Package general principles as actionable assets.
5. Prepare for a building-block world of models.
6. Unified metadata wrapper for all models.





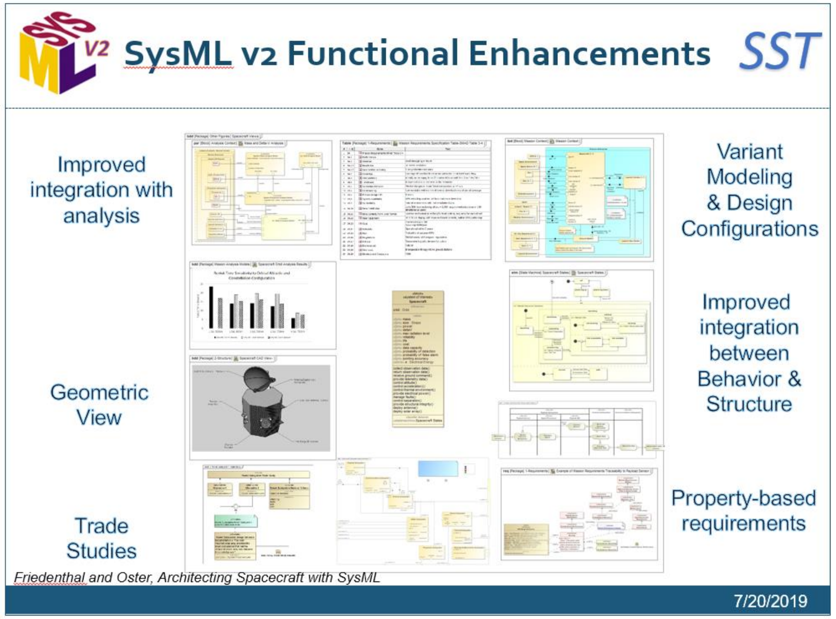
Systems Engineering Foundations

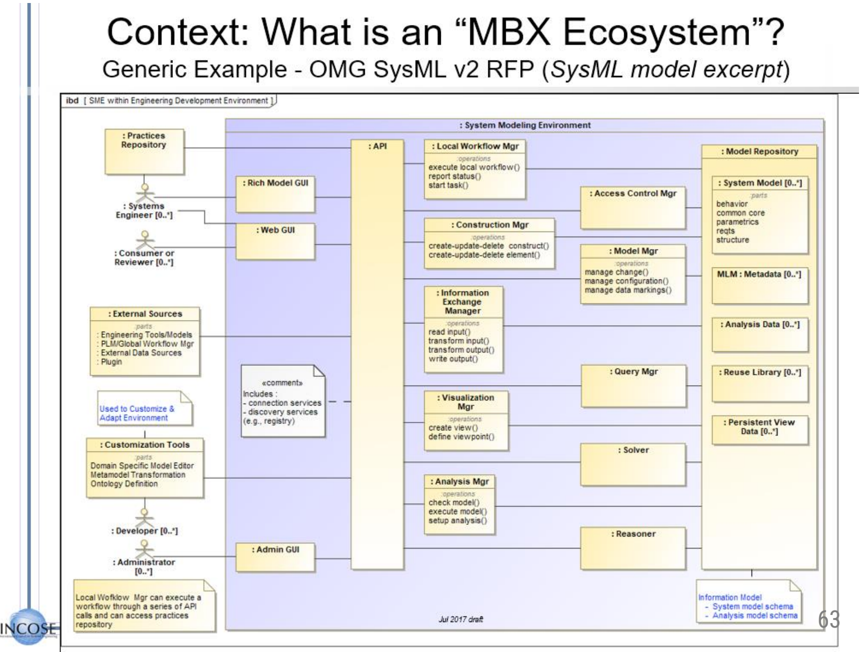
Many INCOSE resources exist to build an understanding of the practical implications of applying MBSE.

SysML v2 Objectives: Increase adoption and effectiveness of MBSE by enhancing…
- Precision and expressiveness of the language
- Consistency and integration among language concepts
- Interoperability with other engineering models and tools
- Usability by model developers and consumers

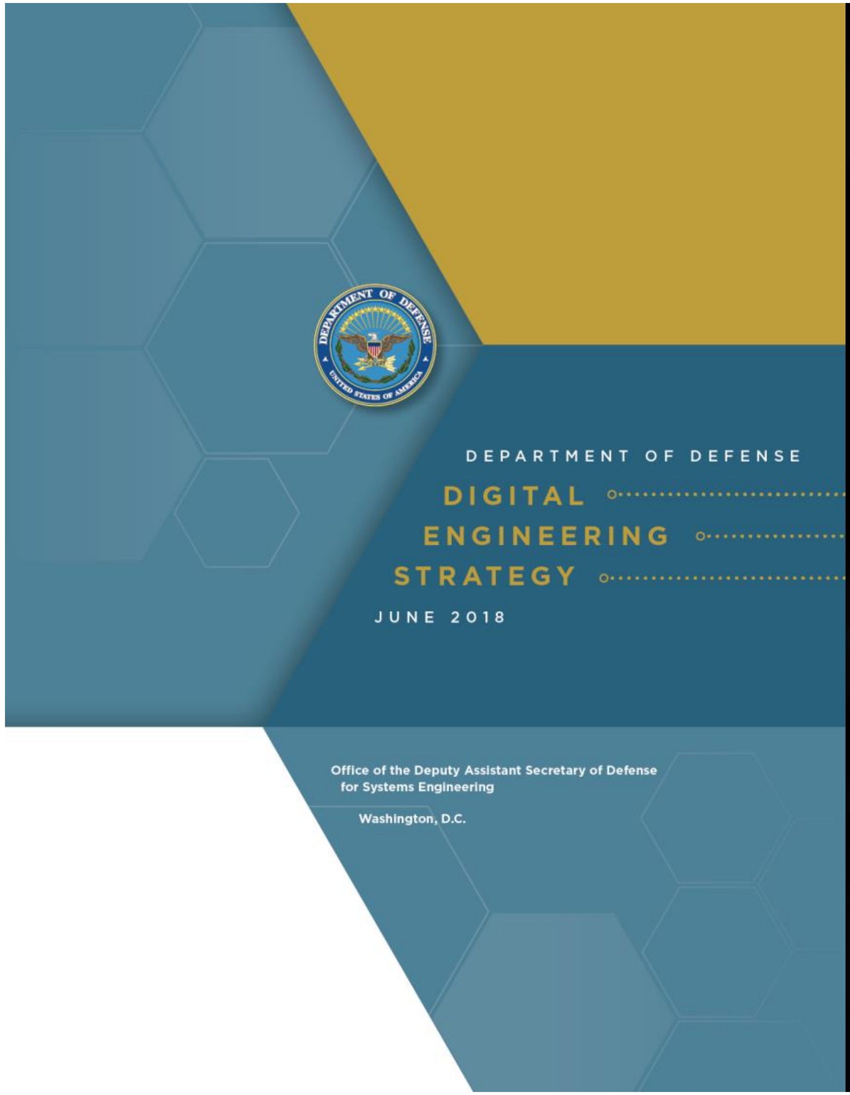
ST4SE / MBSE Patterns WG
- Improve shared systems engineering community-wide knowledge for more effective life cycle engineering of systems, through the identification, availability and distribution, and use of model-based ontological patterns and related semantic web technologies.

INCOSE Fellows Meetings and INCOSE Vision 2025/2030
- Ensuring the Systems Engineering discipline is has its roots in engineering and science principles – interactions, Hamilton's principle, systems phenomenology.





Trends Toward Digital Engineering: Professional Societies



Virtual Engineering
Part of The Digital Revolution

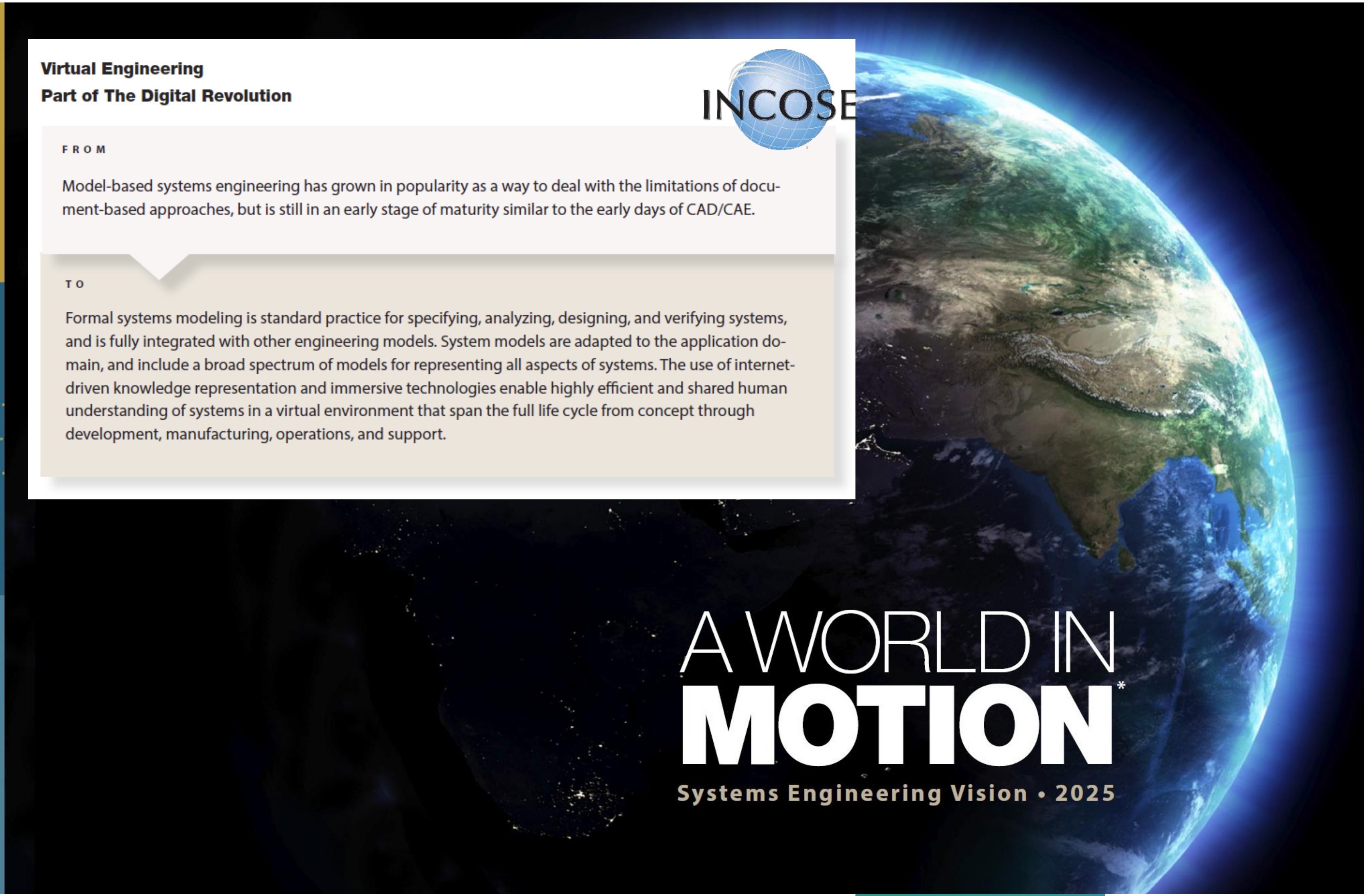
INCOSE

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.

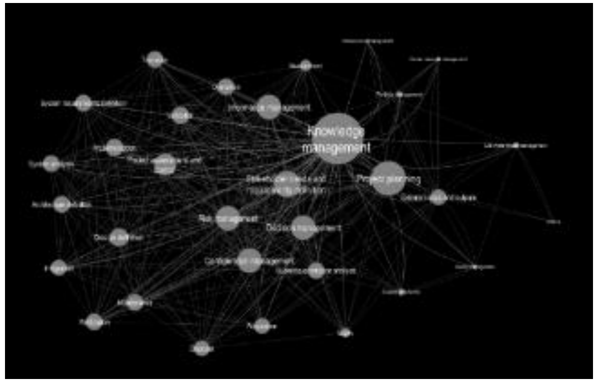
TO

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.



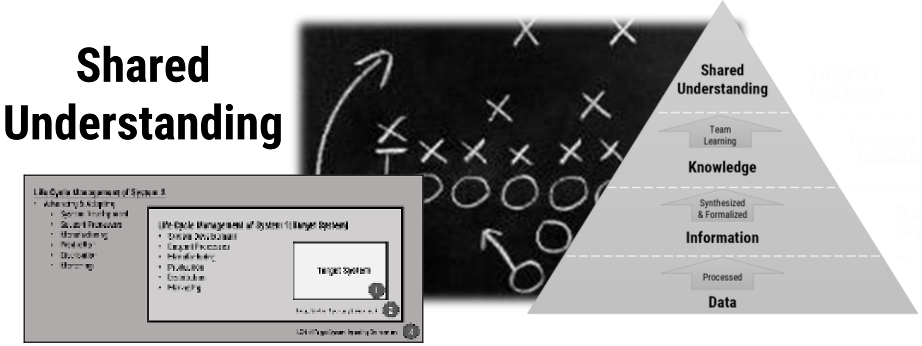
Continuous Learning and Transformation

Capture and Formally Model Knowledge



Apply Model Based Patterns & Build Shared Understanding

Shared Understanding



Employ Augmented Intelligence

Continually Learn and Transform

Simplicity is complexity resolved.

Constantin Brancusi (1876-1957)

Any intelligent fool can make things bigger and more complex… It takes a touch of genius – and a lot of courage to move in the opposite direction.

Albert Einstein (1879 – 1955)

A genius! For 37 years I've practiced fourteen hours a day, and now they call me a genius!

Pablo de Sarasate (1844 – 1908)